Final Report

Automatic Syringe Loading Device

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May 5, 2008

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Abstract

While there are some devices already on the market that can assist diabetes patients in a similar manor, they also fall short of providing the level of accuracy, variability and ease of use that this automated syringe-loading device will. The patient will be able to rely on the device much more than most other products, while maintaining their independence.

The syringe-loading device has the ability to fill both a 0.50 cc and 1.00 cc syringes with insulin to an accuracy of 1/1000th of a cc (or milliliter). The device will have minimal user requirements such as the loading of insulin vials and syringes, input of the amount of insulin to load into the syringe, in addition to amount confirmation. The input of amounts will be done using voice recognition, or an alternative keypad, on the device. The display will be a larger, graphical LCD screen that will display all of the user prompts in the most attractive manor, and will be accompanied by an audio output that will echo the displayed prompts, which is useful for users who may have visual impairments. Along with instructional prompts for action on the user’s behalf, the prompts will also contain information such as the amount of insulin left in the vial and when the vial needs to be replaced.

The portable syringe-loading device will also have various sensors required for the proper usage, such as the orientation and the presence of a syringe, in addition to the size of syringe present. A unique feature of the device is a removable syringe cartridge that will hold ten syringes at once. Once properly loaded, it will relieve the user of individually loading a syringe into the device every time a syringe is requested to be filled. Additionally, the feature of a removable cartridge will have the appeal of the user being able to receive a number of pre-filled cartridges that only would need to be inserted into place once for every ten filled syringes.

The device will also keep time-stamped records of doses drawn. This is useful for doctors to determine any abnormalities and further help educate the patient on the healthiest maintenance of their disease. Bluetooth technology will be used to transfer the file containing the record of doses drawn. All of the features are intended to make the device as safe as possible, while maintaining its user-friendly interface and user independence.
1 Introduction

1.1 Background

Diabetes is a disorder in which the body does not efficiently produce, or properly use insulin. The disorder is important to properly manage since insulin is a hormone that is required to convert, mainly sugars and starches, into energy needed for daily life. Although the cause of diabetes is unknown, much is known about assisting the body with external sources of insulin [1].

The amount of insulin required is dependent upon a variety of factors that the person has just done or intends on doing through the day, such as the level of physical activity they have engaged in and food they are planning to eat. Therefore, the dosages of insulin that a diabetic injects can greatly vary, in addition to the frequency of the dosages. It is extremely important that the required amount of insulin be measured precisely. This measurement can be difficult for those with low vision or trembling hands.

Diabetes affects 20.8 million children and adults in the United States alone. Therefore, it is necessary to explore a variety if injection methods. Among the inherent disorder of diabetes, many are affected by disabilities. One disability that diabetes can cause is blindness and low vision. Such a side effect is especially limiting to the patient. An intended client list has been provided to ensure that the device can be accessible for diabetes patients with a variety of disabilities. The client list for the syringe-loading device is:

- Phyllis, 77 years old, suffers from rheumatoid arthritis. Due to her arthritis, she has diminished hand strength, joint stiffness, and pain. She tends to stay away from the current, high-tech, devices and therefore prefers those with simple interfaces.
- Aaron, 23 years old, is a returning Iraq war veteran who has an arm amputation above the elbow, and suffers from chronic neck pain, and reoccurring headaches. He most often uses one hand instead of wearing a prosthetic device.
- Keisha, 84 years old, recently had a stroke, which caused hemiplegia on her right side and has affected the function of her dominant hand. Due to the hemiplegia, the side affected by it can become paralyzed or weakened [2]. Since the stroke, she has experienced some memory loss so she depends on her family’s care. Independent of the stroke, Keisha also suffers from hearing loss, which has progressively worsened with age and although she has a hearing aid, she rarely uses it.
- Jerry, 82 years old, has Parkinson’s disease. The disease causes him to tremor and his range of motion is rigid and decreased. Jerry is also experiencing the early symptoms relating to Dementia, but with the help of his family, he would like to remain at home as long as possible.
- Jamie, 42 years old, has a T11 spinal cord injury, which causes her to use a wheelchair and despite her condition, she stays active playing basketball.
Betty, 65 years old, has a bad hip that caused limited and asymmetrical lower extremity range of motion. In addition, she has limited strength in her right leg due to the decreased use of her hip, associated with the pain.

Violet, 32 years old, is a very active mother of three that is on blood pressure medication.

Paul, 43 years old, has diabetes, which caused neuropathy in his hands and feet, which also caused two below-the-knee amputations and some loss of vision. Neuropathy can be controlled, but if left untreated can lead to numbness, pain, weakness, and incoordination [3].

1.2 Purpose of the Project

The purpose of the syringe-loading device is to help those with diabetes, and other disabilities, that may inhibit their dependence on insulin. By creating such a device, people who are required to take one or more doses of insulin per day, with amounts that vary, can easily utilize it. The device will be able to fill a syringe with a specific and accurate amount of insulin.

In accordance with the purpose of the syringe-loading device, it will be designed so that the user will have limited responsibilities when it comes to the operation of it. The extent of interaction between the user and the syringe-loading device will include loading the insulin bottle, and syringe into the device, speaking or entering by keypad the dosage amount, and confirming the entries also by speech or manual entry. The overall design of the syringe-loading device will have safety and user-friendly compatibility in mind.

1.3 Previous Work Done by Others

In implementing a justified design for the project, it is important that research is done on similar devices that have already been completed. Products that are on the market and patents that are submitted are two of the resources available. In addition, previous senior design groups have already completed the syringe-loading device project in 2005. The results from those projects are expected to positively contribute to the current design.

1.3.1 Products

There are many syringe-loading products that are on the market, available for consumers. They vary depending on the potential user and their disabilities, but are based on the same concept of delivering a safe and efficient dosage of insulin. The National Federation of the Blind (NFB) provides many products, ideas, and reviews for insulin measurement devices [4].
**Count-A-Dose®**: An insulin-measuring device by Jordan Medical Enterprises. The device comes with cassette instructions and it accepts only one specific syringe type, B-D U100 50 unit (½ cc). The Count-A-Dose® works by using a distinct click that can be heard and felt with each unit of insulin. The device allows two kinds of insulin to be used. It is considered, by NFB, to be easy, reliable, and accurate for non-sighted insulin measurement. Despite NFB reviews, downfalls of this device are that the controls may be hard to see, even for those without visual impairments, the clicking may not be heard by all users, and the adjustment knob can require too much strength. The suggested retail price is $59.95 but it can be purchased for $40 from the NFB.

**The Syringe Support**: A second insulin-measuring device is available from Cleveland Sight Center’s Eye-Dea Shop. Instructions are provided in standard print only and come bilingual (English and French). It also only uses one type of syringe, B-D 1 cc/100-unit disposable syringes. The device can measure insulin by 1- or 2-unit increments in doses from 1 to a maximum of 100 units. In order to use two different types of insulin with the device, it is necessary to remove the vials and switch. The Syringe Support works by using a set screw with a raised flange at 12 o’clock. One full turn of the dial draws two units and one-half turn draws a single unit of insulin. In most cases the error from the dial is minimal, even though it lacks definite tactile or audio indicators. The device is best for those who draw greater than ten units at a time. The price of the Syringe Support is $26.

**The Load-Matic**: The third insulin-measuring device shown on the NFB website is available from Palco Labs, Inc. It comes with cassette and printed instructions. However, the cassette instructions tell the blind user to draw 700 units out of an insulin vial with the device to assure that air isn’t drawn into the syringe, and the printed instructions fail to mention such information. Like the previous two devices, it too accepts only one type of syringe, the B-D 1 cc/100-unit disposable. The device allows two different measurement increments. It works by using a level that the user depresses to measure a 10-unit increment of insulin. By turning the dial on the device, for one click, a single-unit is measured. Similar to the Syringe Support, insulin vials must be removed and switched to change types. Due to the complexity of the operating drill, there are many opportunities for user error. One such error is that if the user fails to completely depress the lever, measurement error is extremely likely. The failure of including complete instructions for the device contributes to the user errors. The Load-Matic device can be purchased for $49.95.

**Insul-Cap®**: The device is made by Palco Labs and comes with instructions. It also comes with two different colored insulin vial caps for distinction between two different vials. The device allows loading of syringes with one hand. It is a one-piece syringe-loading device with a built-in magnifier that magnifies increments by two times. The device is intended for diabetics with impaired vision and unsteady hands. The advantage to the device, unlike the others, is that it can fit most standard syringes. It claims to increase the independence of those who are dependent on friends, relatives, or visiting nurses to prepare insulin-loaded syringes. Insul-Cap® sells for $6.95 [5].
In addition to the insulin measurement systems, the National Federation of the Blind website [4] conveniently includes ideas for homemade insulin measurement gauges. It points out that the simplest devices are ones that allow the plunger, of the syringe, to move a set distance and no more. In doing so, accurate and easy-to-duplicate amounts of insulin can be dispensed. Unfortunately, this technique requires a various set of syringes set at different amounts, which is not practical for an active patient with diabetes. The website includes, in further detail, how gauges can be made for syringes, and the different materials they can and cannot be made from. It also recommends purchasing commercially made gauges, called Insulgauges, from Meditec, Inc. The gauges are made for specific syringe types, B-D or Monoject syringes. The prices of the commercial gauges are $9.75. Meditec, Inc. also sells a device, Holdease needle guide, which guides the syringe into the insulin vial for a price of $15.75.

A new-age system to insulin delivery for diabetic patients is an insulin pump. Although manufactured by different companies, all have the same design. They work by delivering rapid- or short-acting insulin 24 hours a day. The delivery of the insulin is through a catheter placed under the skin. The doses are separated into three types, basal rates, bolus doses that cover carbohydrate in meals, and correction or supplemental doses. The basal insulin is delivered continuously over 24 hours and keeps the blood glucose levels in the correct range between meals and over night. The doctor determines this range frequently, and therefore increased amounts of visits are required with the pump. The amount is programmable and is usually changed over various periods of the day. When eating, the bolus amount of insulin is injected. Depending on the carbohydrates in a particular meal, different amount of bolus doses are required. For instance, if there are more carbohydrates in the meal than planned for, the buttons on the pump can be selected to give a larger bolus of insulin. For the third type of dosages by the insulin pump, a bolus dosage can also be used to treat high blood glucose levels. If a person has high levels before eating, a correction or supplemental bolus of insulin can be injected to bring it back to the target range [6].

The insulin pump itself can be worn as a cell phone. It can be attached to a belt or placed in a pocket, among other places. When showering the pump is disconnected and the tube that runs external to internal of the body and it can be left untouched. For many diabetics, the insulin pump is most favorable because of its convenience and practicality. However, the price of the pump can be over $5,000 with the supplies ranging from $60 to $80 a month [7, 8].

Since this year’s syringe-loading device project is a repeat, there is additional information online on past senior design projects. Information was found on the project through the University of Connecticut, Marquette University, University of Wyoming, and the University of Wisconsin-Madison. The designs used previously will be of careful consideration since there is much to be learned by those with experience.

1.3.2 Patent Search Results
The following patents were found on http://www.freepatentsonline.com:

Patent 4357971 - Syringe gauging, loading and injection apparatus: The apparatus is intended to enable a person with low vision and/or the loss of fine motor control to accurately fill a syringe with the predetermined amount that is followed by self-injection. The device can be adjusted for various dosages and verification of the dosage is accomplished through tactile stimulus and/or audible sound. It included a dial, which measures dosage by rotation, which then results in a signal to the sense of touch and hearing.

Patent 4778454 – Syringe loading fixture: The device is designed to load a syringe from a vial of liquid for those with poor or no vision. The fixture uses a gauge for measuring quantities of air to be injected into the vial prior to loading and the quantity of liquid to be loaded into the syringe.

Patent 7025757 – Syringe loading devices for use with syringes and medical injectors: The device includes a syringe mounting mechanism adapted for use with an attachment mechanism. The syringe is attached to the syringe loader and a drive member is adapted to impart motion to the syringe plunger.

1.4 Map for the Rest of the Report

This final report of the second semester of senior design describes the evolution of the syringe-loading device project. The three alternative designs and the optimal design created over last semester will again be mentioned in this report. They will give the background to understand how the final device has been designed. The final design of the automated syringe-loading device has many insignificant and some significant changes from the optimal design.

The realistic constraints that users of the device may face will be addressed. As well as the safety issues and concerns the team and others have based on the final design. The team will address these issues to hopefully lie to rest some of the current concerns. The team has successfully gained a better understanding of the requirements of disabled diabetic patients and has finally been able to produce a final product is a suitable alternative to a person with disabilities individually filling their syringes. The impact of engineering will explore how diabetes affects a variety of people, including those around the world. Addressed by life long learning, great knowledge has came from being able to educate the team on how to adapt to new components and combine them in such a way that they has worked in unison to further reach the intended design goal. Improvements in everyday life can result from this device for diabetes patients.

The budget for the syringe-loading device will give explanation as to where and how the money allotted for the device was spent. The budget is $2,000 and although the team has thought this was a limiting amount, they did not come very close to spending all of it.

Finally, the team will address the contributions on the behalf's of each member. Discussion
of this part of the project will help summarize how the final design came together. Each team member had specific areas of specialty to add to the research, design and construction of the device.

2 Project Design

The design for the Automatic Syringe-Loading Device had gone through many revisions over the course of the project. The initial thoughts from early brainstorming sessions have been refined and expanded upon to develop possible design approaches for the implementation of the device. From the various alternative designs that were proposed, the best elements were identified and integrated together to create a final design for the project. Below is an overview of the 3 alternative designs that were developed for the Automatic Syringe Loading Device. Following these designs is a more detailed look at what has been chosen as the Optimal Design for the device. Finally, the final design of the project will be discussed and the previous reports will give explanation as to how it was designed.

2.1 Design Alternatives

2.1.1 Design 1

The first design for the Automatic Syringe Loading Device utilized a laptop with a tablet screen as its main interface and control center. The laptop would run a simple menu program which would allow users to prepare new doses or view previous dosage information. Users could specify insulin dosage amounts and respond to menu prompts by pressing virtual buttons on the laptop’s touch screen. The laptop would also be able to interpret voice input using speech recognition software, to allow users that had difficulty seeing and using the screen to have another method of controlling the device. Audio output was also to be handled by the laptop, through the use of its built-in speakers. Sensors, motors, and servos were used to accomplish precision loading of syringe. These components were powered by and communicated with using the laptop’s USB ports. The following sections describe this design approach’s subunits in further detail.

2.1.1.1 Samsung Q1-V000 UMPC Tablet PC

A laptop to be used will be the display and user control faces for the device. The laptop chosen, the Samsung Q1-V000 UMPC, is a touch-screen tablet style PC. From this device, the USB ports mentioned will be utilized. This laptop will house the processor and memory for the device.

2.1.1.2 Programming

The program that will control the main functions of the syringe-loading device will be written in Visual Basic. It will communicate with the sensors using Application Program
Interfaces (APIs) that have been provided by Phidgets, Inc. When prompting the user, it will output text to the screen in large, readable letters to inform users visually. It will also play pre-recorded sound files to inform the user audibly. Buttons displayed on the program’s front panel will be able to be “pressed” by touching the buttons directly on the screen or by using the included stylus to “tap” the keys on the screen.

The program will also interact with a speech recognition module to evaluate vocal input from the user. Vocal input can be used as an alternative to having users enter amounts or choices directly at the laptop’s keyboard or screen. Data for dosages administered will be stored on the laptop’s hard drive. The program will operate a simple menu from which users can choose to view past dosage information or prepare a new dose of insulin, (below is the flowchart that outlines the program’s major processing steps).

Once the initial program has been written and any hardware control issues have been resolved, further configuration options can be considered, (alternative front panel layouts and controls, additional text and audio support for other languages, support for a Braille pad, etc.).

2.1.1.3 Voice-Activation

Some of the intended users of the automated syringe-loading device have visual impairments. Therefore, a voice-activated system would be of significant use to them. In addition to providing a device that the person can maintain their independence without letting their disability interrupt their lives too much, the voice activation system will allow easy usage of the device. This ease-of-use is also valuable to all other patients. There will be simple prompts that will make this high-tech device feel much less complicated while maintaining accuracy and precision.

The voice-activated system considered is a software-orientated program. In using this voice-activation software, a person can talk into a microphone and their speech is translated into words that can be seen on the screen. Some of the companies that sell voice-activated software claim to have up to 99% accuracy.

Voice-activated software applications use algorithms to communicate the speech to the computer. The two issues that determine the effectiveness of the algorithms are their ability to generally evaluate the speech input and its ability to interpret the speech input under adverse conditions. This factor of adverse situations is important for the intended clients for the syringe-loading device. Some of the users may experience hearing loss and this can affect their speech. Since the device is intended to be portable, it may have to work in noisy environments, which is also of consideration with such products of voice-activation. [9]

With increases in processing speeds over the years, there has come the necessary improvement in performance to make possible near real-time speech-recognition using
standard hardware. Some voice-activated software can carry out speech-processing operations using relatively low-end processors (Pentium III or better). [9]

To incorporate voice-recognition software with Microsoft Visual Basic programming code, Microsoft Speech SDK (Software Developer Kit) can be used. The SDK can be downloaded from the web and by “training” between the programs; accuracy of the voice-recognition is increased. Three ActiveX controls that come with SDK that are needed are Voice Commands, Voice Dictation and Voice Text (Text to Speech) in Visual Basics [10].

One such voice activation program that adheres to the requirements imposed on the team for the syringe-loading device is Dragon NaturallySpeaking SDK 9. The advantage to Dragon NaturallySpeaking is that there is no voice training of the program required. The frequency of its use increases the accuracy of the program, in addition to never making spelling errors. Elimination of spelling errors is vital for the syringe-loading device because the computer requires the recognition of the correct inputted information [11].

Dragon NaturallySpeaking SDK Client Edition 9 is the edition that is of most use for the intended device. It allows developers to use any language that supports ActiveX such as Visual Basics. The software itself comes with comprehensive sample code, documentation and it supports six languages. Dragon NaturallySpeaking SDK 9 includes support for pre-recorded .wav input. It also includes tools for building custom language models [12].

In addition to input, the user will be able to use commands to do such tasks as quitting and opening the program if necessary. Although the computer will be able to open and run the program on start of the computer, the program may be quit and other applications such as Internet Explorer, Microsoft Word and Excel can be opened, all using voice activation. The voice activation will also be useful in the execution of the other programs.

In combination with specific programming techniques and the flowcharts intended for this design, algorithms are expected to be implemented into the design, which will allow for accurate dosing of insulin into the syringe by using voice-activated software. The computer provides adequate storage and manipulation of the software.

2.1.1.4 Touch-Screen

Since the team is considering the use of the Samsung Q1-V000 UMPC touch-screen computer, there is no use for an external keyboard input. The screen is 7”, and therefore practical for the intended use. The resolution of the screen is 800 x 480 pixels. Although for such an application as the syringe-loading device, resolution does not have to be perfect, this particular resolution is optimal for the screen size and visual preferences. The landscape orientation can also be selected to maximize the 7” screen. [13]

2.1.1.5 Stylus
Although the device has a touch screen LCD interface, the Samsung Q1 handheld PC also comes with a stylus. This stylus can be used to easily and accurately select options on the screen when voice activation is optionally turned off. The stylus requires an initial calibration that increases the accuracy. This tool would be used against large on-screen buttons, eliminating the risk faced by users that have unsteady and trembling hands. The size of the buttons will be maximized for the 7” screen. The font most appropriate for the design is Times New Roman [14]. This font is chosen because it is popularity in being the most-used default font. In addition to the program reading the instructions to the user, the screen will display the directions. To ensure that the font remains large enough for those with vision impairments to see, a scrolling feature will be used. A large font size of 40 is also optimal for being easy to see and clear. However, different font and sizes can be changed depending on the person’s needs and likes.

2.1.1.6 Array Microphone

Although the software package comes with a headset microphone that blocks out noise, a stand-alone microphone is preferred. This stand-alone microphone is also preferred over the built-in microphone integrated into the computer. The array microphone that the computer comes standard with is not certified for use with the software and since accuracy is the main goal of the device, a separate certified microphone is required. A stand-alone microphone is much more user friendly for elderly patients, compared to a headset-styled microphone.

