Accessible Blood Glucose Monitor

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Abstract:

The gPod Glucose Monitor incorporates features that accommodate diabetic patients with a variety of disabilities such as impaired vision, complete blindness, hearing loss, impaired movement, and tremors. These included features are a legible LCD screen and audible speech to instructions and results. The meter will also have a simple interface to aid in proper operation. A last feature that is unique to the gPod is a separate insulin vial barcode scanner.

A patient who has had their vision significantly impaired would not be able to properly operate a glucose meter that communicates instructions and results solely through a screen. An audible output that the patient could listen to is one method of overcoming this. Large buttons that incorporate a Braille notation is another overlooked feature. The size of the meter is also an important consideration. Having the meter as small as possible does not necessarily make it well-designed. For a patient that experiences tremors, a meter that is palm-sized with rubber grips is much more user-friendly. The clients that have been assigned have ages that range from 12 years old to 64 years old, so simple operation and use of the meter is essential. The quality of life for these diabetic patients greatly depends on the ease of their glucose monitoring. It is crucial that the meter accommodate each of their needs.
**Introduction:**

Diabetes is a disease that currently affects 14.6 million Americans, comprising 6.3% of the American population, with new cases continually developing. It is the fifth leading cause of death in the United States. Diabetes is a disease where the body does not properly use or produce insulin. There are two major types of diabetes, type I and type II. Type I diabetes is where an individual’s body does not produce insulin. Type II diabetes is where an individual’s body does not properly use insulin combined with a relative insulin shortage within the body. Type II diabetes is by far the more common type with about 90% of people with diabetes having this form. Insulin is a hormone produced in the human body which is needed for the conversion of sugar, starches, and other food into energy. Without insulin the body would not be able to receive the amount of energy needed to function, which is why diabetes is such a serious disease.

The major problem with diabetes is that the underlying causes of it are currently unknown. Various factors have been determined to play a role in diabetes such as genetics, obesity, and lack of exercise. At this time, there is no cure for diabetes so lifelong treatment is the only alternative. These treatments can consist of blood glucose monitoring combined with insulin injections, keeping to a strict diet to control sugar intake, and exercise. A diabetic person who does not monitor their blood glucose levels runs the risk of falling into insulin shock and other very serious complications.

The most popular method for monitoring blood glucose levels is through the use of a portable glucose monitor. These devices are made relatively small to maximize their portability, but still perform their intended function. Portable meters are battery operated and can analyze a very small sample of blood to a high degree of accuracy. The majority of the meters currently on the market are designed for an individual who has no physical limitations. There are many disabilities commonly associated with diabetes such as vision loss, hearing impairment, and motor control impairment which hinder the use of a standard meter. Our assigned patients include a young patient who has partial vision loss, an elderly patient who has total vision loss, a patient who has Parkinson’s disease and has tremors, and a patient who has partial hearing loss. While a few meters do take the needs of these disabilities into consideration, they are very expensive and bulky as well.

The following sections will describe other available blood glucose meters and patents. The report will also cover the three different prototype designs and a discussion of the hybrid optimal design. Component descriptions, project timelines, budget, safety, environmental, handling, social, and political concerns will also be discussed.
Market Research:
The diabetes testing market is a $132 billion a year industry. One out of every ten healthcare dollars is spent on the diagnosis and treatment of diabetes. Approximately $13,000 is spent per person per year on diabetes treatment in the United States. The recent rise in obesity and increasing age of the American population is driving an increase in the number of newly diagnosed cases of diabetes. There are many blood glucose meters already on the market. Below is a selective list of some products that are currently available. The features of these meters, and lack there of, influenced the proposed design. Also listed, is the retail price of each meter which is an important consideration in making the proposed meter a competitive product.

Accu-Chek Advantage System:

This product is priced at $65 and is a leading meter in sales. The Advantage System is light at just 1.8 ounces without batteries. It is physically about the size of a stopwatch which makes this device very portable. The Advantage System has a large display with good contrast for easy viewing by the user. The meter has a snap in code key so that the patient can easily calibrate the meter to the test strips that are being used. This is a particularly nice feature since it accommodates patients with vision loss who would otherwise have difficulty calibrating the meter. There is no internal cleaning needed for the meter since all the testing is done on a disposable strip. The Advantage System does have room for improvement. Each test takes approximately 26 seconds to return the results. Other meters available perform tests in a fraction of this time. Another limitation to the Advantage system is the ability to only draw sample blood from the fingertips. Figure 1 shows the Accu-Chek Advantage meter.

Figure 1, Accu-Chek Advantage Meter.
**OneTouch Ultra by Lifescan:**

This product cost $75 and is one of the most popular meters on the market due to its small portable size and easy to use interface. It has a large display with good contrast for easy viewing by the user. The One Touch Ultra has a test result speed of just 5 seconds, one of the fastest on the market. A sample size of 1 micro liter of blood is the required for testing. The One Touch Ultra allows for multiple site testing, meaning samples can be drawn from the finger or the forearm. Up to 150 glucose test results can be stored in the on-board memory. This allows for the meter to do 14 and 30 day averages. The One Touch Ultra does have room for improvement such as a strip calibration method better suited for users with vision impairment. The meter is small and hard to handle. Figure 2 shows the OneTouch Ultra meter.

![OneTouch Ultra Meter](image)

**Figure 2, OneTouch Ultra Meter.**

**Accu-Chek Voicemate System:**

This product is priced at $570 which is quite expensive though it is one of a very few on the market that has audio output. The audio output is the most unique feature on the meter since it outputs step-by-step voice prompt instructions for the user. This allows for patients who have severe to total vision loss to be able to operate the meter. The Voicemate System also has the same snap in code key as the Advantage. The meter also has an insulin vial scanner which checks to see what type of insulin is being used to ensure the correct formulation. Another helpful function of the meter tells the person if there is enough blood on the strip for the test to be run. The Voicemate weighs 11.4 ounces with the batteries and the size is larger than most meters. The size is due to the complexity of the voice unit and vial scanner, in addition to the modular design. The Voicemate returns the test results in 26 seconds. The proposed device plans to incorporate the step-by-step voice prompt instructions while aiming to reduce the size, weight, results time, and cost. A smaller, portable single unit design is the target for the proposed meter. The Accu-Chek Voicemate is shown in Figure 3.
Related Patents
This section is for determination of what products or devices deserve a patent. The patent search can be a useful tool in idea generation since it reveals ideas previously not thought of and can lead to a new idea to accomplish a certain task. A patent search can reveal what patents are currently out there and from whom permission might have to be granted to use a certain patent within your own design.

#5997817 Electrochemical biosensor test strip – December 7, 1999 - Crismore, et al.
This patent describes an electrochemical biosensor with four new features than previous ones. A small indentation was added for where the sample was to be places. The sample application port leads to a capillary test chamber where a test reagent is included. The capillary test chamber now includes a transparent window which acts as a “fill to here” line which identifies when enough blood has been added to the chamber.

This patent has added enhanced features for the ease of use of the patient and for increased function of the test strip. The new sample indentation and window allows for the patient to easily find the sample spot and see when enough sample has been added. The proposed meter will use test strips of this type.

This patent describes an electronically readable information carrier which is an apparatus that provides in combination with and instrument the information for determining the concentration of medically significant components of a biological fluid. There is an integrated circuit carrier included and a socket for receiving the integrated circuit carrier. This patent applies to the code key that carries the calibration information for the Accu-Chek meters. The code key allows for the user to easily add the calibration information into the meter with almost no error involved. This feature will allow visually impaired users the ability to calibrate the meter without assistance.
**Project Design:**

The development period of the gPod project resulted in three potential designs before coming to a final optimal design. These three designs, as well as the optimal design are described in the following sections.

**Design 1:**
A large, high contrast, liquid crystal display (LCD) will be used for easy viewing of the instructions and results for those patients with hearing loss or slight vision loss. It will have step-by-step audio output for those patients with severe to complete vision loss. This audio output will prompt the user through the complete testing procedure and as well as all other functions of the meter. The meter will also have distinctly colored, textured buttons and rubber side grips for those patients who have motor control difficulties. The size and texture of the buttons will allow the user, regardless of their disability, to easily distinguish between them. This will reduce the chance of user errors from their disabilities. The rubber side grips will allow for enhanced grip on the meter which results in easier handling for those patients with impaired motor control. In addition, the device will have an ON/OFF switch different from the operation buttons to reduce patient confusion. Also, to maintain portability, the meter will be battery powered. Figure 4 is an illustration of the casing design, and incorporated external features.

**Figure 4: External Views of Meter**
The glucose meter will be controlled through the use of a microprocessor. This microprocessor will essentially interface and communicate with each part of the proposed meter. Its main function is to communicate with the user interface and allow the patient to control what function the meter is performing. This will be done visually through the LCD screen, audibly through the speaker, or both. The microprocessor will receive incoming data from the glucose test circuit, the site of the chemical testing of the patients’ blood. This will happen when the user inserts a test strip and adds a blood sample of the appropriate size. The LCD screen will display instructions and test results as from the microprocessor at the proper times. The audio output of the proposed meter will be generated from a speech module within the device. This speech module translates the data from the microprocessor and generates an audio output via the attached speaker for the user to hear.

The method for measuring the glucose concentration in a whole blood sample will be of the amperometric type. The glucose sensor is an electrochemical diagnostic strip which uses glucose oxidase enzymes in conjunction with three electrically conductive electrodes. Two of these electrodes are ‘working’ electrodes meaning they are the measured electrodes, and the third is a reference electrode. These electrodes have an impedance which makes them suitable for amperometric measurement. With a strip inserted into the meter, a predetermined current (1 µA) is constantly applied between the working and reference electrodes. The potential difference of this current is constantly monitored by the meter while the strip is in place.

The enzymes of the strip are contained within a ‘reaction zone’. When the enzyme becomes catalytically active (blood sample is applied correctly), the enzyme and mediator compound transfer electrons to the electrode. This then bridges the gap between the electrodes and results in a rapid voltage drop. When this drop goes below a predetermined threshold, sample detection is initiated. A constant voltage (300 mV) is then applied to the strip, and the electrical response is measured for a predetermined amount of time. If there is a 10% difference in electrical response between the two working electrodes, then the meter deems an error. This requires either more blood or inserting a new strip and repeating the test. The determination of this requirement is related to the amount of time that has passed in error.

The current that is produced with correct fluid application is proportional to the glucose concentration of the sample. Determination of the glucose concentration comes from comparison to previously obtained control values. The current-to-glucose relationship becomes linear after about 3 seconds from the initiation time. The measurement is taken at around 5 seconds after, to account for any delay. The measurement could be taken at a later time, but keeping the measurement process relatively fast is beneficial to the user. Of course, once a predetermined time is set (5s), accurate and precise results require that the same time be used each time. In any case, the accuracy of the current determination depends on the accuracy of the initiation determination.
Testing Procedure:

The proposed meter will use commercial test strips designed for the One Touch Ultra® glucose meter made by Lifescan. The testing procedure begins when a single glucose test strip is then inserted into the port at the top of the meter. The meter will then tell the user to apply the blood sample to the strip. The measurement will take approximately 10 seconds and the results will then be displayed on the screen and spoken verbally. Instructions to remove and dispose the test strip will follow.

If the meter is due for calibration with a stock glucose solution, the “C” button will initiate calibration routine. The calibration requires a test strip to be inserted into the meter and a stock glucose solution of a known concentration applied to the strip. The meter compares the results with the known concentration and adjusts accordingly. The “M” button serves as a recall button for the stored test results.
Design 2:
A large, high contrast, liquid crystal display (LCD) will be used for easy viewing of the instructions and results for those patients with hearing loss or slight vision loss. It will have step-by-step audio output for those patients with severe to complete vision loss. This audio output will prompt the user through the complete testing procedure and as well as all other functions of the meter. The meter will also have distinctly colored, textured buttons and rubber side grips for those patients who have motor control difficulties. The size and texture of the buttons will allow the user, regardless of their disability, to easily distinguish between them. This will reduce the chance of user errors from their disabilities. The rubber side grips will allow for enhanced grip on the meter which results in easier handling for those patients with impaired motor control. The meter will be battery powered to maintain portability. The meter will also have the ability to upload test results to a PC using the USB port connection on the bottom. Figure 4 is an illustration of the casing design, and incorporated external features.

The meter will also have a vial scanning module which will allow the user to insert an insulin vial and have its name audibly output by the glucose meter. The vial scanning module will be detachable for those patients who do not need it. This module will connect to the glucose meter through the USB port connection on the bottom.

The glucose meter will be controlled by a microprocessor. This microprocessor will essentially interface and communicate with each module of the proposed meter. Its main function is to communicate with the user interface and allow the patient to control what function the meter is performing. This will be done visually through the LCD screen, audibly through the speaker. The microprocessor will receive incoming data from the glucose test circuit when a test strip is inserted and a blood sample is applied. The LCD screen will display instructions and test results. The audio output of the proposed meter will be generated from a text to speech chip within the device. This chip translates the data from the microprocessor and generates an audio output via a speaker for the user to hear. Figure 3 shows the block diagram of these described processes.

The glucose test circuit will control an LED light source and receive spectroscopic data from an array of infrared photodetectors. The photodetectors will be connected to an amplifier, analog-to-digital converter, and the microprocessor. The LED source and photodetectors will be mounted on a probe that is attached to the meter by a cable.

The sensor probe will be placed on the earlobe during a glucose measurement. The LED in the probe will illuminate the tissue with infrared light in the 2-2.5 μm range. The infrared light will pass through the tissue and be absorbed by the various materials it passes through such as the skin, blood, interstitial fluid, etc. Each of these tissue types has a specific and unique absorption spectrum. Figure 4 the absorption spectrum for a 5 mM (90 mg/dL) solution of glucose at a 1 mm path length. Three unique peaks can be seen in the absorbance spectrum at 2.12 μm, 2.27 μm, and 2.32 μm wavelengths.
Using carefully constructed calibration curves from known glucose and other analyte concentrations, a partial least squares regression can be used to determine the concentration of glucose from the total absorbance spectrum of the tissue. An example of this spectrum is shown in Figure 5. Partial least squares regressions are useful for constructing models of complex systems containing many collinear variables. Glucose concentration is extracted from the absorbance spectrum using a calibration curve. Figure 6 shows a calibration curve constructed using partial least squares regressions. The magnitudes of the peaks on the calibration curve vary depending on glucose concentration.
Testing Procedure:

The user must first attach the probe to their earlobe prior to taking the measurement. Once the probe has been attached, a prompt will instruct the user to press the “M” button to begin the measurement. During the measurement the LED will be pulsed at 1 kHz for 5 seconds. The three photodetectors will have a filter corresponding to the peaks seen on the glucose absorption spectrum (2.12 μm, 2.27 μm, and 2.32 μm). The photodetectors will record the absorbance and take an average of the values to eliminate effects related to blood flow. The absorbance reading, taken as a voltage from the photodetectors, is passed through an amplifier and then to the microprocessor.

