EASELECTRIC

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Client Contact: Brook Hallowell, NSF
Introduction

The goal of this project is to design an easel that is electronically adjustable and that is safe and easy to use within a community of cognitively impaired individuals. The easel is required by our sponsor NSF, specifically Brooke Hallowell, to be light-weight and easy to store when not in use, and be able to move in various directions. Some of the effects of cognitive impairment are that our client, Harry Grim, has limited dexterity and limited arm movement. We have designed an easel according to these specifications and are confident that Harry Grim will be pleased with the outcome of his new easel.

Design

Our easel is electrically controlled by two detachable joysticks which allow the operator to move the easel in three different planes. Each joystick moves the easel in four different directions. We decided to use two joysticks instead of one, because the devices have to be easy for Harry to use. If there are too many directions on one joystick it might be difficult to reach the desired positioning of the easel. The joysticks control relays and this allows for the easel to move up and down, left and right, front to back, and also tilt. Once the user makes an input of which way they would like the easel to move, the easel will respond having the base and carriage subunits make the request movement.

The first action taken to begin a well developed design for our electrically adjustable easel involves a block diagram which states the basics as to what the project must do. This involves an easy set up, elementary styled controls for user input, dynamic movement of the easel, and a basic electrical flow diagram.
The design will essentially be a base attached to a carriage and an under-part to attach to the table that the easel is seated on. The under-part of the design will be clamped to the table with a screw drive for added stability so the easel is sturdily attached to the table while the client is painting and to accommodate for different sized and weighted canvases. The base and carriage will sit on top of the table and each will be responsible for splitting up the different motion that the easel will allow by sliding in their specified draw-like tracks. The tilt of the easel will be operated by a linear actuator.

There are multiple safety features that our design includes. We are making sure that all the wires are safely attached and not exposed to anyone who might be tempted to tug or pull them out. We have also included a master on/off switch that will allow a supervising attendant to decide when the operator is done or in case of an emergency. This switch will be placed in the back of the easel so that it is not easily accessible to people who aren’t authorized to use it. We have also ensured that the movement of the easel itself is not too fast with the actuators or that it will overextend beyond its maximum range and fall off the tracks. This is done through the use of limiting switches.

Our easel has many advantages. It will be designed to be able to fold down after use and stored away without being bulky and in the way. Our easel will be built mostly from aluminum channeling and square tubing which can also be considered an advantage because aluminum is a good design material providing it is cheap, lightweight, and sturdy abilities.

Dimensions

Visio diagrams of the project are seen below. Here, we can see front and side views of the easel with US units. Actuators have not been included to the diagram in order to achieve a less complicated idea as to the overall look of the project. The values are in inches. The square tubing parts A, and T1 rest flat on the tables, while the cantilever arms will extend under the device, clamping it securely. These arms are adjustable with eyeholes along parts B1 and B2. The easel face is also adjustable along part D, accounting for different sized canvasses.
The easel face N will slide horizontally along L, which in turn will slide vertically on sliders M1 and M2 along parts H and I, respectively. These vertical shafts are allowed to rotate about pins O1- O4.
Actuator A rests in the channel piece “Q” and is bolted on each end to allow free movement in two dimensions. Screw clamp A is attached to arm S1 and S2.

Linear Actuators

The first design calls for three linear actuators. From mechanical assessment of the easel, these actuators should support loads no less than 20 to 30 lbs. The movement of the actuators should consist of a slow speed, one of the requirements of the project. The actuators will work in three different planes; one horizontal to move the carriage of the easel back and forth, one vertical to raise and lower the easel face, and one connected through a diagonal plane connected by bolts to tilt the carriage at desired angles. Each actuator has been assigned to have a total adjustable length of 9”. This value has been determined through careful analysis to provide sufficient movement of each part without risking injury to the artist by moving the easel too far. The actuators will be powered
through a circuit controlled by joysticks, and wired safely through aluminum tubing, preventing anyone to mistakenly tamper with the wiring. A diagram of the internal workings of these actuators is seen below:

**Figure 3: Linear Actuator**

![Figure 3: Linear Actuator](image)

Currently, the linear actuators under consideration are 8” and 9” Stroke High Force Linear Actuators. Their cost is roughly $100.00 a piece. They travel at a speed of 1/3” per second, which has been assumed a relatively acceptable speed for an operator with delayed reaction time. A 12 vdc nominal voltage is required for a push/pull force of 165 lbs. Although this value is a bit excessive, it will account for loads greater than expected (i.e. if someone was to sit, or hang a heavy item from the easel, there is less of a probability of mechanical failure). These specific actuators include an IP54 rating, regarding splash and dust resistance. The 2-wire harness inside provides reverse polarity to change direction and built in limit switches to prevent the easel from moving past maximal points of excursion. Their aluminum design will also match the aluminum frame of the easel.