Such a microphone that is most compatible with the design and voice-activation program is the Superbeam Array Microphone by Andrea Electronics. It has been certified to work with the Dragon NaturallySpeaking system. The array microphone requires a USB adapter and software that is included with the device. Andrea’s PureAudio® and DSDA® noise canceling technology increases the accuracy of the microphone in connection with the voice activation software. The microphone has a favorable size of 4.3”x1.7”x0.9”, which would be affixed on top of the computer. It has an operating distance of 18 to 24 inches. [15]

The hardware alternative to the USB adapter is one that is capable of stereo recording and preloaded driver software, using SoundMax 4. This allows a direct connection of the superbeam array to the microphone input jack. This alternative may be the best option because it would be useful in order to free up the two USB ports for other systems.

2.1.1.7 Speakers

Speakers are required for the device to prompt the user for input of the instructions for the device, the amount of insulin, confirmation and the amount of insulin left in the bottle. The two stereo speakers (2 watt each) that come standard on the Samsung Q1 computer are sufficient for the application of the syringe-loading device. The computer has SRS True Sound, which delivers excellent quality. The speakers will be used to prompt the user for input and also verification of the input. [13]
2.1.1.8 **Video Graphics**

The graphics of the Samsung Q1 tablet PC is Intel Graphics Media Accelerator 900 (GMA 900). It is an integrated graphic chip for Intel processors. The advantage to this graphics card is that it has low power consumption and therefore saves battery life. Any component that does not require a large amount of energy is extremely important because the syringe-loading device is designed to be portable. The more time the device can be uncharged, the more convenient it will be for the user. In addition to improved battery life, the computer may stay cooler and more silent. The GMA 900 does not any memory. [16]

2.1.1.9 **Sensors**

A Phidgets communication board will be used to connect 3 Phidget Touch Sensors, and a Phidget Accelerometer 3-Axis Sensor to the laptop via its USB port. These sensors will all be powered directly from the laptop’s USB port; no external power source will be necessary. The accelerometer will be used to determine the orientation of the device. One touch sensor will be used to determine whether the insulin bottle is in contact with the syringe needle port. Another touch sensor will be used to detect if a syringe has been loaded. The last touch sensor will detect if a 50 or a 100-unit syringe has been placed in the syringe holder.

2.1.1.10 **Bottle Holder**

This component needs to securely hold a bottle in a vertical position while a syringe extracts insulin from it. In order to accommodate a wide variety of bottle sizes and shapes, an expandable cylindrical sleeve was designed. The sleeve is made of out six plastic guide segments. These segments are arranged in a circle and are bound together using two rubber bands. The upper portion of the guide segments will be cemented to the top of the device’s case. The rubber bands wrap around the segments just above two sets of notches; these keep the rubber bands from slipping down and off of the sleeve. As a bottle is placed in the holding assembly, the guide segments will automatically adjust to conform to its shape. The equal force being applied on all sides by the rubber bands will automatically center the bottle’s top over the syringe needle port. In order to make sure that the insulin bottle is secure and that it is completely making contact with the syringe needle port, a spring will be used to apply pressure to the bottle’s bottom. The spring will be attached to a removable twist cap. The spring/cap and plastic for the guide segments will be taken from a flashlight that is designed to work using D batteries. Notches will be cut and cemented in place on the segments using epoxy. The finished sleeve should be able to accommodate insulin bottles that are between 12 mm to 40 mm in diameter, and between 40 mm and 70 mm in height.

2.1.1.11 **Syringe Holder**
The syringe holder is used to grip and hold the syringe while it is being loaded with insulin. The syringe holder consists of a main platform, which supports and grips the tube of the syringe, and a plunger claw segment that secures and draws back the syringe’s plunger. The syringe holder has two different types of guides: tube guides and plunger guides. The rounded edges of these guides assist in positioning a horizontally slide syringe into the correct position on the platform.

As a syringe is loaded into position, it will press against a touch sensor. This touch sensor will provide enough upward pressure to push the syringe against the top of the guides, thereby helping it to maintain the necessary position prior to insertion into the bottle.

A second touch sensor will further assist the 1 cc syringes in maintaining position, while also signaling to the program which type of syringe is being used. The solid backing at the rear of the plunger claw is used in pushing the syringe forward, until it’s inserted into the insulin bottle. The plunger guide at the rear of the main platform will hold the syringe in position while the plunger claw draws the plunger back.

The syringe holder and syringe guides will be made using a lightweight aluminum alloy. Phidget Touch Sensors (www.phidgets.com) will be used to assist in securing the syringe in the holder, in addition to detecting its presence and size.

### 2.1.1.12 Motor and Syringe Interaction

A motor that pulls on the plunger, which extracts the insulin, will fill the syringe. The motor will be a simple DC motor that is controlled by a Phidget chip. This chip will interact with the Laptop controls through a USB cable. These units come with a power supply, which will be available to the user, but the device will be built with batteries as the primary power source for the motor. It only requires 6 V (DC), therefore two AA batteries will suffice.

The motor will also be connected to a potentiometer for accurate readings. Some motors come with potentiometers attached for instant readings of distance, but they are not accurate enough for the purpose of the project. By connecting the motor to a hypersensitive potentiometer, the device will be able to administer doses specific to 1/1000th of a milliliter. The potentiometer to be used is the MW22 Wirewound MultiTurn precision potentiometer.

### 2.1.1.13 Bottle and Syringe Interaction

The syringe tray and insulin bottle will lie in the device next to each other, with the tray lying on tracks shown. Once the machine has reached the point in the loading sequence where the syringe must be inserted into the bottle, the servo will be activated. This servo will move the tray along the tracks until the touch-sensor on the bottle holder has been activated. This sensor indicates that the syringe has met the bottle properly and that filling may proceed.
Should the syringe be loaded incorrectly, or should a syringe of incompatible length be loaded, the touch-sensor will not be activated, and loading will cease. An error message will be displayed to indicate the problem. Though the tray will be moving in a linear direction, a cone has been added to the bottle holder to make sure the syringe needle is directed to the exact spot it is needed. Stops have been added to the tracks to make sure the needle does not go too far, in the event the needle missed the sensor or the syringe loaded was too small for the device. If these stops are touched, while the touch-sensors of the bottle have not been touched, an error message appears on the display.

The syringe tray will lie on two tracks. When the servo is activated, it pushes the tray along the tracks until the syringe meets the bottle.

The rotational motion of the servo is turned into linear motion by sending the arm of the servo through a loop on the tray. With this loop, the 2-dimensional rotary force of the servo, with force vectors in the x-axis (horizontal) and y-axis (vertical) is broken into an x-axis force. The force in the y-direction is allowed to slide through the loop, without pushing the tray. The x-directional force pushes the loop, guiding the tray along the tracks.

### 2.1.2 Design 2

This design differs from the previous design in several ways. Design 1 utilized a laptop as its main component; it was used a display, a processor, and a touch & sound input device. Instead of a laptop, the current design uses several individual components to accomplish the same tasks. A touch input enabled LCD Display (the IntelliLCD) is now used to present information graphically to the user and to get touch screen commands from the user. A CUBLOC microprocessor (the CB-405) will be used to run programs to monitor data from the device’s sensors, communicate with LCD Display and sound synthesizer chip, operate the device’s motor and servo, and implement a simple menu interface for the user to interact with. Design 1’s programming was to be written using Visual Basic; in Design 2 programs will be written using BASIC and Ladder Logic. While the BASIC program will run sequentially, similar to what would be done in Design 1’s Visual Basic program, the Ladder Logic program will run using parallel processing. This programming method will allow the microprocessor to gather data from sensors and control components in real time.

Sound input will be handled by a sound recognition chip (the RSC-4128), as opposed to relying on a software package (Dragon Naturally Speaking), such as that used for Design 1. Although this chip will be somewhat limited in the number of words that it will be able to recognize from voice input, its major advantage over Design 1’s software is that it is speaker independent; it will not require any voice training in order for its pattern recognition processing to work. This sound chip will also be used to synthesize speech for system prompts and other audio output.

The syringe platform assembly has been modified from Design 1; the syringe is now incased in a moveable drawer which will be accessible from the rear of the device. The C-shaped guides for holding the syringe have been replaced with grips which will maintain its position.
while allowing easier access for insertion and removal of the syringe. The previous Design 1 accomplished movement of the platform through the use of a linear gear; in the current design a screw gear has been implemented. Previously the stopping of the servo motor was controlled using a sensor; in this design precision movement of the servo will be done using the microprocessor.

The bottle holding assembly has been altered from the original design; instead of implementing an expanding plastic sleeve, a housing will be constructed with four flexible metal brackets. Additional space with be left between the brackets to make it easier for users to reach in and extract bottles. A bottle removal tool will also be incorporated into the housing to further aid users in lifting bottles up and out of the device.

In Design 1 the sensors for the device were pre-built modules that could communicate with the laptop via its USB port. In the current design the sensors are constructed using individual electrical components. These components will be directly connected to the CUBLOC microprocessor.

In the Design 1 the energy needs for the various components of the device were met mostly by drawing power directly from the laptop’s USB ports. In this new design, rechargeable batteries will be used to power all of the components of the design.
2.1.2.1 Monitor/Touch Screen: IntelliLCD

The intended monitor for the design is expected to be IntelliLCD iTL710 by Comfile (cubloc.com). It is relatively inexpensive compared to laptop alternatives. Similar to the once considered portable PC, IntelliLCD has a screen size of 7 in, diagonally. The IntelliLCD screen is also colored and is powered by ~24 V. It features a 1 GB secure digital (SD) card that is removable and can be upgraded with a maximum of 2 GB.

With timekeeping chip, such as the DC1302, the device will be capable of keeping time-stamped records of doses drawn. The chip contains a real-time clock/calendar and 31 bytes of SRAM. By a simple serial interface, the chip communicates with the CUBLOC. The clock operates in either 24- or 12-hour format with AM/PM indicators. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information and is automatically adjusted for months with less than 31 days and also makes corrections for leap year [17].

Additional input slots included on the IntelliLCD are a USB host and device (ActiveSync), RS232, serial port (5 V), and a communications speed switch. ActiveSync software is used to link IntelliLCD with a PC. Although IntelliLCD has a touch screen, adding a mouse or keypad by USB port can allow the user to also make selections. A USB hub can be used to for the device to control by mouse and keypad.

IntelliLCD receives data through the RS232 port. Programs administered by the IntelliLCD can be built with a CUBLOC chip. The chip is attached to a study board that includes two RS232 connection sites. BASIC and/or Ladder Logic languages encode CUBLOC. The advantage of using BASIC is that for those building the program, they don’t need to be familiar with it in order to use it properly because of its simplicity. The language-built program can also be tested for operation status or function with IntelliLCD by being connected to the PC, building the program, by another RS322 port. The CUBLOC CB405 can have up to 200 KB of programmable memory. It has an operating voltage of 4.5 to 5.5 V.

To download the program built on a PC to the CUBLOC board, an USB-to-RS232 converter can be used. When disconnecting IntelliLCD with a PC, the main program is stored on the internal flash memory of CUBLOC and can be retained without power. With the CUBLOC device, the program can be downloaded, modified, and erased an unlimited amount of times.

An Internet modulus, XPORT, converts RS232 signals into TCP or UDP packets. Using the Internet, XPORT can be used in-sync with CUBLOC to download and monitor programs. This means that the programmer can gain access to the device anywhere in the world by use of the Internet. Such a feature is important for distributors of the device to provide customer support and access problems associated with it.

2.1.2.2 Voice Recognition: RSC-4128
RSC-4x Series from Sensory, Inc. (www.sensoryinc.com) is a speech recognition and synthesis microcontroller family. The one-chip design of RSC along with a battery, microphone, speaker, and a crystal or resonator is combined to perform the necessary duties required of the design. The single-chip RSC-4x series is an 8-bit microcontroller. The RSC-4128 model offers an increased amount, 128 KB, of ROM, over the other model, and includes an optional real-time clock. The chip maximizes battery live with a 2.4 – 3.6 V operation. Its typical operating current at 3 V is 12 mA and the RSC-4128 chip has two low power modes.

RSC-4128 operates with FluentChip™ technology. With this technology, in occasions presenting noise, great accuracy is improved. In addition, FluentChip™ technology creates the ability of speaker independent (SI) recognition vocabulary. However, speaker dependent recognition is also available. SI vocabularies create a large population for potential users because it is independent of accents and certain disabilities. Speaker independence also cuts down on training between manufacture and client, and helps to make the device cost effective. This method of recognition can recognize up to 30 words, which is limited by the internal ROM size. With FluentChip™ multiple languages can be accessed for users of the device.

An additional feature of RSC-4128 is Audio Wakeup. This allows the user to start the device when the chip is in power down mode. By simply clapping or whistling, Audio Wakeup will wakeup the device for speech or application tasks. Such a feature is especially useful for the syringe-loading device because it allows minimal battery usage for a device that can be continuously listening. Speaker Verification is also a feature that is appealing because of its voice password capabilities. To access the Speaker Verification feature, the target user speaks the previously trained password. A third available feature, Word Spotting, lets RSC-4128 to spot specific words surrounded by other speech within a phrase. Due to user limitations, being able to spot specific words among phrases is important.

Easy-to-use tools allow developers to record and compress voice recordings for playback specified by the program. These “voice memos” can use either 8 bits (64 Kbps) or 4 bits (32 Kbps) per sample. To compress the speech, external parallel or serial bus Flash or SRAM is required. The recorded information, by the programmer of the syringe-loading device, will be the prompts directed at the user for insulin dosage amounts, verification and any additional instructions or questions. These recordings will be played for the user upon instruction from the programmed CUBLOC chip.

With the addition of an external microphone, an audio signal is passed to the preamplifier and the analog-to-digital converter (ADC) to convert the incoming speech signal into digital data. The speech features are extracted using Digital Filter engine. The microcontroller then processes the speech features using speech recognition algorithms in firmware. This resulting speech recognition results can be ran through the programmed CUBLOC chip for further implementation. This is possible by the included three-bidirectional 8-bit I/O ports that allow the processor to interact with external devices [18].

2.1.2.3 Programming
The programs that will control the main functions of the syringe-loading device will be written in both BASIC and Ladder Logic. The Ladder Logic program will communicate with all the sensors simultaneously, using a parallel processing approach, [19]. Data will be able to be received continuously, allowing the program to acknowledge voice or touch instructions from the user in real time. Real time sensor readings will also be used to ensure that the bottle & syringe are securely in position throughout the syringe loading process, and that the device remains in the correct orientation. Any bottle & syringe position problems or orientation issues will cause the loading process to pause until the condition is corrected. Real time sensing will also be used in operating the motor for drawing the syringe’s plunger; as the plunger is drawn back the potentiometer will be continuously monitored until the calculated resistance value is reached.

The BASIC program for the device will handle all communication with the LCD Display and the sound chip; by accessing the memory that is used by the Ladder Logic program, it will be able to determine if the user is entering data and/or commands via touch or voice input. In addition to reading Ladder Logic memory, the BASIC program will also be able to write to it; allowing it to affect the processing flow of the Ladder Logic program. This will allow the BASIC program to indirectly control the device’s servo and motor operation. The BASIC program will be used to implement a simple menu from which users can choose to view past dosage information or prepare a new dose of insulin. Menu prompts, data, and error messages will be communicated visually using the LCD Display and audibly using the sound chip and speaker connected to it.

2.1.2.4 Bottle Holder

This component needs to securely hold a bottle in a vertical position while a syringe extracts insulin from it. In order to accommodate a wide variety of bottle sizes and shapes, flexible metal brackets will be created and installed in the device case. The top part of each bracket will be affixed to the top of the case, while the bottom arm of the bracket will press against the side of a cylindrical housing. Four brackets will be placed within the housing, in an equally spaced arrangement. When a bottle is lowered into the bottle assembly the brackets will compressed against the sides of the bottle. Pressure from the brackets against the sides of the bottle will automatically center and secure it into position. When attempting to remove a bottle from the device, the space in-between the brackets will make it easier for the user to reach down and get a better grip on its sides. For those users that may have difficulty in reaching into the device to remove the bottle, a bottle removal tool has been incorporated into the assembly’s design. The user can pull up on the two straps of the tool to lift the bottle up and out of the assembly. In order to allow easy access to the bottle assembly, the cover to it will be held in place by two Velcro straps.

2.1.2.5 Motor and Potentiometer
For this design, the plunger will be moved by a brushless DC motor. The one selected is the EC 20 Flat Motor (Part No. 241916) by Maxon Motors (http://www.maxonmotorusa.com/EC_motor.asp).

It requires 9 Volts of DC potential, and will provide the power needed with limited heat and noise. This motor will interact with a potentiometer through the use of gears, according to the figure below. The gears will be on both the motor and the potentiometer. The potentiometer selected is the MW22 Wirewound Precision Multi-Turn Potentiometer by ETI Systems (http://www.etisystems.com/mw22.asp). This potentiometer has an accuracy tolerance of only 0.09% in some places, allowing for excellent precision in distance readings. The loading device will use these two devices to pull the plunger of the syringe by according to the user input. Once the user has input the amount of insulin desired, the device will calculate the distance the plunger must travel to achieve this volume. Then, the device will calculate the resistance that must be met by the potentiometer to achieve this distance using a preprogrammed function. The motor will turn the screw, which moves the plunger, at the same rate it turns the potentiometer. The resistance reading will therefore have a linear relationship with the distance the plunger has moved. It will simultaneously turn the potentiometer until it reads the desired resistance, indicating that the calculated distance has been achieved. The device will then fill the syringe an additional amount, then expel this additional amount in an effort to remove any air bubbles that may have formed. As the motor turns the screw, the potentiometer turns with it to mark the distance traveled as a function of resistance. As the screw turns it moves in a linear motion, pulling the syringe plunger with it.

2.1.2.6 Syringe Tray and Motor

The syringe tray will be made out of lightweight aluminum, with groves for the syringe, and a slot for the plunger grip to slide though. There are also two sensors present in the syringe tray. One sensor tells the processor that a syringe is in the tray, and the other tells the microprocessor that a syringe of 100 units is present. If the first sensor states that a syringe is present, while the second sensor does not confirm that a 100 unit syringe has been loaded, the device assumes a 50 unit syringe has been loaded. The sensors are simple switches that have a normally open characteristic. The switch chosen for the design is the Omron 3635 Momentary Switch (http://www.sciplus.com/category.cfm/subsection/14/category/143). Also, Velcro straps will be added to the tray to secure the syringe during loading.

2.1.2.7 Syringe and Bottle Interaction

The syringe tray, motor, and potentiometer will be placed into a “drawer” so the syringe can be moved to the insulin bottle during loading. The motor and potentiometer will move with the syringe and syringe tray, so the wires that power them and connect them to the microprocessor will be longer. To make movement possible, a servo will be employed. This servo will move the drawer along tracks when the device prompts it to. Because the device
knows the size of the syringe, because of the sensors in the syringe tray, it knows how far to move the drawer. It will move the drawer a short distance when a 100 unit syringe has been inserted and a slightly farther distance when a 50 unit syringe has been loaded. The servo will be able to move the drawer the specified amount, and hold it there, until the microprocessor stops sending a signal to it. The servo chosen for this task is the Futaba S9252 All-Purpose Servo (http://www.gpdealera.com/cgi-bin/wgainf100p.pgm?I=FUTM0222). This device requires 6 volts from the power source.

When activated by the microprocessor, the servo will move everything inside of the drawer along small tracks embedded in the device case, towards the insulin bottle.

2.1.2.8 Orientation Sensor

The orientation sensor is a very simple device. It consists of a cone, a ball bearing, and a Omron 3635 Momentary Switch (http://www.sciplus.com/category.cfm/subsection/14/category/143). To prevent the accumulation of air bubble inside of the syringe, the device will only load the syringe when the bottle is over it. The orientation sensor enables the device to check that this arrangement is satisfied. When the device is properly positioned, the ball bearing will fall on the switch, completing a circuit. If the circuit is complete, the loading process may continue. If the circuit is not complete, it means the bearing is not on the switch, and that the device is not in the correct position. In this case, loading will not be allowed to commence.