Calibration is started when the user presses the “C” button. The calibration procedure requires a glucose solution of a known concentration to be placed in the probe. An absorbance measurement is taken and processed. Any deviation from the expected value of the known solution will be adjusted for at this time.

Methods:

There are many factors that influence the measurement of glucose spectroscopically. Different wavelengths of light interact with tissue in different ways. This design is based on research performed by Jonathon T. Olesberg at the University of Iowa. The experiment performed examined glucose concentrations using wavelengths in the 2-2.5 μm range. This range of infrared light is most suitable for observing glucose because of
the low absorbance of water. The low absorbance of water in this wavelength range helps with the identification of the unique, but small characteristics of the glucose absorption spectrum.

The glucose absorption spectrum has three uniquely identifying peaks. These peaks occur at 2.12 \( \mu \text{m} \), 2.27 \( \mu \text{m} \), and 2.32 \( \mu \text{m} \). The second two peaks are the primary identifiers of glucose in the total absorbance spectrum. Figure 7 shows the absorbance spectra of other analytes in the body.

![Figure 9: Absorbance Spectra of Other Blood Analytes](image)

By observing the overall spectrum at the identifying peak wavelengths, the concentration of glucose can be determined. The absorbance and analyte concentration are related by Equation 1, Beer’s Law.

\[
\Delta A(\lambda) = \Delta c \epsilon(\lambda) l \quad \text{Eq. 1}
\]

Where \( \Delta A(\lambda) \) is the changes in the absorbance spectra, \( \Delta c \) is the analyte concentration, \( l \) is the path length, and \( \epsilon(\lambda) \) is the absorptivity spectrum. Solving for the analyte concentration produces Equation 2.

\[
\Delta c = \frac{\Delta A(\lambda)}{\epsilon(\lambda) l} \quad \text{Eq. 2}
\]
**Design 3:**
A large, high contrast, liquid crystal display (LCD) will be used for easy viewing of the instructions and results for those patients with hearing loss or slight vision loss. It will have step-by-step audio output for those patients with severe to complete vision loss. This audio output will prompt the user through the complete testing procedure and as well as all other functions of the meter. The meter will also have distinctly colored, textured buttons and rubber side grips for those patients who have motor control difficulties. The size and texture of the buttons will allow the user, regardless of their disability, to easily distinguish between them. This will reduce the chance of user errors from their disabilities. The rubber side grips will allow for enhanced grip on the meter which results in easier handling for those patients with impaired motor control. The meter will be battery powered to maintain portability. The meter will also have the ability to upload test results to a PC using the USB port connection on the bottom.

The meter will also have a vial scanning module which will allow the user to insert an insulin vial and have its name audibly output by the glucose meter. The vial scanning module will be detachable for those patients who do not need it. This module will connect to the glucose meter through the USB port connection on the bottom. The glucose meter will be controlled by a microprocessor. This microprocessor will essentially interface and communicate with each module of the proposed meter. Its main function is to communicate with the user interface and allow the patient to control what function the meter is performing. This will be done visually through the LCD screen, audibly through the speaker. The microprocessor will receive incoming data from the glucose test circuit when a test strip is inserted and a blood sample is applied. The LCD screen will display instructions and test results. The audio output of the proposed meter will be generated from a speech module within the device. This speech module translates the data from the microprocessor and generates an audio output via the attached speaker for the user to hear. The glucose test circuit used to make the reflectance readings contains a light source, a reflected light detector, an amplifier, an analog to digital converter, a microprocessor, and a display.

The designed meter is essentially a diffuse reflectance spectrophotometer. With appropriate software, the spectrophotometer can then be made to automatically read reflectance at certain points in time, calculate rate of reflectance change, and output the level of glucose in the blood sample. The schematic for this method is shown in Figure 4. The light source of the meter is simply a high intensity light emitting diode (LED). Using two different LED’s provides the two different wavelengths used to make the measurement. These LED’s project a beam of light onto the reagent pad. A substantial portion of this light is diffusively reflected from the reagent pad and is detected by light detector. This detector is a phototransistor that produces an output current proportional to the light it receives. Readings from the phototransistor are typically taken every 0.2 seconds. The output of the detector is then passed to an amplifier which converts the phototransistor current to a voltage. The output of amplifier is fed to a track and hold circuit. This circuit tracks the incoming voltages along with their respective times and then sends them to be converted into a digital signal. Upon command from the microprocessor, these values can be interpreted into a glucose concentration and output.
The testing procedure begins when a single glucose test strip is then inserted into the port at the top of the meter. The meter will then tell the user to apply the blood sample to the strip. The measurement will take approximately 40 seconds and the results will then be displayed on the screen and spoken verbally. Instructions to remove and dispose the test strip will follow.

If the meter is due for calibration with a stock glucose solution, the “C” button will initiate calibration routine. The calibration requires a test strip to be inserted into the meter and a stock glucose solution of a known concentration applied to the strip. The meter compares the results with the known concentration and adjusts accordingly. The “M” button serves as a recall button for the stored test results.

Measurement Method:

The process begins with a whole blood sample (about 5-10 microliters) being applied to the application site of the test strip. This application site is a single-layer, hydrophilic membrane that is reflective and porous. In addition, it is bound a signal-producing system made up of glucose oxidase, peroxidase and a dye indicator. This system reacts with glucose to form a reaction dye product.

The meter continuously monitors reflectance at the reading site for a decrease in reflectance. Reflectance measurements are made at two separate wavelengths in order to eliminate interferences. These interferences can be caused by hematocrit, blood oxygenation, and other variables which may affect the result. The appropriate wavelengths to do so are 635 nm and 700 nm.
The initial measurement is made prior to application of the blood sample to the matrix. The reflectance value is evaluated by the microprocessor, and then following values can then be compared to this initial unreacted value. When the aqueous solution penetrates the reagent matrix, the drop in reflectance signals the start of the measuring time interval. The change in reflectance that occurs is a measure of dye product formed which directly correlates to the amount of glucose in the sample.

The raw data necessary for calculating a result in a glucose assay are a background current reported as background reflectance, \( R_b \), a reading of the inactive test strip, \( R_{\text{dry}} \), and an endpoint measurement. The endpoint is not particularly stable and must be precisely timed from the initial application of blood. For glucose concentrations below 250 mg/dl, a suitably stable endpoint is reached in 20 seconds, and a final reflectance, \( R_{20} \), is taken. For glucose concentrations up to 450 mg/dl, a 30-second reflectance reading, \( R_{30} \), is adequate. Longer reaction times should provide more suitable readings for the higher levels of glucose concentration.

The 700 nm reflectance reading for the dual wavelength measurement is typically taken at 15 seconds (\( R_{15} \)). By this time blood will have completely saturated the reagent pad. Beyond 15 seconds the dye reaction continues to take place and is sensed, to a small part, by a 700 nm reading. Dye absorption by the 700 nm signal causes inaccuracies; readings beyond 15 seconds are ignored in the calculations.

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The raw data described above are used to calculate parameters proportional to glucose concentration which can be more easily visualized than reflectance measurements. A logarithmic transformation of reflectance analogous to the relationship between absorbance and analyte concentration observed in transmission spectroscopy (Beer's Law) can be used if desired. A simplification of the Kubelka-Monk equations is used to determine analyte concentration. In this derivation \( K/S \) is related to analyte concentration with \( K/S \) defined by Equation 3.

\[
K/S-t = \frac{(1-R^*)^2}{2 \times R^*t} \tag{3}
\]

\( R^* \) is the reflectivity taken at a particular endpoint time, \( t \), and is the absorbed fraction of the incident light beam described by Equation 4, where \( R_t \) is the endpoint reflectance, \( R_{20} \) or \( R_{30} \).

\[
R^*t = \frac{(R_t - R_b)}{(R_{\text{dry}} - R_b)} \tag{4}
\]

\( R^*t \) varies from 0 for no reflected light (\( R_b \)) to 1 for total reflected light (\( R_{\text{dry}} \)). The use of reflectivity in the calculations greatly simplifies the meter design as a highly stable source and a detection circuit become unnecessary since the components are monitored with each \( R_{\text{dry}} \) and \( R_b \) measurement.

For a single wavelength reading \( K/S \) can be calculated at 20 seconds (\( K/S-20 \)) or 30 seconds (\( K/S-30 \)). The calibration curves relating these parameters can be precisely
described by the third order polynomial equation outlined in Equation 5.

\[ \text{YSI} = a_0 + a_1 \frac{(K/S)}{S} + a_2 \left( \frac{K}{S} \right)^2 + a_3 \left( \frac{K}{S} \right)^3 \quad \text{Eq. 5} \]

The algorithm for dual wavelength measurement is by necessity more complex than for single wavelength measurement but is much more powerful. The first order correction applied by the 700 nm reading is a simple subtraction of background color due to blood. In order to make this correction, a relationship between absorbance at 635 nm and 700 nm due to blood color can be and was determined by measuring blood samples with 0 mg/dl glucose over a wide range of blood color. The color range was constructed by varying hematocrit, and fairly linear relationships were observed. From these lines the K/S-15 at 700 nm was normalized to give equivalence to the K/S-30 at 635 nm. This relationship is reported in Equation 6, where K/S-15n is the normalized K/S-15 at 700 nm.

\[ \text{K/S-15n} = \left( \frac{K/S-15}{S} \times 1.54 \right) - 0.133 \quad \text{Eq. 6} \]

Note that the equivalence of the normalized 700 nm signal and the 635 nm signal is only true at zero glucose. The expressions from which the calibration curves are derived are defined by Equations 7 and 8.

\[ \text{K/S-20/15} = (\text{K/S-20}) - (\text{K/S-15n}) \quad \text{Eq. 7} \]
\[ \text{K/S-30/15} = (\text{K/S-30}) - (\text{K/S-15n}) \quad \text{Eq. 8} \]

Test Strip:

The method for measuring the glucose concentration in a whole blood sample will be of the colorimetric type. The glucose sensor is a diagnostic strip containing an inert porous matrix that is saturated with one or more reagents. These reagents will interact with the glucose to produce a light-absorbing reaction product. One function of the matrix is to filter out large particles, such as red blood cells. This is an advantage because the strip does not require previous separation of red blood cells from serum or plasma. When a blood sample is applied to the porous matrix, and is allowed to penetrate, it creates a change in the initial amount of reflectance of the matrix. This initial decrease in reflectance caused by the wetting of the surface triggers the timing circuit of the meter. A reading is then taken at one or more times after to relate the resulting change in reflectance.
Optimal Design:

The proposed blood glucose meter will be able to cater to the needs of vision, hearing, and motor control impaired persons through the addition of several key features and modifications. A large, high contrast, liquid crystal display (LCD) will be used for easy viewing of the instructions and results for those patients with hearing loss or slight vision loss. It will have step-by-step audio output for those patients with severe to complete vision loss. This audio output will prompt the user through the complete testing procedure and as well as all other functions of the meter. The meter will also have distinctly colored, textured buttons and rubber side grips for those patients who have motor control difficulties. The size and texture of the buttons will allow the user, regardless of their disability, to easily distinguish between them. This will reduce the chance of user errors from their disabilities. The rubber side grips will allow for enhanced grip on the meter which results in easier handling for those patients with impaired motor control. The meter will be battery powered to maintain portability. The meter will also have the ability to upload test results to a PC using the USB port connection on the bottom. The meter will also have a vial scanning module which will allow the user to insert an insulin vial and have its name audibly output by the glucose meter. The vial scanning module will be detachable for those patients who do not need it. This module will connect to the glucose meter through the USB port connection on the bottom.

The glucose meter will be controlled by a microprocessor. This microprocessor will essentially interface and communicate with each module of the proposed meter. Its main function is to communicate with the user interface and allow the patient to control what function the meter is performing. This will be done visually through the LCD screen, audibly through the speaker. The microprocessor will receive incoming data from the glucose test circuit when a test strip is inserted and a blood sample is applied. The LCD screen will display instructions and test results. The audio output of the proposed meter will be generated from a text to speech chip within the device. This chip module translates the data from the microprocessor and generates an audio output via a speaker for the user to hear. Figure 11 shows the block diagram of these described processes.
Testing Procedure:

The proposed meter will use commercial test strips designed for the One Touch Ultra® glucose meter made by Lifescan. The testing procedure begins when a single glucose test strip is then inserted into the port at the top of the meter. The meter will then tell the user to apply the blood sample to the strip. The measurement will take approximately 10 seconds and the results will then be displayed on the screen and spoken verbally. Instructions to remove and dispose the test strip will follow.

If the meter is due for calibration with a stock glucose solution, the “C” button will initiate calibration routine. The calibration requires a test strip to be inserted into the meter and a stock glucose solution of a known concentration applied to the strip. The meter compares the results with the known concentration and adjusts accordingly. The “M” button serves as a recall button for the stored test results.
Measurement Method:

The glucose concentration in a whole blood sample will be measured amperometrically. The glucose sensor is an electrochemical diagnostic strip which uses glucose oxidase enzymes in conjunction with three electrically conductive electrodes. Two of these electrodes are ‘working’ electrodes meaning they are the measured electrodes, and the third is a reference electrode (Fig 4). With a strip inserted into the meter, a predetermined current (1 µA) is constantly applied between the working and reference electrodes. The potential difference of this current is constantly monitored by the meter while the strip is in place. This current is used to monitor the presence of the blood sample.

The enzymes of the strip are contained in a ‘reaction zone’. When the enzyme becomes active (blood sample is applied correctly), the enzyme and mediator compound transfer electrons to the electrode. This then bridges the gap between the electrodes and results in a rapid voltage drop. When this drop goes below a predetermined threshold, sample detection is initiated (Fig 5). A constant voltage (300 mV) is then applied to the strip, and the electrical response is measured for a predetermined amount of time (Fig 6). If there is a 10% or greater difference in the voltage between the two working electrodes and error has occurred. This requires either more blood or inserting a new strip and repeating the test.

The current that is produced with correct fluid application is proportional to the glucose concentration of the sample. Determination of the glucose concentration comes from comparison to previously obtained control values. The current-to-glucose relationship becomes linear after about 3 seconds from the initiation time. The measurement is taken at around 5 seconds after, to account for any delay. The measurement could be taken at a later time, but keeping the measurement process relatively fast is beneficial to the user. Of course, once a predetermined time is set (5s), accurate and precise results require that the same time be used each time. In any case, the accuracy of the current determination depends on the accuracy of the initiation determination.

Figure 12 is a plot of applied current and measured voltage that depicts the sample-detection process. Prior to the blood sample being introduced (t < 0), a constant 1 µA) current is applied between the electrodes, but negligible current flows. The measured voltage is determined by the circuit power supply voltage which is 5 volts. When the sample is introduced into the cell (t = 0), the applied current can flow between the electrodes and the measured voltage falls rapidly. When the voltage falls below a threshold voltage, the device switches from constant applied current to constant applied voltage.
Figure 12: Graph of Applied Current and Measured Voltage vs. Time  
Source: U.S. Patent No. 4,545,382

Figure 13: Graph of Applied Voltage and Resulting Current Response vs. Time  
Source: U.S. Patent No. 4,545,382
Figure 13 is a graph of the applied potential and measured current as a function of time after sample detection. Sample is detected at time $t=0$, and a voltage is applied between the working and reference electrodes immediately thereafter. As a result, current flows between the electrodes. The current after a predetermined time, generally at least about 3 seconds for glucose in blood, is a measure of the analyte concentration. That duration generally provides sufficient time to dissolve reagents and reduce an amount of mediator that is readily measurable.

