SAN JOSE STATE UNIVERSITY

Mechanical and Aerospace Engineering Department

Design Project: Ink-B-Gone

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Course	**:**	**ME 106 – Fundamentals of Mechatronics**
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i. Abstract

The objective of this project was to fulfill the ME 154 and ME 106 project requirements. The requirements for ME 154 were to design a mechanism that had at least two degrees of freedom, that incorporated rotational and translational motion, and that would perform a meaningful task. Furthermore, the requirements for ME 106 were to use a microcontroller, at least one sensor, and at least one actuator to control a mechanism that solved a particular problem. To fulfill these requirements the group designed and built a prototype of a whiteboard ink-removing device. The prototype was tested for it functionality and its performance was evaluated in context of its marketability. In conclusion, the design was found to exceed project requirements and objectives but room for improvements were found to increase the device's marketability.

ii. Acknowledgements

We would sincerely like to thank the following people whose help contributed greatly to the outcome of this project.

- Stuart Davis for his donations and technical help
- Dr. Raymond K.Yee for his technical help
- Dr. Burford J. Furman for his technical help

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iv. Nomenclature

Symbol/Variable	Description
$\mathbf{R}_1$	Position vector along ground link (link 1)
$\mathbf{R}_2$	Position vector along crank (link 2)
$\mathbf{R}_3$	Position vector along coupler (link 3)
a	Length of crank
b	Length of coupler
d	Length of ground link
θ_1	Angle between link 1 and ground
θ_2	Angle between link 2 and ground
θ_3	Angle between link 3 and ground
ω_2	Angular velocity of link 2
ω_3	Angular velocity of link 3
$\dot{d}$	Linear velocity of the slider block
$\mathbf{V}_A$	Linear velocity vector of point A
$\mathbf{V}_B$	Linear velocity vector of point B
$\mathbf{V}_{AB}$	Linear velocity vector of A relative to B
$\mathbf{V}_{BA}$	Linear velocity vector of B relative to A
α_2	Angular acceleration of link 2
α_3	Angular acceleration of link 3
$\ddot{d}$	Linear acceleration of the slider block
A_A	Linear acceleration vector of point A
$\mathbf{A}_B$	Linear acceleration vector of point B
$\mathbf{A}^t_A$	Tangential component of linear acceleration vector of point A
$\mathbf{A}^t_B$	Tangential component of linear acceleration vector of point B
$\mathbf{A}^n_A$	Normal component of linear acceleration vector of point A
$\mathbf{A}^t_B$	Normal component of linear acceleration vector of point B
$\mathbf{A}_{BA}$	Linear acceleration vector of B relative to A

$\mathbf{A}^t_{BA}$	Tangential component of linear acceleration vector of B relative to A
$\mathbf{A}^n_{BA}$	Normal component of linear acceleration vector of B relative to A

1. Executive Summary

The objective of our project was to design a mechanism that will erase a whiteboard by the push of a button. The design should also be able to perform this function faster than if it were performed manually by a person. The chief benefit of our device will be its ability to save time and energy in the classroom.

To accomplish this task, our team went through many stages of brainstorming and planning. After various designs, we finally settled on what is essentially a four-bar slider-crank linkage system. We chose this particular mechanism because we had studied it in our ME154 (Mechanical Engineering Design) course earlier in the semester, and thus we saw this as a good opportunity to apply what we had learned. We then mounted this linkage system onto a horizontal printer carriage assembly. Our tem also incorporated concepts from our ME 106 (Fundamentals of Mechatronics) class. Three of the four members of our group, excluding Johan Altamirano, are concurrently taking ME 106 this semester. Using an assortment of components such as DC motors, a diode, MOSFET, H-bridge, resistor and opto-interrupters, we were able to program the mechanism's movements with the help of the Atmel Atmega 128 Microcontroller.

The prototype that we built of our design was scaled down for the purpose of this project. The completed prototype is pictured in Figure 1 below. Due to various constraints such as time, money and availability, we were unable to acquire some of the components we originally choose and we were forced to work with what we could find. Thus, we had to make amendments to our project in order to accommodate these factors. Nevertheless, this did not hold us back and we were ultimately able to make adequate adjustments to our project.

Figure 1: The completed prototype of the mechanical whiteboard eraser

2. Introduction

In the beginning of the semester, our group had many brainstorming sessions in order to generate ideas for our project. From a list of approximately 15 ideas, we narrowed it down and eventually settled on the most interesting, innovating and useful device. Our ideas covered a broad scope of topics, ranging a from relaxation device to foldable means of transportation. Finally, our team settled on a 'mechanical whiteboard eraser.' A drawing of the final design can be seen in Figure 2 below.

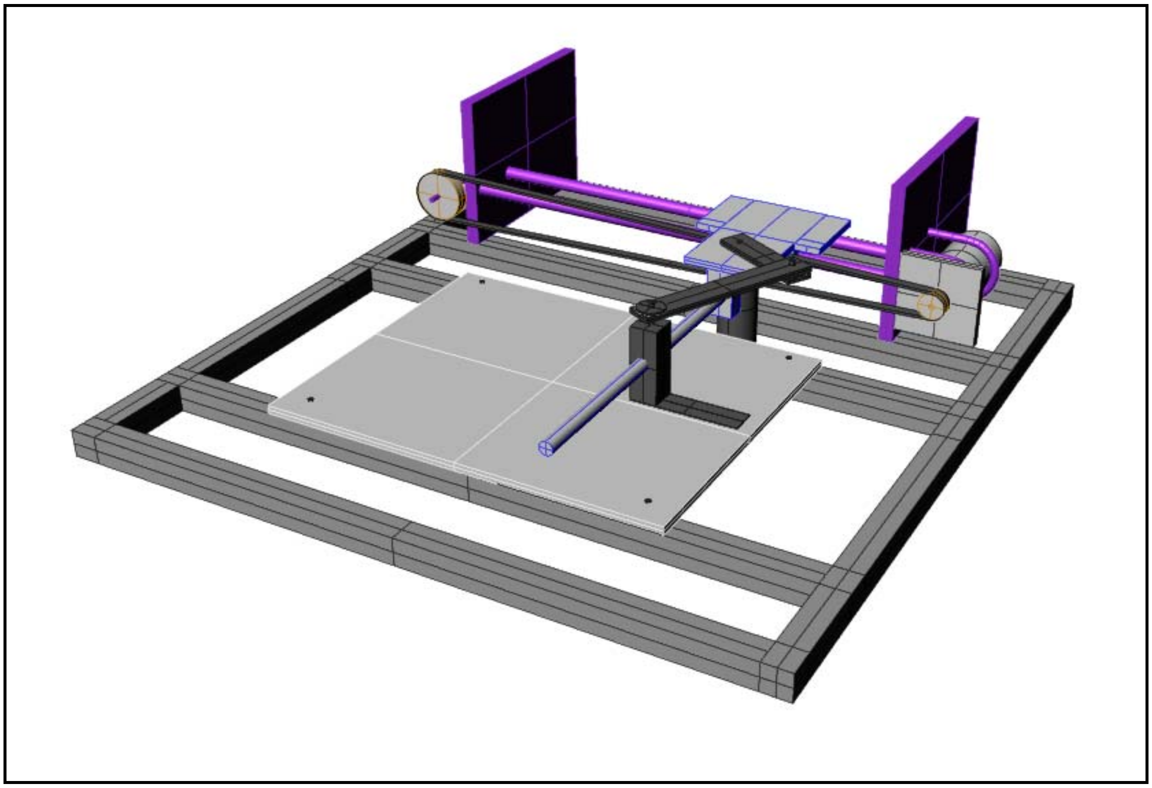

Figure 2: Perspective drawing of the design

We choose the white board eraser because it satisfied project requirements, it seemed like an marketable idea and it was a product that would be helpful to humanity. As students, the whiteboard is something we see very often in our classrooms. We realized that most times, it takes lecture time away from the teacher to erase the board. We believe this valuable time, and energy, could be put to better use. Furthermore, the background research we conducted brought us to the conclusion that no such device had been invented thus far, and this further underlined the need for us to instigate our idea. Designing this mechanical whiteboard eraser would also be our way of saying “Thank you” to all the teachers who have taught us – past, present, and future.

In hopes that the mechanical whiteboard eraser would be as successful of a project that we dreamt it to be, project constraints were specified, discussed and decided on. Aside from being able to perform a specific, meaningful and interesting task, the device was required to demonstrate various degrees of freedom, or mobility. The size of our prototype also needed to be limited. In addition, we wanted our mechanical whiteboard eraser device to be able to erase the whiteboard in the least amount of time possible. Our initial target was to have the design erase the entire board (a 24” x 48”, or 1152ft^2) within 25 seconds. We also chose to have the eraser equipped with the option of erasing certain specified sections of the board as apposed to erasing the entire board at once. In addition, we intended for the design to be as unobtrusive as possible to reduce the risk of someone getting hurt if they got in the way of the mechanism. Furthermore, since the unit was intended to be installed in classrooms, it would be best to keep the noise level down so that it would not distract the class. Therefore, another goal was to have the design be quiet, if not virtually silent. Our group also thought it would be best to have the unit bolted, or clamped, onto the wall so that the device would be stable and secure. However, the device should allow for easy removal in case the need for repair or maintenance arises. As for the power supply, we thought it would be best to have the unit powered via a 120 V wall socket so that the unit will not require frequent battery changes. Last, but not least, we wanted to keep the prototype cost below $200.

3. The Solution

3.1 Pre-fabrication Process: Brainstorming Ideas

To solve the problem, we researched various existing mechanisms that performed similar tasks in order to generate ideas. Included in the Appendix are some of our drawings from the brainstorming process. One of the initial concepts we considered was a windshield wiper. We looked at how windshield wipers work because they bear an analogous goal. We realized that a four-bar mechanism was involved. However, this was not an adequate solution to our problem since it was unable to clean the entire surface. Moreover, even if we modified it to do so, it would only be capable of cleaning the entire surface at one go. Hence, this failed to satisfy one of our performance specifications in which we intended for the eraser to erase the board in sections.