2.1.2.9 Batteries / Charger

The components for the automated syringe loader will be powered by rechargeable batteries. In adding to together the voltage needed for the various electrical components it was determined that the device would require approximately 30v of power. To meet this energy need three AirSoft 10.8v rechargeable batteries will be incorporated into the device. A charging module will be built into the syringe loader’s case so that a detachable power cord will be able to be plugged into a standard wall outlet for charging the device’s batteries.

2.1.2.10 Case Layout

A plastic case will enclose the automated syringe-loading device. The front of the case with have a vertically positioned touch screen monitor, a microphone, and a speaker. The bottle loader door (on the top on the device) and syringe loading door (located in the lower right portion of the device) will be secured using Velcro flaps.

2.1.3 Design 3
The third alternative design for the automated syringe loader features many changes and improvements over previous designs. First of all, the display and input controls have been changed to a graphical LCD, and a 4x4 programmable keypad by Comfile Technology. The display intended for use is the GLK12232-25-WBL graphical LCD display. It is a small display but with the use of available font types and sizes, the characters will be maximized on the screen. With the use of the voice output, the user will have a different method of communication with the device. An advantage to the GLK12232-25-WBL display is that the dimensions of the overall casing of the device will not be influenced by the size of the display. This design communicates by an external microprocessor that also directly communicates to the user through the keypad, unlike the previous designs where the communication is dependent upon the monitor’s specified microprocessor. The keypad being used is a 4x4 programmable keypad. By using a programmable keypad, the team will be able to specify the communication between the user and the device, similar to the previous intended touch screen keypad. However, this is much different than previous keypads being used because it is an external one, whereas the previous were all contained in the touch screen monitor.

The voice output used for this design is the DoubleTalk RC8660 chipset. This is a text-to-speech synthesizer that will receive text from the microprocessor and output speech through the use of a simple speaker. Earlier designs called for voice input capabilities, but this was deemed unnecessarily expensive, given that many diabetes patients may have trouble using it. Diabetes can cause voice tremors in patients, and lower their ability to speak loud and clear. The DoubleTalk chipset will make interaction with the device easy by converting text to speech, and loudly presenting the user with clear instructions and information.

The use of the CXTA02 tilt orientation sensor will determine the proper positioning of the syringe-loading device. The difference from previous designs is that this is a self-contained device that connects to the circuit. The sensor determines the magnitude of gravity parallel to the sensor element.

The microprocessor and the programming were also changed for design three. The previous design utilized a CUBLOC microprocessor that was capable of running programs written in BASIC or Ladder Logic. The BASIC programs utilized a serial processing method while the Ladder Logic programs used a parallel processing approach. The PIC24FJ128GA006 microprocessor that is being considered in this design will be able to run programs written in C or assembly code. The processing flow will be mainly serial in nature; the use of hardware interrupts however will allow programs to react to changes in sensors, key presses, etc. as they occur. In the previous design a separate clock/calendar chip was needed to provide the device with the date/time information that was required when storing syringe dosage data. Since the PIC24 microprocessor has a built in Real Time Clock/Calendar module which can provide this information, this chip is no longer needed. The current microprocessor has less total memory than the CUBLOC processor (128Kb vs. 200Kb), but that shouldn’t be an issue. Unused memory on the DoubleTalk sound synthesizer chip can be accessed and used by the microprocessor to store additional data. Both the CUBLOC and the PIC24
microprocessors can interact with external devices using parallel port and serial port communication. The PIC24 also has two Inter-Integrated Circuit modules (I²C) which can be used for communicating with other device components.

Since the energy needs have changed, the power supply for the device was changed from several large battery packs to a few small rechargeable batteries. The previous device’s design used relatively bulky and heavy rechargeable batteries. The Li-Fe-PO₄ batteries used in the current design take up approximately 40% less space than the previous batteries and weigh 30% less, while providing the syringe loader with the same amount of power.

The bottle holder assembly was re-designed to make it more accessible and make the bottle insertion/removal process more intuitive. Instead of a top case approach, in which the bottle is dropped into and lifted out of the case, a hinge cover is now being used to provide access to the inside of the bottle holder assembly. The process of changing bottles has been modeled after the same steps that are typically followed to change C or D size batteries.

This holding unit needs to interact with the syringe, by having the needle puncture the bottle lid for insulin extraction. To do this, the insulin holder has been set onto tracks, which it will move along to reach the syringe needle. A small servo moves the bottle and holder as a unit towards the needle a short distance, which varies depending upon the size of the needle.

Probably the biggest improvement to the syringe loader implemented in this third design is the syringe cartridge. This is an internal extruded pentagon that holds up to five syringes in place for the user. The cartridge holds one of five syringes to the motor for filling, and then rotates to present the filled syringe to the user at a window on the side of the device. Each syringe is held in place by a simple clip and two stabilizing prongs, in one of five positions along the cartridge sides called bays.

Since the cartridge has to turn to move syringes from the user to the insulin bottle, the motor had to be disengaged from the syringe bay during movement. This was accomplished by housing the motor in a casing along with a potentiometer that is used to monitor its movement. These enclosed parts move along tracks by way of a servo, to and from the syringe for loading. The motor and potentiometer work together the same way they did in the previous design, and the plunger grip still works by being pulled along a screw.

2.1.3.1 Display: GLK12232-25-WBL

The display chosen is the GLK12232-25-WBL by Matrix Orbital. It is a simple graphical LCD display. The GLK12232-25-WBL is designed to be the display unit for an associated controller. The microcontroller will have control over what is displayed on the screen by connection through I²C port. The module size is 98 mm x 60 mm x 13.5 mm (l x w x t). The display size is 76 mm x 25.2 mm, which is relatively small, however, the font size will be maximized to fill out the screen and to appeal to users of the device. The background color of the screen is white and the text color is blue. Since the display is a bit mapped device, graphics would be able to be displayed, if the team chose to do so.
Through the use of programming, different text fonts and graphics can be used and stored in the display’s flash ROM. In power-off modes, the device is able to retain such selections, which will not be changed unless done through reprogramming. The display has a backlight for low-light areas that it is used. The backlight will be on indefinitely while the device is powered on. Adjusting the contrast of the screen can be used to determine the best seeing capabilities for the users of the device. To maximize the display features of the GLK12232-25-WBL, Matrix Orbital offers an interface program that is used to manage font and graphics downloads. This program, “mogd.exe” is provided by CD and a PC can be used to select these features, which are incorporated into the programmed microprocessor.

The GLK12232-25 receives characters and positions them one after the other, as they are received. The feature “auto scroll” will be used to shift the display’s contents up to make room for a new line of text when the text reaches the scroll position set by the “Set font metrics” in the display memory. The “Set font metrics” command is used to determine where on the display the characters will begin to be displayed.

The display also allows the programmer to test the display by connecting directly to a PC. To do so, a PC cable along with the required 5 V power supply is required. To successfully test the display, characters on the keyboard typed should appear on the display of the GLK12232-25. However, keys such as backspace, delete, and clear will not have an effect on the input to the display during testing. The screen displays characters by wrapping the text around to the next line when the end of the line has been reached, which is dependent on the font size being used. This feature can be used to select the appropriate font style and size that will work best for patients with visual disabilities.

2.1.3.2 Data Input: 4x4 Programmable Keypad

The keypad chosen to communicate between user and the syringe-loading device is a 4x4 programmable keypad by Comfile Technology. The size of the keypad is 76.3 mm x 68.8 mm. If desirable, extensions can be made off of the keys to enlarge them, making it more accessible to users with disabilities that may inhibit the correct selection. The team will program the device with numbers 0 through 9, “.”, “YES”, “NO”, “ENTER” and “CLEAR”. The keys will be appropriately labeled in English letters as well as Braille.

Keystrokes are first routed through the microcontroller before displaying on the GLK12232-25-WBL. The keypad connector will be wired with columns on one side and rows on the other side of the connector. They keypad will be directly connected to the PIC24 chip.

2.1.3.3 Text-to-Speech Output: DoubleTalk

The DoubleTalk chip RC8660 by RC Systems will be used as a voice synthesizer. This component is required by the design because the device must be able to read input prompts, input values and verification prompts. The DoubleTalk chip is a text-to-speech processor that translates pain English into speech in real time. The chip does not require a PC or high-powered processor to work. DoubleTalk RC8660 requires 4 mA of operating current at 3.7 V
to run and as little as 0.7 μA when not in use. The RC8660’s audio output would be in analog format for simple instructions and questions for the user of the device to answer by keypad.

Commands for the DoubleTalk RC8660 will be selected based on user disabilities that are using the syringe-loading device. The speech rate will be adjusted to a rate between slow and medium, most likely 2 or 3S where 0S is the slowest rate, 13S the fastest, and 5S being default. The one voice chosen, of the available 11, to speak the text instructed by the microprocessor will be one that has a favorable pitch and tone. An audible “reminder” option can also be selected to sound every ten minutes, resetting every time the device has finished being used, to remind the user that the device is on. This feature can benefit the total device by allowing power-saving abilities on the user’s behalf.

All of the data for the RC8660 is sent through the built-in serial and/or parallel ports. The chip’s Peripheral Input/Output Bus will be used to communicate with the microprocessor’s parallel master port. It is an eight-bit bidirectional peripheral bus that sends text, data and commands. Data is input from a peripheral when PRD# is active. PRD# is an output called “Peripheral Read” that controls the transfer of data from a peripheral to the RC8660. Data is read from the PI00 – PI07 when PRD# is low. Status information is output when STS# us active. The STS# is an output “Status” that controls the transfer of status information from the RC8660 to a peripheral. Status information is driven on the PI00 – PI07 pins when STS# is low. This function is only active when there is new status information.

The RC8660 chip will connect to the microprocessor using its Bus/Printer interface. This interface will allow 8 bit data communication to be established between the sound synthesizer chip and the microprocessor’s Parallel Master Port. Using this method of data transfer, commands and data will be able to be sent to the sound chip, and status codes will be able to be sent back to the microprocessor. The microprocessor will control all of the interactions with the RC8660 over this system data bus using the read (RD) and write (WR#) signals. RD controls the reading of the RC8660’s Status Register and WR# controls the transfer of data into the RC8660 DoubleTalk chip.

**2.1.3.4 Orientation Sensor: CXTA02**

An orientation sensor is required by the device to assure that the device is standing properly in order to load the syringes with insulin. Without such a sensor, the possibilities of loading air instead of insulin are possible if the insulin vial is not in a downward direction. The sensor intended for use is the CXTA02 by Crossbow and is a dual axis analog tilt sensor. The CXTA02 has a small size of 24.1 mm x 50.8 mm x 30.5 mm and is packaged in a lightweight aluminum case. It can be affixed to the inside of the syringe-loading device by screws or adhesive. The sensor uses a 5 V power supply. The device has great accuracy to within ± 0.5° over the angular range. The device can make angle measurements up to 75° in tilt range.

The CXTA02 tilt sensor uses a micro-machined acceleration-sensing element with a DC response to measure inclination relative to gravity. The response of the tilt sensor is
dependent upon the magnitude of gravity parallel to the sensor element. The output of the
tilt sensor will be an offset voltage plus the voltage response proportional to the amount of
gravity measured by the sensor. For angles less than 20°, a linear relation between $V_{\text{out}}$ and
the tilt angle in radians can be approximated. To accurately measure the tilt angle the angle
Eq. 1 is evaluated for $\phi$.

$$\phi = \frac{180}{\pi} \left( \frac{V_{\text{out}} - \text{Zero Angle Voltage}}{\text{Sensitivity}} \right)$$

Equation 1: Tilt Angle Equation

To solve for Eq. 1, $\phi$ can be set to zero, and therefore the device will be properly orientated
when:

$$V_{\text{out}} = \text{Zero Angle Voltage}.$$ 

The Zero Angle Velocity will be calibrated before use.

By properly connecting the CXTA02 to the microprocessor board, the information can
complete the circuit and the loading process can begin.

2.1.3.5 Microprocessor: Microchip’s PIC24FJ128GA006

Microchip’s PIC24FJ128GA006 was selected as the microprocessor to use for the current
design of the syringe loading device. The PIC24 will interface with all of the device’s
electrical components. It will receive information from the various sensors and the keypad
through use of its Capture Input ports. Input Change Notification will be configured for
these ports to allow the microprocessor to react to changes in status. Communication with
the GLK1232-25 graphic display will be accomplished through the use of one the built-in Inter-Integrated Circuit modules. Commands and data will be sent to the DoubleTalk sound synthesizer chip via the PIC24’s Parallel Master Port. Status messages from the sound chip can also be received through this port. If additional memory is needed for storing dosage information, available memory space on the DoubleTalk chip can be accessed and written to using the PIC24’s Parallel Master Port.

The microprocessor will also be able to communicate with a computer through the use of its
Serial Port Interface module (SPI). An R-232 port will be linked to pins for one of the
PIC24’s SPI modules. A standard serial cable will be able to connect the syringe loader’s R-232 port to a computer’s serial port; this will enable data to be transferred between them.

The servos and motors of the syringe loader device will be able to be controlled using the
PIC24’s Output ports. These ports are capable of generating both single and continuous output pulses. Since the motors require 6 volts to operate them they will not be able to be
directly powered by the microprocessor (its normal operating voltage is between 2 and 3.6
volts). Instead the outputs will trigger transistors to “open” and to allow the necessary
current/voltage to be sent to the motors.
The microprocessor will perform several functions during the operating of the syringe loader’s plunger motor:

- It will first need to use the syringe’s size and the user’s requested dosage amount to calculate what voltage the mechanical potentiometer (which is attached to the plunger arm) should be generating when the correct amount of insulin is withdrawn.
- The PIC24 will then compute the number of steps the plunger’s stepping motor will need to complete until 80% of the voltage/distance is reached.
- The microprocessor will then operate the motor in “quick” mode for the number of turns it takes to reach 80% of the voltage.
- At that point the PIC24 will send commands to a digital potentiometer, causing it to generate the “target” voltage of the mechanical potentiometer.
- The voltage from the digital potentiometer will be compared to the mechanical potentiometer using the one of the microprocessor’s comparator modules. If the “target” voltage has not been reached, the plunger motor will be powered for one turn, and the processing will pause briefly before evaluating the comparing the voltages again.
- Once the “target” voltage is reached, the digital potentiometer’s resistance/voltage is returned to zero and program processing resumes.

The PIC24 microprocessor can run programs compiled for it by Microchip’s Application Maestro software. This software can incorporate assembly language or C programming files, and can include references to functions in pre-compiled code modules/libraries. Several pre-built code modules can be directly downloaded from Microchip’s website. These code modules greatly reduce the amount of effort needed developing programs for the microprocessor. Serial and parallel port communication can be accomplished through the use of functions at high level; as opposed to having to read and set pin data values individually, and needing to trigger transfer signal pulses directly. One a program is written and compiled in Application Maestro it can be downloaded to the microprocessor using its In-Circuit Serial Programming module.

2.1.3.6 Batteries / Charger: The 32v Smart Charger

The components for the automated syringe loader will be powered by Li-Fe-PO4 rechargeable batteries. In adding together the voltage needed for the various electrical components it was determined that the device would require approximately 30v of power. To meet this energy need 10 Li-Fe-PO4 rechargeable batteries, (each capable of providing 3.2v), will be bundled together into a battery pack. The 32v Smart Charger for Li-Fe-PO4 battery packs, (from BatterySpace.com), will be used to re-charge the batteries when the user is near an electrical outlet. A charging interface port will be incorporated into the syringe loader’s case so that the user will not need to directly handle the battery pack when charging the device.
2.1.3.7 Bottle Holder

This component needs to securely hold a bottle in a vertical position while a syringe extracts insulin from it. In order to accommodate a wide variety of bottle sizes and shapes, foam rubber will be used to grip and support the sides of the bottle. A spring will be used to apply pressure to the bottle’s bottom to ensure it is flush with the syringe needle port. The head of the bottle will be supported by a neck cone, which will assist in centering the bottle’s opening over the syringe needle port. The completed bottle holder assembly should be able to accommodate bottles that are between 12 mm to 40 mm in diameter, and between 40 mm and 70 mm in height.

The bottle holder assembly is accessible to the user through a hinged cover on the back of the device’s case. The cover can be opened by pressing in on the catch in the center of its side and flipping it away from the case. As the cover opens, the foam rubber attached to the inside of the lid will be lifted away to expose the bottle area. The bottle can then be slid backwards to compress the spring and result in the head of the bottle clearing the neck cone support structure. Once clear of the neck, the bottle can be lifted out of the holder assembly. Bottle insertion would involve placing the bottle’s bottom against the spring and compressing it, positioning the bottle head into the neck cone, releasing the bottle, and closing the cover to the holder assembly. This approach to bottle insertion and removal was modeled after the process that’s typically followed to replace C or D size batteries in most electrical devices. By basing the bottle replacement process on steps that are fairly well-known it is hoped that most users will find the bottle holder assembly simple and easy to use.

2.1.3.8 Insulin Bottle Movement

To fill the syringe, the insulin bottle will move towards it. In previous designs, the syringe moved to the insulin bottle, but this would have been difficult with the addition of the syringe cartridge, so the simpler action of moving the small bottle holder was chosen for this design. To accomplish this action, the holder will be made with small groves along the bottom, which will slide along tracks laid in the device case. A servo will move the holder along these tracks to and from the syringe needle. After the user has placed an insulin bottle in the holder, the user pushes the holder back into the device. As the holder slides inside, a hook on the servo arm catches the holder by a small loop attached to the bottom. When the device is ready to load a syringe, the servo lowers the arm, and the bottle holder slides along the tracks. A sensor on the syringe holder will tell if the syringe is ½ or 1cc, and the servo will move the holder a distance determined by this size. A larger syringe will require that the bottle move a shorter distance than a smaller syringe will. The ½ cc syringe needs the bottle to move a longer distance, \( X_a \). The 1 cc syringe needs the bottle to move a shorter distance, \( X_b \). Sensors on the syringe bay tell the device that a syringe is present, and indicate its size.
The servo chosen for this task is the Futaba S9252 All-Purpose Servo. This selection will provide the necessary power required to move and hold the insulin bottle, without drawing too much power or adding too much weight.

2.1.3.9 Syringe Cartridge

The syringe cartridge is the biggest change seen in this design. It is an extruded pentagon, with each side containing a syringe bay. Each of these bays has two sensors, a syringe clip, and two syringe stabilizers. The first sensor is used to detect the presence of a syringe. If the sensor does not detect a syringe, the device knows that bay to be empty. When loading is about to occur, the device will cycle through the syringe bays until a syringe is located for filling. When the user wishes to add more syringes to the cartridge, the device will present the empty bays to the user. The second sensor detects the size of the syringe. When a ½ cc syringe is in a bay, it does not depress the second sensor. A 1cc syringe, however, will depress the second sensor. This information is used to tell the servo that moves the insulin bottle how far to travel. When the device is ready to load, it will move the syringe bay in position below the insulin bottle, then lower the bottle the required distance. This information is also used when the user inputs the dosage amount they require. If the syringe in the bay is too small to hold the requested dosage, the device will search the bays for a larger syringe.

The cartridge was designed with a stepper motor located in the middle. This allows the device to rotate without extra parts, and saves space in the case. This stepper motor is an Applied Motion size 23 Stepper Motor (#4023-819). It will be able to rotate the cartridge to precisely place the syringe bay in position, so that the syringe is below the insulin bottle and in line with the plunger grip. The motor holds fast to the cartridge with a 5-point wheel that attaches to 5 spots on the cartridge. Using this many connection points prevents slipping, and makes sure the device stays attached, in case one point of contact fails.

The syringe clip is an adjustable adhesive-backed wire clamp made by Micro Plastics, Inc (part # 22AAwC310400). Its design was modified for use. A ring of foam rubber was inserted into the middle to grip the syringe tightly, without crushing it. The two stabilizers work to hold the syringe up when the plunger is being pulled down. These are simple two plastic rods that have been inserted into the syringe cartridge.