The relationship between glucose concentration and current is considered proprietary information and will need to be determined experimentally. This experiment will be conducted as soon as the glucose testing materials are delivered.

Circuit:

The electrical circuit to measure glucose concentrations must perform several functions. First, a current is applied between the working and reference electrodes. The circuit will monitor the potential difference across the electrodes to determine the presence of the blood sample. When the potential drops below a predetermined threshold, the circuit switches to a constant voltage across the electrodes. The resulting current from the test strip is monitored and input to the microprocessor’s analog-to-digital converter. Figure 14 shows the overall glucose test circuit.

![Figure 14: Overall Circuit](image-url)
Figure 15: Negative Feedback Circuit

\[ R = R_1 + R_2 \]
\[ V = IR \]
\[ R = \frac{V}{I} \]

No Sample \( V_1 = +5V \)
Sample \( V_1 = \gg 5V \) (very close to 0V)

Figure 16: Current to Voltage Converter Circuit

\[ V_{out} = I_{in} R \]
Microprocessor:

The microprocessor we have chosen for this design is the PIC16F874A, manufactured by Microchip. This particular microprocessor incorporates all of the functions necessary to meet our specifications. The microprocessor will be used to control the glucose test circuit, analyze measurements, handle user input from buttons, drive an LCD display, and control a speech module. This chip will be easy to program due to the equipment and development software available in the lab. The microprocessor will be programmed in assembly using Microchip MPLabIDE.

Programming:

As previously stated, the microprocessor will be programmed using MPLabIDE and Hi-Tech C. Programming modules will be needed for serial communication to the speech module and LCD display drivers. The code will be written in C or C++ and translated into assembly language and transferred to the microprocessor.

The speech module will be connected to two different ports on the microprocessor. One port will be connected to the Inter-integrated circuit (I2C) to relay measurements to the module. The other port contains the digital pins used to select any of the 30 prerecorded phrases stored on the module.

The LCD display drivers will also be programmed on the microprocessor. An example of this code is found in Appendix A.

LCD:

The LCD screen that has been chosen for our design is a Crystalfontz CFAX12864C-WGH. This screen is ideal for this system because it will easily integrate with the chosen microprocessor. It is also of sufficient size that is needed to display the intended information. The LCD display will be controlled by the microprocessor using the Parallel Data Port. The screen will show the instructions for proper operation of the meter and display results after test completion. The LCD screens technical specifications are found in Appendix B. Figure 17 is a picture of the LCD screen.

Figure 17: LCD Screen
Source: www.crystalfontz.com
Speech Chip:

The Winbond WTS701 speech-to-text synthesizer is a single chip that converts text inputs to spoken audio outputs. The chip can be programmed through an SPI port allowing downloading of different languages as well as multiple voices. These phrases can be instructions to operate the meter, as well as the glucose reading at the end of a test. The audio output of the chip is stored as an uncompressed analog waveform which delivers high quality, natural sounding speech. The chip also allows variable speech playback and changeable pitch control. Figure 18 is picture of the WTS701 chip.

![Winbond WTS701 Chip](source: www.winbond.com)

**Figure 18: Winbond WTS701 Chip**

Vial Scanner Module:

The meter will also come with an available attachment to identify vials of insulin through the use of a barcode scanner. An FDA mandate in 2004 required that all insulin vials be labeled with a barcode of the National Drug Number for that product. The modular attachment consists of a USB connector, barcode reader, and an insulin vial slot.

The module attaches and communicates with the meter using the USB interface. The user inserts a vial of insulin into the vial slot and rotates the vial until the type of insulin is output by the speaker. Rotation of the vial is necessary to ensure proper scanning. Figure 19 shows the vial scanner module.
A handheld CCD barcode scanner will be modified to fit into the modular design of the vial scanner. The POS-X Xi 1000 handheld scanner will be well suited for the task. The scanner is approximately 60mm wide, is able to automatically distinguish between Code 39/Full ASCII, Codabar, Code II, Code 32, Industrial 205, UPC A & E, and outputs the results through a USB interface. Figure 20 is a picture of the POS-X Xi 1000 scanner.

Figure 20: POS-X Xi 1000 Handheld Barcode Scanner
Source: [http://www.posguys.com/images/Catalog/Xi1000_WEB.jpg](http://www.posguys.com/images/Catalog/Xi1000_WEB.jpg)
Optimal Design Components Reasoning

The Optimal Design is a hybrid of the compiled ideas from each of the three designs.

The electrochemical test strips were chosen from Design 1 due to their ease of use and availability. The electrochemical strip currently is the industry standard for glucose monitoring. The strip is an electrochemical bioreactor with the test strip port having electrodes to detect the electrical signal. One disadvantage to using test strips is the pain associated with drawing a blood sample. A less common type of test strip currently on the market is the photochemical test strip. The third way of glucose detection was spectroscopically. The problem with this method is that it is not FDA approved yet due to the inaccuracy of the technique.

The LCD screen was chosen from Design 2 and 3. The Crystalfontz CFA12864CWGH LCD screen was chosen for its low cost and backlight. This screen was the best value and best clarity of image.

The Winbond WTS701 speech chip was chosen over the SP03 speech module to reduce the cost of the blood glucose meter. The speech chip will allow for the same overall functions as the speech module when integrated with the other circuit elements.

A USB connection was chosen over a serial connection because it is the leading industry standard. Serial RS-232 communication is being phased out of most home computers. The USB connector will also provide a more mechanically stable connection between the vial scanner and the handheld meter.

The vial scanning module from Design 3 was added because of project specifications and goals.
Prototype:

The gPod Glucose Monitoring system uses the latest in glucose measurement technology as well as innovative designs to enhance performance. The glucose concentration of a sample is measured by an electro-chemical test strip that produces a current based on the amount. It is this current that then can be measured by the meter for an accurate assessment of the sample. The gPod meter is designed for testing fresh capillary whole blood samples (for example, blood from your fingertip or forearm.)

The gPod also incorporates a talking feature. This allows for audible communication from the meter to the user. For persons with diabetes that also have trouble seeing, the meter can audibly speak the results to ensure that the user has a correct understanding of their glucose level. Other features on the gPod include attachable insulin vial scanner. This feature allows the user to scan an insulin vial and have the meter display and speak the type of insulin.

The gPod Blood Glucose meter is a portable, battery powered unit. The meter is controlled by a PIC16F874 microprocessor. The power for the components is delivered from two 9 volt batteries connected to two voltage regulators, one for +5 volts, and the other for -5 volts. The glucose measurement and filtering circuit includes two LM358 op amps, a TL072CP op amp, and a 7486 XOR gate. The speech capabilities of the gPod are handled through a Sipex 232 chip and the SP03 text-to-speech module. The instructions and measurements are displayed on a 16x2 character LCD.

Figure 21, gPod Glucose Monitoring System
Figure 22, gPod Glucose Meter
OneTouch Ultra Test Strips

The gPod Glucose Measurement System measures the amount of glucose in whole blood. A whole blood sample is applied to the top edge of the OneTouch Ultra Test Strip. The blood will then be automatically drawn into the reaction cell of the test strip.

**TOP EDGE**
- Apply a drop of blood to the reaction cell here in the top of the test strip

**CONFIMATION WINDOW**
- Check here to confirm if enough blood has been applied.

**CONTACT BARS**
- Insert this end of the test strip, contacts facing up, into the meter. Push it all the way in.

*Figure 23, OneTouch Ultra Test Strip*
gPod Operation

Step 1:

While the meter is off, insert a test strip into the slot on the top of the meter as shown. Be sure that the test strip is inserted with the contact bars facing up and going in first. Push the test strip all the way in until it can go no further.

The gPod meter is calibrated to Work with Batch 15, OneTouch Ultra Test Strips. Please verify that these are the strips being used.

Step 2:

With the test strip inserted, turn the meter on by pressing the switch located on the right side of the meter. Once turned on, the meter will display several opening screens along with synchronized speech.
Step 3:

Obtain Sample

Obtain a round drop of blood using the OneTouch Ultrasoft Adjustable Blood Sampler. The blood sample must be at least 1.0 μL in volume to fill the confirmation window.

Step 4:

Apply Sample

When a large enough drop of blood has formed on your fingertip or forearm, touch and hold the drop of blood to the narrow channel in the top edge of the test strip.
- **Do not** apply sample to front or back of the test strip.

- **Do not** push your finger against the test strip.

- **Do not** apply a smeared sample.

Hold the blood drop to the top edge of the test strip until the confirmation window is full. Upon a successful application of blood, the meter will count 2 seconds and compute your glucose level.

If the confirmation window does not fill completely before the meter begins to count down, do not add more blood to the strip. Discard the strip and repeat the test again.

**Step 5:**

**Accurate Results**

Your blood glucose level will appear on the screen about 2 seconds after a successful blood application. This glucose result will also be spoken through a speaker located on the back of the meter. This allows for a verbal verification of the result.
The gPod meter does not store the test results in memory, so you may want to record them in the log book provided with the system.

Once the test is complete, the test strip can be removed from the meter, and the meter can be turned off.

To repeat the test, be sure that the previous test strip has been removed, and the meter has been turned off. Then, you can repeat the procedure as instructed.

**Barcode Scanner**

Another advanced feature of the gPod Glucose Meter is an attachable barcode scanner. This scanner attaches to the bottom of the meter via a RS232 serial port. Whenever an insulin dose is needed, this scanner can be attached to the meter, and the insulin vial can be scanned and verified. All insulin vials have a specific National Drug Code (NDC) that has been administered by the FDA. This NDC number provides specific information about the type, manufacturer, and concentration of the insulin it is labeled on. The gPod barcode scanner allows the user to scan a vial of insulin and have the meter display and speak the brand and type of insulin. Any person who uses multiple types of insulin should use this feature to always verify the correct insulin is being used.
Scanning Procedure

Step 1:

Plug In the Scanner

To attach the barcode scanner to the meter, connect the scanner cable to the serial plug located at the base of the meter. Be sure that the scanner plug is pushed in until it will go no further.

Step 2:

Scan Mode

When the meter display says “gPod Ready”, press the black button located on the left side of the meter. This will switch the meter into the scanning mode. Once this button has been pressed, the meter will display and speak the phrase “Scan Vial”.
Step 3:

Scan the Vial

Hold the vial in one hand, and the scanner in the other. Orientate the two objects so that the scanner will scan the length of the barcode, with the beam of the scanner traveling across each bar.

Press the trigger button on the scanner to scan the barcode. The scanner will emit a beep upon a successful scan.

Step 4:

Insulin Verification

When the vial has been scanned, the meter will display the type and concentration of that insulin. This information will also be spoken by the meter.
Voice Prompts

The gPod is capable of voice output. The following phrases are spoken by the gPod during its normal operation.

“University of Connecticut Biomedical Engineering.”
- Requires no operation.

“gPod ready for test.”
- Informs user that the meter is ready for testing operation

“Testing.”
- Informs the user that the meter is performing a glucose test.

“Blood glucose level is …”
- Informs the user of their results.

“Scan Vial.”
- Instructs the user to scan a vial of insulin.

“Humulin ‘R or N’, 100 units per milliliter.”
- Informs the user that they have scanned a Humulin brand insulin.

“Novolin N, 100 units per milliliter.”
- Informs the user that they have scanned a Novolin brand insulin.
Accuracy and Testing

The gPod Blood Glucose Meter was tested with the control solution and compared to the OneTouch Ultra Results. A preliminary measurement was taken on the OneTouch Ultra to establish the glucose concentration of the control solution. The gPod was then tested using the same control solution and application technique. Figure 24 shows the gPod test results.

![Figure 24, OneTouch Ultra vs. gPod Test Results.](image)

There were some discrepancies between the two meters. The gPod has a greater standard deviation than the OneTouch Ultra, meaning that the results for the gPod vary greatest from the average value. The average glucose reading for the gPod was 124.38 and 127.68 for the OneTouch Ultra, a difference of 3. Overall the gPod presents good accuracy for a prototype. It is shown here that the accuracy of the gPod compared to the OneTouch Ultra is approximately ± 10%. The Food and Drug Administration stipulates that a device’s measurements must fall within a range of ± 20%. The tests performed show that the gPod is well within the FDA requirements.
Client Testing

The gPod was tested using a simulation of blindness. The test subject was blindfolded so they were completely unable to see. The subject was instructed how to operate the meter and then asked to complete a blood glucose test. Figure 25 shows the subject after having punctured their skin with the lancet.

![Image: Test subject after drawing blood.](image1)

**Figure 25, Test subject after drawing blood.**

The subject then inserted the test strip and turned on the meter, without assistance. The subject was then able to apply the blood to the test strip to take a measurement. Figure 26 shows the subject applying the blood to the test strip.

![Image: Test subject applying blood to test strip.](image2)

**Figure 26, Test subject applying blood to test strip.**
The subject was then asked to perform an insulin vial scan without eyesight. They switched off the meter and removed the test strip. The subject then had to plug in the scanner. The vial was then scanned correctly on the first try. Figure 27 shows the test subject scanning an insulin vial.

![Image of a subject scanning an insulin vial](image_url)

**Figure 27, Test subject scanning insulin vial.**

Multiple subjects were asked to perform the same procedure outlined above. After the test they were asked for their thoughts about the operation of the gPod Glucose Monitoring System. The following statements were made by the test subjects:

"The gPod was surprisingly easy to use, even with no prior knowledge of glucose testing."

"It was very easy to find the test strip hole with my finger."

"Scanning the vial was really simple because the vial fit so well into the scanner."

Subject testing has shown that the gPod Glucose Monitoring System is accessible to a user with poor or no vision. The large size of the meter also allows for users with limited mobility and motor control to perform a glucose test as well. The simple user interface allows any person, regardless of their mental capacity to operate the meter.
**gPod Technical Description:**

Microprocessor:

The microprocessor is connected to each component of the meter. The processor is responsible for the analog-to-digital conversion, LCD control, speech control, user interface, and communication with a serial device. The microprocessor uses a 5 MHz clock. Figure 28 is a schematic of the connections to the microprocessor.

