Automated TV Wall Mount

A Baccalaureate thesis submitted to the
School of Dynamic Systems
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Joshua K. Bragg

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Thesis Advisor: Janet Dong PhD

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ABSTRACT

An automated television wall mount was designed and a prototype built to provide remote control adjusting of the physical orientation of a flat screen television. Research of existing products was conducted to understand the current market conditions and identify where potential improvement opportunities existed. It was found that all existing products retail for over $400 and have limited range at the lower price points. A system was designed that utilizes cable systems, unlike any of the competitors. The concept was continuously refined and resulted in a simple system that is composed of three winches and two joints. This prototype cost less to produce than any of the automated mounts currently on the market are retailing for, and provides a range equal to that of the greatest competitor.

INTRODUCTION

Problem & Solution

Television viewing is most desirable when watched head on, (i.e. perpendicular to screen). Having the television positioned directly at the viewer maximizes the viewable surface and optimizes the effects of in home 3D systems. Seating arrangements reduce the ability to get the best possible viewing experience and often put the most comfortable seat off to the side (e.g. recliner), thus disconnecting comfort from quality entertainment.

A remote controlled wall mount that allows a 55 inch television to pivot 45 degrees side to side and pitch 90 degrees up and down will be constructed to alleviate our viewing dilemma.

Existing Products

Current automated TV wall mounts all utilize mechanical linkages to orient the television. Some designs hide these links inside flexible rubber housing as shown in Figure 1 (1) and Figure 2 (2), while others do not.

Figure 1: CLO Systems

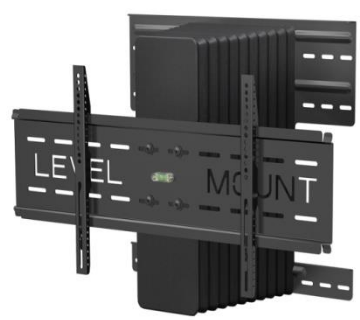

Figure 2: Level Mount

Some models allow for centering in the horizontal direction that allows for an aesthetically pleasing placement of the screen (e.g. above a fireplace), as shown below in Figure 3 (3) and Figure 4 (4).

Figure 3: Sanus

Figure 4: OmniMount

The swing arm design seems to be prominent and already exists in a variety of different styles. Two different designs are shown below in Figure 5 (5) and Figure 6 (6).

Figure 5: Future Automation

Figure 6: Chief

High end custom mounts do exist and some offer alternative approaches such as the swivel type design from Inca (7), which can be seen in Appendix A. All of the researched models hold a minimum of 110 pounds and support at least a 55 inch television. They all also come with a remote control, some allowing for preset positions to be programmed in by the user. In addition, some can be controlled via existing universal remotes that can be programmed to control the mount. All available models require two studs that are 16 inches apart for wall mounting, and range from around $400 to $2,000 in cost. Detailed information pertaining to existing models can be found in Appendix A.

Survey

A survey was completed by 30 people who currently use a flat screen television. Those surveyed are of no specific demographic or technical background, but many were young adults. The survey results, which show how important each feature is to the customers, is as follows in the customer importance column of Table 1, while the actual survey with data value selection frequency can be found in Appendix B. Data from the survey was interpreted to find the features that are most important to the customers by ranking them based on their relative importance. This information will be used to make decisions during the design process and were used to determine the weights of the engineering characteristics.

Table 1: Customer Input Data

	Customer Importance	Designer's Multiplier	Modified Importance	Relative Weight	Relative Weight %
Affordable	4.93	1.2	5.9	5.89	20%
Easy to Install	4.90	1	4.9	4.88	17%
Stylish	4.97	1	5.0	4.95	17%
Easy to Integrate & Program	4.76	1	4.8	4.74	16%
Easy to Use	4.00	1.1	4.4	4.38	15%
Safe	4.30	1	4.3	4.28	15%

The percent value for "Affordable" was increased by the designer, to increase its overall importance, due to the fact that many existing models currently cost more than the televisions they hold. Based on the survey, a value of how much the customer will be willing to pay for this product was computed to be between \$290 and \$390. In response to customer input this project will focus on cost minimization and simplicity. A designer multiplier was also used on the "Easy to Use" feature, in response to the wide range of technical capabilities among end users.