2.1.3.10 Syringe Loading

The syringe is loaded by a claw pulling on the plunger. This plunger claw operates in a manner very similar to the second design. A motor turns a screw and a potentiometer simultaneously. As the screw turns, a nut on the screw is forced up or down depending on the direction of the screw’s rotation. As the nut moves, the plunger claw attached to it moves as well. This motion moves the syringe plunger when the claw and plunger are together. The simultaneously rotation potentiometer increases in resistance as it turns, which is used in a computer program to determine the distance traveled by the plunger.
First, the potentiometer is hooked up to an inverting amplifier. Using the equation of gain for inverting amps,

\[ \frac{V_{out}}{V_{in}} = \frac{R_f}{R_t} \]

Equation 2: Gain of an Inverting Amplifier

and by locating a potentiometer at the position \( R_t \) changes the output voltage of the circuit. As the motor turns, the potentiometer’s resistance values increases, and the output voltage increases. This output voltage is sent to the computer to be compared to the voltage coming from the digital potentiometer.

To load the syringe, the cartridge rotates the selected syringe bay below the insulin bottle, and in line with the plunger claw. After the insulin bottle has been lowered to the syringe needle, the plunger claw then moves to the syringe plunger, and pulls it down. To get the plunger claw, and the motor and potentiometer that are attached to it in place, a servo moves them along tracks in the case. The servo is the same Futaba All-Purpose Servo as the one used to move the insulin bottle.

The motor selected is the Applied Motion size 23 Stepper Motor (#4023-819), and the potentiometer chosen is the MW 22 Wirewound Precision Multi-Turn Potentiometer.

2.1.3.11 The Case

The case will consist of a plastic outer shell, where the keyboard and display will be mounted. On the back, the door for the insulin holder will appear, and the plug for the battery charger will be at the bottom of the rear side. The hump on the right side of the case encloses the syringe cartridge. Under the hump, there is a hole for the extended syringe handle. The slit that extends the length of the hump is the window through which the syringe can be inserted or removed. A clear plastic window will be present over this bump, to ensure nothing falls out of the device while it is being carried, and that no dust or other foreign particles get in.

2.2 Optimal Design

2.2.1 Objective

This is the optimal design for an automated syringe-loading device. The automated syringe loader is a device designed to simplify the lives of diabetes patients by enabling them to fill their prescriptions without the help of another person, thereby supplying them with independence and confidence. Diabetes is a disease that affects the body and its blood sugar level, and it currently affects more than 20 million Americans. Those with diabetes have trouble naturally producing or utilizing insulin, a hormone that transforms sugar into energy. To correct this, diabetes patients need to monitor their blood sugar levels, and inject
themselves with appropriate amounts of insulin. While this is not a particularly difficult task in and of itself, diabetes compounds the difficulty of this task by affecting patients with a list of other problems that can include low vision and trembling hands. These problems make filling a syringe with accuracy extremely difficult and dangerous.

The device will assist patients by filling insulin syringes for them. All the user is required of is load syringes into the device, one at a time, and load an insulin bottle into a specially designed holder. With these materials, the loader will take insulin dosage amounts from the user that range from 0 to 100 units, increase in increments of 0.1 units, and automatically fill the syringe for the user precisely, with accuracy within $1/1000$ of a milliliter. For ease of use, this device will implement a voice output, large character controls, and a clearly visible display.

The optimal design for the automated syringe loader is a result to the optimal changes and improvements over the three alternative designs. In choosing the GLK240128-25 graphical LCD screen, the best and most practical expectations for device and user interaction can be achieved. A main advantage to this LCD module is that many processors are able to interface with it, making the choosing of a microprocessor much easier. It is much larger than previously considered LCD modules, 130 mm diagonally. It is also has a low cost and included 4 x 4 keypad that connects directly to the screen. The device will utilize a large font point to appeal to many users. The familiarity of a regular keypad may also appeal to older users of the device who may be intimidated by touch-screen keys once considered.

The voice output used for this design is the DoubleTalk RC3660 chipset. This is a text-to-speech synthesizer that will receive text from the microprocessor and output speech through the use of a simple speaker. Earlier designs called for voice input capabilities, but this was deemed unnecessarily expensive, given that many diabetes patients may have trouble using it. Diabetes can cause voice tremors in patients, and lower their ability to speak loud and clear. The DoubleTalk chipset will make interaction with the device easy by converting text to speech, and loudly presenting the user with clear instructions and information.

The use of the CXTA02 tilt orientation sensor will determine the proper positioning of the syringe-loading device. The difference from previous designs and why it will be chosen as an optimal one is that this is a self-contained device that connects to the circuit. The sensor determines the magnitude of gravity parallel to the sensor element.

For the optimal design of the syringe loading device the PIC24FJ128GA006 from Microchip was chosen as its microprocessor. This microprocessor (excluding the cost of its development kit) was the least expensive of all the processors being considered, and yet it provides the most flexibility in regards to inter-component communication. The PIC24 can use both serial and parallel port communication to interact with other components, in addition to having two Inter-Integrated Circuit modules ($^{1}C^2$), which can also send and receive data to other system devices. Having many communication options to choose from allows for greater flexibility in the device’s design. If one method of communication isn’t working with a component, another approach can be taken. Having multiple methods of communication also
allows for a greater selection of possible parts for the device. If a component in our original
design needs to be replaced with some other part, the chances are good that the PIC24 will
still be able to interface with it directly.

Another plus of the PIC24 microprocessor over some of the other processors that were
considered was that it has a number of built-in modules that handle functions such as
analog-to-digital conversion, voltage comparison, and date/time tracking. These functions
would otherwise need to be carried out by external components and their results would
need to be transmitted back to the microprocessor after they had been computed. Having
these modules built directly into the microprocessor, allows these functions to be executed
quicker and easier.

The batteries and charger components that were selected for the optimal design were
significantly smaller and lighter than those that were being looked at in earlier design
approaches for the syringe-loading device. 10 Li-Fe-PO4 rechargeable batteries will be used
to provide the device with approximately 30v power. This is more than will typically be
needed by the device; only in a worst case scenario in which almost all of the electrical
components, (the display, microprocessor, sound chip, sensors, potentiometers, and one or
more of the motors), need to be active simultaneously would the device come close to
needing that amount of voltage.

The selected batteries and charger will be able to provide more power than our current
design approach requires. This allows for flexibility in the device’s implementation; if later
on different or additional components need to be incorporated into the syringe loader,
having enough power for them shouldn’t be a concern. Once the prototype has been
completed, and any power saving options or design changes have been implemented, any
unneeded batteries will be removed from the device.

For the optimal bottle holder assembly design, we decided to use a hinge cover approach to
allow direct access to the bottle area, as opposed to a top case approach, in which the bottle
is dropped into and lifted out of the syringe loader through a circular opening. The process of
changing bottles has been modeled after the same steps that are typically followed to change
C or D size batteries. By patterning bottle insertion and removal on a fairly well known
procedure, it is hoped that users will find the bottle changing process to be intuitive and easy
to use.

For the interior of the bottle holder assembly we decided to use foam rubber pads, a neck
cone, and a spring to support and hold the insulin bottle in position while doses are being
prepared. This approach provides greater accessibility to the holder area; allowing users
more room in which to grasp and manipulate the bottle. The foam pad/spring method of
bottle support also has the advantage of being cheaper and easier to implement than the
expandable plastic sleeve and the flexible metal strut assemblies that were also being
considered.

The syringe holding unit needs to interact with the syringe, by having the needle puncture
the bottle lid for insulin extraction. For the optimal design of the insulin bottle component,
the insulin holder has been set onto tracks, which it will move along to reach the syringe
needle. A digitally controlled servo moves the bottle and holder as a unit towards the needle a short distance, which varies depending upon the size of the syringe. The servo will know how far to move the bottle, utilizing sensors on the syringe holder.

While most assistive devices have the user insert syringes one at a time, this design will hold up to 5 syringes for quick and easy loading. The moving syringe cartridge accomplishes this. The cartridge is a platform for syringe placement, shaped like an extruded. To load the syringes, the cartridge holds one of five syringes to the motor for filling, and then rotates the cartridge to move the loaded syringe and present it to the user at a window on the side of the device. Knowing the effect diabetes can have on patients, each syringe is held in place by a simple clip and two stabilizing prongs, in one of five positions along the cartridge sides called bays. This design makes it easy for users to put in and take out syringes.

Since the cartridge has to turn to move syringes from the user to the insulin bottle, the motor had to be disengaged from the syringe bay during movement. Otherwise, there would need to be one motor per syringe bay. Creating a power source for loading the syringes that could move to and from presented syringes was accomplished by housing the motor and its attachments in a casing. The potentiometer that is used to monitor the syringe loading movement is packed in the casing along with the motor. These enclosed parts move along tracks by way of a servo, to and from the syringe for loading. The potentiometer monitors the syringe loading by turning with the motor. As the motor turns, the syringe plunger moves, and the potentiometer increases its given resistance. This creates a simple linear plot of changing plunger position against changing resistance. Manipulating these values gives the devices microprocessor a constant of the loading procedure.

In completing the optimal design report, the team was able to put together a parts order list (see Appendix, Table 1). The team is currently planning on spending 75% of our allowable budget (which has a maximum limit of $2,000). This budget is being provided by the Rehabilitation Engineering Research Center’s (RERC). The components involved in the current budget are explained in the following subsections. The most expensive single-component anticipated so far is the DV164033 Explorer 16 Kit, however this will be extremely useful in being able to work with the microprocessor over the break to get a better idea of what will be involved in writing the program for it.

Below is the current case design and internal component layout that is being considered for the Automatic Syringe Loading Device. The device’s case and layout will be discussed in further detail at the end of the Optimal Design’s Subunits section.
Figure 1: Case External Design (left) and Internal Component Layout (right)
2.2.2 Subunits

All of the parts in this design work together to carry out the actions outlined here. These are the action steps of the syringe-loading device.

1) Load Syringes
   a. The user can go to the main menu of the device, and select “Load Syringes”
   b. The user selects “Load New Syringes” or “Replace Syringes”
      i. “Load Syringes” moves to step 1e
      ii. “Replace Syringes” tells the device to move the cartridge to an empty bay so a larger syringe can be placed
         1. The syringe size is detected by an extra sensor on the syringe bay
            If no bay is empty, the device moves to syringe bay 1, and the user replaces the syringe with a larger one
         2. After the syringe is replaced, the user presses “OK” and the device proceeds with the next step
   c. If the user continues with the loading process without inserting syringes, and when filling is about to begin, the device realizes the syringe cartridge is empty, it will go to the load syringes screen, and follow the same steps as the “Load Syringes” selection
   d. All syringe bays on the cartridge will have sensors to detect the presence of syringes.
   e. The device will check the sensors, and any bay that does not have a syringe will rotate to the user window, starting with a default bay (called “syringe bay 1”) and progressing in one direction from this initial bay to syringe bays 2 thru 5
   f. After lining up the plunger grip of the device with the plunger handle of the syringe and the syringe supports of the device with the syringe handle, the user pushes the syringe into the bay, until the grips “snap” onto the cylinder of the syringe. Once the user has placed a syringe into a previously empty bay, they press the OK button on the screen (or any equivalent button to be later selected), and the cartridge turns to the next empty bay
   g. This continues until all bays are full OR the user presses “finish” button (or any equivalent button to be selected later)

2) To Load
   a. The user turns the device on, and selects the “Load Syringe” option
   b. The device checks the syringe bays to make sure a syringe is available
   c. User is prompted by the device to input the desired amount of insulin
   d. The device displays, and speaks, the volume selected by the user, and prompts the user to decide if the amount displayed is correct
      i. If yes, the device proceeds to step 2e
ii. If no, the device returns to step 2c

e. The current insulin bottle is checked for volume
   i. If the volume of insulin in the bottle can accommodate the desired dosage, the device proceeds to step 2f
   ii. If the volume is insufficient, the device prompts the user to replace the bottle with a new one, then returns to step 2d

f. The device rotates the syringe cartridge to the default starting point, “syringe bay 1”
   i. If syringe bay one has a syringe of sufficient size, the device moves on to step 2g
   ii. If a syringe is not present, or the syringe in that bay is smaller than the dosage requested by the user, the cartridge rotates to the next bay with an available syringe, and then moves on to step 2g

1. If every bay in the cartridge is checked, and no syringes are present, the device returns to step 1
2. If no syringes of adequate size are detected, the device displays a message “The syringes are too small. Please replace one with a syringe of adequate size, or split your dosage into smaller amounts.” The device then returns to step 1b(ii)

g. A servo moves the motor assembly to the syringe, so the motor can interact with the plunger grip

h. The comparator circuit is prepared
   i. The device calculates the amount of insulin as a distance the plunger must travel
      1. The distance is determined by the size of the syringe, and the volume of insulin desired:
         \[ \text{Volume} = \pi \times (\text{Radius of Syringe})^2 \times \text{Distance} \]
   ii. The device uses a calculation to determine the voltage put out by the resistor when the desired length as been met
   iii. This voltage is sent to a comparator circuit, to be used later
   iv. The number of steps the motor must make to move the plunger the predetermined distance is estimated. This number of steps is the cut to 80%.

i. The insulin bottle drawer is moved to the syringe needle
   i. The distance the bottle moves is determined by the size of the syringe

j. The device powers the motor
   i. The motor turns the screw and the potentiometer, which moves a nut on the screw
      1. This screw pulls on the plunger grip
   ii. The resistance is sent through a comparator circuit
      1. The device powers the screw until 80% of the estimated number of steps
required

2. After these steps are taken, the motor slows down, so the comparator circuit can keep up

3. The motor continues to turn the screw at a slower pace until the comparator circuits match

4. Once the voltages match, the device stops the motor

k. The motor assembly and insulin bottle are moved away from the cartridge

l. The cartridge rotates the loaded syringe to the window for removal

2.2.2.1 Display: GLK240128-25-GW [20]

The display chosen for the optimal design is the GLK240128-25-GW by Matrix Orbital. It is a larger graphical LCD display. The GLK240128-25-GW is designed to be the display unit for an associated controller. The microcontroller will have control over what is displayed on the screen by connection through I²C port. The module size is 104 mm x 144 mm x 15 mm (l x w x t). The display size is 64 mm x 114 mm, which is larger for this style of LCD modules, compared to those previously considered.

In addition to a larger display area, a larger font point of 32 (approximately 10 mm in height) will be chosen to display user commands and verifications. Figure 2 shows the font point relative to the module size. The background color of the screen is light gray and the text color is dark blue. Figure 4 illustrates the different color options available to the team, however the gray background seemed to be most appropriate based on the visual disabilities some users of the device face. The dark blue font will stand out and hopefully appeal to more users. Since the display is a bit mapped device, graphics would be able to be displayed, if the team chose to do so.
Figure 2: GLK240128-25-GW LCD Module (dimensions in mm)

Figure 3: GLK240128-25-GW Module (back)
The GLK240128-25-GW requires 5 V of power to work and this voltage is attached to the Power/Data connector. Pins one and four of the Power/Data connector are those which the voltage is applied through. The other two, pins two and three are reserved for serial transmission using the I²C protocol. Additional power requirements can be seen in Table 2. The current values listed in the table help in determining the battery required for the entire device.

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>-V</th>
<th>-VPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>+5Vdc ±0.25V</td>
<td>+9V to +15V</td>
<td>+9V to +35V</td>
</tr>
<tr>
<td>Supply Current</td>
<td>31 mA typical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Backlight Current</td>
<td>160 mA typical</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Power Requirements for GLK240128-25-GW

To maximize the display features of the GLK240128-25, Matrix Orbital offers their latest interface program that is used to manage font and graphics downloads. This program, MOGD#, is provided by CD or by online download, and a PC can be used to select these features, which are incorporated into the programmed microprocessor. When using MOGD#, configurations, seen in Fig. 6, are required at the initial start up.
Through the use of programming and MOGD#, different text fonts and graphics can be displayed, in addition to those built-in. The downloaded fonts and graphics will be stored in the GLK240128-25-GW’s 16 KB flash memory. Using the font identification number, which is sent along with the command bytes, also known for a set font, sets the font for the display. In addition to using fonts provided by MOGD#, the program can also be used to create fonts which can be useful to fit individuals with needs disabilities. Figure 7 is a small example of bit patterns for \( h, i \) and \( j \) bitmap data. In power-off modes, the device is able to retain such selections by flash memory, which will not be changed unless done through reprogramming.
The display has a backlight for low-light areas that it is used in. Using “Backlight On” and “Backlight Off” commands, the backlight can say ON and OFF for specified times in times of use and nonuse. In addition, a command can be used to set the backlight brightness. Adjusting the contrast of the screen can be used to determine the best seeing capabilities for the users of the device.

The GLK240128-25 receives characters from the keypad and positions them one after the other, as they are received. The feature “auto scroll” can be used to shift the display’s contents up to make room for a new line of text when the text reaches the scroll position set by the “Set font metrics” in the display memory. However, the “Auto scroll” feature will not be accessed to allow people of various needs the time required to visually interpret the displayed message, without interruption or concern on the user’s behalf. Instead, through programming, the amount of characters for user commands and questions will be limited to what can fit sufficiently on the screen without having to “make room” for more text. The “Set font metrics” command is used to determine where on the display the characters will begin to be displayed.

Through the use of a twenty-five key, matrix style, keypad the GLK240128-25 can be configured to allow key presses to be automatically transmitted to the device. The “Auto Transmit Key Process” mode, allows all key presses to be sent immediately to the host system without the use of poll keypad command will be selected to be OFF. Therefore, the key presses are stored in a ten-character buffer until they’re read by the microprocessor using the “Poll Key Press” command. By using the “Poll Key Press” command 254 38, data is only sent to the microprocessor when it’s ready. If it all sent at the same time, data may get lost when in the middle of communicating with another device, such as the DoubleTalk sound chip.
As seen in the figure above, the letters “Y”, “N”, “E” and “C” on the right-hand side of the keypad will stand for “YES”, “NO”, “ENTER” and “CLEAR”, respectively. The keys will also be covered with Braille labels to ensure users who may have visual impairments that they are, indeed, pressing the correct key.

The display also allows the programmer to test the display by connecting directly to a PC. To do so, a PC cable along with the required 5 V power supply is required. To successfully test the display, characters on the keyboard typed should appear on the display of the GLK240128-25. However, keys such as backspace, delete, and clear will not have an effect on the input to the display during testing. The screen displays characters by wrapping the text around to the next line when the end of the line has been reached, which is dependent on the chosen font size. This feature can be used to select the appropriate font style and size that will work best for patients with visual disabilities.

2.2.2.2 Text-to-Speech Output: DoubleTalk

The DoubleTalk chip RC8660 by RC Systems will be used as a voice synthesizer. This component is required by the design because the device must be able to read input prompts, input values and verification prompts. The DoubleTalk chip is a text-to-speech processor that translates plain English into speech in real time. The chip does not require a PC or high-powered processor to work. DoubleTalk RC8660 requires 4 mA of operating current at 3.7 V to run and as little as 0.7 µA when not in use. The RC8660’s audio output would be in analog format for simple instructions and questions for the user of the device to answer by keypad.
Commands for the DoubleTalk RC8660 will be selected based on user disabilities that are using the syringe-loading device. The speech rate will be adjusted to a rate between slow and medium, most likely 2 or 3S where 0S is the slowest rate, 13S the fastest, and 5S being default. The one voice chosen, of the available 11, to speak the text instructed by the microprocessor will be one that has a favorable pitch and tone. An audible “reminder” option can also be selected to sound every ten minutes, resetting every time the device has finished being used, to remind the user that the device is on. This feature can benefit the total device by allowing power-saving abilities on the user’s behalf.

All of the data for the RC8660 is sent through the built-in serial and/or parallel ports. The chip’s Peripheral Input/Output Bus will be used to communicate with the microprocessor’s parallel master port. It is an eight-bit bidirectional peripheral bus that sends text, data and commands. Data is input from a peripheral when PRD# is active. PRD# is an output called “Peripheral Read” that controls the transfer of data from a peripheral to the RC8660. Data is read from the PI0 – PI7 when PRD# is low. Status information is output when STS# is active. The STS# is an output “Status” that controls the transfer of status information from the RC8660 to a peripheral. Status information is driven on the PI0 – PI7 pins when STS# is low. This function is only active when there is new status information.