![Figure 28, connection diagram of PIC microprocessor.](image-url)
Analog-to-digital converters:

The connections to the glucose circuit are made through Pin 2 and Pin 4. The input to the analog-to-digital is Pin 2 and the input from the glucose trigger is Pin 4. The microprocessor is capable of 10-bit analog-to-digital conversion. Analog-to-digital conversion is the process of converting an analog voltage into a discrete digital count. The resolution is controlled by the number of bits of the converter. Equation 9 shows the function to calculate the resolution.

\[
\text{Resolution} = 2^{\text{bits}} \quad \text{Eq. 9}
\]

\[\text{bits} = 10\]

\[\text{Resolution} = 2^{10}\]

\[\text{Resolution} = 1024\]

The digital counts are related to the input voltage through the use of a reference voltage. The reference voltage \((V_{\text{ref}})\) used in the meter is equal to \(V_{DD}\) (5 V). Equation 10 shows the function to convert a digital count to the actual voltage.

\[
\text{Voltage} = \frac{\text{Count} \times V_{\text{ref}}}{\text{resolution}} \quad \text{Eq. 10}
\]

\[
\text{Voltage} = \frac{\text{Count} \times 5}{1024}
\]

The analog-to-digital converter is configured with two control registers, ADCON0 and ADCON1. ADCON0 is used to configure the conversion clock, the input channel, and to power on the module. The analog-to-digital converter is set up to use an \(F_{\text{osc}}/8\) conversion clock, read channel 0, and turn the module on. The \(F_{\text{osc}}/8\) conversion clock is selected according to the maximum device frequency. The maximum device frequency is 5 MHz. Table 1 shows the A/D acquisition time vs. the maximum device frequency.

<table>
<thead>
<tr>
<th>AD Clock Source ((T_{AD}))</th>
<th>ADCS2:ADCS1:ADCS0</th>
<th>Maximum Device Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (T_{\text{osc}})</td>
<td>000</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>4 (T_{\text{osc}})</td>
<td>100</td>
<td>2.5 MHz</td>
</tr>
<tr>
<td>8 (T_{\text{osc}})</td>
<td>001</td>
<td>5 MHz</td>
</tr>
<tr>
<td>16 (T_{\text{osc}})</td>
<td>101</td>
<td>10 MHz</td>
</tr>
<tr>
<td>32 (T_{\text{osc}})</td>
<td>010</td>
<td>20 MHz</td>
</tr>
<tr>
<td>64 (T_{\text{osc}})</td>
<td>110</td>
<td>20 MHz</td>
</tr>
<tr>
<td>(R_{E}(1,2,3))</td>
<td>x11</td>
<td>((\text{Note} 1))</td>
</tr>
</tbody>
</table>

Table 1, \(T_{AD}\) vs. Maximum Device Frequency.
Glucose Trigger:

The glucose trigger is used to start the analog-to-digital conversion. The trigger is made using a LM358 op amp as a comparator. The outputs of the comparator are input to an XOR gate. A schematic representation of the trigger is shown in Figure 29.

![Glucose Trigger Schematic](image)

Figure 29, Glucose trigger schematic.

Comparator 1 is set up with a reference voltage of 0.05 V. Comparator 2 is set up with a reference voltage of 0.10 V. These voltages were picked because they are very near the start of the glucose signal. When the glucose voltage level reaches 0.05 V the output of Comparator 1 goes HIGH. Once the glucose voltage level goes above 0.10 V the output of Comparator 2 goes HIGH. The outputs of the comparators are input into the XOR gate. When one of the comparators is HIGH, the output of the XOR gate is HIGH. If both of the outputs of the comparators are either HIGH or LOW the output of the XOR gate is LOW. Table 2 shows a truth table for the glucose trigger.

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>Comparator 1 Out</th>
<th>Comparator 2 Out</th>
<th>XOR Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>0.05</td>
<td>HIGH</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>0.07</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
<tr>
<td>0.10</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
<tr>
<td>0.15</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>

Table 2, Glucose Trigger Truth Table.

The microprocessor detects the falling edge of the trigger pulse. This signal is then used in the programming of the microprocessor to start the delay and acquisition sequence in the code. Two seconds after the trigger pulse occurs, the analog-to-digital converter takes a single measurement. Figure 30 shows the voltage curve (orange) and the trigger pulse (blue).
Figure 30. Voltage curve and trigger pulse.

The connection diagram for the glucose trigger circuit is shown in Figure 31. The only difference between the theoretical schematic in Figure 29 and the actual circuit is the 1k pull-up resistors on the inputs and outputs of the 7486 XOR gate. The pull-up resistors ensure that the input and output voltages do not drop below 5 volts. Without the pull-up resistors the input and output voltages were only reaching approximately 4 volts and could be lower than the digital threshold required for a HIGH input on the microprocessor.

Figure 31. Glucose trigger connection diagram.
Glucose Filter:

The glucose voltage curve shown above in Figure 30 is filtered with a low pass filter. The filter uses a TL072 dual op amp and is configured as a 100 Hz Sallen-Key Low Pass Butterworth filter. Figure 32 shows the filter schematic created using Filter Pro.

![Figure 32, 100 Hz Low Pass Butterworth Filter.](image)

The glucose measurement originates as a small current generated by the chemical reaction occurring in the test strip. The test strip contains glucose oxidase, a chemical that binds to D-glucose to start a redox reaction. The redox reaction breaks down the glucose and releases electrons. The flow of electrons is known as current and is collected by electrodes built-in to the test strip. The current is converted to voltage through the use of a current-to-voltage converter.

A current-to-voltage converter is simply an op amp with a feedback resistor. The op amp is used as a high impedance source that forces all of the current to flow through the resistor. Figure 33 shows the theoretical schematic for a current-to-voltage converter.

![Figure 33, Current-to-Voltage Converter Schematic.](image)

Show in Equation 11 is Ohm’s Law which is used to calculate the value of the resistor. Experimental data shows that an average current produced by the glucose test strip is 20μA.

\[ V = I \times R \quad \text{Eq. 11} \]
Because an average value is being used, V is chosen to be 2 volts so that it is about half the maximum voltage that can be used by the analog-to-digital converter.

\[ 2 = 20 \times 10^{-6} \times R \]
\[ R = 100000 \text{ Ohms} \]

Glucose Detection Circuit:

The circuits described above are all connected to produce the glucose detection circuit. The glucose detection circuit includes the current-to-voltage converter and the 100 Hz low pass Butterworth filter. Figure 34 shows the glucose detection circuit connection diagram.

Figure 34, Glucose detection circuit connection diagram.
Glucose Test Strip:

The glucose test strip is connected to the circuit at the component labeled S1. A potential of -400 mV is applied between the first and third pins. This voltage difference is required to initiate the redox reaction on the test strip. The current produced from the test strip comes from pin 3 of S1 and connects to the inverting input of the LM358. The current is converted to a voltage in the LM358 and output at pin 1 where it goes to the filter.

Another potential is applied across pins 4 and 5 of S1 to detect when a test strip is inserted. The test strip has an electrode across the bottom which connects the two pins when inserted properly into the meter. The test strip is shown in Figure 35.

**Figure 35, Test strip illustration.**

Glucose Voltage Measurement:

The glucose measurement is taken from a single acquisition from the analog-to-digital converter. When a sample is applied to the test strip the voltage jumps to a peak value and then begins to decay linearly between 1 and 5 seconds. The voltage reading is taken 2 seconds after the sample is applied. Figure 36 shows a typical voltage curve for glucose.

**Figure 36, Glucose voltage curve.**


The voltage level is then converted to a glucose concentration. This equation was determined experimentally. To determine the glucose-voltage characteristic measurements were taken at 2 seconds over a range of glucose concentrations (20-400 mg/dL). The glucose concentration was plotted as a function of voltage and is shown in Figure 37. A linear trend line was applied to the curve to determine the slope and intercept of the line. This trend line is the glucose-voltage equation shown in Equation 12.

\[
\text{concentration} = (\text{voltage}) \times 922.23 - 22.9
\]

**Eq. 12**

![Figure 37, Glucose-Voltage Relationship.](image)

**Meter Calibration:**

The gPod is configured to use Code 15 test strips. The procedure for determining the calibration curve is simple. The slope of the glucose-voltage curve changes with the type of test strip. Figure 37 is the glucose-voltage relationship for Code 2 test strips. The slope of the curve can be determined by measuring the voltage 2 seconds after the sample is applied for a range of glucose concentrations. Table 3 shows the glucose-voltage equations for a few test strip codes.
Test Strip Code | Equation
---|---
2 | \( y = 922.23 x - 22.903 \)
9 | \( y = 700 x - 19 \)
15 | \( y = 760 x - 19 \)
22 | \( y = 461 x - 19 \)

Table 3, Test Strip Calibration Table.

The difficulty with meter calibration is obtaining the different codes of test strips. Lifescan produces 50 types of test strips. Testing each type of test strip would require almost $1400 in diabetes testing supplies if 25 strips of each calibration code were tested. Due to budgetary constraints test strip calibration was not a viable option for the scope of this project. The concept of glucose test strip calibration has been proven by the gPod through the use of 4 different codes of test strips.

LCD Screen:

The glucose measurements are displayed on a 16 x 2 character LCD screen. The LCD connects to the microprocessor using 14 pins. There are eight parallel pins used for data transfer, one pin for the enable clock, one for the instruction/register select, and one for the read/write control. The LCD is controlled by a Hitachi 44780 LCD driver. Figure 38 shows the connection diagram for the LCD screen.

![LCD connection diagram](image-url)
The text and instruction data are sent across pins 7-14 on the LCD screen. The instruction / register select commands are sent across pin 4. Pin 5 is used to receive the read / write commands from the microprocessor. Pin 6 is the enable clock and is used to latch in the data on pins 7-14. Pin 3 is used to set the contrast on the LCD. Pin 2 and Pin 1 are 5 volts and ground respectively.

The instruction / register select command is used to tell the LCD if data or a control instruction is being written. The instructions available to the LCD are shown in Table 4.

<table>
<thead>
<tr>
<th>R/S</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>Clear Display</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>D</td>
<td>C</td>
<td>B</td>
<td>Enable Display / Cursor</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>DL</td>
<td>N</td>
<td>F</td>
<td>-</td>
<td>-</td>
<td>Interface Length</td>
</tr>
<tr>
<td>1</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>Write a Character</td>
</tr>
</tbody>
</table>

**Table 4. LCD instructions.**

Table 5 defines the modes that can be set using the structure set up in Table 4. The bold instructions are the settings used for the LCD.

<table>
<thead>
<tr>
<th>Enable Display/Cursor</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td><strong>Display On</strong></td>
<td>Display Off</td>
</tr>
<tr>
<td>C</td>
<td><strong>Cursor On</strong></td>
<td><strong>Cursor Off</strong></td>
</tr>
<tr>
<td>B</td>
<td><strong>Cursor Blink On</strong></td>
<td><strong>Cursor Blink Off</strong></td>
</tr>
<tr>
<td>Interface Length</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>DL</td>
<td>8 data lines</td>
<td>4 data lines</td>
</tr>
<tr>
<td>N</td>
<td>2 display lines</td>
<td>1 display line</td>
</tr>
<tr>
<td>F</td>
<td>5x10 font</td>
<td><strong>5x7 font</strong></td>
</tr>
</tbody>
</table>

**Table 5. LCD instruction definitions.**

Text is written to the LCD screen by setting the R/S bit to 1 and writing the ASCII text to the eight pin data bus. The LCD screen will read in the data on the data bus when the enable clock is set high and then low. The text information is read on the falling edge of the data clock.

When the LCD is initialized properly the screen should be blank. If the first row of characters is filled with dark boxes turn the power off and back on. The instructions for the meter should be displayed correctly after doing this.

Printed Circuit Board:

The printed circuit board was designed in ExpressPCB. Express PCB is free software available from [http://www.expresspcb.com](http://www.expresspcb.com). The software allows a user to draw an electrical schematic and then link it to a printed circuit board layout. Figure 39 shows a screenshot of the program.
The schematic is drawn in ExpressSCH. The entire schematic for the gPod is shown in Figure 40. The schematic is used to create the connections on the printed circuit board. Every component necessary on the printed board is included on the schematic. Each part is given a unique name. ExpressSCH include a large library of parts and the user has the ability to define custom parts as well. The speech module (U2), LCD (U1), 7486 (U8), LM358 (U3, U4), and TL072 (U5) were created as custom parts. The Max232 and PIC16F874A were available in the program.
The printed circuit board must be designed to fit the case. Mounting holes and board shape are factors when building the board. The location of the components is also an important design consideration. Each part must be able to fit inside the case as well as not interfere with the operation of the other components on the board. The printed circuit board has traces on both the front and back. Traces cannot cross over one another on the board, requiring some to be routed to the opposite side of the board. Figure 41 shows the bottom side of the printed circuit board used in the gPod Blood Glucose Meter. The bottom of the board contains all of the integrated circuit chips, voltage regulators, and speech module.

Figure 41, Printed Circuit Board bottom.
The top side of the printed circuit board is shown in Figure 42. This side of the board has the glucose test strip connector and LCD screen on it.

Figure 42, Printed Circuit Board top.

Speech Module:

The measurements and instructions of the gPod glucose meter are not only displayed on a LCD screen but are spoken as well. The speech module is used to output the measurements and instructions in a voice output for users who are blind or have diminished eyesight. The module is capable of taking an ASCII string of text and converting it to sentences or words. A photo of the module is shown in Figure 43.

Figure 43, SP03 text-to-speech module.
The speech module is connected to the microprocessor’s UART (Universal Asynchronous Receiver Transmitter). The speech module communicates with the microprocessor through RS232 protocols. The connection diagram for the speech module is shown in Figure 44.

![Figure 44. Speech module connection diagram.](image)

The Max232 chip shown in the diagram is used to convert the 3 volt logic produced by the speech module to the 10 volt logic required by RS232 communication. The Max232 chip is then connected to the microprocessor where the speech routines are implemented. The command sequence for the speech module is shown in Table 6.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x80</td>
<td>Start command</td>
</tr>
<tr>
<td>0x00</td>
<td>Speech Volume (Full)</td>
</tr>
<tr>
<td>0x05</td>
<td>Speech Pitch (Level 5)</td>
</tr>
<tr>
<td>0x00</td>
<td>Speech Speed (Level 0)</td>
</tr>
<tr>
<td>ASCII text</td>
<td>Text phrase sent as a string of characters</td>
</tr>
<tr>
<td>0x1A</td>
<td>Stop command</td>
</tr>
<tr>
<td>0x00</td>
<td>Speak phrase</td>
</tr>
</tbody>
</table>

Table 6. Speech module command sequence.

The speech module will start filling its input text buffer when it receives the 0x80 command. The next three commands sent tell the speech module what volume, pitch, and speed to speak the text. Following the volume, pitch, and speed commands the phrase is read by the speech module. Each character of the phrase must be read individually. The 0x1A command tells the speech module the phrase is finished and to wait for the 0x00 command to speak the phrase. Table 7 shows an example of the speech module speaking the phrase “Hello World.”
<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x80</td>
<td>Start command</td>
</tr>
<tr>
<td>0x00</td>
<td>Speech Volume (Full)</td>
</tr>
<tr>
<td>0x05</td>
<td>Speech Pitch (Level 5)</td>
</tr>
<tr>
<td>0x00</td>
<td>Speech Speed (Level 0)</td>
</tr>
<tr>
<td>0x48</td>
<td>H</td>
</tr>
<tr>
<td>0x65</td>
<td>e</td>
</tr>
<tr>
<td>0x6C</td>
<td>l</td>
</tr>
<tr>
<td>0x6C</td>
<td>l</td>
</tr>
<tr>
<td>0x6F</td>
<td>o</td>
</tr>
<tr>
<td>0x20</td>
<td></td>
</tr>
<tr>
<td>0x57</td>
<td>W</td>
</tr>
<tr>
<td>0x6F</td>
<td>o</td>
</tr>
<tr>
<td>0x72</td>
<td>r</td>
</tr>
<tr>
<td>0x6C</td>
<td>l</td>
</tr>
<tr>
<td>0x64</td>
<td>d</td>
</tr>
<tr>
<td>0x1A</td>
<td>Stop command</td>
</tr>
<tr>
<td>0x00</td>
<td>Speak phrase</td>
</tr>
</tbody>
</table>

Table 7, Speech module “Hello World” example.