We also looked at telescoping arms and scissor-arm mechanisms, with the possibility of mounting this design on the board and having it expand and retract to move the eraser across the board. Unfortunately, this mechanism presented a series of complications as well as safety hazards. Initially, we had the mechanism mounted on one side of the board so that it would move along the horizontal axis. After realizing that this option had a high potential of someone getting hurt if they got a finger, or an arm, caught in the mechanism we then considered mounting the device on the top of the board. In this case, the arm would expand and retract along the vertical axis. However, although the safety risks involved were somewhat lower as compared to the side mounting technique, they were still too prominent to ignore. Thus, we decided to move on to other types of mechanisms.

Another option we came up with was to build a roller that would erase the board horizontally. This design would be mounted on the top and the bottom of the board and would be driven by two crank-slider mechanism attached to the top and bottom of the roller. There would also be tracks on the top and bottom of the board to guide the movement of the roller. The problem with this design was the awkward length of the links and the potential for the user to get hurt.

An alternative design was a swing arm that would have been mounted in the top corner of the board. The arm, attached with an eraser at the end, would have the ability to retract and fold completely in the stationary position and extend sufficiently to reach all necessary sections of the board. The retractable arm was supposed to return to the original position after the task was completed. This design was intended to either have a remote control to direct the arm where to erase. Alternatively, the design could use a series of automated motion and force sensors on the mechanism and around the board instead. Since this design would only be fastened at one point, we were initially concerned about how to maintain adequate pressure on the eraser and the board in order for the markings to be properly erased. We realized that the majority of whiteboards typically have a metallic layer which gives the board a magnetic property. Hence, we came up with the idea of using a magnet and toilet paper where the eraser was installed. However, considering the constraints surrounding this project, we realized that it would most likely be too expensive, delicate, and difficult to build at this point in time.

One more roller-like design was brought up that was rather similar to the first design. This mechanism was aimed to have only one motor mounted on the top of the roller and this would allow the eraser to move horizontally on top and bottom tracks. Moreover, this design also had to retract in a way that could only erase the programmed section of the board desired. This last task on the mechanism would be possible by some links at top and bottom. As a result, this design was discarded due to lack of means to retract the roller and erase desired sections.

3.2 The Selected Solution

Eventually we arrived at the idea of using a four-bar slider-crank mechanism, shown in Figures 3 to 5 below, which would translate across the board. Hence, we were able to fulfill our preliminary specifications, including being able to erase the entire board as well as be able to erase in sections.

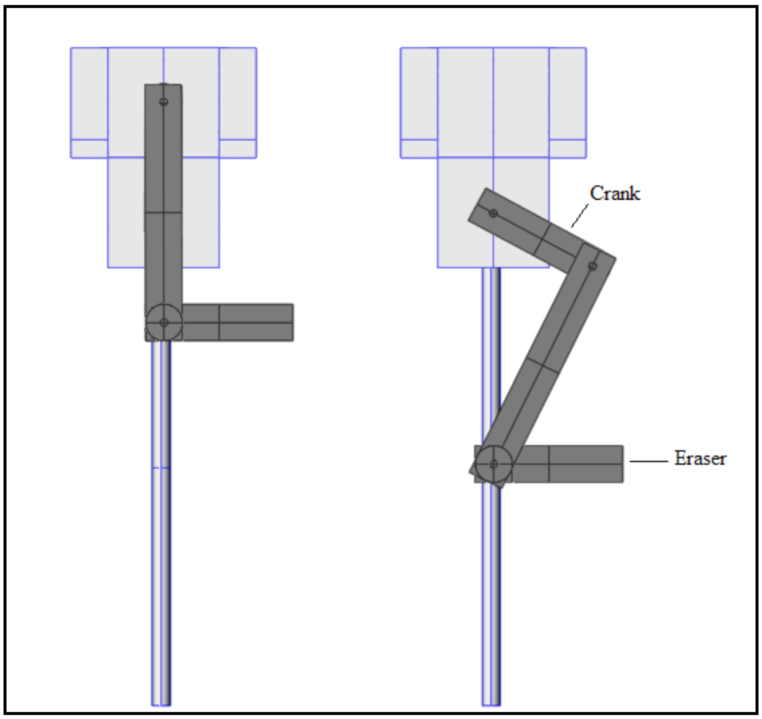

Figure 3: Front view of the four-bar slider-crank mechanism. The drawing on the left represents the four-bar in its initial position, and the figure on the right illustrates the four-bar as the slider moves along the vertical rod.

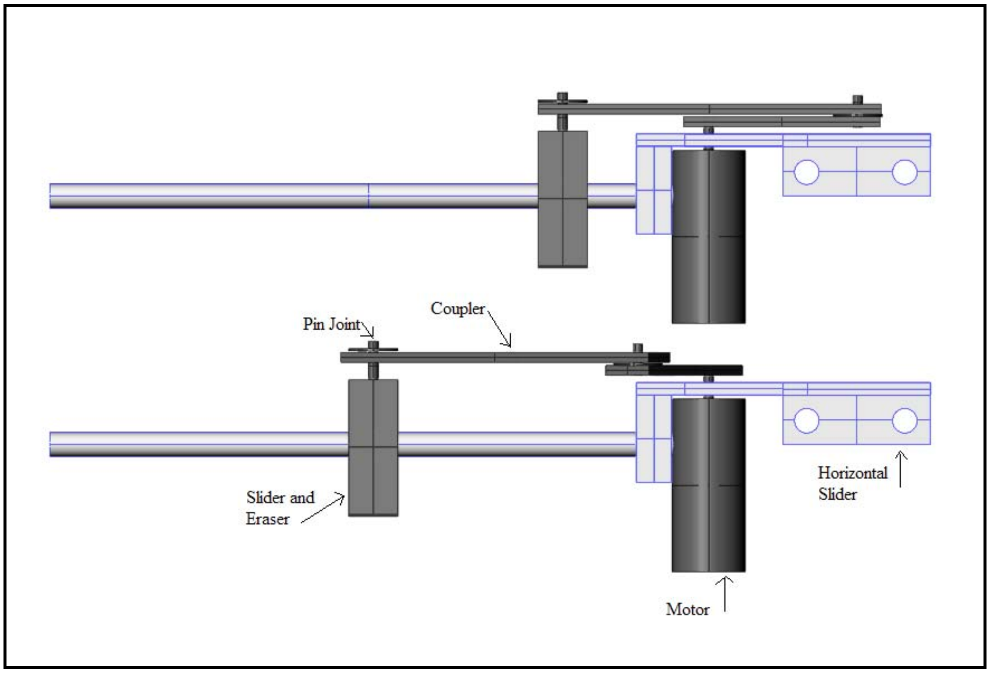

Figure 4: Side view of the four-bar slider-crank mechanism at two different positions

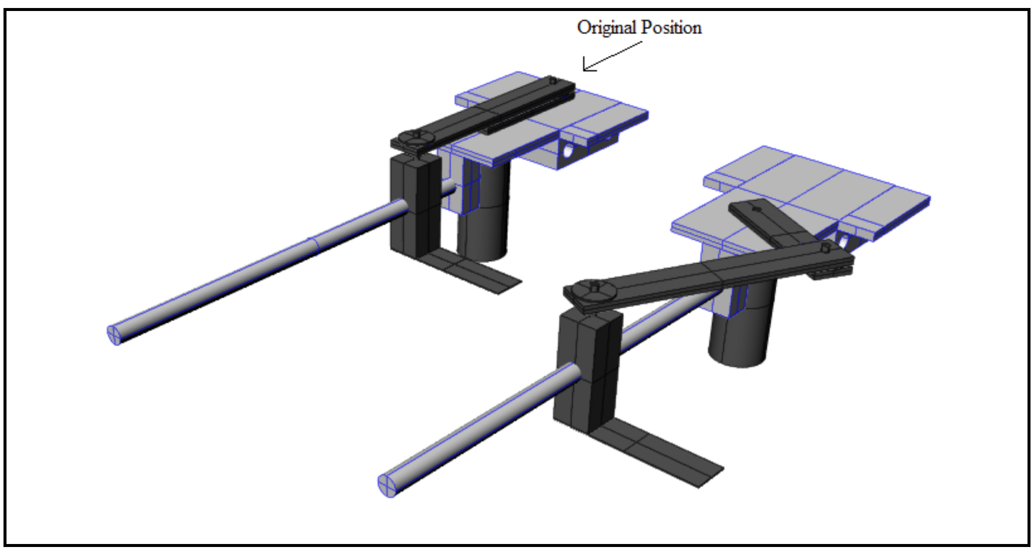

Figure 5: Perspective view of the four-bar slider-crank mechanism at two different positions

Our first approach to achieving translational motion was by the way of a lead screw. However, we could not find any affordable lead screws that were long enough to be used in the construction of our prototype. For instance, one of the supply stores we visited, Triangular Machinery, had a 4ft lead screw, which was priced at over $100. Therefore, we brainstormed for more ideas and finally decided to implement a pulley mechanism, removed from a printer. A drawing of the printer carriage component can be seen in Figures 6 and 7 below.