The RC8660 chip will connect to the microprocessor using its Bus/Printer interface. This interface will allow 8 bit data communication to be established between the sound synthesizer chip and the microprocessor’s Parallel Master Port. Using this method of data transfer, commands and data will be able to be sent to the sound chip, and status codes will be able to be sent back to the microprocessor. The microprocessor will control all of the interactions with the RC8660 over this system data bus using the read (RD) and write (WR#) signals. RD controls the reading of the RC8660’s Status Register and WR# controls the transfer of data into the RC8660 DoubleTalk chip.

2.2.2.3 Orientation Sensor: CXTA02

An orientation sensor is required by the device to assure that the device is standing properly in order to load the syringes with insulin. Without such a sensor, the possibilities of loading air instead of insulin are possible if the insulin vial is not in a downward direction. The sensor
intended for use is the CXTA02 by Crossbow and is a dual axis analog tilt sensor. The CXTA02 has a small size of 24.1 mm x 50.8 mm x 30.5 mm and is packaged in a lightweight aluminum case. It can be affixed to the inside of the syringe-loading device by screws or adhesive. The sensor uses a 5 V power supply. The device has great accuracy to within ± 0.5° over the angular range. The device can make angle measurements up to 75° in tilt range.

![Figure 10: CXTA Tilt Sensor](image)

The CXTA02 tilt sensor uses a micro-machined acceleration-sensing element with a DC response to measure inclination relative to gravity. The response of the tilt sensor is dependent upon the magnitude of gravity parallel to the sensor element. The output of the tilt sensor will be an offset voltage plus the voltage response proportional to the amount of gravity measured by the sensor. For angles less than 20°, a linear relation between $V_{out}$ and the tilt angle in radians can be approximated. To accurately measure the tilt angle the angle Eq. 3 is evaluated for $\phi$.

$$\phi = \frac{180}{\pi} \left[ \frac{V_{out} - \text{Zero Angle Voltage}}{\text{Sensitivity}} \right]$$

Equation 3: Tilt Angle Equation

To solve for Eq. 3, $V_{out}$ can be set to zero, and therefore the device will be properly orientated when: $V_{out} = \text{Zero Angle Voltage}$. The Zero Angle Velocity will be calibrated before use.

![Figure 11: Pin Diagram for CXTA02](image)

By properly connecting the CXTA02 to the microprocessor board, the information can complete the circuit and the loading process can begin.
2.2.2.4 Microprocessor: Microchip’s PIC24FJ128GA006

Microchip’s PIC24FJ128GA006 was selected as the microprocessor to use for the current design of the syringe loading device. Table 3, below, is a list of the microprocessor’s main features. Following the table is a diagram of the microprocessor’s pin layout, (see Fig. 12).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Up to 16 MIPS at 32 MHz</td>
</tr>
<tr>
<td>Memory</td>
<td>200 Kb</td>
</tr>
<tr>
<td>Flash Program Memory Retention</td>
<td>20 years</td>
</tr>
<tr>
<td>Programming Languages</td>
<td>Assembly Code and C</td>
</tr>
<tr>
<td>Pins</td>
<td>64</td>
</tr>
<tr>
<td>Parallel Master/Slave Port</td>
<td>8 or 16 bit data</td>
</tr>
<tr>
<td>Serial Port Interface Modules</td>
<td>2</td>
</tr>
<tr>
<td>UART Modules</td>
<td>2</td>
</tr>
<tr>
<td>Inter-Integrated Circuit Modules</td>
<td>2</td>
</tr>
<tr>
<td>10 bit Analog-to-Digital Converter</td>
<td>16 Channels</td>
</tr>
<tr>
<td>16 bit Timers/Counters</td>
<td>5</td>
</tr>
<tr>
<td>Comparator Modules</td>
<td>2</td>
</tr>
<tr>
<td>16 bit Capture Inputs</td>
<td>5</td>
</tr>
<tr>
<td>16 bit Compare Outputs</td>
<td>5</td>
</tr>
<tr>
<td>External Interrupt Sources</td>
<td>5</td>
</tr>
<tr>
<td>Input Change Notification</td>
<td></td>
</tr>
<tr>
<td>Real-Time Clock/Calendar Module</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: PIC24FJ128GA006 Microprocessor Features
The PIC24 will interface with all of the device’s electrical components. It will receive information from the various sensors and the keypad through use of its Capture Input ports. Input Change Notification will be configured for these ports to allow the microprocessor to react to changes in status. Communication with the GLK12232-25 graphic display will be accomplished through the use of one the built-in Inter-Integrated Circuit modules. Commands and data will be sent to the DoubleTalk sound synthesizer chip via the PIC24’s Parallel Master Port. Status messages from the sound chip can also be received through this port. If additional memory is needed for storing dosage information, available memory space on the DoubleTalk chip can be accessed and written to using the PIC24’s Parallel Master Port.

The microprocessor will also be able to communicate with a computer through the use of its Serial Port Interface module (SPI). An RS-232 port will be linked to pins for one of the PIC24’s SPI modules. A standard serial cable will be able to connect the syringe loader’s RS-232 port to a computer’s serial port; this will enable data to be transferred between them.

The servos and motors of the syringe loader device will be able to be controlled using the PIC24’s Output ports. These ports are capable of generating both single and continuous output pulses. Since the motors require 6 V to operate them they will not be able to be directly powered by the microprocessor (its normal operating voltage is between 2 and 3.6 volts). Instead the outputs will trigger transistors to “open” and to allow the necessary current/voltage to be sent to the motors.

The microprocessor will perform several functions during the operating of the syringe loader’s plunger motor:

- It will first need to use the syringe’s size and the user’s requested dosage amount to calculate what voltage the mechanical potentiometer (which is attached to the plunger arm) should be generating when the correct amount of insulin is withdrawn.
- The PIC24 will then compute the number of steps the plunger’s stepping motor will need to complete until 80% of the voltage/distance is reached.
- The microprocessor will then operate the motor in “quick” mode for the number of turns it takes to reach 80% of the voltage.
- At that point the PIC24 will send commands to a digital potentiometer, causing it to generate the “target” voltage of the mechanical potentiometer.
- The voltage from the digital potentiometer will be compared to the mechanical potentiometer using the one of the microprocessor’s comparator modules. If the “target” voltage has not been reached, the plunger motor will be powered for one turn, and the processing will pause briefly before evaluating the comparing the voltages again.
- Once the “target” voltage is reached, the digital potentiometer’s resistance/voltage is
returned to zero and program processing resumes.

The PIC24 microprocessor can run programs compiled for it by Microchip’s Application Maestro software. Figure 13 shows the Application Maestro programming interface, through which modules can be added to a project, their parameters can be configured, and their code can be recompiled. Once compiled, a project’s functions can be reference by other modules or programs.

![Figure 13: Application Maestro Programming Interface](image)

Projects can incorporate assembly language or C programming files into them, and can include references to functions in pre-compiled code modules/libraries. Several pre-built code modules can be directly downloaded from Microchip’s website. These code modules greatly reduce the amount of effort needed developing programs for the microprocessor. Serial and parallel port communication can be accomplished through the use of functions at high level; as opposed to having to read and set pin data values individually, and needing to trigger transfer signal pluses directly. Once a program is written and compiled in Application Maestro it can be downloaded to the microprocessor using its In-Circuit Serial Programming module.

This software will be used to create a simple menu program for the syringe loading device, which will allow users to use the device to either prepare new syringe dosages or view dose amount and date/time information for previously administered dosages. Below is a flowchart (see Charts 1-5) that outlines the major processing steps of this program.
Chart 2: Menu Flowchart – Part 2
Chart 3: Menu Flowchart – Part 3
To aid in the implementation and configuration of the microprocessor the Explorer 16 Starter Kit will be purchased, (see Fig. 14). In addition to providing all the hardware and software necessary for programming the microprocessor, it comes with a demonstration protoboard. This protoboard has a built-in LCD display, multiple input keys, multiple output LED’s, and a small bread board area that can be used for custom circuit/component work. These integrated components will allow us to work on and test the program for the microprocessor without having wait for other device subunits to be completed first. With this board the majority of menu navigation & input/output testing will be able to be conducted prior to attempting to connect the processor directly to other system components. As work continues on the project, this demonstration board could aid greatly in troubleshooting, inter-component communication problems by allowing us to test the microprocessor independently.

![Figure 14: Explorer 16 Starter Kit](image)

2.2.2.5 Batteries / Charger: The 32v Smart Charger

Li-Fe-P04 rechargeable batteries will be used to power the automated syringe-loader. In adding together the current needed for the various electrical components it was determined that the device would require between 1.5A - 2A of current to drive the circuit. This current value reflects a “worst case” scenario, in which the majority of the components need to be active simultaneously. The main components requiring the bulk of the current are the stepping motors, (which need between 700mA – 1000mA), and the LCD Display, (which requires 280mA to power it when it’s backlight is active). To meet this energy need 8 3.2v Li-Fe-P04 rechargeable batteries, (each capable of providing 260mA of current), will be bundled together into a battery pack. The 32v Smart Charger for Li-Fe-P04 battery packs, (from BatterySpace.com), will be used to re-charge the batteries when the user is near an electrical outlet. A charging interface port will be incorporated into the syringe loader’s case
so that the user will not need to directly handle the battery pack when charging the device.

![Li-Fe-PO4 Rechargeable Battery - 3.2v](image)

**Figure 15:** Li-Fe-PO4 Rechargeable Battery – 3.2v

![32v Smart Charger for Li-Fe-PO4 Battery Packs](image)

**Figure 16:** 32v Smart Charger for Li-Fe-PO4 Battery Packs

In order to protect the devices electrical components from possible damage as the Li-Fe-PO4 batteries begin to discharge and their current begins to drop, voltage regulators will be incorporated into the circuit’s design. These regulators will maintain constant voltages (at 3.3v for the processor & sound synthesizer chip, and at 5v for the LCD Display, motors, and servos) for as long as sufficient energy is available. Once the power drops below a regulator’s minimum energy level, the voltage is dropped get is turned off and the energy drops to 0 volts.

2.2.2.6 Bottle Holder

This component needs to securely hold a bottle in a vertical position while a syringe extracts insulin from it. In order to accommodate a wide variety of bottle sizes and shapes, foam rubber will be used to grip and support the sides of the bottle, (Fig. 17). A spring will be used to apply pressure to the bottle’s bottom to ensure it is flush with the syringe needle port. The head of the bottle will be supported by a neck cone, which will assist in centering the bottle’s opening over the syringe needle port. The completed bottle holder assembly should be able to
accommodate bottles that are between 12 mm to 40 mm in diameter, and between 40 mm and 70 mm in height.

The bottle holder assembly is accessible to the user through a hinged cover on the back of the device’s case. The cover can be opened by pressing in on the catch in the center of its side and flipping it away from the case. As the cover opens, the foam rubber attached to the inside of the lid will be lifted away to expose the bottle area. The bottle can then be slid backwards to compress the spring and result in the head of the bottle clearing the neck cone support structure. Once clear of the neck, the bottle can be lifted out of the holder assembly. Bottle insertion would involve placing the bottle’s bottom against the spring and compressing it, positioning the bottle head into the neck cone, releasing the bottle, and closing the cover to the holder assembly. This approach to bottle insertion and removal was modeled after the process that’s typically followed to replace C or D size batteries in most electrical devices. By basing the bottle replacement process on steps that are fairly well known it is hoped that most users will find the bottle holder assembly simple and easy to use.

![Figure 17: Bottle Holder Assembly – Interior View](image-url)
2.2.2.7 Insulin Bottle Movement

To fill the syringe, the insulin bottle will move towards it. While this creates more work and requirements for the insulin bottle holder, this was deemed the best way to put the syringe to the bottle. The syringe already has to move and so does the loading motor assembly, so causing the bottle to move reduces the work for other components. To accomplish this action, the insulin bottle holder will be made with small groves along the bottom, which will slide along tracks laid in the device case. A servo will move the holder along these tracks to and from the syringe needle. After the user has placed an insulin bottle in the holder, the user pushes the holder back into the device. As the holder slides inside, a hook on the servo arm catches the holder by a small loop attached to the bottom. When the device is ready to load a syringe, the servo lowers the arm, and the bottle holder slides along the tracks.

Because the sizes of syringes will vary between 2 choices, 50 units or 100 units, the insulin bottle will have to move different distances. A larger syringe will require that the bottle move a shorter distance than a smaller syringe will, as seen in Fig. 19. The \( \frac{1}{2} \) cc syringe needs the bottle to move a longer distance, \( \Delta X_a \). The 1.00 cc syringe needs the bottle to move a shorter distance, \( \Delta X_b \). One of the sensors on the syringe bay, seen as blue squares in Fig. 19, tell the device that a syringe is present. To determine whether the syringe in place is 50 or 100 units, a second sensor on the top of each of the syringe bays will complete an “if/else” statement. “If” the sensor is pressed, then a long syringe is in place and the insulin bottle moves a short distance. “Else” a shorter syringe must be present, and the insulin bottle will have to move the longer distance. A 100 unit syringe will depress the sensor, completing an “if” statement. A 50 unit syringe will be too short to reach it, so the statement is completed in the “else” case.

The servo chosen for this task is the Futaba S9252 All-Purpose Servo. This selection will provide the necessary power required to move and hold the insulin bottle, since the bottle and its holder will weigh less than 0.75 kilograms and the distance it has to travel will be less than 5 cm. This load does not exceed the maximum torque of the device (6.6 kg-cm), and the
device will not draw too much power or add too much weight.

![Image](image-url)

**Figure 19: Syringe and Bottle Action**

2.2.2.8 Syringe Cartridge

The syringe cartridge is one of the features of this loader that sets it apart from other assistive devices. It is an extruded pentagon, with each side containing a syringe bay. Five bays were chosen because insulin syringes come in packs that are multiples of 5. Each of these bays has two sensors, a syringe clip, and two syringe stabilizers (see Fig. 20). The first sensor is used to detect the presence of a syringe. If the sensor does not detect a syringe, the device knows that bay to be empty. When loading is about to occur, the device will cycle
through the syringe bays until a syringe is located for filling. When the user wishes to add more syringes to the cartridge, the device will present the empty bays to the user. The second sensor detects the size of the syringe. When a \( \frac{1}{2} \) cc syringe is in a bay, it does not depress the second sensor. A 1 cc syringe, however, will depress the second sensor. This information is used to tell the servo that moves the insulin bottle how far to travel. When the device is ready to load, it will move the syringe bay in position below the insulin bottle, and then lower the bottle the required distance. This information is also used when the user inputs the dosage amount they require. If the syringe in the bay is too small to hold the requested dosage, the device will search the bays for a larger syringe.

The cartridge was designed with a stepper motor located in the middle (see Fig. 21). This allows the device to rotate without extra parts, and saves space in the case. This stepper motor is an Applied Motion size 23 Stepper Motor (#4023-819). Since the motor turns 1.8 degrees per step, the motor will perform 40 steps between bays \((40 \times 1.8 = 72\) degrees, the angle between the center of each side in a pentagon). It will be able to rotate the cartridge to precisely place the syringe bay in position, so that the syringe is below the insulin bottle and in line with the plunger grip. The motor holds fast to the cartridge with a 5-point wheel that attached to 5 spots on the cartridge. Using this many connection points prevents slipping, and makes sure the device stays attached, in case one point of contact fails.
The syringe clip is an adjustable adhesive-backed wire clamp made by Micro Plastics, Inc (part # 22AAwC310400). Its design was modified for use. A ring of foam rubber was inserted into the middle to grip the syringe tightly, without crushing it. The two stabilizers (seen in Fig. 20) work to hold the syringe up when the plunger is being pulled down. These are simple two plastic rods that have been inserted into the syringe cartridge. Also, two hole will be drilled into each side of the clamp bases for screws. This is being done because the glue used in the adhesive backs cannot be tested yet for holding ability. So a more permanent means of securing the clamps is necessary.

![Figure 21: The Syringe Cartridge](image_url)
2.2.2.9 Syringe Loading

A syringe is loaded by pulling the plunger away from the syringe needle. To perform this task, a stepper motor (Figure 22) turns a leadscrew (Figure 23) and a potentiometer (Figure 24) simultaneously. A leadscrew is a long screw with precisely laid threads. As the leadscrew turns, a sleeve nut (seen in Figure 23) on the leadscrew is forced up or down depending on the direction of the screw’s rotation, and at a speed and force determined by the threads. As the nut moves, the plunger claw attached to it moves as well (Figure 25). This motion moves the syringe plunger when the claw and plunger are together.

Before loading begins, however, the distance the plunger must move is calculated. Since the cross-sectional area of the syringes inner diameter is known, the distance the plunger travels is simply volume/area. The volume is the insulin dose. When the user inputs the amount of insulin they require, they are entering this dosage information as units of a “cc”, or “cubic centimeter.” So one unit is 0.01 cubic centimeters, or 10 cubic millimeters. Using this information, the distance the plunger must travel is:

\[
\text{Distance (mm)} = \frac{\text{Insulin dose (units)} \times 10 \text{ mm/ unit}}{\text{cross-sectional area (mm}^2)}
\]

The computers next step is to calculate the number of steps the motor must take to travel this distance. Each step is 1.8 degrees, or 1/200th of a revolution, meaning the motor will take 200 steps to make 1 revolution. For each revolution, the sleeve nut on the leadscrew travels 1.27 mm’s (manufacturer’s claim). Therefore, for a distance in mm’s D, the number of steps taken, X, will be:

\[
X = \frac{D (\text{mm}) \times (1/1.27 \text{ mm/revolution})}{\# \text{ of revolutions}} = \# \text{ of revolutions} \times 200 \text{ steps/revolution}
\]

Once X has been calculated, the device multiplies X by 0.80 to determine 80 percent of the
steps. Then, during loading, the device will perform 80% of the steps determined for X. After the 80%, the device slows the motor down, so the steps can be counted accurately while the comparator circuit double checks the system. This double checking system will be explained later, but it works to check on the performance of the stepper motor so an accurate dose of insulin is prepared every time.

The sleeve nut will move with a force proportional to the torque of the motor. This proportionality is shown in Equation 4, and it explains what is called the drive torque \( T_d \).

\[
T_d = \text{Load}\,(\text{lbf}) \times \text{Drive Torque Ratio} \left( \frac{\text{in} \times \text{lbf}}{\text{lbf}} \right)
\]

**Equation 4:** Drive torque relating to linear force.

The load in this equation is the force required to pull the plunger of the syringe, and the drive torque ratio is a ratio of torque about the screw axis relative to unit axial loads, determined by the manufacturer. In other words, the drive torque ratio states the amount of torque put on the screw by the motor for each unit of linear force produced by the system.

The linear force required to pull down a syringe plunger, while small, needs to be evaluated since the stress applied to it by the motor will go through a complex mechanical system that could produce more friction and power loss. The forces will also be cyclic which could cause fatigue in the device. Using a universal testing machine (UTM) at Teleflex Medical of Coventry, CT six syringes were tested for plunger pulling force requirements. The syringes were placed one at a time in the jaws of the UTM, which pulled each plunger at a rate of 8 inches/min. While the UTM pulled, it recorded the force applied to the plunger to keep it moving at a steady velocity, and tallied this against the distance the plunger had traveled. The result of this work was a table of forces applied to the syringes along the path the plunger travels. The forces required varied for each syringe, but they all had a maximum force at the beginning where static friction was broken. A table of these maximum forces is seen in Table 4, with the highest force requirement being 8.36 N. Using this information, it was decided that the device must put out at least 10 N of linear force to act on the plunger. This amount was chosen to provide a buffer for future loading. In the event one syringe is slightly malformed, causing a need for higher than normal forces for loading, the device should be able to handle it without any problems. To determine how much torque this requires of a motor, the minimum linear force value of 10 N is applied to the drive torque equation explained above using the drive torque ratio of the chosen leadscrew.
<table>
<thead>
<tr>
<th>Syringe Trial</th>
<th>Maximum Force Applied (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>3.05514</td>
</tr>
<tr>
<td>Trial 2</td>
<td>3.05514</td>
</tr>
<tr>
<td>Trial 3</td>
<td>2.64363</td>
</tr>
<tr>
<td>Trial 4</td>
<td>8.35807</td>
</tr>
<tr>
<td>Trial 5</td>
<td>4.84154</td>
</tr>
<tr>
<td>Trial 6</td>
<td>2.96426</td>
</tr>
</tbody>
</table>

Table 4: Maximum tensile forces applied to syringe plungers.