Product Objectives

Below are the same customer features from the survey followed by specific engineering characteristics that the product aims to achieve in order to satisfy each customer requirement. The percentage next to each customer feature is its relative importance weight taken directly from the customer input data found in Table 1.

1. Affordable (20%)
    a. Less than $350 retail
    b. Less than $700 prototype

2. Easy to Use (17%)
    a. Simple up-down and left-right controls
    b. Always powered on

3. Easy to Integrate & Program (17%)
    a. Designated remote
    b. Control from existing remote

4. Safe (16%)
    a. Hold up to 55 in. 120 lb. TV
        i. Yaw 45°, Pitch 30°
    b. Product weight under 80 lbs.
    c. Durable
        i. 10,000 cycles

5. Easy to Install (15%)
    a. Detailed installation instructions
    b. Less than 30 minutes with two people
    c. Basic home tools
        i. Standard screws, bolts, and nuts

6. Visually Appealing (15%)
    a. Appears as one with TV
        i. Black
        ii. Case covering inner workings
    b. Wires concealed

Engineering Characteristics

Through data interpretation of the survey and assignment of correlation values between the customer features and engineering characteristics, each engineering characteristic was assigned a relative importance percentage as seen below in Table 2. The entire “House of Quality” that was used to obtain these values can be found in Appendix C.

Table 2: Engineering Characteristics Importance

Existing Remote Compatible	20%
Designated Remote	19%
Black Finish	10%
30 Minute Installation	10%
Always Powered On	9%
Component Concealment	8%
Wire Concealment	8%
Supports 55 in. 120 lb. TV	7%
Fatigue Loading	7%
Basic Tool Installation	2%
Single Stud Mounting	2%

The top two engineering characteristics correspond directly with the “ease” of using, programming and integrating as desired by the customers. All of these engineering characteristics will influence design decisions but the top few will guide the direction of the project.

DESIGN & ANALYSIS

A SolidWorks model of the final design is shown below in Figure 7, and an exploded view in Figure 8. It encompasses a carbon steel frame with two movable joints and three winches. The lower joint swivels and pivots to position the TV in the desired rotational and height position, while the upper joint only pivots in the vertical direction to achieve a desired tilt orientation.