Each command in the sequence is separated by a 1 ms delay to ensure that the speech module receives the data correctly. The speech module may not function correctly if the batteries are running low. If the speech is choppy, broken up or inaudible replace the batteries.

Barcode Scanner:

The barcode scanner is connected through a DB9 connector located at the bottom of the meter. The barcode scanner is used to scan the National Drug Code printed on bottles of insulin. A patient who uses insulin and is unable to read the label can scan the barcode and the meter will output the type of insulin.

The barcode scanner communicates using RS232 protocol. Programming the settings for the barcode scanner requires the user to simply scan the corresponding code. The scanner must be configured for RS232 communication, 38400 baud, 8 bits no parity, 1 stop bit, no handshaking. The barcodes to set these parameters are shown below in Figure 45.
Scan the following codes to configure the barcode scanner to work with the gPod Blood Glucose Meter.

**Set scanner to RS232 communication.**

```
.C002$
```

**Set scanner for 38400 baud rate.**

```
.E022$
```

**Set scanner for 8 Bits, No Parity.**

```
.E008$
```

**Set scanner for 1 Stop Bit**

```
.E016$
```

**Set scanner for No Handshaking.**

```
.E018$
```

**Figure 45, Required barcode scanner settings.**
The meter should be powered off when connecting the barcode scanner. The power cable must be connected in order for the barcode scanner to work. Once connected to the meter the user can power on the meter and wait for the command to insert a test strip or scan vial. When ready the user should press the black button located to the left side of the meter. If the button is pressed, the meter will wait until a barcode is scanned. If more barcodes are desired to be scanned press the button again. Turn off the meter when finished. Scanning barcodes must be done as a separate activity from glucose testing. The user will be unable to scan a barcode if a glucose test has already been run on the meter.

The insulin vial should be held flush to the surface of the barcode scanner. Rotate the vial until an audible beep is heard from the scanner and the meter speaks the insulin type. Figure 46 illustrates the function of the barcode scanner.

![Barcode scanner and insulin vial.](image)

**Figure 46, Barcode scanner and insulin vial.**

**Batteries:**

The positive power is supplied from a 9 volt battery and a 7805 positive voltage regulator. The 7805 produces +5 volts when the input voltage is above 7.5 volts. The power required to supply the speech module may cause battery life to be significantly shortened. The negative power for the glucose circuit is supplied for a 9 volt battery and a 7905 negative voltage regulator.

The batteries are expected to last 4 hours if the meter is run continuously.
Realistic Constraints:

The largest economic consideration would have to be the total price of the meter that the user will be purchasing it for. Our blood glucose meter will cost $374.16 which might seem high when compared to the commonly bought meters on the market but those meters do not cater to the needs of patients with disabilities. Our meter is more in line with the Accu-Chek Voicemate which has audio output of those patients who have hearing loss, though the Accu-Chek Voicemate costs around $570. Our blood glucose meter will also have a barcode scanner that can be plugged in for scanning of insulin vials. This allows for the user not to purchase this barcode scanner if they are not in need of its assistance which results in a savings of about $100. The Accu-Chek meter does have the insulin vial scanner though it is coupled with the voice unit resulting in a hefty price increase for those who do not need the insulin vial scanning assistance but that of the audio output assistance.

With further development another economic consideration will be the use of a voice module for the audio output or just the use of the voice chip and assembling the voice module ourselves. The voice module would be easier to use and cut down on assembly time though be more expensive. The use of just the voice chip would cut the total meter price down by about $60 so the voice chip was chose instead on the voice module.

Research and development costs are an important economic consideration. This is a cost which is not directly passed onto the user but must be taken into account for the company. Overall a company needs to make a profit on its products otherwise the company will go under. Our research and development costs so far are only a few hundred dollars which compared to the overall budget is very small. This is the where a company may sink a lot of money depending of the setbacks its research encounters. This leads to the need to have enough money set aside for final prototyping and for emergency spending. Having this emergency money reserve is necessary for when a new part is needed because the old one has broken. By having taken that into account there is less of a chance that the project will run over budget.

Manufacturing costs would be the last economic condition to take into account. The cost of manufacturing a product is very important since some products are very expensive to manufacture while others are not. The goal is to minimize the manufacturing cost of the product which will allow for either greater profits or a reduced selling price. This can be accomplished through the use of common commercially used parts and processes since they have been established and refined resulting in lower costs.

Handling Considerations:

The environment can be detrimental to almost any product if certain considerations are not taken into account such as temperature, water, gases, etc. Our glucose meter circuitry will be completely enclosed within the glucose meter case so that the used will not be able to be harmed. This enclosing of the circuitry also protects the circuitry from the elements such as air and water which could cause the circuitry to malfunction. The
enclosure will allow the glucose meter to be seal off from the environment but not water tight. So the meter should not be placed in water or used in the rain for safety. The meter should also not be exposed to extreme heat or cold which can effect how the meter functions. Extreme cold can be detrimental to the LCD screen. Extreme heat can be most detrimental to the circuitry which can degrade with extreme heat. The case of glucose meter will be made of a strong durable plastic so that the weather will not harm the meter or the meters casing.

Environmental Considerations:

The manufacturing wastes should be considered for the different pieces of the blood glucose meter such as the plastic casing, and the electronic components. Electronics manufacturing produces many pollutants which as carefully regulated and collected for proper disposal. Plastics have very little wastes produced that are not recycled right away. Only the air emissions are of concerns and those are taken care of with air scrubbers.

Glucose meters have to be disposed carefully and not just thrown in the trash due to the printed circuit boards within the device. Since the glucose meter is a portable home device the user should dispose of them through their local hazardous waste disposal days. This is due to the fact that the printed circuit board is hazardous to the environment.

Sustainability Considerations:

The sustainability of a device is important since the longer a product can be made to last with as little maintenance as possible. Our blood glucose meter will be very sustainable since the meter will be able to support its self and need no maintenance other than switching of its battery when needed. The meters casing will keep the integrity of the meter intact and allow for its everyday use. Since the meter is made to be portable there is the expectation that the meter will take its share of bumps and drops. Other considerations are that of securing the circuits on the inside of the meter so that when the meter is handled roughly the circuitry will stay in place.

Manufacturing Considerations:

The manufacturability of a product is an important aspect to consider since the easier the product is to manufacture the faster it can be brought to market. Our blood glucose meter is made of all widely available components such as a plastic casing, circuit boards, microchips, and speaker. This wide availability of the components will allow for the easy access to the components. These different components have been used widely for some time now showing that they are reliable and good components.

Ethical Considerations:

Ethics are important for a company and their products because if they start taking short cuts then there can be consequences. Our product will use parts that will work within the
designed system and will be reliable. There will be no parts used that are inferior just so that the cost can be cut. This will ensure that the meter will be made of quality components that will fail prematurely. Other ethical considerations are the manufacturing site for the product and the theft of ideas from other products on the market or companies.

For the development and manufacturing of our blood glucose meter there were no animals used. Animal use for any research and development is an ethical concern since you are willing hurting an animal not for their own benefit. This has people deeply divided on whether or not it should even be allowed.

Health and Safety Considerations:

Health and safety is one of the most important considerations a company can consider since when developing and manufacturing a product. The health and safety considerations are not just meant for the user but for the public also.

Our device will be grounded within its casing so that it will not shock the user. The meter will not have any sharp corners or edges that the user or others would be able to cut or injure themselves on the meter. The meter will be made out of non-toxic materials so that the user will not be affected by the meter while interacting with it. The casing is the most important component to be non-toxic as with the LCD screen.

When replacing the meters battery the meter should be turned off this to ensure that the user will not get shocked. The vial scanning module contains a laser for barcode scanning and therefore should not be looked into for the chance that the laser could shine into the person’s eye. Finally there were no animals or people hurt during the development and manufacturing of this device.

Social Considerations:

Due to the similarity to other blood glucose meters on the market, no significant social concerns are an issue. Blood glucose meters are a socially acceptable method for diabetics to measure blood glucose. No controversial topics are involved with blood glucose meters.

Political Considerations:

As with social considerations, no significant political considerations are a factor. Glucose meters have been on the market for years and no major issues have risen. The similarity to these existing meters allows for quick FDA approval avoiding any political involvement in regulation.
**Safety Issues:**

Accurate glucose measurements from the gPod can be safely and reliably obtained when done properly. Please read the appropriate sections of the gPod Owner’s Manual thoroughly before performing any function with the meter.

The gPod glucose meter will only reliably work with One Touch Ultra Test Strips that are **Batch 15**. It is imperative that only these specific test strips be used with the meter for proper function and measurement. Other batches of OneTouch Ultra test strips can be used; however this requires some simple recalibration.

When performing a glucose test, the unit of measure for the results will **always** be in **mg/dL**. Please do not confuse this with any other unit of measure. A mistake in the unit of measure could lead to improper diagnosis.

Testing your own glucose requires exposing blood to the surface of your skin, please wash your hands with warm water and soap before performing a test. This will greatly reduce any chance of infection.

Do not reuse lancets. Once a lancet has been used, properly dispose it.

Do not leave test strip vials open. Humidity and other environmental factors can lead to inaccurate results.

Do not open or tamper with the meter. Any tampering with the contents of the meter can potentially damage the meter.

Only use 9 volt batteries with the gPod meter. Also, do not attempt to recharge batteries while they are still in the meter.

Do not use any other AC adapter with the barcode scanner. Doing so may cause damage to the scanner, and possibly the meter as well.
Impact of Engineering Solutions:

Biomedical engineering, in all of its vast disciplines, greatly affects the quality of life for millions of people all over the world. Advancements continue to be made everyday that help to save lives and better care for those with illnesses or complications. These solutions that engineers create impact many aspects of living that all contribute to a better, more satisfying life. Globally, economically, environmentally, and in everyday life you can see the differences that biomedical engineering has made. More specifically, the gPod blood glucose meter has an impact on all these aspects of life as well. A meter as versatile and functional as the gPod has great potential to better the lives of all people who use it.

Currently, the world has no cure for diabetes. As a result of this, management and daily monitoring of an individual’s glucose level is the only way to effectively live with diabetes. Although there are countries where diabetes is more prevalent, there are people living with it all over the globe. This means that treatment for diabetes is needed globally as well. The gPod’s portability, ease of use, and fast results, allow for a user to perform a glucose test almost anywhere and at anytime. The result of all of these qualities put together into one product is one that is very beneficial to the user. Better management of one’s diabetes means a healthier life for that person. The ability to quickly confirm states of hyper- or hypoglycemia (high or low sugar) can allow for faster treatment which decreases the chance for injury. From a global standpoint, the gPod glucose management system may be the most effective means of monitoring and treating one’s diabetes.

The gPod is also a very valuable tool economically. When priced against other blood glucose meters with comparable options and features, the gPod meter is cheaper. Producing a cheaper, but just as reliable meter means more patients can afford it. People will be able to better care for themselves regardless of their income or economic status. This once again improves the quality of life on a global perspective. The gPod could be produced for well under $300 if done on a mass scale. This price is considerably lower than the comparable products sold today. Offering a meter as equipped as the gPod for a price that’s very affordable helps consumers in ways other than better management. As much as glucose monitoring is a daily activity for millions of people, it is also a business. Producing products that offer just as much to the user at less of a price keeps the economy competitive. It forces companies to be more innovative and come up with new and better technologies. These new technologies keep the company in business, but more importantly offer better methods of treatment. A product like the gPod could set the new standard in glucose monitoring, giving people a variety of valuable features all while saving them money.

Environmentally, the gPod has an effect as well. Although it is a very small effect, the gPod could make a difference. The gPod is a very efficient meter with its long battery life and accurate testing. Efficiency leads to less waste involved, which to some extent, helps keep the environment cleaner. Waste management is a very important issue at this time and the gPod keeps waste to a minimal. Accurate testing means that less retests will
be needed. This will cut down on the amount of test strips and lancets will have to be used.

Lastly, the gPod has potential to create an impact on societal aspects as well. The way it can impact society is much like its global impact, just on a smaller scale. The gPod makes its contributions to society by allowing people to better manage their diabetes. Keeping people within normal, healthy glucose ranges can help them live longer with diabetes. Because people will be able to better manage themselves, it also can potentially reduce the amount of complications that arise because of the diabetes. It is well known that living with diabetes can lead to significant loss of vision. The extra features such as a speech module and a vial scanner are great accommodations to such a problem. From the ground up, this meter was designed with the user in mind. An easy interface, plus several other catering features make the gPod a top example of an accessible blood glucose monitor interface.

Overall, the gPod offers its user a superior means of managing their glucose. Better management of an individual’s diabetes will result in a better life for that person. People can use the gPod with the confidence that it is accurate and reliable; all while being easy to use, affordable, and efficient.
**Life-Long Learning:**

This project has taught us a lot of new techniques and material. The whole design process has taught us a lot about design, research, diabetes, electronics, troubleshooting, and time/money management.

Our project started with the research part of the design process. We had to learn about performing patent searches and market analysis. The design also required research on components and their functionality. Understanding the impact of diabetes was another important part of the design process. We had to learn how to perform a glucose measurement and the different techniques used in the industry. We also learned about the basic chemistry involved with the test strip and glucose reaction. After the initial research and paper design of the project we learned how to apply the concepts to produce a working prototype.

Everyone on the team learned about analog signals and the processing and filtering of them. We learned about the importance of filtering small analog signals. The filter was designed using a software program called FilterPro. We also learned about the use of microprocessors in a portable design. The team had to learn about analog-to-digital conversion, LCD control, RS232 communication, and the complexities of USB communication. The microprocessor also required programming in either assembly or C++. We learned how to do the programming in both languages.

The integration of the systems taught us a lot about troubleshooting. The use of an oscilloscope proved very valuable to the troubleshooting process. We also learned about the difficulties of noise in a microprocessor circuit. Other issues involved electronic tricks that are not taught in a classroom setting and could only be learned in a hands-on setting.

After the prototyping was completed we learned the aspects of printed circuit board design. The PCB design required us to learn ExpressPCB, a circuit design software program. We also learned about surface mount soldering and printed circuit board assembly.

Other things learned from this project involved the management of a budget and maintaining a schedule. The process of purchasing and ordering parts was also a new skill learned. Finally, maintaining a website and the use of Dreamweaver was also learned.