*These values were obtained using a UTM at Teleflex Medical of Coventry, CT.*

The leadscrew for this device is a stainless steel 3/8-20 right-hand acme screw by Roton Products, Inc. The screw is 3/8 inches in diameter with 20 threads for every 1 inch length of screw and a drive torque ratio of 0.035 inch-lbs/lbs. It will utilize a plastic sleeve screw (different from that shown in Figure 23). Converting newtons to pounds (1 newton equals 0.2248 pounds), the 10 N minimum linear force value becomes 2.248 lbs. Therefore, the torque the motor must push is equal to the drive torque ($T_D$), calculated to be:

$$T_D = \text{Load (lbs)} \times \text{Drive Torque Ratio \left( \frac{\text{inch}^2\text{lbs}}{\text{lb}} \right)}$$

$$T_D = 2.248 \text{ lbs} \times 0.035 \left( \frac{\text{inch}^2\text{lbs}}{\text{lb}} \right)$$

$$T_D = 0.0787 (\text{inch}^2\text{lbs}) \text{ or } 0.0889 \text{Nm}$$

Figure 23: The Leadscrew

In order to operate correctly, according to the 10 N linear force requirement specified earlier, the motor must produce at least 0.0889 Nm. The chosen motor was the Applied Motion size 23 Stepper Motor (#4023-819). This motor has a minimum (holding) torque of 0.3743 Nm, which is four times the minimum requirement. While a motor with torque capacities closer to the target could be found, using the Applied Motion size 23 motor would maintain lower vibrations, lower noise, and last for a long time. A while a weaker motor would sacrifice these benefits without cutting down enough of the price.

The simultaneous rotation of the M22 Multi-turn potentiometer with the leadscrew increases the resistance of the potentiometer as the leadscrew turns. This increasing resistance is used in a computer program to determine the distance traveled by the plunger. This action is performed as a means of double checking the accuracy of the loading device. First, the potentiometer is hooked up to an inverting amplifier, like the one shown below, in Fig 26. Using the equation of gain for inverting amps, seen in Equation 5, it can be shown that gain increases if $R_f$ (the value of resistance produced by the potentiometer) increases.
Figure 24: The Multi-turn Potentiometer

\[ A = \frac{V_{in}}{V_{out}} = \frac{R_T}{R_f} \]

Equation 5: Gain of an inverting amplifier.

Figure 25: The Motor, Potentiometer, and Plunger Grip
By locating a potentiometer at the position $R_f$, changes in its resistance creates changes in the output voltage of the circuit. As the motor turns, the potentiometer’s resistance increases, and the output voltage increases. This output voltage is sent to the comparator to be compared to the voltage coming from the digital potentiometer, described in section 2.2.2.4.

The comparator circuit, shown in Figure 27, is an op amp with a small operating voltage. The “signal voltage” from the processor is amplified according to the calculations performed for the insulin dose, and then enters the inverting input of the op amp producing an output voltage equal to the positive operating voltage. When the variable voltage running off of the M22-potentiometer amplifies to meet the signal voltage, the output voltage will go to zero. This output voltage is wired to the processor, and as long as the processor reads a negative signal from the comparator it knows the voltages have not met. Once the output voltage goes to zero, the processor knows to turn off the motor.
To load the syringe, the cartridge rotates the selected syringe bay below the insulin bottle, and in line with the plunger claw. The stepper motor is equipped to turn 1.8 degrees with each step. Since the cartridge is a pentagram, the motor will have to turn 72 degrees between syringe bays. This angle is calculated as \[
\frac{72 \text{ (degrees)}}{1.8 \text{ (degrees/step)}}
\] to equal 40 steps.

After the cartridge rotates the syringe bay into place and the insulin bottle has been lowered to the syringe needle, the plunger claw then moves to the syringe plunger, to pull it down. To get the plunger claw, and the motor and potentiometer that are attached to it, in place, a servo moves them along tracks in the case. The set-up is seen in Figures 28. The servo is the same Futaba All-Purpose Servo as the one used to move the insulin bottle.
2.2.2.10 The Case

The case was designed to fit around all of the device’s components. The positions of these components are seen in Fig. 29.

Figure 29: Parts Layout

Considering the positions and motions of these components, the case seen in Fig. 30 was
The case will consist of a plastic outer shell, where the keyboard and display will be mounted. On the back, the door for the insulin holder will appear, and the plug for the battery charger will be at the bottom of the rear side. The hump on the right side of the case encloses the syringe cartridge. Under the hump, there is a hole for the extended syringe handle. The slit that extends the length of the hump is the window through which the syringe can be inserted or removed. A clear plastic window will be present over this bump, to ensure nothing falls out of the device while it is being carried, and that no dust or other foreign particles get in.
2.3 Prototype

2.3.1 Objective

This is the final prototype of the syringe-loading device. As previously stated, the initial goal of the device was intended to provide simplicity to a task that is often very difficult for disabled diabetic patients. The final prototype of the device accomplishes this goal by adding greater functionality to many of the components, compared to the optimal design. By increasing the abilities of the device, the user will have even greater independence from their diabetes. While the final device may not be portable, as it had previously been expected to be, it is portable in the sense that when a patient travels, the device is small enough to easily fit into most bags and it can be plugged in to any standard US outlet.

The final design of the automated syringe-loading device is a result to even greater changes from the optimal design. The design provides more positive qualities and although there have been some components that have had significant downgrading, it does not affect the final product in any way that will inhibit a person from easily accessing their insulin-filled syringes.

The final design contains many of the same components as the optimal design had. It includes the same large LCD screen. The “large” aspect to the LCD ensures that people of various visual disabilities will easily be able to see the font on the screen. The text will fill three lines on the LCD and has a large font point of 32. An upgrade from the optimal design is the voice recognition. It will further aid visually impaired users to access insulin through simple responses. The responses will be limited and this will help ensure that the patient will be able to operate the device fairly easily.

The voice output of the device had been changed only slightly. It was changed from the DoubleTalk device to the Davantech text-to-speech synthesizer. It is a simple, self-contained module that has been used in many of the current and past senior design projects. This was changed for various reasons will be discussed in greater detail.

Many sensors were also added to the final design. There are a total of six areas of the device that will allow the device to properly fill syringes by using many the same kind of sensors, or very similar. The sensors chosen were based on simplicity that will allow the user of the device to retrieve the correct responses by the device when it is in operation. One area, which uses a set of sensors, is used to determine that the device is sitting upright and on a relatively flat surface. Two more areas that use one sensor each are used to determine the presence of
each the bottle holder, and the syringe. A forth set of sensors, of quantity two, is used to
determine the highest and lowest height of the bottle holder assembly. A fifth sensor is to
account for the size of syringe inserted onto the syringe cartridge. Finally, a sixth sensor is
used to determine when the plunger claw is at the very bottom of the lead screw. It is
necessary for the claw to be at the bottom between every load of the syringe in order for the
syringe cartridge to properly rotate. All six areas of the sensors are required for the accurate
filling of insulin into a syringe. Without such sensors, the device cannot be ensured to, for
example, fill a syringe without retrieving air bubbles from a partly filled insulin bottle
because the device was not seated correctly on a table and the actual fluid has been forced on
the opposite of the bottle due to gravity.

The final prototype design has included Microchips’ PIC24FJ64GA002. This was changed
from the PIC24FJ128GA006 because of the inability to prototype with it using a printed
circuit board. For the most part, the current and past processors are the same. The two
differences being the pin count was decreased from 80 to 28 pins and there is less memory
with the current processor, changing from 128 Kbytes to 64 Kbytes.

The device takes up much greater voltage and current than initially considered so the
prototype requires an outlet to power it. Although this may decrease the portability of the
automated syringe-loading device, it does not inhibit the user from accessing an accurately
filled insulin syringe at home or on vacation because it is small and light enough that they
can still carry it with them.

A difference from the optimal design is that the final prototype has changed the insulin
bottle assembly. Instead of using a cover to hold the insulin bottle, direct access will be
allowed to be able to insert and remove the bottle from the outside of the device.
Additionally, the user will not have to remove the entire bottle holder assembly at any time,
adding simplicity. Access to it will be granted through an opening in the case. The window
is protected, when not in use, by a clear door that will easily lock and unlock.

The syringe cartridge is considered to be a great improvement from the optimal design. The
amount of syringes that it can hold is ten. This will allow for even greater mileage between
uses of the syringes. Since it is estimated that a person can use any less than 10 syringe over
a period of a few days, and many disabled diabetic patients have visiting aids, the aid would
not be required to stop and refill the device everyday. Additionally, the cartridge is designed
to swing out of the case. The appeal to this is that, in the long-term development of the
device, the syringe cartridge may be “purchased” containing syringes on it at any pharmacy,
adding simplicity for the user.
The expenses of the final prototype of the automated syringe-loading device were kept under budget. This is attributed to the team purchasing many of the components at local stores which made it easier for different, small, aspects to be built more quickly and easier than it would have to wait to purchase through ordering. However, there were many avoidable purchases such as the LCD screen which had a final quantity of three purchases because of simple avoidable mistakes attributed to the testing.

2.3.2 Subunits

Similar to the optimal design, all of the parts in the final prototype work together to carry out the actions modified from the optimal design and are shown here. The following are steps of the automated syringe-loading device.

1) To Review Past Dosages
   a. The user turns the device on and selects the “Preview Dosages” option
      i. The device prompts the user to choose between “View” or “Transfer”
         1. If “View” is chosen (ii) is followed
         2. If “Transfer” is chosen, the device follows with the transferring procedure to allow dosage record to be transferred to a PC
            a. Transfer procedure automatically returns to the Main Menu when finished
      ii. The device shows the most recent dosage including time and date
      iii. The device allows the user to select to “Preview Last 10” or to return to the Main Menu
           1. If a preview of the last 10 is chosen it is shown and automatically returns to the Main Menu
           2. If Main Menu is chosen, the Main Menu is accessed

2) To Initiate Loading of Insulin
   a. The user turns the device on and selects the “Load Syringe” option
   b. The device checks the syringe bays to ensure a syringe is available
      i. If it is not, it proceeds to (3)
   c. The user is prompted by the device to input the desired amount of insulin
   d. The device prompts by both displaying and speaking the user to determine if the amount retrieved by the users input is correct
      i. If yes, the device proceeds to (2) e
      ii. If no, the device returns to (2) c
   e. The current insulin bottle is checked for volume by verifying stored dosage amounts for the current bottle
i. If the volume of insulin the bottle can accommodate the desired dosage, the device proceeds to (2)

ii. If the volume is insufficient, the device prompts the user to replace the bottle with a new one, then returns to (2)

f. Sensor 4, determines the size of syringe in place

g. The amount of insulin requested is compared against the syringe present

i. If there is no syringe present step (3) continues

ii. If the required size is present step (3) d continues

iii. If the required sized syringe does not match the device prompts the user to change amount requested or insert adequate syringe

3) Load syringe cartridge

a. The device will automatically determine, using sensor 4, if the syringe is present in the correct position for carrying out the further steps necessary to fill the syringe

i. If the syringe is not in the correct position, one is moved to it by means of servo 1

ii. If there are no syringes present, the device prompts the user for action on refilling the cartridge

b. If the user continues with the loading process without inserting syringes, and when filling is about to begin, the device realizes the syringe cartridge is empty, it will go to the load syringes screen

c. Once the syringe is in place, step (3) is followed

d. The stepper motor will rotate the lead screw to bring the plunger claw up to meet the syringe plunger

e. When the plunger is determined to be at the maximum height to ensure the plunger is fully into the syringe, the plunger clip is expected to have properly “clipped” onto the plunger

f. Step (4) is followed

4) Expulsion of Insulin

a. The comparator circuit is prepared

i. The device calculated the amount of insulin as a distance the plunger must travel

1. The distance is determined by the size of the syringe, and the volume of insulin desired:

\[ \text{Volume} = \pi \cdot (\text{Radius of Syringe})^2 \cdot \text{Distance} \]

ii. The device uses a calculation to determine the voltage put out by the resistor when the desired length has been met

iii. The voltage is sent to a comparator circuit to be used later

iv. The number of steps the motor must make to move the plunger the predetermine distance is estimated, the number of steps is cut to 80%
b. The insulin bottle holder is lowered, by servo 2, until sensor 2b is triggered, this distance is the same for both size syringes.

c. The device powers the stepper motor
   i. The motor turns the lead screw which moves a nut on the screw when the moves the plunger claw
      1. The screw pulls on the plunger grip
   ii. The resistance is sent through a comparator circuit
      1. The device powers the screw until 80% of the estimated number of steps required
      2. After these steps are taken, the motor slows down so the comparator circuit can keep up
      3. The stepper motor continues to turn the lead screw at a slower pace until the comparator circuit match
      4. Once the voltages match, the device stops the motor
   iii. The lead screw is instructed to rotate a predetermined additional set of steps to add additional insulin to the syringe and then rotate back upwards the same amount to remove the insulin to discharge any air bubbles that may have accumulated in the syringe during the filling


d. Servo 2 lifts the bottle holder unit up until sensor 2a determines the device is entirely lifted to the maximum height to ensure the syringe is no longer inside the bottle

e. The cartridge rotates, by servo 1, to the window for easily removal of the syringe

2.3.2.1 Display: GLK 240128-25-GW

As stated previously, the display is the same the chosen for the optimal design, seen in Fig. 30. It measures 104 mm x 144 mm x 15 mm. The display size is 64 mm x 114 mm. The font point decided upon is 32. The LCD had been one of the main contributions in determining the width of the case. The LCD will display a maximum of three lines of text at one time. Since a large font point is used, there is some limitation for what can be displayed. By integrating the text-to-speech device, the team was able to correctly, and in greater detail, inform the patient of what actions are required by them. By using the associated computer software, the font and other various options pertaining to programming the LCD were experimented with before deciding upon in the final design. Additional technical information can be found on pg. 37.
2.3.2.2 Text-to-Speech Output: Devantech

The text-to-speech synthesizer, chosen for the final prototype of the automated syringe-loading device, is the Devantech by Acroname Systems, see Fig. 31. It has a built in speaker and therefore it only requires power and communication. Some greater advantages to the module are that it can store up to 30 phrases that can be up to 1,925 characters total. The stored phrases do not include what can be programmed into code, which is what the syringe-loading devices speech output is comprised from. The module includes an audio amplifier, 3 V regulator and communication to host processor. A second, similar, speaker that was taken from an audio greeting card to replace the small 40 mm speaker that was provided with the module. This new speaker provides greater sound and quality that was not supported by the original.

Figure 31: Devantech Text-to-Speech Synthesizer

2.3.2.3 Keypad
Although voice recognition has been added to the device, the team thought it is important to provide an alternative to speech input. For patients who are not visually impaired, voice recognition may take longer. Therefore, the keypad, also in large text will suit other users just as well. As seen in a preview of the keypad in Fig. 32, it is designed to be very simple and with “self-explained” keys. The “Menu” button will bring the user back to the Main Menu screen, regardless of where they had been in the menu navigation. “Menu” can be considered a quit feature used at any point in navigation. The “Back” button will return the user to the previous screen they had been on. This feature will allow users to change an amount or check on anything they had done in the previous screen. “Clear” cancels the last input, acting as a backspace key, this feature can also be considered a “No” button. It allows users to instantly correct data entry mistakes. The “Enter” button submits the data entered, this feature can also be considered a “Yes” button. The numbered buttons are used to specify the dosage amounts, for choosing menu items and will serve any other purpose prompted through menu navigation.

![Keypad, Computer Version](image1)

**Figure 32:** Keypad, Computer Version

![Keypad of Automated Syringe-Loading Device](image2)

**Figure 33:** Keypad of Automated Syringe-Loading Device
The voice recognition has a significant impact from the optimal design. It serves a greater range of disabled diabetic patients and is an overall technological advance to the automated syringe-loading device. The module chosen is the SR-06 by Images Co., seen in Fig. 34.

![Figure 34: SR-06 by Images](image)

The two similar modules that were considered are the SR-06 and the SR-07. The only difference is that the 06 version is the unassembled speech recognition kit. The module SR-06 was chosen over SR-07 because it is less expensive and very simple to construct. The module is voice dependent, meaning that the user of the device must train the speech recognition to recognize their voice. Although first considered a disadvantage, this aspect can act as a security system. Any users that are not authorized to access the automated syringe-loading device will not be allowed to do so when it is in speech recognized mode. The security also holds for keypad mode since there will be a code that must be entered to proceed further. The code is also something simple such as the user’s birthday month and date.

The SR-06 module can recognize either forty 0.96-second words or twenty 1.92-second words. It has 8kx8 static RAM on board. There are two operational modes available. Manual
allows for one to build a stand-alone speech recognition board that doesn’t require a host computer and it can be integrated into other devices to utilize speech control. The second mode, CPU allows the chip to work under a host computer and it operates as co-processor to the main CPU. The manual mode is utilized in operation for the automated syringe-loading device. Training of the device is extremely simple. By pressing only a few buttons on the keypad, a word can be trained to a specific number that is further referenced to be used in the coding of the microprocessor.

The user of the device will enter dosage amounts, for example 12.00 cc by voicing “one”, “two”, “point”, “zero”, “zero” and “Enter”. The cursor is formatted as “_ _ _ . _ _”. This accounts for any value of dosage amounts up to 100.00 cc. The response of the VR unit is less than 300 ms. It requires a 5 V power supply. Since the module is extremely sensitive to pitch and volume, the user programs the device four times for the same word and greater recognition is accomplished. Unfortunately, the pronunciation of numbers considers them to be homonyms, creating greater difficulty for the module to distinguish them apart, which is why recording the same numbered words over a series of four times will increase recognition accuracy. Once the SR-06 makes the match of input to programmed value, it creates an 8-bit output signal to send to the microprocessor platform, which will then respond with the corresponding response to the programmed action.

The microphone that came with the speech recognition module is a headset and the actual microphone had to be positioned about one inch away from the user’s mouth. Therefore, a new microphone, Fig. 35, was purchased that is of a desktop design so there is no aspect that must be worn, or even held. Although a user must relatively close to the microphone, about 5”, it is a great improvement from the previous microphone.
2.3.2.5 Sensors

There are a total of six areas in which sensors are used for the correct operation of the device. Each area of the device covered by the sensors reflects an aspect that must be satisfied in order for the device to function without failure. All of the sensors, excluding the orientation sensor use a simple tab-like sensor from Radio Shack, pictured in Fig. 36. These sensors are rectangular in shape and have a metal tab that projects outward allowing activation when it is depressed. They are of a simple design that allowed the team to set them to be normally open or normally closed, allowing no voltage to pass. The orientation sensors are button-like, also purchased from Radio Shack. When the small buttons are depressed voltage is allowed to pass. Connecting four of these sensors, picture in Fig. 37, ensure that voltage only passes when all four are depressed at one time.
The first area of the device, the bottom, uses sensors at the four corners to determine if the device is positioned properly. In order for the device to operate all of the buttons must be depressed. For that situation to occur it would mean that the device is on some surface that is completely flat or a surface that is very close to being flat. When determining if buttons are suitable for this purpose, many situations that the device could be placed upon were considered which led to the determination that buttons at four corners of the bottom of the automated syringe-loading device is accurate for the purpose. Without the satisfaction of the orientation sensors, the device will not operate at all. The purpose of the correct orientation ensures that the insulin is closes to the needle of the syringe. When the bottle is nearing empty, it is important to use as much of the insulin as possible without obtaining air in place of insulin.

The second area considered suitable for a sensor is the interior of the bottle holder. It is appropriate for the device to automatically determine, by the sensor, that the bottle is in place to be able to retrieve insulin without requesting a response by the user. The sensor is a contributing factor to creating a user-friendly device. It is placed at the top cap of the bottle holder since this position is the same for both insulin bottles.
A third placement area for a sensor is at the position of the syringe that is to be used in the loading of insulin. The purpose for the device to know if a syringe is present at that location is to simply determine if there are the appropriate components required for loading. Without it, the device would proceed through the entire loading procedure without actually loading any syringe. To determine if the syringe is present, the tab that is projected out is depressed which is then communicated to the microprocessor.