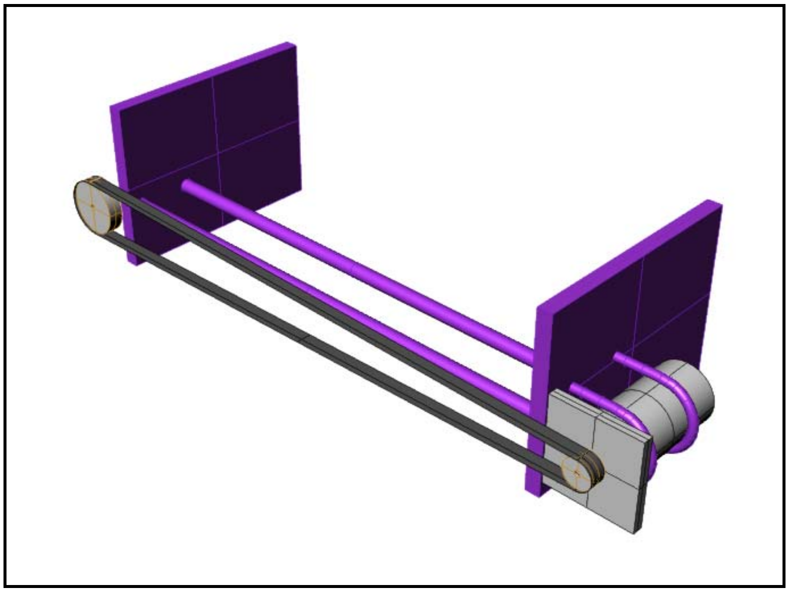

Figure 6: Perspective view of the printer carriage mechanism

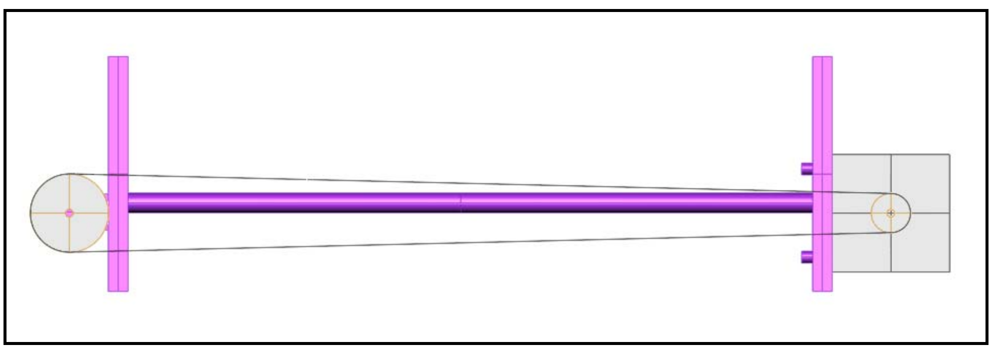

Figure 7: Front view of the printer carriage mechanism, showing the belt and pulleys

Our final design therefore involved two main systems, the four bar crank slider and the printer carriage mechanism. The slider of the four-bar slider-crank mechanism would translate along a vertical cylindrical rod. By attaching the magnetic toilet paper eraser to the slider, the eraser would move vertically, up and down, thereby erasing the whiteboard. As can be seen in Figure 8 below, a motor would actuate the four-bar's crank and consequently move the eraser up and down the vertical axis of the board.

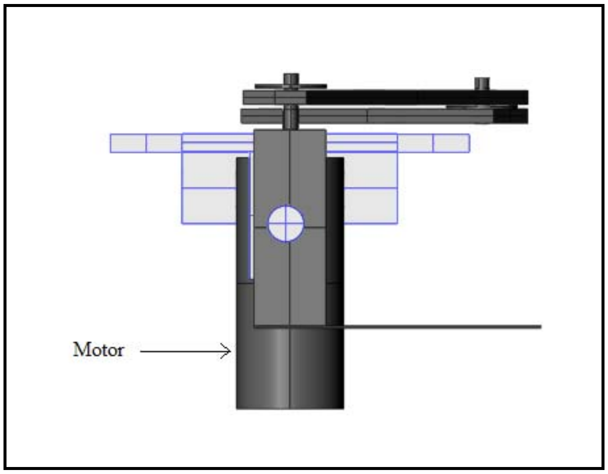

Figure 8: DC motor which for the crank on the four-bar mechanism

The entire four bar mechanism, including motor, would be fastened the printer carriage in order to achieve translational motion. The motor attached to one end of the printer carriage mechanism would cause the pulleys to spin the belt, resulting in a horizontal motion of the eraser to specified sections of the board. This motor is pictured in Figure 9 and 10.

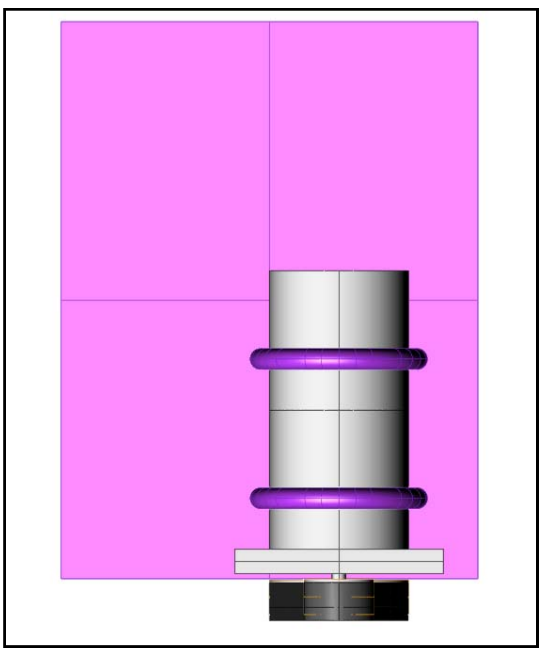

Figure 9: DC motor for the printer carriage mechanism

Figure 10: Photograph showing the placement of the printer carriage DC motor in relation to the rest of the prototype

The translational motion achieved by adding the printer carriage improved the functionality of our device, because not only was the eraser now able to cover more areas of the board, it was also equipped with the flexibility to erase sections selectively. In our prototype, pictured in Figure 10 above, the board was divided into two sections to demonstrate this function. There would also be horizontal rods for the mechanism to slide along to guide the mechanism and improve stability. Furthermore, the magnetic eraser was incorporated into the prototype in order to maintain a constant pressure between the eraser and the board.

In conclusion, the four-bar slider crank design was decided upon because it allowed us to fulfill the ME154 aspect of the project and used a relatively simple design, one that would actually be able to be built given the groups lack of machining experience. As of now no one in our group has taken ME110 or any other machining class. Furthermore, we chose to include acuators, sensors, an H-bridge, a MOSFET, and a microcontroller in our design to enhance the functionality as well as to fulfill the ME106 course requirements. The microcontroller will allow us to incorporate user interfacing into our design – meaning a person will be able to control the device easily with a button. Figures 11 to 13, below, show drawings of the Ink-B-Gone prototype from various angles.

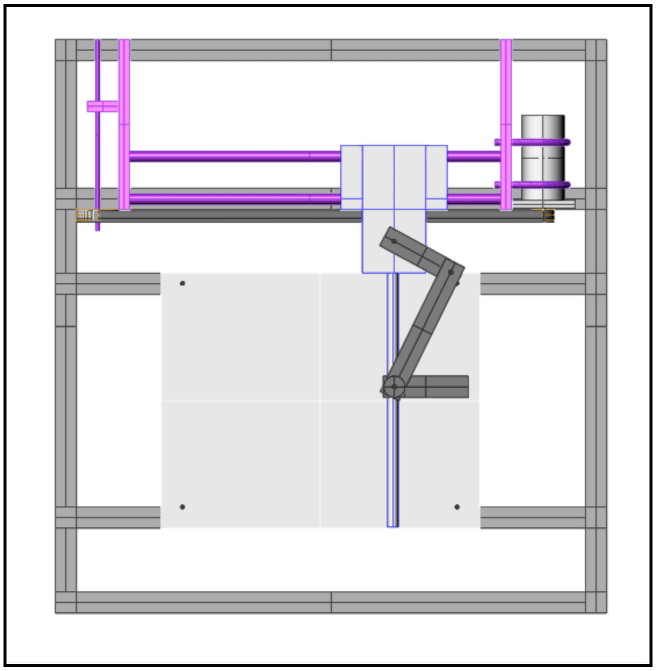

Figure 11: Front view drawing

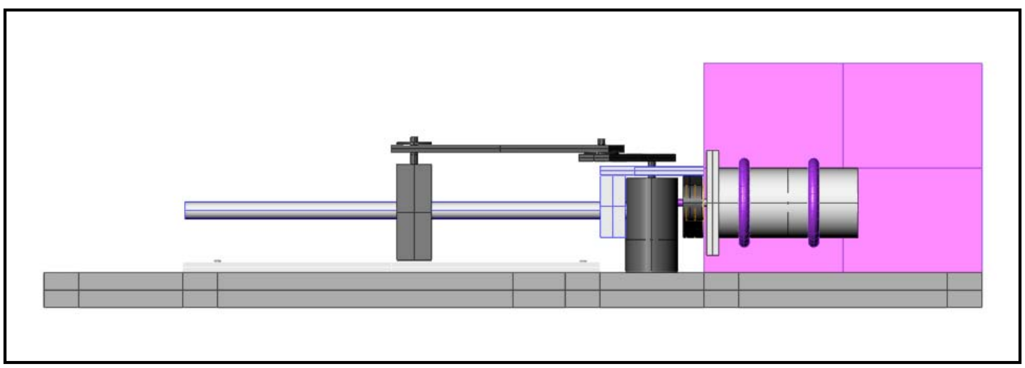

Figure 12: Side view drawing

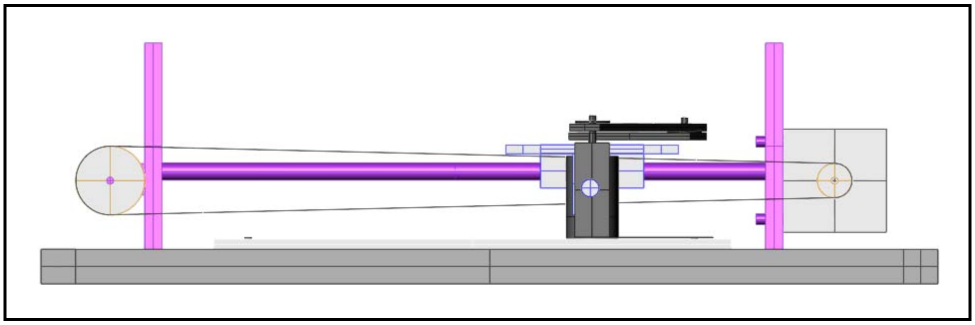

Figure 13: Bottom view drawing

3.3 Materials, Gathering Parts, Fabricating, and Assembling

The final design incorporated aluminum framing, a salvaged printer carriage mechanism, a personal whiteboard, a custom-made aluminum four-bar slider-crank mechanism, a solder less breadboard, an Atmega Atmel 128 microcontroller, two DC motors, one MOSFET, one H-bridge, three 1K resistors, one diode, and three opto-interrupt sensors. Nuts, bolts, screws, "C" clamps, Velcro, and zip-ties were used as fasteners.