For the horizontal displacement a non-captive linear actuator will be used. This allows the easel to move as far left or right as we want. The drive that the rod will rest on will be fabricated to our specified dimensions.

**Drawer Tracks**

The movements of the easel will depend on the type of tracking system integrated into the project. For the vertical and front to back displacements, drawer tracks have been included into the design. Track 1A and 1B on the base diagram of the device will provide essential low frictional movement of the carriage. Track 2A and 2B will provide vertical displacement of the horizontal screw drive and easel face.

The drawer tracks under consideration are the Dynamic NT Self-Close Full Extension Drawer Slides, with maximal excursion load capabilities of 100 lbs. Designed at 5/8” wide, they will easily fit onto the ¾” vertical parts “H” and “I” as well as the 2” tubing pieces “P1” and “P2”. Using 15” tracks will provide a traveling distance of 9” taking into account 6” sliders that will mount on top. These tracks cost $14.00 for a pair, maintaining a very cost efficient design.
Mechanical Design

The base of this design must maintain sturdy and solid principles while the easel is in motion. As specified by our contact, a table top design will be best suited for the needs of the client. A problem arises as to the dimensions of the table. In order to provide an easel that will work properly, the base should adjust to fit tables of different dimensions, shapes, and locations. The design of the extending arms which will clamp the base to the table have been designed to properly match the above criteria. By designing the arms to go under the table rather than to the sides will allow the easel to be used on tables propped against walls or in cluttered, space limited areas. The base is also designed for different table shapes, allowing not only square or rectangular surfaces to be clamped, but also circular or oval shaped tables. The width of the table was the most important feature of the clamping mechanism to consider. The screw clamp will adjust to widths of zero to six inches. Using the adjustable cantilever (parts B1 and B2) allows arms S1 and S2 to slide up and down, providing movements around any possible lips or overhangs of the table unaccounted for. Mechanical analysis of the clamp and base will be considered next.

1. Clamp

One of the most important components of the device is how it is secured to the table. Without a robust system to attach the easel to the table, there is an enormous risk of injury to the user due to a large moment created by the full extension of the drawing surface or misuse. In order to handle this moment, a strong frame constructed of one-inch square aluminum tubing is used which capable of handling a maximum stress of 4,000 psi (Figure 3.1.1). As can be seen in “Static Analysis of Clamp Under Own Weight,” under normal operating conditions these features are under nearly no stress due to the extreme light-weight properties of the Aluminum, it is only under misuse that their mechanical properties are tested. The clamp is designed to be adjustable to accommodate tables with varying lips and extends and clamps via a threaded screw 16 inches under the table, allowing it to counteract any large moment arms placed upon the device by misuse.

The weight of the clamp, located at the centroid, produces a small moment of only 3.92 lb-in and is exposed to a downward force of 0.87 lb, producing a shear of 8.86 psi in the pin connecting the clamp to its receptacle in the base. Under normal operating conditions, the weight of the carriage and drawing surface are directly over the table to which the easel is attached, meaning that the load is handled by the base and transmitted directly to the table. This direct transformation of load means that no additional moment is transferred to the clamp during the majority of the operating time resulting in a factor of safety in the clamps of around 1700.