The two sensors in Fig. 41 are used to determine where the position of the bottle holder is. One location is at the very top of the case and the second is at the lowest point allowed by the gear rack attached to the bottle holder. The purposes of the two are to provide communication the processor to ensure that the reset and loading procedures can be carried out properly. Prior to extracting insulin, the bottle holder is moved to the top of the case until the upper sensor is triggered. At that time, the plunger claw is moved to the bottom of the case which triggers the sixth sensor pictured in Fig. 43. By moving to the top of the case, the holder gives clearance for the potentially syringe-filled cartridge to rotate and also for it to swing out of the case to be replaced. When the bottom sensor is triggered, communication is sent to the microprocessor to assure it that the bottle holder, and therefore insulin bottle, is in place and has been punctured by the syringe needle and therefore ready for insulin to be loaded.

The fifth sensor is used to determine the size of the syringe present. It is positioned in an area that it will only be depressed when the 1.00 cc syringe is in place. When it is not depressed it is meant to correspond to the presence of a 0.50 cc syringe. Since it will also not be depressed when there is no syringe present at all, the sensor used to determine syringe presence will be vital.

Figure 43 shows the sensor in place to determine that the plunger claw is completely at the bottom of the lead screw. Once this sensor is triggered, it ensures the device that it has a baseline to move the motors from. When the syringe plunger is positioned at the bottom of the lead screw, the syringe-filled cartridge can be rotated properly and also be allowed to swing out of the device, similar function for the bottle holder sensors. This sensor is also used to ensure the proper positioning if the situation were to occur in which the device was unplugged during the loading process.

2.3.2.6 Microprocessor: Microchips’ PIC24FJ64GA002

The microprocessor is another component that changed from the optimal design. It was discovered, after more careful attention to the actual chip and related documentation, the
PIC24FJ128GA006 would be too difficult to solder to a printed circuit board. The current microprocessor has a pin configuration that led to the ability to incorporate into a printed circuit board. The chosen processor is the 28-pin SPDIP version of the PIC24 processor. All of the specifications listed under the previous processor is the same for the final one chosen other than the memory and number of pins, and can be found under “Optimal Design”.

The microprocessor performs several functions during the operating of the syringe loading procedure in which the plunger is moved by the servomotor.

- It will first need to use the size of the syringe and the user requested dosage amount to calculate what voltage the stepper motor, which will rotate to in turn pull the syringe plunger down, should generate when the correct amount of insulin is withdrawn.
- The PIC24 then computes the number of steps the plunger’s stepper motor will complete until 80% of the voltage/distance is reached.
- The microprocessor will operate the motor in “quick” mode for the number of turns it requires to reach 80% of the voltage.
- The PIC24 will then slow the stepper motor to rotate the rest of the distance required to complete the filling of the syringe.
- Finally, when the “target” voltage is reached, the stepper motor’s resistance/voltage is returned to zero and the program processing resumes.

Figure 38: 28-pin SPDIP of PIC24 microprocessor
Chart 6: Main Menu options leading to Syringe Loading Process
Chart 7: Syringe Loading Process Leading to Syringe Removal Process
Chart 8: Syringe Removal Process

Sensor 1 = Orientation
Sensor 2a = Bottle Position <Up>
Sensor 2b = Bottle Position <Down>
Sensor 3 = Bottle Presence
Sensor 4 = Syringe Presence
Sensor 5 = Syringe Size
Sensor 6 = Plunger Claw Position
Servo 1 = Rotation of Syringe Cartridge
Servo 2 = Movement of Bottle Holder
Stepper = Syringe Plunger Movement
2.3.2.7 Power Supply

The power supply is another subunit that changed from the optimal design. The power and current requirements of the device is much greater than anticipated. The device is therefore required to plug into an outlet. To accomplish this, an AC to DC power adaptor is used to provide a 9 V supply to the device from a wall outlet.

![Power cord](image)

**Figure 39:** Power cord

2.3.2.8 Bottle Holder

The bottle holder went through a few revisions before the final product was produced. It is a standalone structure that is not removed from the device. Instead, there is a window that provides accessibility to it. The holder itself is made of light plastic material. The servomotor to move the holder requires that it be a light component, which is why plastic was chosen. As seen in Fig. 40, the user will insert the bottle by placing the bottom of the insulin bottle into the insulin bottom cap, which then presses upwards to compress the spring. The cap of the insulin bottle will fit tightly into the foam insulin bottle top cap. The “bottom cap” is designed to fit the two different bottle sizes. Additionally, a side of the holder is cut out to allow for users to easily fit their fingers into it to insert and remove the bottle. The design of the bottle holder is simple enough for someone with poor coordination or tremors to access. Although the plastic material used in the construction is very light and thin, it is stable enough to account for additional pressure from the bottle onto the case to hold.

The bottle holder also has two additional small holes positioned on the bottom of the case where the two neighboring syringes to the active one are located. The purpose is to ensure that when the holder is lowered to meet the syringe carrying out the loading process, the needles of its neighbors are not damaged. The positions are constant since the cartridge is
symmetric. The holes are also large enough to provide some clearance if the cartridge is offset by some small amount.

Figure 40: Computer model of final bottle holder design

The first bottle size, pictured on the left of the two with a red cap in Fig. 40, is a shorter bottle but with a greater diameter. This size will fit securely into the wider part outlined in the photo of the bottom cap. The second bottle size required to fit into the device is pictured with a silver cap on the right in Fig. 40. This bottle, as seen compared to the first, is slightly taller with a smaller diameter, which will fit into the taller thinner section of the bottom end cap. Figure 41 shows, with actual dimensions (in mm), how exactly the bottle holder will fit the two sizes of insulin bottles. Figure 42 shows the final product of the bottle holder and containing the two differently-shaped/sized bottles.

Figure 41: Computer model of how the two sizes of bottle fit the holder
The bottle is positioned vertically upside down. This will allow all of the insulin to be at the “top” (being at the neck and cap of the bottle) for the extraction by the syringe. The position is based on the method of extracting insulin from a bottle by hand of diabetic patients. The spring used in the bottle holder is intended to ensure that the insulin bottle is fit securely into the holder. It was chosen to not be too stiff, since a user may not be able to easily insert the insulin bottle, or not stiff enough, because it has to hold the bottle down with the pressure of the needle entering. Without it, the puncture of the needle into the bottle might force the bottle out of the holder and damage the needle and also disrupt many additional aspects of the device.

2.3.2.9 Bottle Holder Motor & Assembly

To fill the syringe, the insulin bottle holder moves towards it. This concept remains the same from the optimal design. It is the most simple and effective way for the device to work properly to puncture the bottle with the syringe needle. Figure 43 shows the assembly that includes the gear track located on the bottle holder, the associated gear that attached to the servomotor. The bottle holder track is located on the backside of the bottle holder and can be seen in Fig. 44. It is used as a for the bottle holder to move along when in operation by the servomotor.
Although the device must account for both a 0.50 cc and 1.00 cc syringes, the bottle holder will still only move to one set position. The position, which uses a sensor to act as a double check for it being there, accounts for both syringes and does not make either syringe enter to an insufficient or an over-sufficient amount of the insulin bottle. Since the difference in height between the 1.00 and 0.50 cc syringe is about 5 mm, there is not a large distance that must be accounted for. Both depths reached by the respectively sized syringe are accounted for when determining if the sufficient amount of insulin is contained in the bottle. Therefore, depending on which size syringe is present, there is a specific required amount of insulin to be remaining in the bottle after that current requested dosage is expected to be expelled from the bottle. Both amounts will ensure that it is the maximum amount of insulin to be remaining in the bottle to not waste insulin.

The motor chosen for the final prototype is a standard servo purchased from All Electronics Corp. A tab that allowed only half rotations was removed to allow the gear to make complete and additional rotations. The speed was initially varied to determine which was
most suitable for moving the bottle holder up and down in a timely fashion. The servo allowed the team to experiment with a wide range of speeds, which was a great advantage.

2.3.2.10 Syringe Cartridge

The syringe cartridge, as stated previously is a great advantage over the optimal design. It is the same concept but the functionality was increased to include five additional syringes to be held at one time, bringing the total to ten syringes. This allows a user of the device to use it for twice as long without having to refill the cartridge. The following two images, Fig. 45 and 46 show both a computer and actual version of the final syringe cartridge.

![Figure 45: Computer model of current syringe cartridge](image1)

The cartridge is made of solid aluminum that was then hollowed out to reduce much of the weight. It is a sturdy design that contains ten cartridge bays that each has a binder clip that
is bent to fit both sized syringes securely in place. At the bottom of the cartridge there are grooves that fit the part of the syringe that is used to hold the body of the syringe when pulling back the cartridge. The above photograph illustrates how each of the syringes fit onto the cartridge.

2.3.2.11 Syringe Cartridge Motor & Assembly

Another concept and design that did not change from the optimal design to the final prototype of the automated syringe-loading device is the syringe cartridge and motor assembly. For the final design, the gear assembly was, again, attached to the bottom of the cartridge. Therefore, when the syringe cartridge is removed, so is the gear assembly. It is designed to fit the cartridge as close as possible without disturbing the functionality of each bay contained on the cartridge. Attaching the gears the bottom of the cartridge will allow the rotation and save as much space as possible, which is important when designing a device to be as small as possible.

The assembly is rotated by the same kind of servo used in the bottle holder assembly and is positioned, as seen in Fig. 47, off to the side of the cartridge. It is situated that it will not disturb the syringes; however the plunger of each must be positioned completely inside of the syringe for it to rotate past the gear of the servo with clearance.

![Syringe cartridge and motor assembly](image)

**Figure 47:** Syringe cartridge and motor assembly

2.3.2.12 Syringe Loading & Assembly

The syringe loading has also not changed considerably from the previous design. A syringe is loaded by pulling the plunger away from the syringe needle. To perform this task the same stepper motor described in the optimal design is used. However, there is no required potentiometer. The stepper turns the attached gear, which turns a second gear that then rotates a lead screw. Attached to the leadscrew is the plunger claw seen in Figs. 48 and 49.
Figure 48: Computer version of syringe loading assembly

Figure 49: Assembly for syringe loading

Figure 50: Plunger claw seen in white
The leadscrew is a long screw with precisely laid thread. As it turns, a sleeve nut contained in the plunger claw and positioned on the leadscrew, is forced up or down depending on the direction of the screw’s rotation. The motion followed by the assembly is that the plunger claw is initially set to the bottom position, depressing the sensor, which informs the microprocessor. The leadscrew is, when instructed by the processor, rotated to move the plunger claw upwards to meet the plunger. Since the cartridge holds both sized syringes at the same height, according to their plunger’s, the claw is instructed to go to the uppermost position at which time the plunger tab will be forced into a groove of the claw. The groove is design to fit the tab of the plunger in order to hold it with enough force to then subsequently pull the plunger downwards to fill with insulin. When the syringe has finished being loaded, the processor instructs the servo for the cartridge, again, to rotate in a clock-wise fashion to position the same syringe at the door for the user to remove it. When the cartridge holding the syringe is rotated it will slide out of the groove and the claw will then be returned to the bottom of the case at the beginning of the next loading of the syringe.

2.3.2.13 The Case

The case is a simple rectangular box with dimensions 300 mm x 200 mm x 120 mm, seen in Fig. 51. The frame seen in Fig 52 was built according to the case. The fame is made of aluminum and the case of plastic. The frame made the positioning of the various components extremely easy and when it came time to cut out the actual case for the LCD, keypad and windows for the syringe cartridge and insulin bottle holder, the frame gave the exact model to be followed for the correct positioning.

Figure 51: Aluminum frame without components
Figure 52: Final prototype of the automated syringe-loading device
The intended design to satisfy the problem faced by many diabetic patients with a variety of conditions causes factors, based on limitations, to be followed when considering not only the pure design of the device but the user’s capabilities. For the automated syringe-loading device, health and safety of the user are important to keep in mind when proposing a design. The device should be able to impact their lives in a positive way and not compromise what has already been by their disability.

A constraint that is proposed by this design is the interaction between the user and device input selection by voice recognition. A significant problem may arise if the voice recognition module does not correctly interpret the user. It can lead to great frustration and an incorrect loading of the dosage. The alternative to the voice recognition is the keypad interface designed to specifically target any difficulties faced by disabled users.

The visual display and audio output may also be difficult for the user to interact with. The device must be tested on a number of patients to determine their comfort level with the size and clarity of the characters. It will also be necessary for the audio output to be tested and reprogrammed as necessary. Different voices may carry through more clearly, making it easier for the patient to understand what is being said.

The device is not intended to be completely portable. This requires a wall outlet to be accessible as the power supply. If there is not one available, the user does not come into a dilemma that may cause their health to be in jeopardy. Since the device is designed to be lightweight, it will be simple to carry and place near an open wall outlet.

The size of the device is a consideration for reasons pertaining to portability and to ensure that the user will not feel the device is a nuisance. The self-contained device should be as lightweight as possible since some of the users do not have great strength. For active users, the device should not hinder other aspects of life such as carrying young children and objects. By putting the device, intended to be the size of a briefcase, in a bag that can be worn on the shoulder, across the chest, or even in a backpack fashion, the user will be able to select their choice of style and what is most comfortable to them.

The device should be protected in the case, in the event that the device drops to the ground or is shaken around. The layout of the internal casing will be designed in such a way that every component is affixed to the frame inside the case and protected. The layout will has been maximized so the case is not larger then it absolutely must be.
4 Safety Issues

Accuracy and durability of sensors is a main safety issue for the automated syringe-loading device. Without accurate sensors, incorrect doses of insulin will most likely be drawn. Such errors may result in too much insulin or not enough. Air bubbles will also be a product of the errors, which will give the user false confirmation of the intended dosing. These errors can become significant to a person who must have the correct amount of insulin.

The device should have no exposed electrical wires. The patient can be harmed in the occasion that it produces an electrical shock. The device must also be contained in such a way that if a spill accidentally occurred, there would not be any risk to the user. To assure that there is no additional hazards to the user, a clear shielding made out of lightweight plastic can be used to cover the mechanical components.

An additional safety issue is malfunction within the mechanical components. Failure in the syringe guides could lead to mis-positioning or jamming of the syringe during loading. In addition, failure in the bottle holding assembly could lead to misalignment of the bottle, which could result in syringe needle damage or breakage. All have the possibility of injuring the user of the device.

Sterilization of all syringes is an important safety consideration. Each syringe comes individually packaged for sterilization reasons so it is therefore necessary to maintain an environment in which the patient will know they are being protected from harmful conditions. It may become necessary to ensure that all components will stand up to sterilization techniques, such as chemical washing or autoclaving.

5 Impact of Engineering Solutions

As a growing number of diabetic cases occur due to various factors, such as obesity and low physical activity on an individual’s behalf, a better design for syringe-loading devices is vital. As a growing population ages, an additional increased risk of diabetes is present. With the growing numbers of diabetes cases, come an increasing number of people with disabilities. These disabilities can greatly inhibit a person’s ability to properly inject themselves with the correct amount of insulin. Without the correct amounts, a person’s health deteriorates and can lead to greater risks and dangers.

There are many great consequences if a diabetes patient does not properly take care of their condition. Strokes, blindness, heart disease, kidney failure, amputation, and nerve damage are all possible effects caused by diabetes if untreated or not treated properly. With the use of the syringe-loading device, diabetes patients will find their condition more easily controlled with a device contributes to great accuracy and simplicity.

By incorporating various languages into the device, it will be able to be used on a global level. The simple-to-use design will appeal to large numbers of people from different backgrounds. Patients who may be unfamiliar with technology or who have other lifestyles
can also utilize the same features intended for users with disabilities.

It is important that devices intended for all different people in different income brackets be able to afford these essential devices. By building an affordable and simple device, many people will benefit for the attainability of it. Widespread distribution of the device is also an important factor. An economical device within typical syringe-loading devices is necessary because normal insulin pumps can cost well over $5,000 not including monthly supplies and increased doctor visits to maintain the device. By designing and building within a budget of $2,000 future designs will be able to properly mimic while cutting down on individual components and therefore reducing the overall price. With increased distribution of the components being used, the device will benefit from lowered manufacturing costs.

The portability of the intended syringe-loading device allows diabetes patients to explore other opportunities and will give them the confidence that they lacked before regaining such independence. Allowing the user to bring the device on day trips and vacations will give them the freedom they may have thought was gone. Such a design of portability will appeal to more patients and help give them the confidence of receiving an accurate amount of insulin.

The accuracy of the device will allow insulin users to receive the maximum benefits from a precise amount of required insulin. This precision can improve their everyday activities and allow the user to receive the benefits intended by the design.

The design of the project is meant to appeal to everyone regardless of their familiarity of technology. The intended design will allow various patients with disabilities to use the device in a similar fashion as any other non-disabled diabetes user. The simple user instructions will deliver an accurate dosing of insulin to all users.

6 Life-Long Learning

With greater knowledge of components that can be used to assist the designing of the syringe-loading device, the team is able to explore greater opportunities to further assist diabetes patients with disabilities. Devices that currently also help with disabilities can be modified to fit this application appropriately by using the lessons taught in the designing of the device.

Through researching the different components for the device, many new techniques in designing abilities were encountered. By using a different display that does not contain an incorporated microprocessor and can also be used with a wide variety of microprocessors, the team was able to explore greater programming languages and to learn and understand how to use the current design to implement the correct steps into the program.

By using an external keypad, different opportunities can be explored to decide on what is the best method to go by for appealing to an overall population. The text-to-speech synthesizer has been able to teach the team members a new way of communicating to the
user by use of the microprocessor. The different selections incorporated into the speech output will continue aid the team in learning about the various disabilities diabetes patients encounter and a way to assist them in greater places than just the syringe-loading device.

Over the second semester, each team member has been challenged with new equipment they had to learn in order to successfully accomplish the final product of the device. Much of the electrical interactions were learned through greater research than the first semester and many trial and error occurrences. The team was also able adapt to the weekly changes presented by various constraints and suggestions based on David Price and Dr. John Enderle’s input. The weekly meetings with them encouraged each teammate to become very knowledgeable on all aspects of the device. Also, through the meetings, the team was able to enhance presentation skills from communication to visual displays in the PowerPoint slides put together each week.

Overall, the team has been challenged with learning to work as an actual team. It was important for each to maintain good communication frequently throughout any given week. Dr. Enderle’s method of forming the teams encouraged people to talk and work together with those they hadn’t before. It was an excellent learning tool in preparing each teammate for either graduate school or the work environment that will present on landing their first biomedical engineering jobs.

7 Budget

During the research, development, and design of this device, the impact of cost was always kept in mind. In fact, one of the biggest differences between all alternative designs was the cost of the project. Design 1 was as minimalist as possible, in order to bring the device to as many people without regard to income. Design 2 was extravagant, with a tablet pc as the core of the device. And finally design 3, which makes up much of the optimal design, was the middle ground between the two. It came largely from creativity, but also from the large amount of positive and negative feedback designs 1 and 2 received. Finding out what ideas others thought were useful and desirable in a syringe loader, or foolish and unnecessary, made design 3 much easier to imagine.

In the final prototype of the automated syringe-loading device, the team was able to remain very under budget. The total expenses came to $1,600.46. This can be attributed to the different components each team member individually spent to receive things faster. Below is a spreadsheet of the final expenses.
8 Team Member Contributions to the Project

Team Member - Daniel Littleton

Throughout the semester Daniel has assisted the team by: purchasing insulin needles for testing, testing these needles, participating in and contributing to regular team meetings, writing drawing and developing the motor and syringe interactions in all three alternative designs, drawing and describing the syringe cartridge in the third and optimal design, developing the motor and potentiometer physical/electrical interactions, providing information on parts, drawing diagrams in Microsoft Visio, calculation the budget, compiling the schedule for the device build in Microsoft Project, assembling alternative design write-ups, gathering contributions and finalizing Team papers, organized the flow table for the device actions, completing parts orders, speaking with pharmacists to obtain expert information, developing the syringe clip on the syringe cartridge, performing PSpice simulations, submitting various Team paper subsections, developed circuit amplifiers and comparators, researched voltage regulators, utilized digital devices such as the digital potentiometer, and was normally responsible for the motors, servos, electrical diagrams, and part movements for the designs.