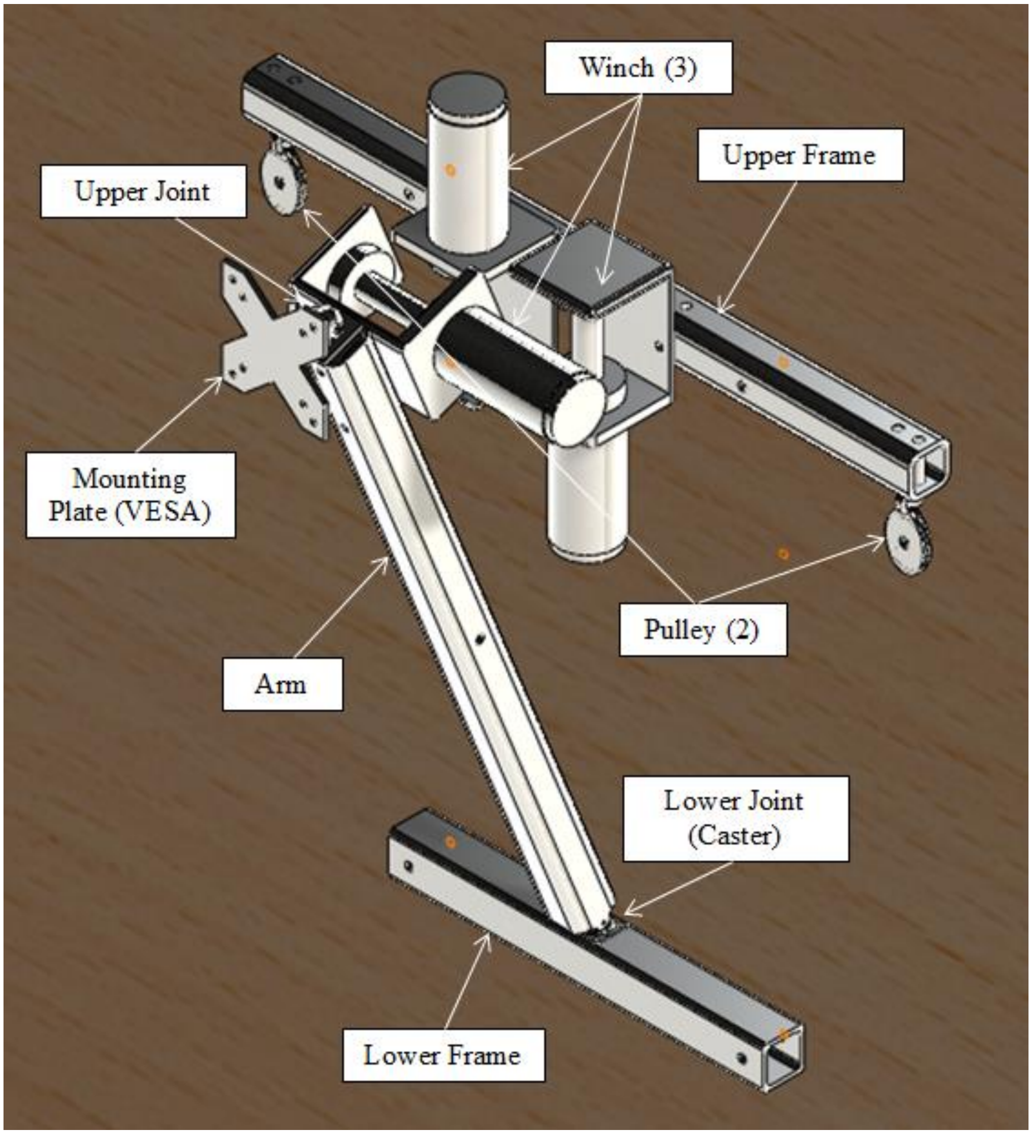

Figure 7: SolidWorks Model (Cables Not Included)