As can be seen in figure 4 and the Static Analysis, the clamp has the ability to drop down an additional 4 inches and is secured by a pin with a diameter of approximately 0.250 in. This hole causes a stress concentration which was calculated to be Kf= 2.55. This concentration drops the ultimate strength of the 1/8th inch thick aluminum from 10,000 psi to around 4,000 psi, however once the normal stress is calculated it is clear to see that this factor is not even an issue; the stress is only 2.32 psi. The result of this design, using two pieces of strong square tubing made of lightweight aluminum joined by extremely strong welds, is a clamping mechanism that is portable, lightweight, and capable.
2. Base

As stated, the base (Figure 5) serves two very important functions in the device. First off, the base is the foundation of the easel, and without a strong and stable foundation the device would be a complete failure. To achieve this strong and stable base, two-inch square aluminum tubing will be used and the base will basically form the shape of a square with two protrusions on the front to facilitate the clamping mechanism. The second function of the base is movement. A linear actuator is attached to the rear of the base and extends to the carriage, which rides on a heavy duty I-beam door track capable of handling a tensile force of 300lb (http://jhus.com/2000.asp) that is attached back to the base. This setup allows for a total movement of 8 inches of motion front and back, extending a maximum of 6 inches from the front of the base and retracting to a minimum of 2 inches behind the front of the base (Figure 6).

As can be seen in the “Static Analysis of Base,” the base is subjected to rather small stresses as well. Without the carriage which weighs approximately 15 lb, the weight of the base alone, a surprisingly small 7.84 lb, is subjected to a stress of only 0.0426 psi and a negligibly small moment created by the combined weight of the two clamps which is easily counteracted by the weight of the base and the center of gravity pushed to the rear of the base. When the weight of the carriage is added in to the weight of the base, approximately 23 lb, the stress exerted is increased to 0.124 psi and when the device is fully extended a moment of 210 lb-in is generated. The only real challenge for the structural integrity of the base comes when the device is misused and it is either hung off of or somehow sat on. When a 300lb person, the carriage, base, and clamps are added to a fully extended device a moment is generated equaling 5400lb-in, translating to a bending stress of 4050 psi, well within the ultimate stress of 10,000 psi and giving a factor of safety of $N = 2.5$. 

Figure 4. Side and Top Views of Clamp and Tube
3. *Carriage*

The carriage slides along the base as discussed. Actuator “A” is detachable from the vertical columns, allowing the easel to be collapsible and easy to store. This is seen in figure 7. The movable capabilities of the carriage and this actuator are seen in Figure 8.
Figure 7. Collapsing Abilities

Figure 8. Movement of Actuator and Carriage
Movement of the carriage is defined by the angle the actuator makes with the base. This angle $\theta$ is defined to have an angular acceleration:

$$a \equiv (r^2 - \theta''^2) - \frac{3r^2}{3t} + (r\theta' + 2\theta')\theta$$

It depends on the velocity of the radius of curvature and change in $\theta$ as a function of time. In order to evaluate the carriage components, including the bearing force on pins at A and B, we will work backwards from the easel face, working downwards.

The mass of the easel face is simply the addition of the five flat-stock aluminum pieces situated around the front plate. Using the density of aluminum, $\rho = .095 \text{ lbs/in}^3$, the mass of the easel face is found by calculating the volume of each part:

- $V_a = .5 \text{ in} \times .25 \text{ in} \times 24 = 3 \text{ in}^3 \times .095 = .285 \text{ lbs}$
- $V_b = .5 \text{ in} \times .25 \text{ in} \times 30 = 3.75 \text{ in}^3 \times .095 = .35625 \text{ lbs}$
- $V_c = .5 \text{ in} \times .25 \text{ in} \times 16 = 2 \text{ in}^3 \times .095 = .19 \text{ lbs}$
- $V_d$ and $V_e = .5 \text{ in} \times .25 \text{ in} \times 31.04 \text{ in} = 3.88 \text{ in}^3 \times .095 = .3686 \text{ lbs}$

Adding these values together yields a total mass for the easel face of 1.996 lbs. This weight is exerted down, off the end of the non-captive actuator. This will create a moment about the point of attachment two inches from the center (the non-captive actuator face is position 2 inches from the horizontal drive).

An important consideration is the weight of the canvas. Although the size of the canvas was mentioned in the dimensions section, the weight of the canvas has not been quantified. We will assume a maximum canvas weight of 10 lbs. Adding to the weight of the face of the easel gives a downward force of 12 lbs from the non-captive actuator.