In the second semester, Daniel spent a significant amount of time in the machine shop. He sometimes built a few different components more than once to ensure the final would fit accurately and precisely. He also contributed to a couple different circuit designs. Daniels also learned and mastered the AutoCAD program when planning for many of the

<table>
<thead>
<tr>
<th>Part Description</th>
<th>Quantity</th>
<th>Company</th>
<th>Total Cost</th>
</tr>
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<tbody>
<tr>
<td>LCD Display</td>
<td>3</td>
<td>Matrix Orbital</td>
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<tr>
<td>PIC24 Microcontroller</td>
<td>15</td>
<td>Microchip Direct</td>
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<tr>
<td>PIC24 Microcontroller Book</td>
<td>1</td>
<td>Amazon</td>
<td>$43.96</td>
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<td>Speech Output</td>
<td>1</td>
<td>Acroname Robotics</td>
<td>$123.95</td>
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<tr>
<td>Speech Recognition</td>
<td>2</td>
<td>Omnibrom Electronics</td>
<td>$219.80</td>
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<tr>
<td>Speech Recognition Chip</td>
<td>2</td>
<td>Images St. Inc.</td>
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<td>Stepper Motor</td>
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<td>Alltronics</td>
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<td>Servomotor</td>
<td>2</td>
<td>Tower Hobbies</td>
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<td>Bottle Holder Assembly Components</td>
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<td>Gear Accessories</td>
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<td>Other Various Supplies</td>
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<td><strong>Total Current Cost</strong></td>
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<td></td>
<td><strong>$1,606.49</strong></td>
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</table>

Table 4: Final Expenses
components. Daniel also contributed to the upkeep of the website. Overall, he did an excellent job designing the frame of the case and the components to fit inside of it.

Team Member - Scott Relation

Scott participated in design discussions, researched potential components & vendors, and took turns with other team members in the final preparation of project deliverables. For reference purposes he acquired 50 cc and 100 cc syringes for the Team to consult when working on various design approaches for the device. Scott was primarily responsible for the microprocessor evaluation & selection, the microprocessor programming, and the microprocessor inter-component communication aspects of the device designs. He developed the initial menu program for the automatic syringe loader, and created flowcharts describing its navigation and operation. He conducted the initial research regarding tablet laptops and the Phidget devices that were proposed for Alternative Design 1, and initially suggested using Dragon NaturallySpeaking for use as voice input software. Scott conducted initial research on the DoubleTalk sound chip that was used in Alternative Design 3. He was in charge of the device’s Bottle Holder and Battery/Charger subunits in all the design versions, and was responsible for the Syringe Holder subunit in Alternative Design 1. He was also responsible for the case layout approach take was taken in Alternative Design 2. In addition to reviewing and trying to contribute to other Team Member sections when possible, Scott was primarily responsible for maintaining the Team’s website.

Scott continued to help maintain the website in the second semester of the design. He did all of the programming and circuitry design and also set up all of the motor components. The motor components he was involved was the servos and the stepper motors. He assembled and tested the microprocessor circuit. Scott also programmed the voice recognition and sound output. He also assisted in the design of various components.

Team Member - Kathryn Tempe

Kathryn provided external communication with those more familiar with diabetes by meeting with a diabetes patient who useful insight on the topic. The patient also helped the group to understand the proper loading of a syringe along with providing recommendations on user interaction with the device. In addition, she met with a Diabeatologist that addressed some of the team member's additional concerns regarding patients with disabilities and ability to work the device. Kathryn mainly worked on the user interface components of the device. Researching various display options including those with and without built-components such as microprocessors and speakers. She also did research on the keypad alternatives such as the touch-screen and various external keypad-styled inputs. Although decided against as an optimal design, Kathryn spent a significant amount of time on speech-input options mentioned in Design 1 and 2. Kathryn was responsible for putting together Design 1 and the Optimal Design write-up. With the review and advice from her teammates,
she also wrote the following sections: Realistic Constraints, Safety Issues, Impact of Engineering Solutions and Life-Long Learning.

In the second semester, Kathryn also continued research of many newly considered components, some of which replaced the optimal design choices. She also worked to provide Scott with the final menu navigation to be programmed and also worked on the six areas of sensors required for the device. Kathryn attributed to the mechanical aspects of the device by building the bottle holder and the assembly. She helped in constructing the pre-final components such as the plunger motor assembly before Daniel proceeded to build it in the machine shop. Many of her attributions were to help move the design forth by practicing the motor and component interactions before building a final. This was useful in determining what could and could not work in a final design. Kathryn also contributed to suggestions and comments on both Scott and Daniel’s components and was also involved with updating the website.

9 Conclusion

The final design for the syringe-loading device addresses concerns from diabetes patients with disabilities. The device will accurately fill any standard 50 and 100-milliliter syringe to a value of 1/1000th of a milliliter. To accomplish this task, programming in combination with sensors and motors, are used. The components used successfully accomplish the task of retrieving various products and making them work in such a way that resolves the goal for the design. Each of the components decided on for the final design was after careful consideration and analysis on the team’s behalf as well as the instructor’s. After the concern of many different options, the LCD interface and speech output will allow easy and ideal communication to the user. The newly added speech recognition will further aid patients with disabilities to fill a syringe accurately by providing the required communication. The speech output will permit those with visual impairments to receive the same instructions as those who are hard-of-hearing and rely on the LCD screen. The programming involved will have favorable prompts requiring simple “yes” and “no” responses, and also simple tasks from the user. An orientation sensor will allow the program to determine if the device is orientated correctly so that it is safe and able to correctly load the syringe. The bottle-holder assembly produced provides the best option for the device to access the insulin. A servomotor will move this assembly, which is set on tracks to the appropriate syringe needle. The syringe-cartridge offers a considerable advance in the device by making it much more user friendly and also adheres well to the overall design.

This syringe-loading device is an ideal design for patients with diabetes who may have a various disabilities. The design is built to be economical, user-friendly and will address the engineering constraints set forth. The device will prove to be extremely accurate, which will put wary users’ minds to rest. The accuracy and the layout of the device will help make it as safe as possible. Everything is enclosed in the device so there will be no risk to the user and children will not be able to easily access sharp syringe needles if left unsupervised. The
ability to design this device has produced many opportunities to study new techniques and look deeper into others previously learned. The budget allotted for the project has been used to help the team learn how to manage a project that depends on their ability to retrieve the specific products requested. The team worked diligently to follow the timeline since it is an important guide to successfully completing the syringe-loading device. The design that has been built will accurately measure a specified amount of insulin in an economical and friendly way to allow the diabetes patient to remain active and independent.
References


Products. 2 Oct. 2007


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GB RAM, 60 GB Hard Drive, Vista Premium).” Amazon.com.
<http://www.amazon.com/dp/B000PBGLH0?tag=carrypad-
20&camp=15309&creative=331461&linkCode=st1&creativeASIN=B000PBGLH0
&adid=1RTM938AR607JX7QCM78&>.


Acknowledgements

Team 2 would like to acknowledge the following individuals and institutions for the contributions they’ve made towards the development of the Automatic Syringe Loading Device.

Thanks to Dr. John Enderle of the University of Connecticut for the instruction, guidance, and feedback he has provided throughout the project’s development.

Thanks to Dave Price of the University of Connecticut for the feedback and direction he has provided throughout the entire design process.

Thanks to Rehabilitation Engineering Research Center (RERC) for sponsoring the Student Design Competition and for funding our project.

Team 2 would also like to acknowledge contributions made by the following individuals:

Serge and Rich from the machine shop

Lee VanHennik – a diabetes patient who contributed valuable insight on typical patient concerns and issues regarding the preparation and administering of insulin injections, and provided a patient’s perspective on what features & design considerations should be incorporated into our device.

Dr. Edward Etkind – a diabetetologist from the Connecticut Medical Group who provided information on diabetes and insulin, discussed current insulin treatment devices & methods, and provided a physician’s perspective on what features & design considerations should be incorporated into our device.
# Appendix

## Updated Specifications

<table>
<thead>
<tr>
<th>Mechanical Parameters (mm)</th>
<th>Keypad</th>
<th>Overall Height 114.30</th>
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</thead>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Width (sm) 15.24</td>
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</tr>
<tr>
<td></td>
<td>Width (lg) 38.10</td>
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<tr>
<td></td>
<td>Acutation Pressure Little</td>
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<td>Diameter 50.80</td>
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</tr>
<tr>
<td>Case</td>
<td>Duraibility Very***</td>
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<td>***All mechanical components are affixed to the frame</td>
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### Electrical Parameters

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<tbody>
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<td>Diodes</td>
<td>6V, 50mA</td>
</tr>
<tr>
<td>LCD</td>
<td>5V, 191mA</td>
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<tr>
<td>Illumination</td>
<td>Backlight</td>
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<tr>
<td>Voice Recognition</td>
<td>9V, 34mA</td>
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<tr>
<td>Microphone</td>
<td>3.0V (2 AA batteries)</td>
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<tr>
<td>Speech Output</td>
<td>5V, 100mA</td>
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<tr>
<td>Bluetooth</td>
<td>5V, 34mA</td>
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<tr>
<td>Lever Sensors</td>
<td>125V, 5A</td>
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<tr>
<td>Button Sensors</td>
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<tr>
<td>Relays</td>
<td>60V, 0.5A</td>
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<tr>
<td>Power Supply</td>
<td>9V, 800mA</td>
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</tbody>
</table>

### Environmental Parameters

<table>
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<th>Location</th>
<th>Indoors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature (°C)</td>
<td>5 to 40</td>
</tr>
</tbody>
</table>
#include "p24fj64ga002.h"
#include "string.h"
#include "stdio.h"
#define XTFREQ          6000000          //Crystal frequency
#define PLLMODE         2              //On-chip PLL setting
#define FCY             XTFREQ*PLLMODE   //Instruction Cycle Frequency
#define BAUDRATE        38400
#define BRGVAL          ((FCY/BAUDRATE)/16)-1
#define DELAY        50
#define VOLUME       0
#define SPEED        3
#define PITCH        7
#define DELAY_StepperMotor 300
#define DELAY_BottleServo 1200
#define DELAY_CartridgeServo 1000

_CONFIG2(FNOSC_PRIPLL & POSCMOD_XT);

void DisableUART(void)
{
    IEC0bits.U1TXIE = 0;        // Disable UART1
    RPOR4bits.RP9R = 0;     // Clear the TX mapping to Pin RP9
    RPOR4bits.RP8R = 0;     // Clear the TX mapping to Pin RP8
}

void InitScreen(void)
{
    DisableUART();
    RPOR4bits.RP9R = 3;     // Make Pin RP9  U1TX
    U1BRG  = 77.125;           // Set Baud Rate
    U1MODE = 0x8810;      // UARTx is enabled; UxTX & UxRX are enabled
                          //   8 bit, no parity, 1 stop bit; 16 clocks per period
                          //   Rx idle is 0
    U1STA  = 0x4400;         // Tx idle is 0, UTxEN is enabled
    while (TMR1<100){} TMR1 = 0;
}

void InitSoundOutput(void)
{
    DisableUART();
    RPOR4bits.RP8R = 3;     // Make Pin RP8  U1TX
    U1BRG  = 18.53125;          // Set Baud Rate

U1MODE = 0x8811; // UARTx is enabled; UxTX & UxRX are enabled
//   8 bit, no parity, 2 stop bit; 16 clocks per period
//   Rx idle is 0

U1STA = 0x4400; // Tx idle is 0, UTxEN is enabled
while (TMR1<100){} TMR1 = 0;
}

void SetupLCDScreen(void)
{
    InitScreen();
    // Turn off backlight
    while(!U1STAbits.TRMT);  U1TXREG = 0xFE;   while(!U1STAbits.TRMT);
    U1TXREG = 70;
}

void writeUART(char *str2Write)
{
    InitScreen();
    // Clear the screen
    while(!U1STAbits.TRMT);  U1TXREG = 0xFE;   while(!U1STAbits.TRMT);
    U1TXREG = 88;
    // Write text to the screen
    while (*str2Write != '\0')
    {
        while(!U1STAbits.TRMT);
        U1TXREG = *str2Write;
        *str2Write++;
    }
    while (TMR1<5000){} TMR1 = 0;
    DisableUART();
}

void speakUART(char *str2Write)
{
    InitSoundOutput();
    // Begin a Text-to-Speech command; setting the Volume, Pitch, and Speed to use
    while(!U1STAbits.TRMT);  U1TXREG = 0x80;   while(TMR1<DELAY){} TMR1 = 0;
    while(!U1STAbits.TRMT);  U1TXREG = VOLUME; while(TMR1<DELAY){} TMR1 = 0;
    while(!U1STAbits.TRMT);  U1TXREG = PITCH;  while(TMR1<DELAY){} TMR1 = 0;
    while(!U1STAbits.TRMT);  U1TXREG = SPEED;  while(TMR1<DELAY){} TMR1 = 0;
    // Write the text that is to be synthesized into speech
    while (*str2Write != '\0')
    {

while(!U1STAbits.TRMT); U1TXREG = *str2Write; while (TMR1<DELAY){} TMR1 = 0; *str2Write++; } while(!U1STAbits.TRMT); U1TXREG = 0x00; }

void TurnBottleServo(int Direction) {
  if (Direction == -1) { // Turn Servo counter clock-wise if the A0 pin is low
    while (TMR1<50){} TMR1 = 0; _RA4 = 1; // Set the servo control lead high
    while (TMR1<10){} TMR1 = 0; _RA4 = 0; // Set the servo control lead low
    while (TMR1<DELAY_BottleServo){} TMR1 = 0;
  }
  else { // Turn Stepping Motor counter clock-wise if the A0 pin is high
    while (TMR1<150){} TMR1 = 0; _RA4 = 1; // Set the servo control lead high
    while (TMR1<DELAY_BottleServo){} TMR1 = 0; _RA4 = 0; // Set the servo control lead low
  }
}

void TurnCartridgeServo(int Direction) {
  if (Direction == -1) { // Turn Servo counter clock-wise if the A0 pin is low
    while (TMR1<50){} TMR1 = 0; _RB5 = 1; // Set the servo control lead high
    while (TMR1<10){} TMR1 = 0; _RB5 = 0; // Set the servo control lead low
    while (TMR1<DELAY_CartridgeServo){} TMR1 = 0;
  }
  else { // Turn Stepping Motor counter clock-wise if the A0 pin is high
    while (TMR1<150){} TMR1 = 0; _RB5 = 1; // Set the servo control lead high
    while (TMR1<DELAY_CartridgeServo){} TMR1 = 0; _RB5 = 0; // Set the servo control lead low
  }
}

void TurnStepperMotor(int Direction) {

if (Direction == -1) { // Turn Stepping Motor counter clock-wise if the A0 pin is low
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0001000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0011000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0110000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0100000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1100000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1000000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1001000000000000; // Specify direction
}
else { // Turn Stepping Motor counter clock-wise if the A0 pin is high
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1001000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1000000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b1100000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0100000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0110000000000000; // Specify direction
    while (TMR1<DELAY_StepperMotor) {} TMR1 = 0;
    PORTB = 0b0001000000000000; // Specify direction
}

int main(void)
{
    AD1PCFG = 0xffff; // Disable the Analog/Digital converter function to allow full use of
                      // Port A pins
    TRISA = 0b00;     // Config Port A pins 0-7 for input
    TRISB = 0x0000;   //
T1CON = 0x8030;           // Configure Timer 1 parameters
TMR1 = 0;                 // Initialize Timer 1

SetupLCDScreen();
char Prompt[50];
int VoiceInput;
int Loop;
_RA1 = 0; while (TMR1<10000){} TMR1 = 0;   // Disable Stepper Motor Control Pins

while(1)
{
    writeUART("Main Menu
Load Dose
View Data\0");
    while (TMR1<10000){} TMR1 = 0;
    // Enable Voice Recognition for input
    _RB6 = 1;
    VoiceInput = 0;
    while (1) {
        while (TMR1<40000){} TMR1 = 0;
        VoiceInput = _RB15 + _RB14 * 2 + _RB13 * 4 + _RB12 * 8 + (_RB11 + _RB10 * 2 + _RB7 * 4) * 10;
        sprintf(Prompt, "Turn On\nVoice Rec\nPort B: %d\0", VoiceInput);
        writeUART(Prompt);
        while (TMR1<40000){} TMR1 = 0;
        while (TMR1<40000){} TMR1 = 0;
        switch (VoiceInput) {
            case 3:   goto ThreeEntered; break;
            case 13:  goto ThreeEntered; break;
            case 23:  goto ThreeEntered; break;
            case 4:   for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(-1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
            case 14:  for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(-1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
            case 24:  for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(-1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
            case 5:   for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
            case 15:  for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
        }
    }
}
case 25: for(Loop=1;Loop<20;Loop++) { TurnCartridgeServo(1); sprintf(Prompt, "Servo Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; } break;
case 7:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
  _RA1 = 1; while (TMR1<10000){} TMR1 = 0; // Enable Stepper Motor
  for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(-1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; }
  _RA1 = 0; while (TMR1<10000){} TMR1 = 0; // Disable Stepper Motor
  _RB6 = 1;; while (TMR1<10000){} TMR1 = 0; // Enable Voice Recognition
break;
case 17:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
  _RA1 = 1; while (TMR1<10000){} TMR1 = 0; // Enable Stepper Motor
  for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(-1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; }
  _RA1 = 0; while (TMR1<10000){} TMR1 = 0; // Disable Stepper Motor
  _RB6 = 1;; while (TMR1<10000){} TMR1 = 0; // Enable Voice Recognition
break;
case 27:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
  _RA1 = 1; while (TMR1<10000){} TMR1 = 0; // Enable Stepper Motor
  for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(-1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; }
  _RA1 = 0; while (TMR1<10000){} TMR1 = 0; // Disable Stepper Motor
  _RB6 = 1;; while (TMR1<10000){} TMR1 = 0; // Enable Voice Recognition
break;
case 8:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
  _RA1 = 1; while (TMR1<10000){} TMR1 = 0; // Enable Stepper Motor
  for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; }
  _RA1 = 0; while (TMR1<10000){} TMR1 = 0; // Disable Stepper Motor
  _RB6 = 1;; while (TMR1<10000){} TMR1 = 0; // Enable Voice Recognition
break;
case 18:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
  _RA1 = 1; while (TMR1<10000){} TMR1 = 0; // Enable Stepper Motor
  for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000){} TMR1 = 0; }
  _RA1 = 0; while (TMR1<10000){} TMR1 = 0; // Disable Stepper Motor
  _RB6 = 1;; while (TMR1<10000){} TMR1 = 0; // Enable Voice Recognition
break;
case 28:
  _RB6 = 0;; while (TMR1<10000){} TMR1 = 0; // Disable Voice Recognition
RA1 = 1; while (TMR1<10000) {} TMR1 = 0; // Enable Stepper Motor
for(Loop=1;Loop<20;Loop++) { TurnStepperMotor(1); sprintf(Prompt, "Step Loop %d\0", Loop); writeUART(Prompt); _RB5 = 0; while (TMR1<40000) {} TMR1 = 0; } _RA1 = 0; while (TMR1<10000) {} TMR1 = 0; // Disable Stepper Motor
_RB6 = 1;; while (TMR1<10000) {} TMR1 = 0; // Enable Voice Recognition
break;

default:
while (VoiceInput != 0) {
  // Voice Recognition - Clear/Reset
  _RB6 = 0; while (TMR1<10000) {} TMR1 = 0; _RB6 = 1;
  VoiceInput = _RB15 + _RB14 * 2 + _RB13 * 4 + _RB12 * 8 + (_RB11 + _RB10 * 2 + _RB7 * 4) * 10;
}

ThreeEntered:
writeUART("3 Selected\0");
while (TMR1<40000) {} TMR1 = 0;
while (TMR1<40000) {} TMR1 = 0;
while (TMR1<40000) {} TMR1 = 0;
while (TMR1<40000) {} TMR1 = 0;
return 0;