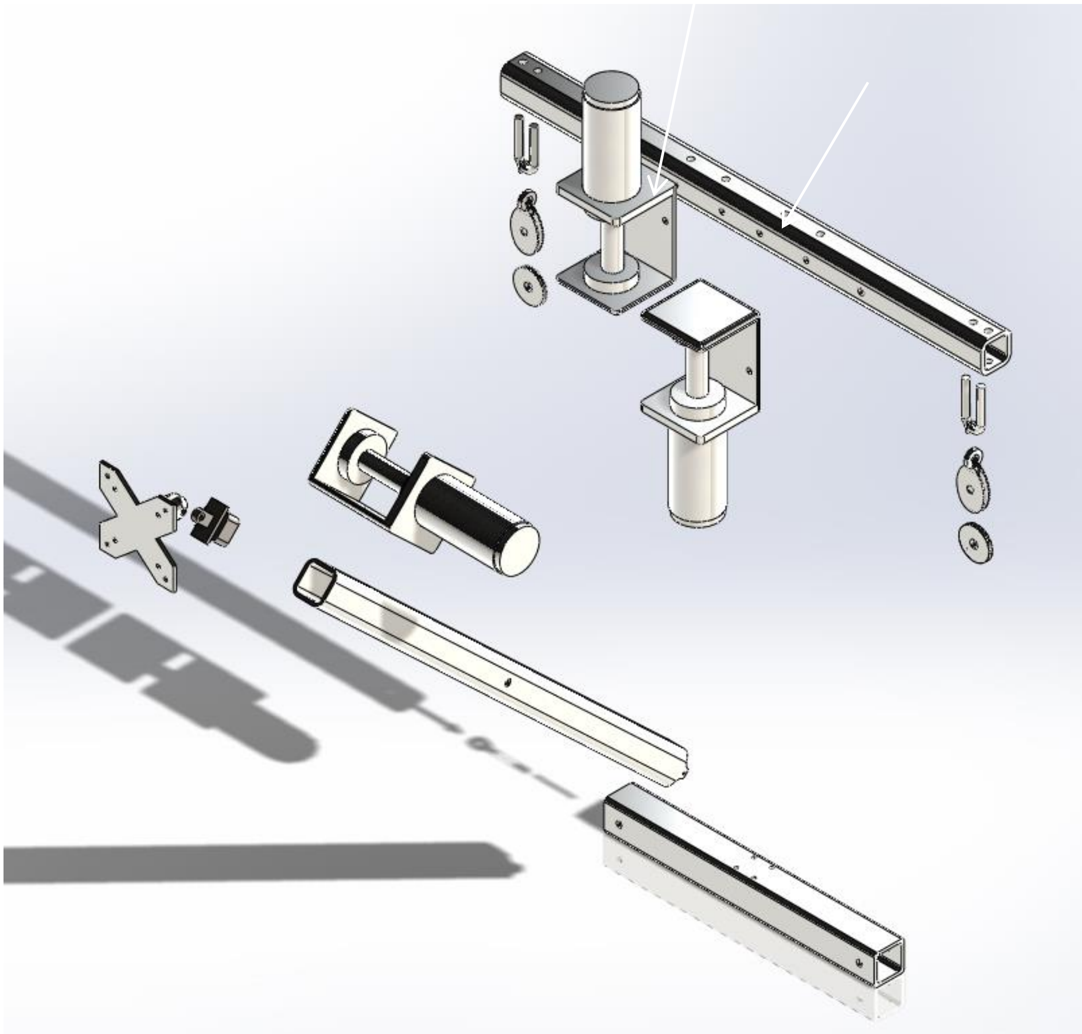

Figure 8: SolidWorks Exploded View

Design Evolution

Design configurations, similar to those shown in the existing products section, that utilize rigid links were analyzed and it was determined that that approach was used extensively. In order to create a product that would supersede all existing models, a new approach was needed. A cable based system was adopted out of necessity to deviate from the norm. The original cable design, shown below in Figure 9, locates the two arm positioning winches towards the outer edge of the frame.

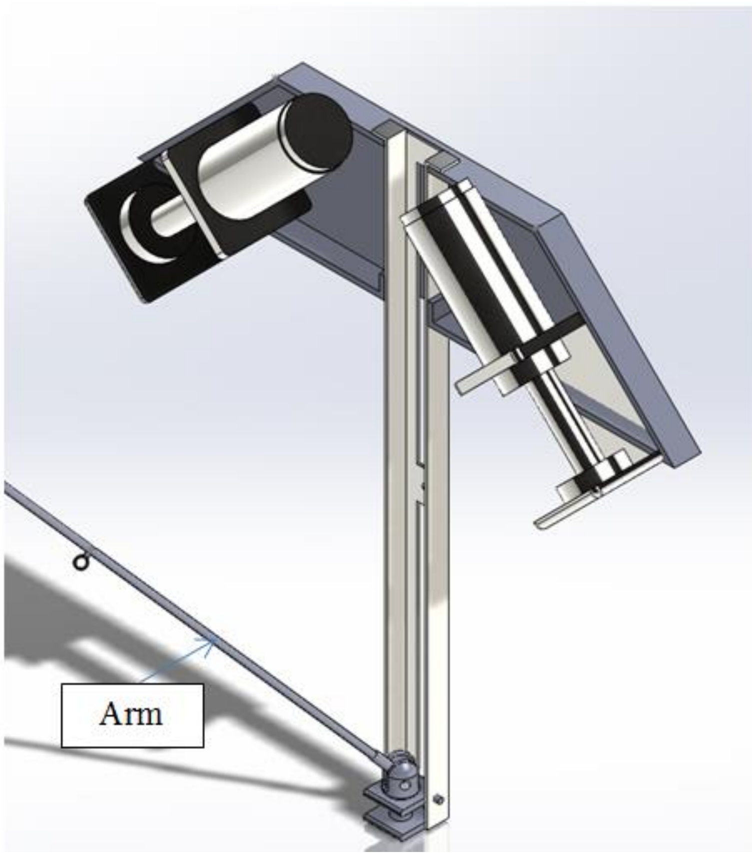

Figure 9: Original Cable Design

This design would work, but as the arm travels side-to-side the winch cables would not always protrude perpendicularly to the axis of rotation, thus reducing the winches' effectiveness. To alleviate this problem a new design was created that utilizes pulleys on the outer sides of the frame that would maintain a relatively stable cable tension direction from the winches perspective, as seen in the final design. The winches were originally slated to be electric stepper motors with spools attached to their shafts, but after further investigation it was concluded that it would be much easier and cheaper to use off the shelf winches. It was also found that less material will be needed for manufacturing the product with the winches being brought in towards the center of the mount.

Failure Analysis

A solid model was generated and tested using SolidWorks. First, rigid links were attached in place of where the cables will be located (flexible cables not available in SolidWorks simulation). The wall was fixed in place and a 240lb downward force was applied to the mount where the TV will fixate to as shown below in Figure 10.