Next, the actuator is positioned to move vertically, which will be fastened securely to sliders along the vertical columns “H” and “I” as previously mentioned. The non-captive actuator itself will have a weight around 2.5 lbs. Thus the forces here, acting along the vertical displacement collars of the easel will have a downward vector quantity of roughly 14.5 lbs. The dynamic equations for calculating the force exerted by the actuators will easily be accounted for by the optimal load capacities of the actuator.
Next, the pins along parts O1-O4 in figure 1, will contain shear and bearing stress from the weight of the carriage. Bearing stress is defined as: $\tau = \frac{F_{pin}}{td}$
Using a pin of diameter .25 inches, and thickness of the vertical columns as .5 inches, we can calculate the bearing stress once the force exerted down by the pin is estimated. Each vertical column has masses of .784 lbs. Considering the actuators weigh 2 pounds each, and the force on the collars was 14.5 lbs, the total weight acting down on these pins is 20.0 lbs (accounting for a 10 lb canvas). Dividing this weight into two pins results in an accurate estimation. The bearing stress of the pin is thus:

\[
\tau = \frac{10.0}{.25 \cdot .5} = 160.5 \text{ lbs/in}^2.
\]

Stainless steel pins will easily maintain this load.

Electrical System

The electrical system controlling the easel is a vital component in the overall functioning of the system. While it requires little mechanical design, the mechanism controlling current flow throughout the system must be efficient, practical, and reliable as it powers the actuators which are perhaps the most important modules in the design.

The easel itself will be powered by 120VAC which will be supplied from a standard wall socket. The ground terminal of from the socket will be attached to the aluminum frame of the easel to protect against any electrical shocks in the event of an accident. The 120V line from the socket will feed into a single pole single throw switch which will be mounted to the frame and serve as a master control for the easel. By turning the switch off, all current flow to the easel and its circuit is halted. The output leg of the switch and the neutral line of the socket will then be run into a transformer and the voltage will be stepped from 120VAC to 12VDC. The majority of the electrical system will run on the 12VDC power.

The actuators used in the system will run on 12 volts DC and at a full load will draw 3 amps. Because a maximum of two actuators can be run at any time the total current draw for the circuit should not exceed 6 amps. To protect against this, a fuse will be inserted into the +12 VDC leg from the transformer. Any circuit portion drawing more than 6 amps at any given time would indicate a malfunction with the unit. The +12VDC and ground legs from the transformer will then run to a number of locations. Eight relays will be used to control the current to the actuators. These relays will be double pole double throw and rated for 5 amps at 12V. The main terminal of each pole will be connected to +12VDC and ground respectively. The normally closed terminals will be left unwired, and the normally open terminals will be wired to the two legs of the actuator. Two relays are needed for each actuator; one to control extension and a second retraction. This is because the direction of the actuator is controlled by simply reversing the wire connections. Therefore each set of 2 relays will be wired oppositely.

The joysticks used to control the movement of the easel consist of a 4 directional handle and 4 separate momentary micro switches – one switch for each direction. Currently, the joysticks that are planned for use in the easel are Universal Microswitch Joysticks manufactured by Happ Controls. Because the switches are not capable of carrying the high 3amp load of the actuators, each switch will be connected to a 12 VDC supply. The output of each switch will be wired to one end of the coil on one of the relays. The second end of the relay coils will be connected in parallel to ground. As a result, when one of the joysticks is moved in a certain direction, the micro switch will be
activated. This will allow the 12VDC to power the coil in a particular relay. The relay mechanism will then engage the contacts on its poles and allow the actuator to be powered.

This design allows for more than one actuator to be active at a time by using the two joysticks. However, because of the mechanics of the joystick, only one direction of any actuator can ever be active at a time. A full circuit diagram can be found in Figure 10.

**Figure 10 Electrical Wiring Diagram**

![Electrical Wiring Diagram](image)

**Budget:**
Total = $750.00 allowed

- (3) Actuators .................. $99 ea.
- (3) Sliding Tracks ................. $25 ea.
- (2) Joysticks ..................... $15 ea.
- (8) Relays ....................... $70  Magnecraft General Purpose
Timeline:

A timeline for the project can be found attached to this report.