The first step in building the mechanism was acquiring the parts, listed above. The SJSU Equipment Technician, Stuart Davis, donated most of the parts except for the microcontroller, aluminum stand framing, and the slider rod portion of the four-bar slider-crank mechanism. The microcontroller was borrowed from Dr. Furman ($40 deposited). The slider rod and clamps were purchased from Triangle Machinery ($10), whereas the aluminum stand framing and "C" clamps were purchased from Orchard Supply Hardware ($30). After acquiring these materials, we were ready to begin the building process of our designed project.

The next steps in constructing the mechanism included fabrication and assembly. The building of the project took many hours of milling, drilling, cutting, tapping, threading, bending, soldering, crimping and wiring. The mechanism was assembled as follows:

1) The printer carriage was bolted to the aluminum frame.
2) The aluminum “crank bracket” that holds the DC crank motor and slider shaft was fabricated.
3) The crank motor and slider rod was bolted to “crank bracket”.
4) The whiteboard was bolted to the aluminum frame.
5) The four-bar crank mechanism was fabricated, assembled, and mounted to the DC crank motor and crank arm (crank arm, coupler arm, slider block, linear ball bearing, and pin joints).
6) The aluminum stand was built and attached to the frame.
7) The original printer carriage DC motor was replaced with a geared down DC motor.
8) The sheet metal backing was cut and mounted to the framing.
9) The microcontroller was attached to the metal backing with Velcro, and the breadboard was screwed into the sheet mettle backing.
10) 1KΩ resistors were connected and soldered to the opto-interrupt sensors.
11) The sensor flags and mounts were fabricated and installed onto the crank bracket and printer carriage frame, respectively.
12) The sensors were zip tied into location.
13) The MOSFET, diode, and H-bridge were wired to the sensors, motors, and microcontroller as can be seen in various figures on the following pages.
14) Lastly, the magnetic eraser was attached to the end of the slider block with Velcro.

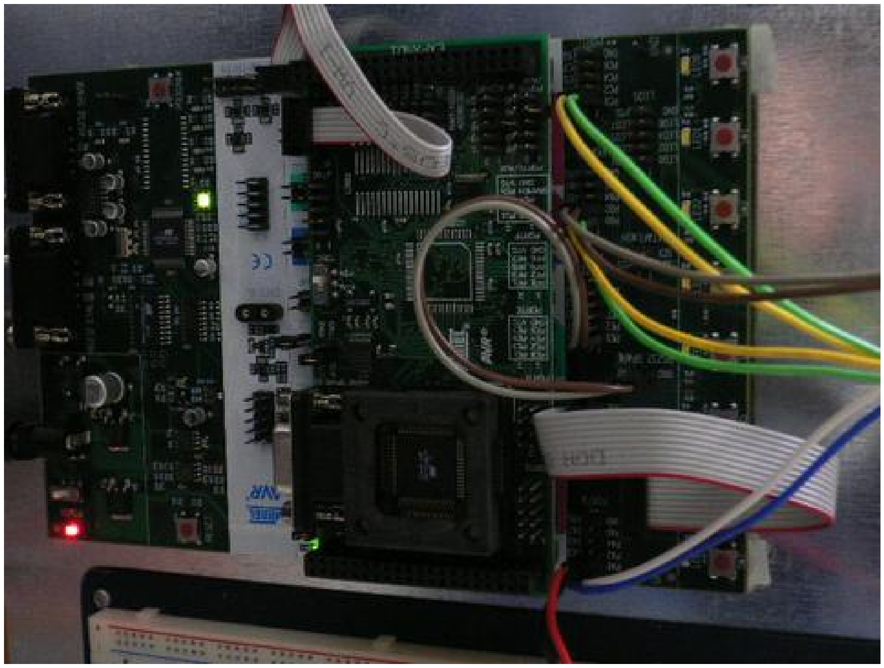

Figure 14: The Atmega Atmel 128 microcontroller

The Atmega 128 microcontroller is pictured in Figure 14 above. As can be seen in Figure 15 and 16 below, the microcontroller was wired to a MOSFET and DC motor in order to allow the microcontroller to turn the motor on and off.

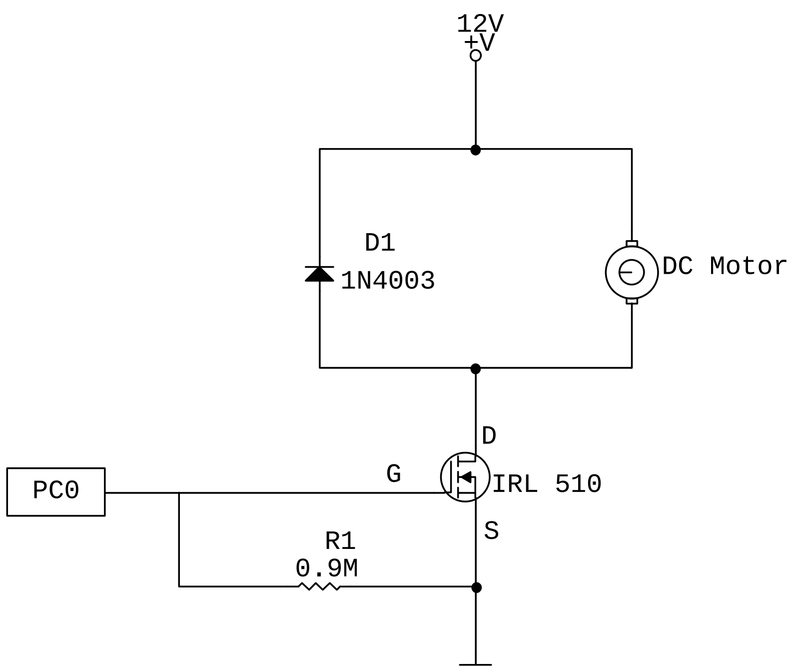

Figure 15: DC Motor Driver Circuit. The circuit uses an IRL 510 power MOSFET

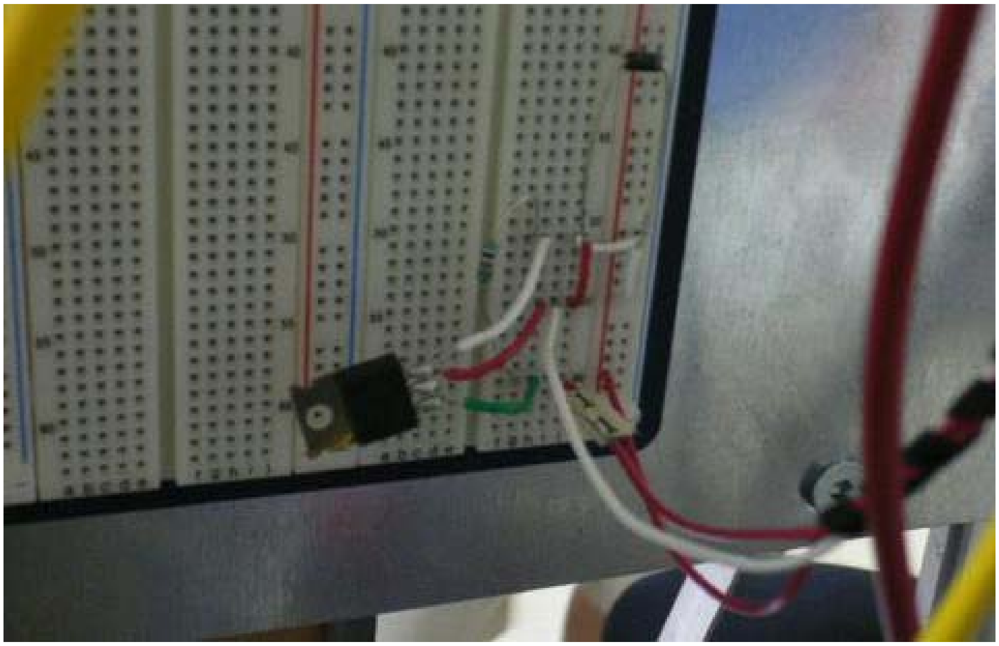

Figure 16: Photograph of the DC motor driver circuit

Furthermore, the diode was wired in parallel to the motor to keep back emf from ruining the circuit components. This particular motor only needed to be turned off and on, thus a MOSFET is all that was needed. In contrast, the printer carriage motor needed to be ran in forward and reverse. Therefore, an H-bridge was incorporated into the printer carriage motor's circuit. The printer carriage motor's circuit can be seen in Figure 17 and 18 below. The H-bridge was wired to the microcontroller and the motor. Pin 16 was found to power the chip. Pin 1 enabled the inputs (pin 2 and pin7) and the outputs (pin 3 and pin 6). The applied motor voltage was applied to Pin 8.