The skills learned throughout the project will be very helpful in industry. The process of researching, designing, prototyping, testing, and building a product is educationally rewarding.
Budget:

The total cost of the meter has been calculated to be about $374.16, as shown in Table 8. This $374.16 cost has broken down into the individual components as listed below. The total cost of the development for the meter has been calculated to be about $1818.58, as shown in Table 9. This $1818.58 cost has been broken down into the individual components as listed below.

<table>
<thead>
<tr>
<th>Part</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microprocessor</td>
<td>PIC16F874A</td>
<td>1</td>
<td>$7.80</td>
<td>$7.80</td>
</tr>
<tr>
<td>Character LCD</td>
<td>16x2 Character LCD</td>
<td>1</td>
<td>$11.39</td>
<td>$11.39</td>
</tr>
<tr>
<td>Circuit Components</td>
<td>Speaker</td>
<td>1</td>
<td>$5.38</td>
<td>$5.38</td>
</tr>
<tr>
<td></td>
<td>5MHz Resonator</td>
<td>1</td>
<td>$0.35</td>
<td>$0.35</td>
</tr>
<tr>
<td></td>
<td>8 Pin Dip Socket</td>
<td>3</td>
<td>$0.42</td>
<td>$1.26</td>
</tr>
<tr>
<td></td>
<td>14 Pin Dip Socket</td>
<td>1</td>
<td>$0.73</td>
<td>$0.73</td>
</tr>
<tr>
<td></td>
<td>16 Pin Dip Socket</td>
<td>1</td>
<td>$0.83</td>
<td>$0.83</td>
</tr>
<tr>
<td></td>
<td>40 Pin Dip Socket</td>
<td>1</td>
<td>$2.09</td>
<td>$2.09</td>
</tr>
<tr>
<td></td>
<td>Switch</td>
<td>1</td>
<td>$3.39</td>
<td>$3.39</td>
</tr>
<tr>
<td></td>
<td>LM358</td>
<td>2</td>
<td>$0.86</td>
<td>$1.72</td>
</tr>
<tr>
<td></td>
<td>.1 Single Header</td>
<td>2</td>
<td>$1.29</td>
<td>$2.58</td>
</tr>
<tr>
<td></td>
<td>100 Ω Resistor</td>
<td>3</td>
<td>$0.09</td>
<td>$0.26</td>
</tr>
<tr>
<td></td>
<td>220 Ω Resistor</td>
<td>1</td>
<td>$0.09</td>
<td>$0.09</td>
</tr>
<tr>
<td></td>
<td>1K Ω Resistor</td>
<td>6</td>
<td>$0.08</td>
<td>$0.47</td>
</tr>
<tr>
<td></td>
<td>2K Ω Resistor</td>
<td>1</td>
<td>$0.08</td>
<td>$0.08</td>
</tr>
<tr>
<td></td>
<td>2.2K Ω Resistor</td>
<td>1</td>
<td>$0.08</td>
<td>$0.08</td>
</tr>
<tr>
<td></td>
<td>10K Ω Resistor</td>
<td>3</td>
<td>$0.09</td>
<td>$0.26</td>
</tr>
<tr>
<td></td>
<td>22K Ω Resistor</td>
<td>3</td>
<td>$0.09</td>
<td>$0.26</td>
</tr>
<tr>
<td></td>
<td>33K Ω Resistor</td>
<td>1</td>
<td>$0.05</td>
<td>$0.05</td>
</tr>
<tr>
<td></td>
<td>100K Ω Resistor</td>
<td>1</td>
<td>$0.09</td>
<td>$0.09</td>
</tr>
<tr>
<td></td>
<td>1μF Capacitor</td>
<td>5</td>
<td>$0.45</td>
<td>$2.26</td>
</tr>
<tr>
<td></td>
<td>0.1μF Capacitor</td>
<td>7</td>
<td>$0.88</td>
<td>$6.15</td>
</tr>
<tr>
<td></td>
<td>47000pF Capacitor</td>
<td>2</td>
<td>$0.73</td>
<td>$1.46</td>
</tr>
</tbody>
</table>
Table 8: gPod Calculated Prototype Cost.

The table above is a component break down for the cost of one gPod glucose meter with a cost of just $374.16. This price though could be greatly reduced if the speech module was further refined and a speech circuit was developed with just a $30.00 Windbond speech chip. Also with further work the PCB board could be greatly reduced and in turn the case would then be reduced. The whole system could be streamlined. Finally if mass production is to be taken into account then the price of a single gPod meter could be reduced to under $100.00.

<table>
<thead>
<tr>
<th>Components</th>
<th>Part</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microprocessor</td>
<td>PIC16F874A</td>
<td>4</td>
<td>$7.80</td>
<td>$31.20</td>
<td>$31.20</td>
</tr>
<tr>
<td>LCD</td>
<td>16x2 Character LCD</td>
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<td>$11.39</td>
<td>$11.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultra Compact Graphic LCD</td>
<td>1</td>
<td>$25.62</td>
<td>$25.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compact Graphic LCD</td>
<td>1</td>
<td>$50.00</td>
<td>$50.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Test and Demonstration PCB</td>
<td>1</td>
<td>$32.08</td>
<td>$32.08</td>
<td>$119.09</td>
</tr>
<tr>
<td>Circuit Components</td>
<td>56 Pin Breadboard Adapter</td>
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**Shipping**

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**Total Spent**

Total Spent: $1818.58

**Total Left**

Total Left: $181.42

Table 9: gPod Calculated Development Costs for Prototype
Team Member Contributions:

David Price:

David Price worked primarily on the systems integration and software of the gPod Blood Glucose Meter. This process involved working with the microprocessor, LCD screen, speech module, barcode scanner, and the glucose circuit. Each subsystem was tested prior to its integration with the whole meter. David was also involved in the assembly of the printed circuit board.

David developed the glucose trigger required for taking an accurate blood glucose measurement. This circuit involved knowledge in basic electronics and digital logic. He first learned to program the microprocessor using assembly language. While programming in assembly, David learned the process of analog-to-digital conversion with a microprocessor. David also learned to program the microprocessor in C++, using the PICC compiler made by Hi-Tech Software. The C++ helped streamline the programming process because of David’s previous knowledge in the language. The analog-to-digital routines were then written in C++.

The LCD screen was the next subunit to be tested and integrated. The project design included a 16 x 2 character LCD screen, powered by a standard LCD controller. Using information found on the web, David was able to write initialization, control, and display routines for the LCD. The LCD was tested on a protoboard to work out all possible problems with the microprocessor. Routines for clearing the LCD, writing to both lines, and displaying numbers were also developed. Measurements from the A/D converter had to be converted from binary to a decimal number and then converted to a character string that the LCD could display. The code is capable of displaying all the necessary instructions and measurements the gPod requires for simple operation.

David then worked to integrate the speech module to the microprocessor. This was a difficult process due to the poor documentation of the SP03 module. The instructions for the speech module were included in the manual but only described their function and not how to implement them in software. The speech module was connected to the PC and tested using the free software included with the unit. David used a port monitor to identify the command sequence being used by the speech module software. He then wrote a LabView program to emulate the speech module software. This LabView program was used to extensively test the speech module to ensure proper operation. The routines developed in LabView were then rewritten for the microprocessor in C++.

The final aspect of the project, the barcode scanner, was then worked on by David. Using a USB barcode reader, he developed a LabView routine that read the data from the scanner and transmitted the information to the microprocessor. The computer was used to mediate the USB to RS232 conversion. Later, a serial RS232 barcode scanner was purchased. The new scanner was simple to integrate with the microprocessor due to the previous hardware involved for RS232 communication with the speech module.
The entire meter was completely integrated and tested thoroughly. David fine tuned the software to calibrate the meter to different types of test strips. He also developed the user interface and the structure to the meter’s operation. Finally, he assembled the printed circuit board by soldering all of the surface mount components.

Matthew Bularzik:

Matthew Bularzik worked mainly on the development of the speech circuit, PCB development, and Casing of the gPod. Though he spent time working on many aspects of the design as a whole. Matthew helped in the development of the glucose circuit in the beginning with David. This development included a few variations of the circuit till the final configuration was achieved. Then he was responsible for the development of the Winbond speech circuit which ended up becoming very complicated. This was due to the need for multiple oscillators and the fact that some pins on the Winbond chip required 5V and others 3V. The SP03 speech module was instead adopted due to time constraints.

Though, the major part of Matthew’s time was spent with the PCB development and the casing for the gPod. For the PCB development Matthew had to learn how to use the program ExpressPCB. This program allows for the user design their PCB exactly as they would like it and then send the file directly to the company who will then manufacture and ship it. First he had to record and draw the entire circuit schematic into one section of the program. Then the circuit schematic was linked with the PCB layout section of the program. In the PCB layout section the board dimensions had to be determined along with where the PCB mounting holes were. This took Matthew a few tries due to the spacing allot by the case.

At the same time Matthew was working on the casing of the gPod since the PCB size and layout were very closely related to the casing. The board had to be able to fit into the case with the PCB mounts lining up. Placement of the many components on the PCB board had to be carefully taken into account for spacing around the battery case, post holes for the case, and vertical spacing. This later led to a few difficulties that could not have been avoided in the designing of the PCB layout.

Once the designing of the board was completed Matthew had to modify the case for the different buttons and components that had to be added. The power switch and scan vial button both needed holes near the screen on the side faces of the case. A serial port had to be installed in the bottom face and a small slot on the top face was needed for the test strip. Then 4 holes were drilled in the back of the case for increased ability to hear the voice output of the speech module. Finally the battery case was modified so the batteries would fit better by adding a separator for less battery movement. Ribbon tabs were also added to the battery case for easy removal of the batteries.

Matthew looked into the necessary parts that were needed for the voltage divider circuit. This power circuit was needed to drop the incoming 9V from the batteries to the outgoing 5V needed for the whole circuit. Matthew also kept track of the budget for the whole project and the ordering of parts. He had a running budget excel sheet that included all
expenses including shipping. Most purchase orders were drawn and up and recorded by Matthew also.

Michael Rivera:

Michael Rivera worked on a variety of tasks in building of the optimal design. He began by constructing a circuit that would effectively produce a voltage curve from the test strips. This voltage curve is the essential component that the glucose measurements are made from. It is this voltage output that varies with the amount of glucose in a sample. Performing this task required knowledge in circuit design as well as development. Once the circuit for the voltage curve was successfully working, it needed to be cleaned up. To be able to obtain accurate, reliable results, the voltage signal could not be as noisy as it currently was. This issue was resolved by the use of a filter. Using Texas Instruments FilterPro software, Mike was easily able to design a 4 pole, low-pass, Sallen-Key Butterworth filter that greatly reduced the amount of noise in the signal. Although the software helped simplify the design of the filter, it took much time to build the filter and get it to work properly. Op-amp selection and other proto-board components had significant effects on the functionality of the filter.

Once the filter had been built, and was working correctly, the glucose to voltage relationship needed to be determined. This was done by performing a series of tests using and oscilloscope, diluted control solution, and a purchased OneTouch Ultra meter. The oscilloscope was attached to the output of the filter so that the responding voltage curve could be observed, measured, and recorded. Diluting the control solution allowed Mike to perform trials at many different levels of glucose spanning from 20 mg/dL all the way to 398 mg/dL. These two endpoints are well below and above any value that would ever be measured from a person. The process of the whole experiment was simple, but time consuming. It started by diluting the control solution to some unknown level within a clean, sterile, lab beaker. This new solution would then be applied to the OneTouch Ultra meter as well as the designed circuitry. Based on the result from the OneTouch meter, Mike could identify the voltage response with a glucose level. Doing this repeatedly allowed Mike to have many glucose values with their corresponding voltage outputs. All this data was then loaded into Excel for analysis. After performing several operations to make the data usable, he was able to take the data point that occurred at 2 seconds after a sample was applied. Plotting this point against the corresponding glucose value gave the glucose-voltage relationship. This test was done a few times for different batches of test strips. Each batch of test strip has a specific glucose-voltage relationship. Knowing this relationship for all the batches of test strips is what allows for easy calibration of a meter.

The next part Mike worked on was a voltage comparator. The comparator was needed inorder to make the voltage measurement at exactly the correct time. It is critical to the accuracy of the measurements that each measurement be taking at the same time after sample has been applied. Essentially what the comparator did was notify the microprocessor when a blood sample had been applied. The microprocessor would then count 2 seconds and take a measurement. The comparator works by constantly
comparing an input voltage signal to a determined reference voltage. Once the input signal exceeds the value of the reference voltage (sample applied), the comparator then sends a +5V pulse to the microprocessor. It is this pulse that is a digital 1 to the microprocessor telling it to initiate timing.

Upon completion of what was then a working glucose circuit, Mike began looking into USB to Serial conversion. It was the group initial intent to have a USB barcode scanner that would attach to the meter. However, the microprocessor only has RS232 capabilities so a converter was needed somewhere in between. After spending much time researching and constructing circuits, USB conversion was much more difficult than expected. It was then decided to simply use a serial scanner that would require no conversion.
Conclusion:

Current blood glucose meters do not adequately accommodate all of the needs of diabetic clients. The gPod Glucose Monitor will incorporate features to assist blood sugar monitoring in patients with vision impairment, hearing loss, tremors, and motor control difficulties. The user interface will be easy to learn for clients of all ages and abilities. The proposed meter will be easy to calibrate, operate, and handle. The on-screen and audio instructions will make blood glucose monitoring more accessible for patients. The available insulin vial scanner module will aid visually impaired patients in insulin administration. The gPod Glucose Monitor is the low cost alternative for accessible blood glucose testing.
Acknowledgments:

Dr. John Enderle
Christopher Liebler
Tracy Makuck
Dr. Robert Northrop
Cr. Monty Escabi
Dr. Martin Fox
Dr. Quing Zhou
Dave Kaputa
Tom Price
Anne Marie Bularzik
Rebecca Langlais
The RERC
Appendix A

PIC 16F874A Microprocessor

Processor Features
- Operating Speed: 20 MHz clock input
- FLASH Program Memory: 4096 words
- Data Memory: 192 bytes
- EEPROM Data Memory: 128 bytes

Peripheral Features
- Synchronous Serial Port (SSP) with SPI (Master mode) and I2C (Master/Slave mode)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI)
- Parallel Slave Port (PSP) 8-bits wide with external Read, Write, and Chip Select controls

Analog Features:
- 10-bit, 8 Channel Analog-to-Digital Converter (A/D)
- 2 Analog Comparators
- Programmable on-chip voltage (Vref) module
- Programmable input multiplexing from device inputs and internal voltage reference

Special Features:
- 100,000 erase/write cycle Enhanced FLASH program memory
- 1,000,000 erase/write cycle Data EEPROM memory
- In-Circuit Serial Programming
- Programmable code protection
- Power saving SLEEP mode
- In-Circuit Debug
Figure A-1: Microprocessor Pin Diagram