Conclusion:

Designing the most efficient electrically adjustable easel is a task that involves intricate evaluation of mechanical, material, and electrical principles of a device. After gathering a variety of information and doing a surplus of research, a well developed plan as to the fabrication and achievement of the easel has been derived. Specified dimensions, movements and safety features have all been incorporated and integrated within this design.
References

CMC Technical Support and Service Department:
7550 Hub Parkway
Cleveland, OH 44125 USA
(800) 321-8072 : Toll Free
(216) 642-5164 : Direct Dial
(216) 766-8480 : After Hours
(216) 642-5159 : Fax

9”actuator

Drawer Tracks
http://www.udb.cc/ProductType.aspx?product_type_id=113

Screw Drives
http://www.servostar.de/doku/neff/gt_katalog_e.pdf#search='Screw%20Drives'

Non-captive linear actuator
http://www.duffnorton.com/spiracon_rolaram.asp
http://www.motionshop.com/pr/HSI-8-Noncaptive.shtml

Joysticks
http://www.happcontrols.com/joysticks/joysticks_amusement.htm
 Static Analysis of Clamp Under Own Weight - Aluminum

\[ \rho_{Al} = 0.095 \text{ lb/in}^3 \]

\[ V_1 = (4)(1)(1) - (4)(0.75)(0.75) = 1.75 \text{ in}^3 \]

\[ V_2 = (17)(1)(1) - (17)(0.75)(0.75) = 7.44 \text{ in}^3 \]

\[ V = V_1 + V_2 = 9.19 \text{ in}^3 \]

\[ W = V \rho_{Al} = (9.19)(0.095) = 0.87 \text{ lb} \]

\[ Cc = (5, 1.25) \]

\[ \sum F_Y = 0 = F_A - W \]

\[ \sum F_X = 0 \]

\[ F_A = 0.87 \text{ lb} \]

\[ \sum M_A = 0 = -(0.87)(4.5) + M_A \]

\[ M_A = 3.92 \text{ lb - in} \]

\[ FBD 1 \]

\[ \frac{D}{d} = \frac{1}{0.75} = 1.33 \]

\[ \frac{r}{d} = \frac{0.125}{0.75} = 0.17 \]

\[ S_U = 10,000 \text{ psi} \]

\[ \sigma_{MAX} = \frac{10,000 \text{ psi}}{2.55} = 3921.57 \text{ psi} \]

\[ A = 0.1875 + 0.1875 = 0.375 \text{ in}^2 \]

\[ \sigma_W = 2.32 \text{ psi} \]

\[ N = \frac{3921.57}{2.32} = 1690.33 \]

\[ \text{Pin Through Hole} \]

\[ \tau_{PIN} = \frac{0.87 \text{ lb}}{2\pi(0.125)^2} = 8.86 \text{ psi} \]
**Static Analysis of Base - Aluminum**

\[ \rho_{Al} = 0.095 \text{ lb/in}^3 \]

V_1 = V_4 = (2)(2)(22) – (1.75)(1.75)(22) = 20.63 in³
V_2 = (2)(2)(24) – (1.75)(1.75)(24) = 22.50 in³
V_3 = (2)(2)(20) – (1.75)(1.75)(20) = 18.75 in³
V_B = 2V_1 + V_2 + V_3 = 82.51 in³

\[ W = \rho_{Al} V_B = (0.095)(82.51) = 7.84 \text{ lb} \]

**Stress Exerted on Table (Own Weight)**

\[ A = (2)(2)(24) + (2)(20) + (2)(24) = 184 \text{ in}^2 \]

\[ \sigma = \frac{7.84}{184} = 0.0426 \text{ psi} \]

**Approx. Stress Exerted on Table (Base + Carriage)**

\[ A = 184 \text{ in}^2 \]

\[ \sigma = \frac{7.84 + 15}{184} = 0.124 \text{ psi} \]

**Approx. Moment Exerted on Center of Mass of Base by Fully Extended Drawing Surface**

\[ Cc_x = 10 \]

\[ \sum M_{Cc_x} = -M_{Cc_y} + (15)(14) = 0 \]

\[ M_{Cc_x} = 210 \text{ lb - in} \]

**Approx. Moment Exerted on Center of Mass of Base by Misuse (Hanging off by 300lb User)**

\[ Cc_x = 10 \]

\[ \sum M_{Cc_x} = -M_{Cc_y} + (300)(18) = 0 \]

\[ M_{Cc_y} = 5400 \text{ lb - in} \]

\[ \sigma_B = \frac{Mc_x}{I} = \frac{(5400)(1)}{\frac{1}{12} \cdot 2^4} = 4050 \text{ psi} \]