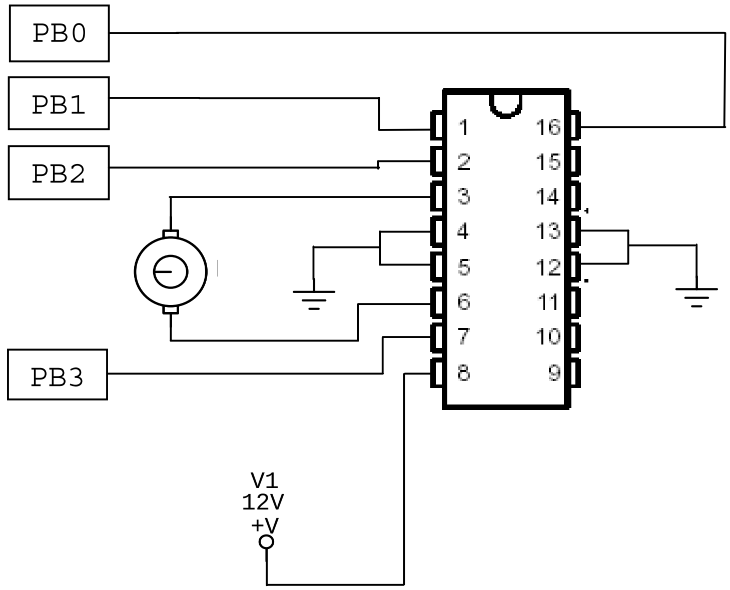

Figure 17: The printer carriage motor circuit using the H-bridge

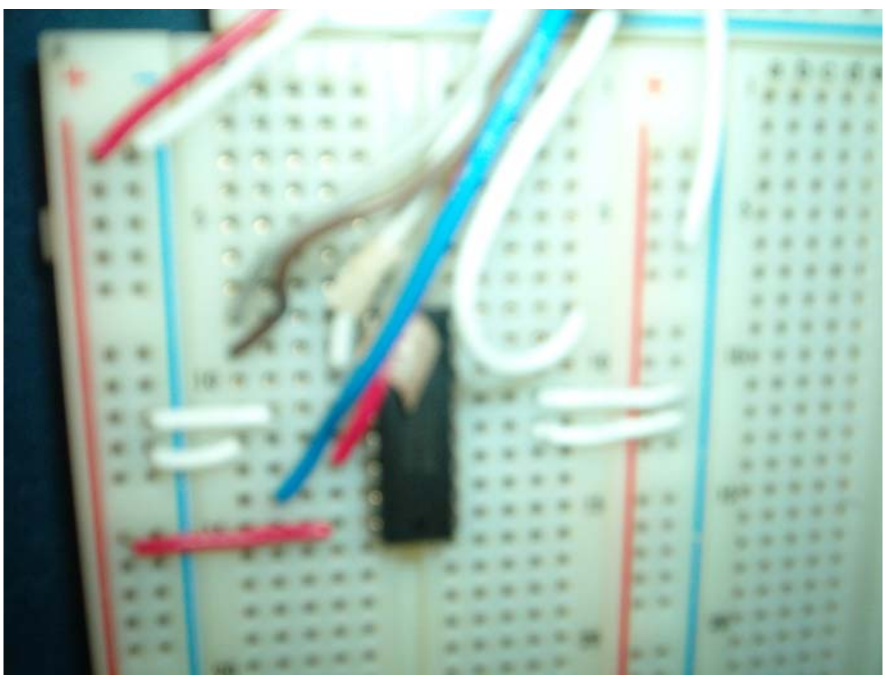

Figure 18: Photograph of printer carriage motor circuit

Figure 19 shows the schematics of the opto-interrupt switches. These switched were wired to the microcontroller pins. For our prototype, we utilized the SX460-P9 opto-interrupters manufactured by Omron.

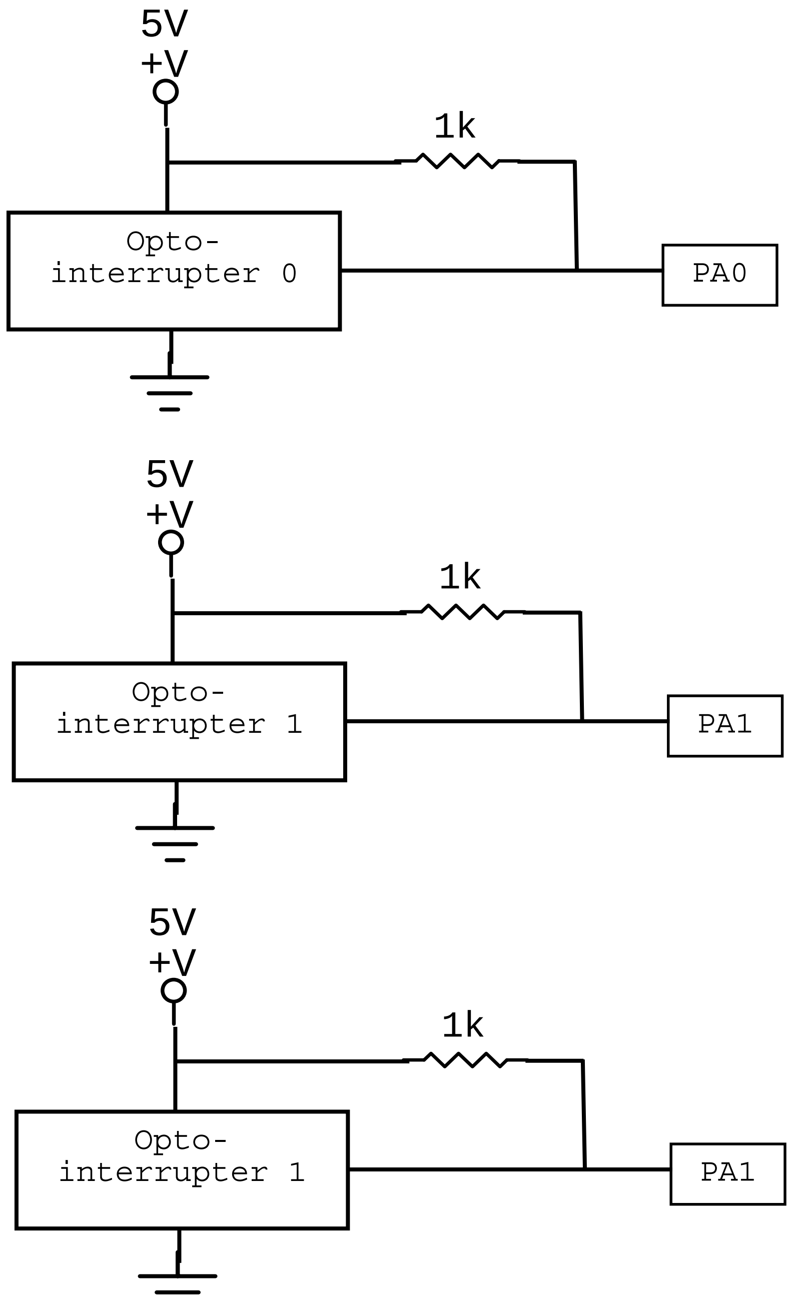

Figure 19: Opto-interrupter switch circuits.

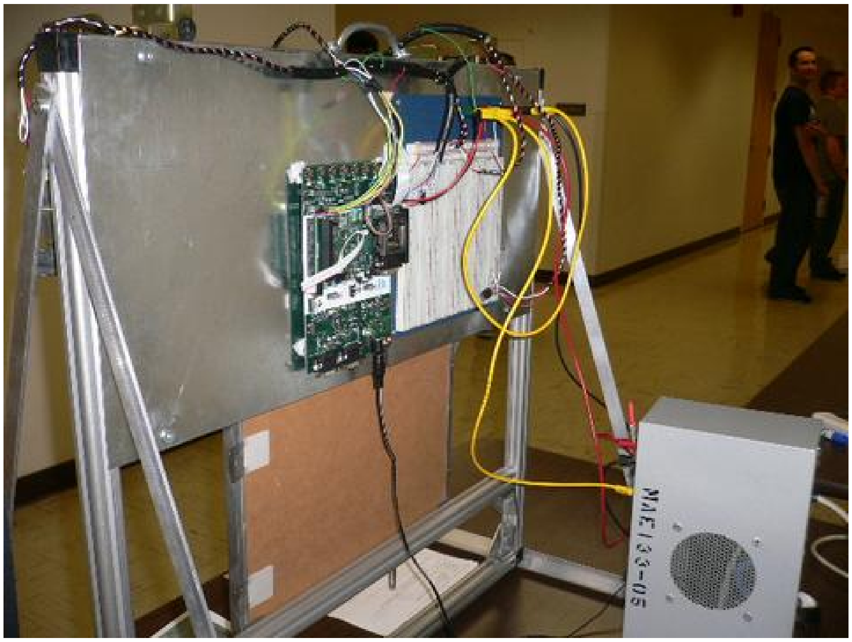

Figure 20: Photograph of rear view

As can be seen in Figure 20 above, the microcontroller and the breadboard were installed onto the back of the prototype. We decided that installing them at the back would be the most practical option because it would be neater and hidden from the front view (pictured in Figure 21).

Figure 21: Photograph of front view

The simple breakdown of the entire circuit can be seen in the system block diagram in Figure 22 below.