<table>
<thead>
<tr>
<th>Pin Description</th>
<th>Pin Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCLR/VPP</td>
<td>1</td>
</tr>
<tr>
<td>RA0/AN0</td>
<td>2</td>
</tr>
<tr>
<td>RA1/AN1</td>
<td>3</td>
</tr>
<tr>
<td>RA2/AN2/VR+</td>
<td>4</td>
</tr>
<tr>
<td>RA3/AN3/VR-</td>
<td>5</td>
</tr>
<tr>
<td>RA4/T0CKI/C1OUT</td>
<td>6</td>
</tr>
<tr>
<td>RA5/AN4/SS/C2OUT</td>
<td>7</td>
</tr>
<tr>
<td>RE0/RD/AN5</td>
<td>8</td>
</tr>
<tr>
<td>RE1/WR/AN6</td>
<td>9</td>
</tr>
<tr>
<td>RE2/CS/AN7</td>
<td>10</td>
</tr>
<tr>
<td>VDD</td>
<td>11</td>
</tr>
<tr>
<td>VSS</td>
<td>12</td>
</tr>
<tr>
<td>OSC1/CLKIN</td>
<td>13</td>
</tr>
<tr>
<td>OSC2/CLKOUT</td>
<td>14</td>
</tr>
<tr>
<td>RC0/T1OSO/T1CKI</td>
<td>15</td>
</tr>
<tr>
<td>RC1/T1OSI/CCP2</td>
<td>16</td>
</tr>
<tr>
<td>RC2/CCP1</td>
<td>17</td>
</tr>
<tr>
<td>RC3/SCK/SCL</td>
<td>18</td>
</tr>
<tr>
<td>RD0/PSP0</td>
<td>19</td>
</tr>
<tr>
<td>RD1/PSP1</td>
<td>20</td>
</tr>
<tr>
<td>RD2/PSP2</td>
<td>21</td>
</tr>
<tr>
<td>RD3/PSP3</td>
<td>22</td>
</tr>
<tr>
<td>RD4/PSP4</td>
<td>23</td>
</tr>
<tr>
<td>RD5/PSP5</td>
<td>24</td>
</tr>
<tr>
<td>RD6/PSP6</td>
<td>25</td>
</tr>
<tr>
<td>RD7/PSP7</td>
<td>26</td>
</tr>
<tr>
<td>RC5/SDO</td>
<td>27</td>
</tr>
<tr>
<td>RC6/TX/CK</td>
<td>28</td>
</tr>
<tr>
<td>RC7/RX/DT</td>
<td>29</td>
</tr>
<tr>
<td>RC4/SDI/SDA</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: www.microchip.com
Figure A-2: Processor/Module Block Diagram

PORT A
- RA0/AN1
- RA1/AN1
- RA2/AN2/Vref-/CVref
- RA3/AN3/Vref+
- RA4/T0CKI/C1OUT
- RA5/AN5/SS/C2OUT

Glucose Circuit
- WORK1
- WORK2

PORT B
- RB0/INT
- RB1
- RB2
- RB3/PGM
- RB4
- RB5
- RB6/PGC
- RB7/PGD

User Interface
- BUTTON1
- BUTTON2

PORT C
- RC0/T1OSO/T1CKI
- RC1/T1OSI/CCP2
- RC2/CCP1
- RC3/SCK/SCL
- RC4/SDI/SDA
- RC5/SDO
- RC6/TX/CK
- RC7/RX/DT

Sound Chip
- SCLK
- MOSI
- R/B
- INT
- MISO

PORT D
- RD0/PSP0
- RD1/PSP1
- RD2/PSP2
- RD3/PSP3
- RD4/PSP4
- RD5/PSP5
- RD6/PSP6
- RD7/PSP7

USB
- TX
- RX

PORT E
- RE0/AN5/RD
- RE1/AN6/WR
- RE2/AN7/CS

LCD
- DB0
- DB1
- DB2
- DB3
- DB4
- DB5
- DB6
- DB7
Table A-1: Module Pin Descriptions

<table>
<thead>
<tr>
<th>Module Pin Names</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORK1</td>
<td>Voltage from working electrode 1</td>
</tr>
<tr>
<td>WORK2</td>
<td>Voltage from working electrode 2</td>
</tr>
<tr>
<td>Button 1</td>
<td>User Button 1</td>
</tr>
<tr>
<td>Button 2</td>
<td>User Button 2</td>
</tr>
<tr>
<td>SCLK</td>
<td>SPI Serial Clock</td>
</tr>
<tr>
<td>MISO</td>
<td>SPI Serial Data Out</td>
</tr>
<tr>
<td>MOSI</td>
<td>SPI Serial Data In</td>
</tr>
<tr>
<td>INT</td>
<td>Interrupt Output</td>
</tr>
<tr>
<td>R/B</td>
<td>Module busy speaking</td>
</tr>
<tr>
<td>RX</td>
<td>Serial Receive</td>
</tr>
<tr>
<td>TX</td>
<td>Serial Transmit</td>
</tr>
<tr>
<td>DB0</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB1</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB2</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB3</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB4</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB5</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB6</td>
<td>Parallel Data In for LCD</td>
</tr>
<tr>
<td>DB7</td>
<td>Parallel Data In for LCD</td>
</tr>
</tbody>
</table>

Table A-2: Microprocessor Pin Descriptions

<table>
<thead>
<tr>
<th>PIC16F87XA Pin Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA0/AN0</td>
<td>Analog Input 0</td>
</tr>
<tr>
<td>RA1/AN1</td>
<td>Analog Input 1</td>
</tr>
<tr>
<td>RB0/INT</td>
<td>Digital I/O</td>
</tr>
<tr>
<td>RB1</td>
<td>Digital I/O</td>
</tr>
<tr>
<td>RB2</td>
<td>Digital I/O</td>
</tr>
<tr>
<td>RB3/PGM</td>
<td>Digital I/O</td>
</tr>
<tr>
<td>RC3/SCK/SCL</td>
<td>Serial Clock Input/Output for SPI Mode</td>
</tr>
<tr>
<td>RC5/SDO</td>
<td>SPI Data Out</td>
</tr>
<tr>
<td>RC6/TX/CK</td>
<td>USART Asynchronous Transmit</td>
</tr>
<tr>
<td>RC7/RX/DT</td>
<td>USART Asynchronous Receive</td>
</tr>
<tr>
<td>RD0/PSP0</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD1/PSP1</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD2/PSP2</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD3/PSP3</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD4/PSP4</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD5/PSP5</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD6/PSP6</td>
<td>Parallel Slave Port Data</td>
</tr>
<tr>
<td>RD7/PSP7</td>
<td>Parallel Slave Port Data</td>
</tr>
</tbody>
</table>
Figure A-3: Sample Code for Serial/USB Communication

Interface PIC  
Microprocessor: Microchip PIC16F87x  
Compiled with: Hitech-C v7.87, developed using MPLAB v5.3  
Note: all references are to PIC16C7X PDF version of Microchip manual, DS30390E  
Overall goal: serial comms using USART to comm port of an ibm pc compatible computer

*/
#include <pic.h>
#include <conio.h>
#include <stdio.h>
#include "always.h"
#include "delay.h"

void serial_setup(void)
{
    /* relates crystal freq to baud rate - see above and PIC16F87x
    data sheet under 'USART async. modes'
    * Comms setup:
    */
    #define BAUD 19200
    #define DIVIDER ((PIC_CLK/(16UL * BAUD) -1))
    #define HIGH_SPEED 1
    SPBRG=DIVIDER;
    BRGH=HIGH_SPEED; //data rate for sending  
    SYNC=0;         //asynchronous  
    SPEN=1;         //enable serial port pins  
    CREN=1;         //enable reception  
    SREN=0;         //no effect  
    TXIE=0;         //disable tx interrupts  
    RCIE=0;         //disable rx interrupts  
    TX9=0;          //8-bit transmission  
    RX9=0;          //8-bit reception  
    TXEN=0;         //reset transmitter  
    TXEN=1;         //enable the transmitter
    unsigned char dummy;
    #define clear_usart_errors_inline
    if (OERR)
{  
  TXEN=0;
  TXEN=1;
  CREN=0;
  CREN=1;
}
if (FERR)
{
  dummy=RCREG;
  TXEN=0;
  TXEN=1;
}
//writes a character to the serial port
void putch(unsigned char c){
  while(!TXIF) //set when register is empty
  {
    clear USART_errors_inline;
    CLRWDTH();
  }
  TXREG=c;
  DelayUs(60);
}
writes a character to the serial port in hex
if serial lines are disconnected, there are no errors
void putchhex(unsigned char c){
  unsigned char temp; // transmits in hex
  temp=c;
  c=(c >> 4);
  if (c<10) c+=48; else c+=55;
  putch(c);
  c=temp;
  c=(c & 0x0F);
  if (c<10) c+=48; else c+=55;
  putch(c);
}
void putinthex(unsigned int c){
#define ramuint(x) (*((unsigned int *) (x)))
#define ramuint_hibyte(x) (*((unsigned char *)&x)+1))
#define ramuint_lobyte(x) (*((unsigned char *)&x)+0))
#define ramuchar(x) (*((unsigned char *) (x)))
  putchhex(ramuint_hibyte(c));
  putchhex(ramuint_lobyte(c));
#undef ramuint(x)
#undef ramuint_hibyte(x)
#undef ramuint_lobyte(x)
#undef ramuchar(x)
}
Figure A-4: Sample Code for LCD display drivers

;;; Included files (including library headers).

    #include "lcd_lib.h" ; LCD routine headers.
    #include "del_lib.h" ; Delay routine headers.

--

;;; Assembler Equates Section. Define assembly-time constants here
;;; using the EQU assembler directive.
RESETVECTOR EQU 0x000 ; Address of RESET vector.
PERIPHVECTOR EQU 0x004 ; Address of peripheral interrupt vector.
CODESTART EQU 0x008 ; Starting location of program code.

--

;;; Variable Address Assignments.

    UDATA  ; Start of uninitialized data section.
    ; Reserve memory for variables using the
    ; "RES" directive here. Note that the
    ; linker will assign addresses.

    COUNT RES 1  ; A variable to keep track of the
    ; custom character to send out to the
    ; LCD.

--

;;; Establish the OPTION register bit values.

--

;;; The '__CONFIG' directive is used to embed PIC configuration data
;;; within an assembly file. The labels following the directive
;;; are located in the .inc file. See the device data sheet for
;;; additional information on the configuration word.
ifndef A_Device

    _CONFIG _CP_OFF & _WDT_OFF & _BODEN_ON & _PWRT_ON & _XT_OSC &
    _WRT_ENABLE_ON & _LVP_OFF & _CPD_OFF

endif

;;; _CP_OFF: turn off code protection. Don't change this unless you
;;; want a device that can never be programmed again. This
;;; is a "bug" in some PIC devices.

;;; _WDT_OFF: turn off the watchdog timer.

;;; _BODEN_ON: turn on power brown-out reset.

;;; _PWRT_ON: turn on power-up timer.

;;; _XT_OSC: specify that the device is using an XT oscillator.

;;; _WRT_ENABLE_ON: enable writing to data EEPROM.


;;; _CPD_OFF: disable data EEPROM write protection.

ifdef A_Device

    messg "A revision device."

    _CONFIG _CP_OFF & _WDT_OFF & _BODEN_ON & _PWRT_ON & _XT_OSC &
    _WRT_OFF & _LVP_OFF & _CPD_OFF

endif

;;; _CP_OFF: turn off code protection. Don't change this unless you
;;; want a device that can never be programmed again. This
;;; is a "bug" in some PIC devices.

;;; _WDT_OFF: turn off the watchdog timer.

;;; _BODEN_ON: turn on power brown-out reset.

;;; _PWRT_ON: turn on power-up timer.

;;; _XT_OSC: specify that the device is using an XT oscillator.

;;; _WRT_OFF: disable write-protection of program FLASH.
CPD_OFF: disable data EEPROM write protection.

Main Program.

CODE  ; Start of the code section.

Main:

Make PB0-3 ground for 4-bit mode testing.
This is here only because I use the same LCD connections
as 8-bit parallel to test 4-bit mode.
Note that when the LCD is used in 4-bit mode, DB0-DB3 (LCD) need
to be grounded.

The interface to the LCD module is configured in file
"lcd_config.h",
which is included by the LCD library, lcd_lib.asm, directly.
Ensure that this file contains appropriate information for your
system.

banksel PORTB
movlw 0x00
movwf PORTB
banksel TRISB
movlw 0xF0
movwf TRISB

call LCD_Init

; Default initialization turns the cursor on.
; Turn the cursor off: this demo looks better.
movlw 0x0C

call LCD_Ctrl_Write

; Display line 1 text.
; Establish a pointer to the NULL-terminated string.
banksel LCD_PTRLOW
movlw low Sline1
movwf LCD_PTRLOW
movlw high Sline1
movwf LCD_PTRHIGH

call LCD_TxStringK

; Move down to start of second line.
movlw 0xC0

call LCD_Ctrl_Write

; Send out the string to the second line.
banksel LCD_PTRLOW
movlw low Sline2
movwf LCD_PTRLOW
movlw high Sline2
movwf LCD_PTRHIGH

call LCD_TxStringK

; Change to CGRAM mode.
movlw 0x40
call LCD_Ctrl_Write

;; Send 8 characters of data.
banksel LCD_PTRLOW
movlw low CustomChar0
movwf LCD_PTRLOW
movlw high CustomChar0
call LCD_Ctrl_Write

movlw 64 ; 8 chars * 8 bytes/char = 64
movlw 0xC0
call LCD_TxStringKN

;; Change back to DDRAM mode.
movlw 0xC0
call LCD_Ctrl_Write

DisplayPause:

;; Display the full face.
movlw 0xCE
call LCD_Ctrl_Write
movlw 0x06
call LCD_Data_Write
;; Delay 1/2 a second.
movlw 50
movlw 0x90
呼叫 DELAY_Wx10ms

displayPause2:

;; Display the top of the eyes.
movlw 0xCE
movlw 0x00
movlw 0x06
call LCD_Data_Write
;; Delay 1/2 a second.
movlw 50
movlw 0x90
呼叫 DELAY_Wx10ms

goto DisplayUp

Source: http://www.ece.ualberta.ca/~ee401/resource/software/PIC/test/lcd/lcdtest.asm
Appendix B

Crystalfontz CFAX12864C-WGH LCD Screen

Table B-1: LCD Screen Technical Specifications

3. General Specification

<table>
<thead>
<tr>
<th>Item</th>
<th>Dimension</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Characters</td>
<td>128 characters x 64 Lines</td>
<td>–</td>
</tr>
<tr>
<td>Module dimension</td>
<td>56.0 x 42.5 x 2.4(MAX)</td>
<td>mm</td>
</tr>
<tr>
<td>View area</td>
<td>52.0 x 33.5</td>
<td>mm</td>
</tr>
<tr>
<td>Active area</td>
<td>47.76 x 30.29</td>
<td>mm</td>
</tr>
<tr>
<td>Dot size</td>
<td>0.37 x 0.42</td>
<td>mm</td>
</tr>
<tr>
<td>Dot pitch</td>
<td>0.35 x 0.4</td>
<td>mm</td>
</tr>
<tr>
<td>LCD type</td>
<td>STN, Positive, Translber, Gray</td>
<td></td>
</tr>
<tr>
<td>Duty</td>
<td>1/64</td>
<td></td>
</tr>
<tr>
<td>View direction</td>
<td>6 o’clock</td>
<td></td>
</tr>
<tr>
<td>Backlight Type</td>
<td>EL, White</td>
<td></td>
</tr>
</tbody>
</table>

4. Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>$T_{OP}$</td>
<td>-20</td>
<td>–</td>
<td>+70</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>$T_{ST}$</td>
<td>-30</td>
<td>–</td>
<td>+80</td>
<td>°C</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>$V_i$</td>
<td>$V_{SS}$</td>
<td>–</td>
<td>$V_{DD}$</td>
<td>V</td>
</tr>
<tr>
<td>Supply Voltage For Logic</td>
<td>$V_{IN}$-$V_{SS}$</td>
<td>2.4</td>
<td>–</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Supply Voltage For LCD</td>
<td>$V_{O}$-$V_{SS}$</td>
<td>4.0</td>
<td>–</td>
<td>15.0</td>
<td>V</td>
</tr>
</tbody>
</table>

5. Electrical Characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Condition</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage For Logic</td>
<td>$V_{DD}$-$V_{SS}$</td>
<td>–</td>
<td>2.4</td>
<td>–</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Supply Voltage For LCD</td>
<td>$V_{DD}$-$V_{SS}$</td>
<td>$T_a=-20 \degree C$</td>
<td>–</td>
<td>–</td>
<td>9.2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>$V_{DD}$-$V_{SS}$</td>
<td>$T_a=25 \degree C$</td>
<td>–</td>
<td>8.2</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>$V_{DD}$-$V_{SS}$</td>
<td>$T_a=70 \degree C$</td>
<td>7.2</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Input High Volt.</td>
<td>$V_{IN}$</td>
<td>–</td>
<td>0.8 $V_{DD}$</td>
<td>–</td>
<td>$V_{DD}$</td>
<td>V</td>
</tr>
<tr>
<td>Input Low Volt.</td>
<td>$V_{IN}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.2 $V_{DD}$</td>
<td>V</td>
</tr>
<tr>
<td>Output High Volt.</td>
<td>$V_{OUT}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Output Low Volt.</td>
<td>$V_{OSS}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.4</td>
<td>V</td>
</tr>
<tr>
<td>Supply Current</td>
<td>$I_{DD}$</td>
<td>$V_{DD}=5V$</td>
<td>–</td>
<td>1.5</td>
<td>–</td>
<td>mA</td>
</tr>
</tbody>
</table>

Source: www.crystalfontz.com
Table B-2: Pin Assignments for LCD Screen:

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>I/O</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NC</td>
<td>—</td>
<td>No connection</td>
</tr>
<tr>
<td>2</td>
<td>TEMPS</td>
<td>I</td>
<td>Selects temperature coefficient of the reference voltage. TEMPS=’L’: -0.05%°C, TEMPS=’H’: -0.2%°C</td>
</tr>
<tr>
<td>3</td>
<td>INTRS</td>
<td>I</td>
<td>Internal resitors select pin. This pin selects the resistors for adjusting V0 voltage level. INTRS=’H’: use the internal resistor. INTRS=’L’: use the external resistor. V0 voltage is controlled with VR pin and external resistor divider</td>
</tr>
<tr>
<td>4</td>
<td>HPM</td>
<td>I</td>
<td>Power control pin of the power supply circuit for LCD driver. HPM=’H’: high power mode HPM=’L’: normal power mode This pin is valid in master operation</td>
</tr>
<tr>
<td>5</td>
<td>DCDC3B</td>
<td>I</td>
<td>Stares boosting circuit enable input pin. When this pin is low in 4 times boosting circuit, the 5-time boosting voltage appears as VOUT.</td>
</tr>
<tr>
<td>6</td>
<td>BSTS</td>
<td>I</td>
<td>Select input voltage of the built-in voltage converter. Voltage converter input BSTS=’H’: 4V (VDD=4V) BSTS=’L’: VDD (2.4V≤VDD≤5.5V) When BSTS pin is ‘L’, VDD must be higher than 4V in our 4-time boosting.</td>
</tr>
<tr>
<td>7-11</td>
<td>V0~V4</td>
<td>I/O</td>
<td>LCD driver supply voltages. The voltage determined by LCD pixel is impedance-converted by an operational amplifier for application. Voltages should have the following relation; V0≥V1≥V2≥V3≥V4≥VSS</td>
</tr>
<tr>
<td>12</td>
<td>VR</td>
<td>I</td>
<td>V0 voltage adjustment pin. It is valid only when on-chip resistors are not used(INTRS=’L’).</td>
</tr>
<tr>
<td>13</td>
<td>C2-</td>
<td>O</td>
<td>Capacitor 2 negative connection pin for voltage converter.</td>
</tr>
<tr>
<td>14</td>
<td>C2+</td>
<td>O</td>
<td>Capacitor 2 positive connection pin for voltage converter.</td>
</tr>
<tr>
<td>15</td>
<td>C1-</td>
<td>O</td>
<td>Capacitor 1 negative connection pin for voltage converter.</td>
</tr>
<tr>
<td>16</td>
<td>C1+</td>
<td>O</td>
<td>Capacitor 1 positive connection pin for voltage converter.</td>
</tr>
<tr>
<td>17</td>
<td>C3-</td>
<td>O</td>
<td>Capacitor 1 negative connection pin for voltage converter.</td>
</tr>
<tr>
<td>18</td>
<td>C3+</td>
<td>O</td>
<td>Capacitor 1 positive connection pin for voltage converter.</td>
</tr>
<tr>
<td>19</td>
<td>VOUT</td>
<td>I/O</td>
<td>Voltage converter input/output pin.</td>
</tr>
<tr>
<td>20</td>
<td>VDD</td>
<td>—</td>
<td>Power supply pin for logic.</td>
</tr>
<tr>
<td>21</td>
<td>VSS</td>
<td>—</td>
<td>Ground pin, connected to 0V</td>
</tr>
</tbody>
</table>
| 22 | PS | 1 | Parallel/Serial data input select pin. Interface Data Read/Write Serial clock 
PS="H": Parallel DB0~DB7 E_RD,RW_WR 
PS="L": Serial SCLK(DB7) Write only SCLK(DB6) 
In serial mode, it is impossible to read data from the on-chip RAM. And DB0 to DB7 are high impedance and E_RD and RW_WR must be fixed to either "H" or "L". |
| 23 | MI | 1 | Microprocessor interface select pin 
MI=H: 8080-series MPU interface 
MI=L: 8080-series MPU interface |
| 24 | CLS | 1 | Built-in oscillator circuit enable/disable select pin. 
CLS="H": enable 
CLS="L": disable (external display clock input from CL pin) |
| 25 | MS | 1 | Master or Slave mode operation select pin. 
MS="H": master operation 
MS="L": slave operation |
| 26 | DUTY1 | 1 | The LCD driver duty ratio depends on the following table 
| 27 | DUTY0 | 1 | Duty ratio 
| | L | L | 1/33 |
| | L | H | 1/49 |
| | H | L | 1/65 |
| 28~35 | DB7~DB0 | I/O | 8-bit bi-directional data bus that is connected to the standard 8-bit microprocessor data bus. 
When the serial interface selected (PS="L") 
DB0~DB5: high impedance 
DB6: serial input clock (SCLK) DB7: serial input data (SID) 
When chip select is not active, DB0~DB7 may be high impedance |
| 36 | E_RD | 1 | When connected to 80-family MPU: Read enable clock input pin. When RD is "L", DB0~DB7 are in an output status 
When connected to 68-family MPU: RW = "H". When E is "H", DB0~DB7 are in an output status 
RW = "L": The data on DB0~DB7 are latched at the falling edge of the E signal |
| 37 | RW_WR | 1 | When connected to 80-family MPU: Write enable clock input pin. The data on DB0~DB7 are latched at the rising edge of the WR signal. 
When connected to 68-family MPU: RW = "H": read RW = "L": write |
| 38 | RS | 1 | Register select pin 
RS="H": DB0~DB7 are display data 
RS="L": DB0~DB7 are control data |
| 39 | RESETH | 1 | Reset input pin 
When RESETH is "L", initialization is executed. |
| 40 | CS2 | 1 | Chip select input pins 
Data/instruction I/O enable only when CS1B is "L" and CS2 is "H". 
When chip select is non-active, DB0~DB7 may be high impedance |
| 41 | CS1B | 1 | 
| 42 | DISP | I/O | LCD display blanking control input/output 
When K50713 is used in master/slave mode (multi-chip), the DISP pins must be connected each other. 
MS="H": output MS="L": input |
| 43 | CL | I/O | Display clock input/output pin 
When the K50713 is used in master/slave mode (multi-chip), the CL pins must be connected each other. |
| 44 | M | I/O | LCD AC signal input/output pin 
When K50713 is used in master/slave mode (multi-chip), the M pins must be connected each other. 
MS="H": output MS="L": input |
| 45 | FRS | O | Static driver segment output pin 
This pin is used together with the M pin. |
| 46 | NC | — | No connection. |

Source: www.crystalfontz.com
Appendix C

Winbond WTS701 Speech Chip

Table C-1: WTS701 Pin Descriptions

<table>
<thead>
<tr>
<th>PIN NO.</th>
<th>SYMBOL</th>
<th>I/O</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>INT\</td>
<td>O</td>
<td>Interrupt Output; an open drain output that indicates that the device wishes an interrupt service. The device can request an interrupt when it finishes an operation or needs more data to process. Under what conditions the device generates an interrupt can be configured through the user configuration registers. This pin remains LOW until a Read Interrupt command is executed.</td>
</tr>
<tr>
<td>26</td>
<td>R/B\</td>
<td>O</td>
<td>Ready/busy signal; This pin defaults HIGH indicating the device is ready for data transfer. The pin is driven LOW to handshake a pause in SPI data transfer.</td>
</tr>
<tr>
<td>7</td>
<td>XTAL2</td>
<td>O</td>
<td>CRYSTAL 2: This is the crystal oscillator output. It is the inversion of XTAL1.</td>
</tr>
<tr>
<td>8</td>
<td>XTAL1</td>
<td>I</td>
<td>CRYSTAL 1: This is the crystal oscillator input. This pin may be driven by an external clock. The clock to the WTS701 processor is configured by a clock configuration register, which is set by the host processor during the initialization phase.</td>
</tr>
<tr>
<td>15</td>
<td>SS\</td>
<td>I</td>
<td>SPI Slave Select input. This is an active LOW input used to select the device to respond to an SPI transaction.</td>
</tr>
<tr>
<td>16</td>
<td>SCLK</td>
<td>I</td>
<td>SPI Serial clock input.</td>
</tr>
<tr>
<td>6</td>
<td>MISO</td>
<td>O</td>
<td>SPI Master In, Slave Out pin. Serial data line used to communicate with SPI master. Pin is tri-state when SS=1.</td>
</tr>
<tr>
<td>14</td>
<td>MOSI</td>
<td>I</td>
<td>SPI Master Out, Slave In. Serial data input from Master</td>
</tr>
<tr>
<td>25</td>
<td>CS\</td>
<td>I</td>
<td>Chip Select (active LOW) Pin must be LOW to access WTS701 device.</td>
</tr>
<tr>
<td>27</td>
<td>RESET</td>
<td>I</td>
<td>Global reset signal.</td>
</tr>
<tr>
<td>3</td>
<td>VCLK</td>
<td>I</td>
<td>CODEC master clock</td>
</tr>
<tr>
<td>4</td>
<td>VFS</td>
<td>I</td>
<td>CODEC frame synchronization signal</td>
</tr>
<tr>
<td>5</td>
<td>VDX</td>
<td>O</td>
<td>CODEC data output. This pin puts data out in the linear PCM unsigned or 2's complement format. It is tri-stated until the user requests a CONVERT operation.</td>
</tr>
<tr>
<td>52</td>
<td>AUXIN</td>
<td>I</td>
<td>Analog input pin. This pin should be capacitively coupled.</td>
</tr>
<tr>
<td>54</td>
<td>AUXOUT</td>
<td>O</td>
<td>Analog Output for single ended output from the device.</td>
</tr>
<tr>
<td>46</td>
<td>SP+</td>
<td>O</td>
<td>Differential Positive Speaker Driver Output.</td>
</tr>
<tr>
<td>42</td>
<td>SP-</td>
<td>O</td>
<td>Differential Negative Speaker Driver Output.</td>
</tr>
<tr>
<td>40</td>
<td>ATTCAP</td>
<td>I/O</td>
<td>AutoMute Capacitor Pin. Should have a 4.7uF capacitor to VSSA.</td>
</tr>
<tr>
<td>----</td>
<td>--------</td>
<td>-----</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>11,12</td>
<td>VCCD</td>
<td>P</td>
<td>Positive Digital Supply pin. These pins carry noise generated by internal clocks in the chip. They must be carefully bypassed to Digital Ground to ensure correct device operation.</td>
</tr>
<tr>
<td>9,10</td>
<td>VSSD</td>
<td>G</td>
<td>Digital Ground pin.</td>
</tr>
<tr>
<td>2,36,44</td>
<td>VSSA</td>
<td>G</td>
<td>Analog Ground pins.</td>
</tr>
<tr>
<td>48</td>
<td>VCCA</td>
<td>P</td>
<td>Positive Analog Supply pin. This pin supplies the LOW level audio sections of the device. It should be carefully bypassed to Analog Ground to ensure correct device operation.</td>
</tr>
</tbody>
</table>
Appendix D

Software

Figure D-1: Software Flowchart
Appendix E: Specifications

Technical Specifications

Test Parameters:

Result Range: 20-600 mg/dL
Calibration: Plasma – Equivalent
Sample: Fresh Capillary Whole Blood
Sample Size: 1.0 µL minimum
Test Time: 5 Seconds
Assay Method: Glucose Oxidase Biosensor
Glucose Units: mg/dL
Hematocrit Range: 30-55% (% of red blood cells in whole blood)

Electrical Specifications:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Voltage/Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Battery Voltage</td>
<td>7.5 Volts</td>
</tr>
<tr>
<td>Microprocessor Operating Voltage</td>
<td>5.0 Volts</td>
</tr>
<tr>
<td>LCD Operating Voltage</td>
<td>5.0 Volts</td>
</tr>
<tr>
<td>Speech Module Minimum Operating Voltage</td>
<td>5.0 Volts</td>
</tr>
<tr>
<td>Barcode Scanner Operating Voltage</td>
<td>120 Volts AC</td>
</tr>
<tr>
<td>Speech Module Operating Current</td>
<td>100 mA</td>
</tr>
<tr>
<td>Meter Operating Current</td>
<td>140 mA</td>
</tr>
<tr>
<td>Peak Operating Current</td>
<td>220 mA</td>
</tr>
</tbody>
</table>
Accessible Blood Glucose Monitor

University of Connecticut
Biomedical Engineering Senior Design
Team 2

Sponsored by the Rehabilitation Engineering Research Center on Accessible Medical Instrumentation (RERC on AMI)

Team 2 is: Matthew Bularzik, David Price, Michael Rivera

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