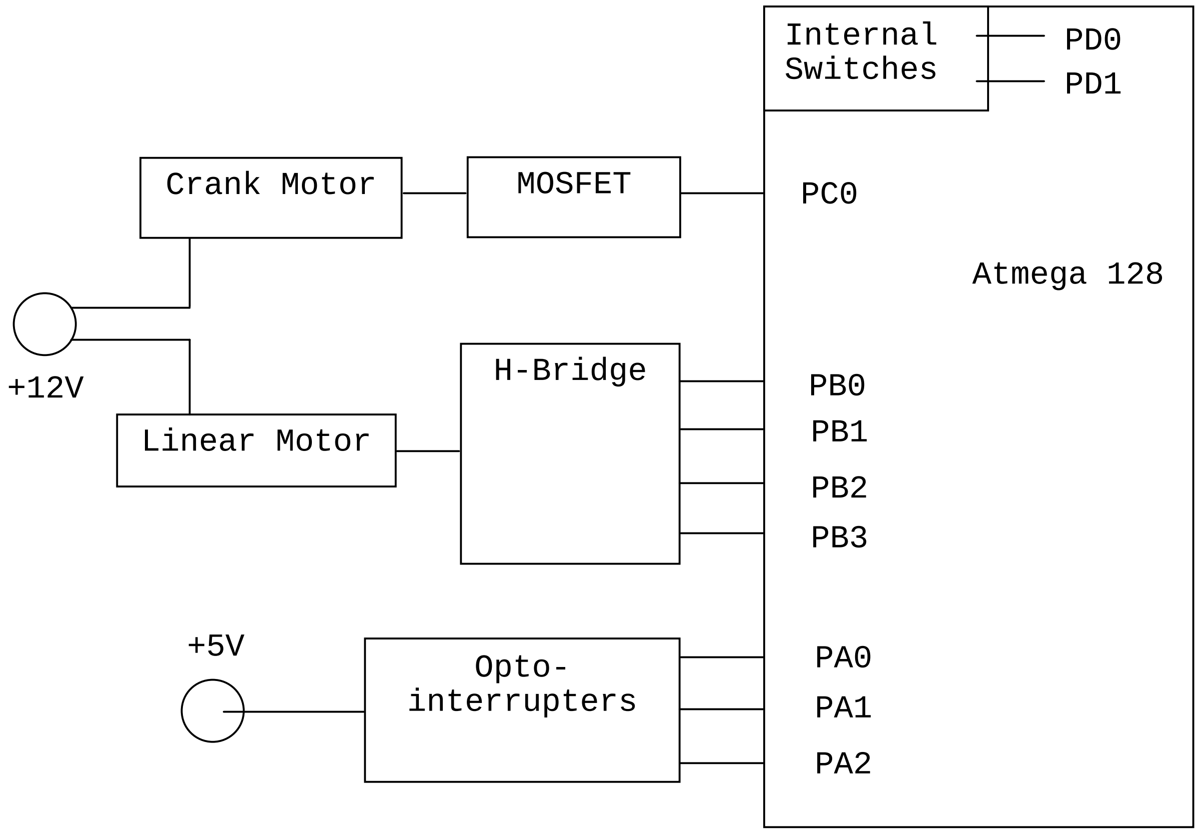

Figure 22: System Block Diagram

The flowchart below outlines how the design and software operate. As can be seen in the Figure 23 below, the program runs a single ‘while’ statement that continually checks the state of input ports A and D.

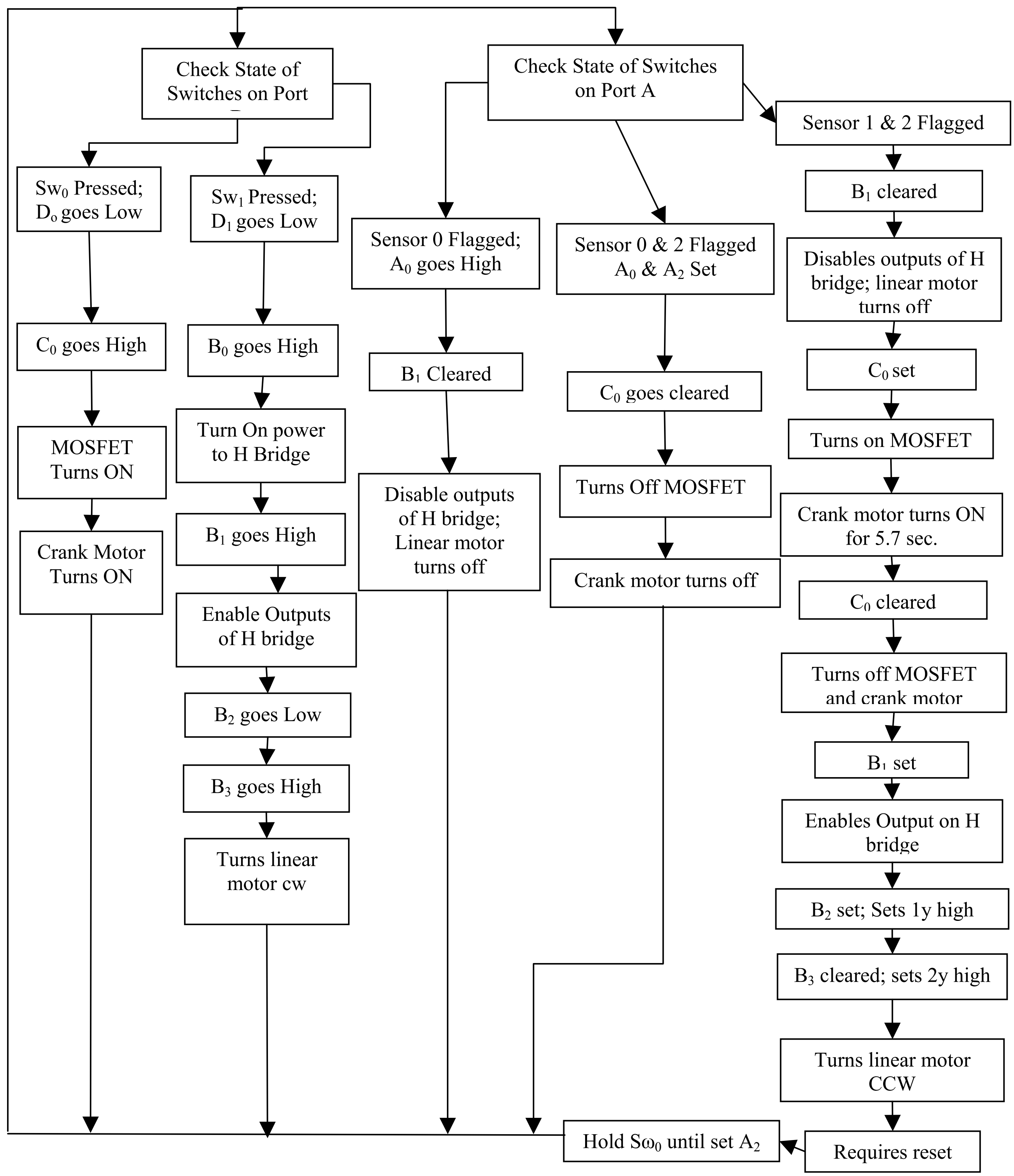

Figure 23. Flow chart of design and program

4. Analysis and Performance Results

In order to determine the maximum force being applied to the pin at point A, position, velocity, acceleration and force analysis was conducted. The equations used in our analysis were found in Design of Machinery by Robert L. Norton and applied using the Engineering Equation Solver (EES) software. The diagram in Figure 24 below shows the four-bar slider-crank mechanism excerpted from Design of Machinery. However, we would like to point out that in our design, the offset, c, is zero and the analysis was done when θ_2 is 180°.

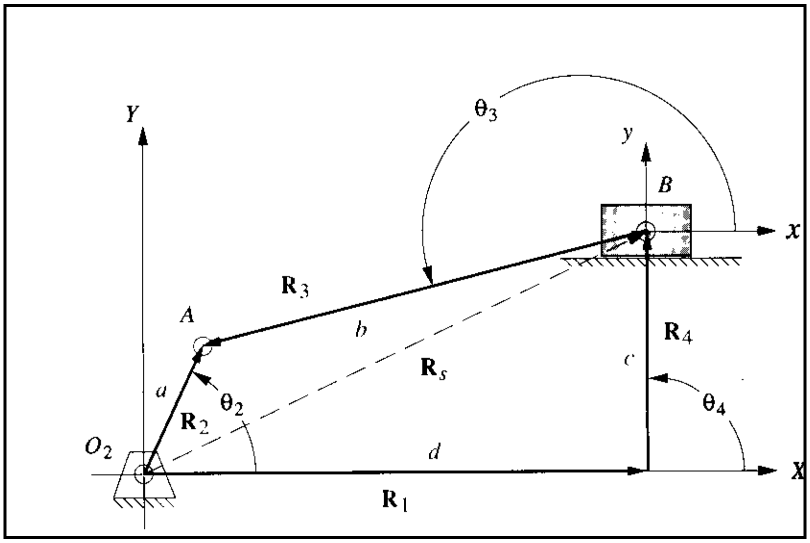

Figure 24: Diagram of the four-bar slider-block mechanism

Position, Velocity, Acceleration and Force Analysis

"All calculations done at 180 degrees where there is max torque"

Position Calculations

a = 3.75 [in] "Crank length"
b = 6.75 [in] "Coupler length"
c = 0 [in] "Offset"
d=(a*COS(theta_2))-(b*COS(theta_3)) "Ground"
theta_2=PI "Angle between Ground and Crank"
theta_3=PI+ARCSIN((- (a*SIN(theta_2)-c) /b)) "Angle between Slider and Coupler"

Velocity Calculations

omega_2=((2*PI)/5.5[sec])
omega_3= ((a*COS(theta_2)*omega_2))/(b*COS(theta_3))

```
d_dot=(-a*omega_2*SIN(theta_2))+(b*omega_3*SIN(theta_3))
"!Acceleration Calculations"
alpha_2=(omega_2)/(10E-1[sec])                "7E-1 was an assumed value
of time required to start the motor iterations are performed to approximate
real value"
alpha_3=(   (a*alpha_2*COS(theta_2))  -(a*( (omega_2)^2)*SIN(theta_2)
)+(b*(  (omega_3)^2)*SIN(theta_3) )   )/(-b*COS(theta_3))
d_dot_dot=(-a*(alpha_2)*SIN(theta_2))-
(a*((omega_2)^2)*COS(theta_2))+(b*alpha_3*SIN(theta_3))+(b*((omega
_3)^2)*COS(theta_3))
```

Force Calculations

```
w_crank=2.25[oz]
m_crank=2.25[oz]/(386[in/(sec^2)])
w_coupler=3.5[oz]
m_coupler=3.5[oz]/(386[in/(sec^2)])
w_block=5.5[oz]
m_block=5.5[oz]/(386[in/(sec^2)])
w_mount=7.25[oz]
m_mount=7.25[oz]/(386[in/(sec^2)])
w_motor=16[oz]
m_motor=16[oz]/(386[in/(sec^2)])
width=(7/8)[in]

"link2"
a_t_2=alpha_2*(a/2)
a_r_2=((omega_2)^2)*(a/2)
a_G_2=SQRT(((a_r_2)^2)+((a_t_2)^2))
phi_2=ARCTAN((-a_t_2)/(a_r_2))
a_G_2x=a_G_2*COS(phi_2)
a_G_2y=-a_G_2*SIN(phi_2)
I_2=((m_crank*(   (a^2)+(width^2)   ))/12)+(m_crank*((a/2)^2))

"link3"
a_t_3=alpha_2*(b/2)
a_r_3=((omega_2)^2)*(b/2)
a_G_3=SQRT(((a_r_3)^2)+((a_t_3)^2))
phi_3=ARCTAN((-a_t_3)/(a_r_3))
a_G_3x=a_G_3*COS(phi_3)
a_G_3y=-a_G_3*SIN(phi_3)
I_3=((m_coupler*(   (b^2)+(width^2)   ))/12)+(m_coupler*((b/2)^2))


F_32yI=(I_3*alpha_3)/(b/2)
F_32ym=(m_coupler)*a_G_3y
```

Solutions:

Variables in Main
a=3.75 [in]
alpha_2=1.142 [1/sec^2]
alpha_3=-0.6347 [1/sec^2]
a_G_2=3.252 [in/sec^2]
a_G_2x=2.447 [in/sec^2]
a_G_2y=2.142 [in/sec^2]
a_G_3=5.854 [in/sec^2]
a_G_3x=4.405 [in/sec^2]
a_G_3y=3.856 [in/sec^2]
a_r_2=2.447 [in/sec^2]
a_r_3=4.405 [in/sec^2]
a_t_2=2.142 [in/sec^2]
a_t_3=3.856 [in/sec^2]
b=6.75 [in]
c=0 [in]
d=3 [in]
d_dot=-4.921E-13 [in/sec]
d_dot_dot=2.175 [in/sec^2]
F_32yI=-0.02601 [oz]
F_32ym=0.03496 [oz]
I_2=0.0277 [oz-sec^2-in]
I_3=0.1383 [oz-sec^2-in]
m_block=0.01425 [oz-sec^2/in]
m_coupler=0.009067 [oz-sec^2/in]
m_crank=0.005829 [oz-sec^2/in]
m_motor=0.04145 [oz-sec^2/in]
m_mount=0.01878 [oz-sec^2/in]
omega_2=1.142 [1/sec]
omega_3=0.6347 [1/sec]
phi_2=-0.719 [rad]
phi_3=-0.719 [rad]
theta_2=3.142 [rad]
theta_3=3.142 [-]
width=0.875 [in]
w_block=5.5 [oz]
w_coupler=3.5 [oz]
w_crank=2.25 [oz]
w_motor=16 [oz]
w_mount=7.25 [oz]

The ‘tear out stress’ of pin A was calculated by translating the maximum peak torque of the Pittman crank motor, as stated in the data sheet, to a force applied to pin A.

The tear out force was found to be less than the yield stess of the aluminum, thus the prototype is not expected to fail, even if maximum torque is applied.

In order to size the Pitman crank motor the continuous torque of the motor was looked up in the data sheet, was also compared to the torque that was calculated using Newton's laws when θ_2 was set to 90 degrees and the velocity was constant. This angle was chosen because it caused the highest torque applied, after the initial acceleration to the crank's constant velocity. These calculations can be found in the appendix.

In order to size the linear crank motor the torque needed to accelerate the carrage to constant velocity was calculated with equations found in the appendix as well. The torque was noted.

One of the requirements from ME154 was to have the device demonstrate various degrees of freedom, and have rotational as well as translational motion. The mobility for our four-bar slider-crank mechanism can be algebraically determined using Kutzbach's equation:

Number of links, L	= 4
Number of full joints, J_1	= 3
Number of half joints, J_2	= 0

Using the Kutzbach equation,

$$
\begin{aligned}
\text{Mobility, M} &= 3(L - 1) - 2J_1 - J_2 \\
&= 3(4 - 1) - 2(3) - 0 \\
&= 3(3) - 2(3) \\
&= 6 - 5 \\
&= 1
\end{aligned}
$$

5. Discussion

5.1 Outcome and Performance

After going through the design and fabrication process, we ran and tested the prototype in order to evaluate its outcome and performance. We also compared the results to our initial design specifications. Furthermore, recommendations were made in order to make the product more marketable.

From the Kutzbach's equation we found that our four-bar slider-crank has one degree of freedom. This was expected because the actual device only has one input from the motor that is actuating the crank. Similarly, we have one motor controlling the printer carriage and this provides that mechanism with one degree of freedom as well. This leaves the entire mechanism with a mobility of two, and uses translational as well as rotational motion. This fulfills the requirement of the device having various degrees of freedom with translation as well as rotational motion.

The scale of the white board eraser was changed during the fabrication process. Initially, we wanted to use a 24" by 48" board, but we realized that this would be unsuitable for our prototype because the size was far too large. Not only would it be difficult to transport the prototype around to work on, it would also increase the cost of the project by increasing the scale of the project. Hence, we choose a smaller whiteboard, measuring only 11" by 14". Although we were slightly concerned at first with not being able to properly demonstrate the machine's capabilities with this smaller board. it turned out that this was an ideal size to showcase the potential of our device. Hence, we were able to fabricate the prototype while successfully limiting its size as for our design specifications.

An important issue in our design was the time it would take to erase the board, especially since one of our objectives was to have the device erase the board as quickly as possible. We aimed for the 24" by 48" board to be completely erased within 25 seconds. In other words, we wanted to erase a 1152 in^2 area in 25 seconds, or a 46.08 in^2 area per second. As far as our prototype is concerned, it erases an area of approximately 72.5 in^2 area, as shown in Figure 4 below.

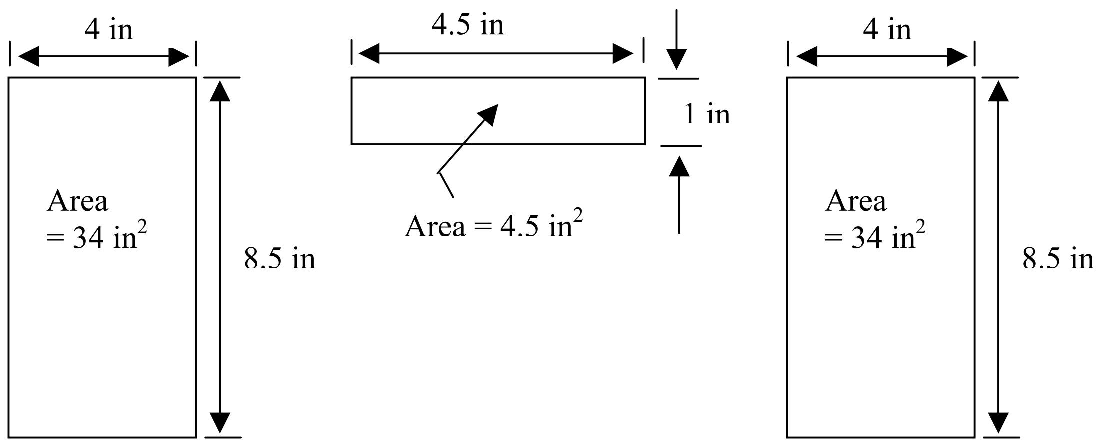

Figure 4: Areas of the prototype board to be erased

From the results of our tests, we found that the eraser takes 5.5 seconds to erase a 34 in^2 area, or one section of the board, and another 2 seconds to travel once along the horizontal printer system. That would give us a total time of approximately 15 seconds to erase the board. Hence, our prototype is only able to erase 4.83in^2 per second. Unfortunately, this means we did not achieve out original goal of erasing a 46.08 in^2 area per second. This is due to several reasons. For starters, we were forced to size down the motor actuating the pulley system because the original printer carriage motor was old and tired. We decided to proceed with this second motor because of the lack of time and resources to acquire another motor. Additionally, our prototype only utilizes a 1" by 4" magnetic eraser. Had we used a larger eraser, we would have been able to cover a larger area of the board per revolution of the crank and translation of the pulley belt. However, this might have compromised on the efficiency of the device because we would not have been able to divide the board into 3 sections. Furthermore, a larger surface area of Velcro would be needed counteract the added frictional force.

As previously mentioned, we wanted to have the option of erasing certain sections of the board as needed and desired. Our team managed to achieve this function with the help of the opto-interrupters and microcontroller, enabling us to basically divide the board into 3 sections. However, our prototype erases the right and left sections of the board only, and this was done deliberately. We would like to point out that we could have programmed the board to erase the entire middle section as well by installing another opto-interrupter, but we decided that setting it up this way was sufficient to demonstrate the behavior of the mechanism.

Another requirement was to have the device run quietly. We managed to fulfill this criteria successfully. Therefore, if we proceeded with marketing this device in the future, it would be unlikely that this factor would be an issue.

Furthermore, we intended for our machine to be clamped onto a wall. However, as far as our prototype is concerned, we needed it to be portable in order to work on the fabrication as well as be able to perform our class presentations. Therefore we improvised and mounted the device onto an aluminum stand frame instead, which provided the stability we needed for the prototype. If the product were to be marketed a mounting plate and printer carriage mechanism would need to be fabricated.

Unfortunately, we were unable to meet one significant design specification to have a built-in power supply. To do this, we would need to implement AC to DC conversion step the 120V to 12volts to run the motors and microcontroller, as well as to 5V to run the sensors. We did not have sufficient time to incorporate this into our prototype so we had to use an external power supply.

Considering the $200 budget we had originally set for the project, we successfully kept the cost down to a minimum. In total, we only spent approximately $40 on the fabrication, in addition to another $40 to rent the microcontroller from Dr. Furman. If Stuart Davis would not have donated what he did we estimate the project to exceed the 200-dollar budget.

In general, judging by how much the end result met up to our initial design specifications, we believe that our prototype performed exceptionally well and thus our team considers the design and fabrication to be successful.

5.2 Recommendations and Future Enhancements

While we were able to achieve almost all of our design specifications, as aspiring engineers we know that there is always more room for improvement. This section of the report outlines the avenues we could have pursued in terms of improvement had we had more time, funding, and equipment.

Firstly, we would like to incorporate our design with a built-in power supply. Currently, the prototype of Ink-B-Gone uses an external power supply which is rather bulky. However, having a built-in power supply will enable us to plug our machine directly into a 120V wall socket. This would make the design neater as well as more convenient to use.

Another way with which we hope to enhance our design is by including more sensors. The first idea is to have sensors to help locate any ink markings left behind on the board. The eraser would move towards these markings and erase them automatically even after it has already gone over the section. This will help to make sure that the board is sufficiently cleaned. Furthermore, we would also like to include motion sensors to detect presence in a room. If the sensors doesn't pick up motion in the room after a specified amount of time, the entire whiteboard will be erased to avoid ink from being left for too long and staining the board.

Additionally, we would like to improve on the aesthetics of our design by including covers to encase certain parts of the mechanism, such as the printer carriage area and circuitry (minus the input buttons). This would make the machine appear a lot neater and it would also help to protect the components from external damage.

Having the casings would also help reduce the safety hazard level of our design.

Another factor to improve in the design is to increase the area per second that the prototype erases. This can be achieved by using more powerful motors and by increasing the size of the links to handle the added torque.

6. Conclusions

In conclusion, the objectives of this project, to fulfill the ME 154 and ME 106 project requirements, were fulfilled by the white board ink removing device 'Ink-B-Gone. The project was designed to have at least two degrees of freedom, that incorporated rotational and translational motion. Furthermore, the project used a microcontroller, three opto-interrupt sensors, two DC motors, a diode, a MOSFET, an H-bridge, and three resistors control the mechanism. A prototype was built and tested for it functionality and its performance was evaluated in context of its marketability. Though the devise was found to exceed project requirements it did not meet all of the group's objectives. The group evaluated the project as successful and noted improvements that would be made if given more time.

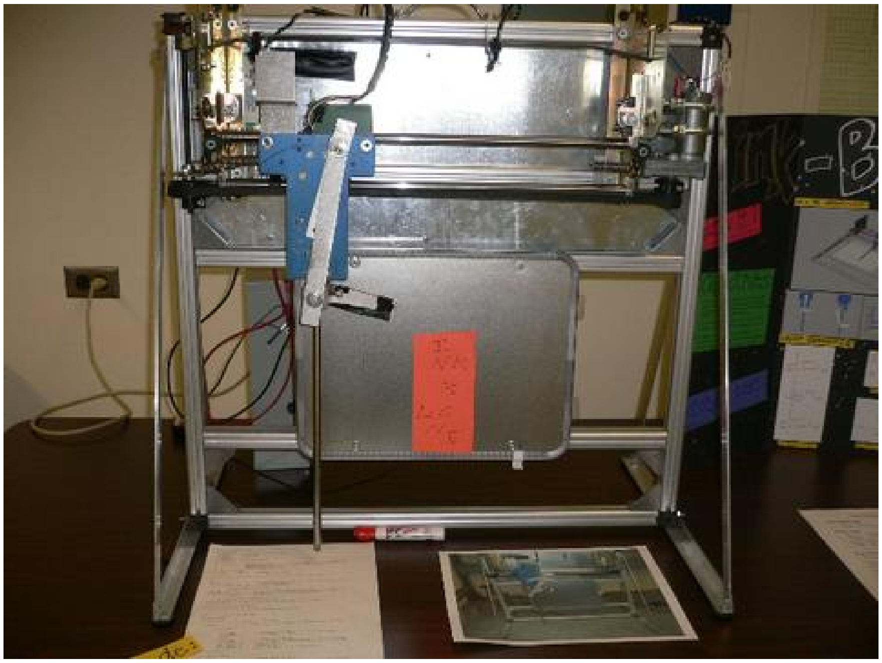

Figure …….: The completed prototype

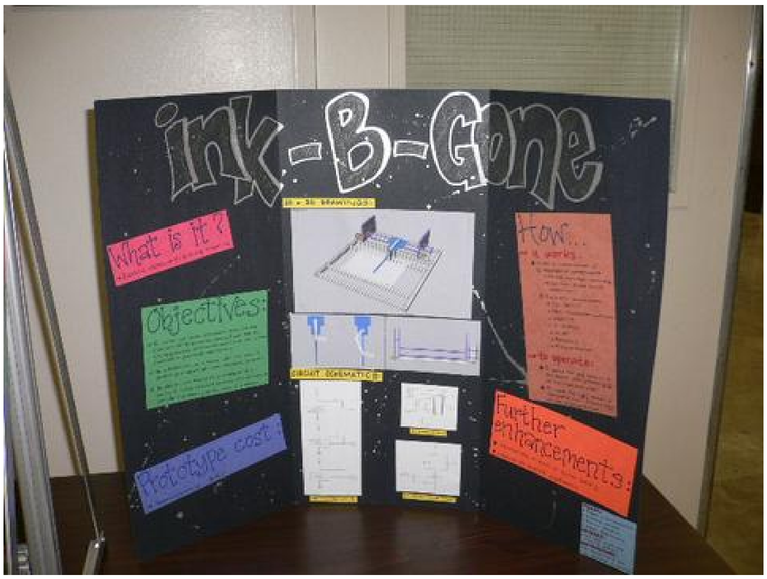

Figure ……: The poster used in the project presentations

References

Norton, Robert L. (2004). Design of Machinery: Introduction to Synthesis and Analysis of Mechanisms, 3rd Edition, McGraw-Hill

Norton, Robert L. (2006). Machine Design, 3rd Ed, Prentice Hall

Texas Instruments. "SN754410 Quadruple Half-H Driver Datasheet" (1995) Retrieved …….. from: http://focus.ti.com/lit/ds/symlink/sn754410.pdf

Pittman Express. "GM9413-4 DC Motor Datasheet" (2001) Retrieved ……. from: http://www.pennmotion.com/part_num_database/pdf/GM9413_4.pdf#search='pittman%20GM94134'

Appendixes

CODE

```
//***************************************************************************
//
// File Name     : 'inkbgone.c'
// Title         : program to drive two motors off the STK500
// Author        : Tony Cacace
// Created       : 24APR2006
// Revised       :
// Version       : 1.0
// Target MCU    : Atmel AVR series
// Editor Tabs   :
//
//  Description :   Turns on motors when SW0 or SW1 are pressed, else turns keeps off
//                  Assumes motors on STK500 connected to PORTC and PORTB pins,
//                  switches conected to PORTD pins
//                  PORTA pins are optical sensor inputs
//
//  Revision History:
//  When         Who          Description of Change
//  -------      ---------    ---------------------------
//
//***************************************************************************

/*---------Macros----------*/

#define BV(bit) (1<<(bit)) //byte Value=> convers bit into a byte. one a bit location
#define cbi(reg, bit) reg &=~(BV(bit)) //clears bit
#define sbi(reg, bit) reg |= (BV(bit)) //sets bit

/*---------Include Files----------*/

#include <avr/io.h>          // include I/O definitions (port and pin names, etc)
#include "global.h"          // include global settings for the microcontroller
#include "timer.h"           // include timer function library


/*---------Function Prototypes----------*/

void init(void);    // sets up PORT pins and makes sure motors are off


/*---------Global Variables----------*/

                    // declare any global variables here


/*---------Body of Program Code----------*/

int main(void)
{
    init();         // initialize everything

    while(1)        // 'Super Loop' code: stuff between the braces is done forever
    {
        switch(PIND)
        {

            case 0xfe:           // checks state of SW0
            sbi (PORTC, 0);      // powers pin 0 of PORTC turning on crank motor
            break;

            case 0xfd:           // checks state of SW1
            sbi (PORTB, 0);      // powers pin 0 of PORTB turning on power to Hbridge
            sbi (PORTB, 1);      // powers pin 1 of PORTB enabeling outputs on Hbridge
            cbi (PORTB, 2);      // sets 1Y low
            sbi (PORTB, 3);      // sets 2Y high
                                 //above two lines turns linear motor cw
            break;
        }

        switch(PINA)
        {
            case 0x01:           // Checks state of Pin A0
            cbi (PORTB, 1);      // ground pin 1 of PORTC disabeling outputs on Hbridge
```

```
            break;

            case 0x05:      // Checks state of Pin A2 and A0
            cbi (PORTC, 0); // grounds pin 0 of PORTC turning off crank motor
            break;

            case 0x06:          // Checks state of Pin A1 and A2
            cbi (PORTB, 1);     // ground pin 1 of PORTC disabeling outputs on Hbridge
            sbi (PORTC, 0);     // powers pin 0 of PORTC turning on crank motor
            timerPause(5700);   // pauses program for 5 seconds
            cbi (PORTC, 0);     // grounds pin 0 of PORTC turning off crank motor
            sbi (PORTB, 1);     // powers pin 1 of PORTB enabeling outputs on Hbridge
            sbi (PORTB, 2);     // sets 1Y high
            cbi (PORTB, 3);     // sets 2Y low
                                //above two lines turns linear motor cw

            break;
        }


    }
return 0;
}

/*---------Function Definitions-----------*/

void init(void) // init function: makes sure all motors are off
                // turns on pullup resistors on PORTD pins
{
    DDRA = 0x00;    // sets Data Direction Reg for PORTA to make all pins inputs
    PORTA = 0x00;   // enables pull-up resistors on PORTA pins: optoswitches will
                    // read 0 when not interupted
    //PORTB = 0x00; // sets PORTB driver register to all ZEROS: linear motor off
    DDRB = 0xFF;    // sets Data Direction Reg for PORTB to make all pins outputs
    PORTB = 0x00;   // sets PORTB driver register to all ZEROS: linear motor off
    //PORTC = 0x00; // sets PORTC driver register to all ZEROS: crank motor off
    DDRC = 0xFF;    // sets Data Direction Reg for PORTC to make all pins outputs
                    // (program reset clears DDRC - all pins initially are inputs)
    PORTC = 0x00;   // sets PORTC driver register to all ZEROS: crank motor off
    DDRD = 0x00;    // sets Data Direction Reg for PORTD to make all pins inputs
    PORTD = 0xff;   // enables pull-up resistors on PORTD pins: switches will
                    // read 1 when not pressed
    timerInit();    // initialize the timer system
}
```