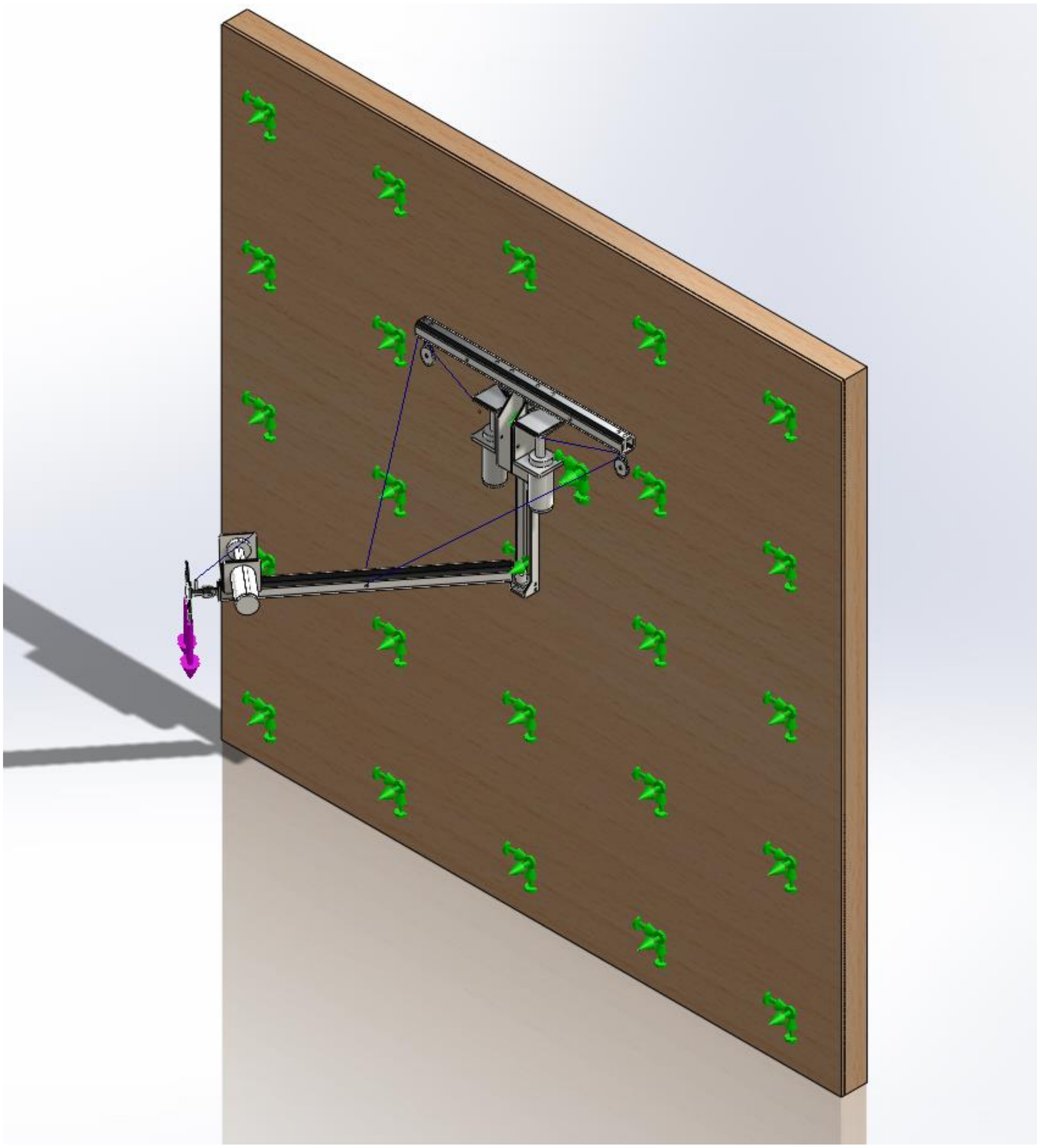

Figure 10: FEA Setup

The model was static tested at its most extreme position and produced the results shown below in Figure 11. All of the material is assumed to be plain carbon steel and has a yield-strength of 32 ksi. This places the entire model, except for the joints at each end of the arm, above a factor of safety of 2. The upper joint will be modified as I have already obtained a much more durable link with bearings already in place. Note: the force applied in the static test is twice the intended use weight.

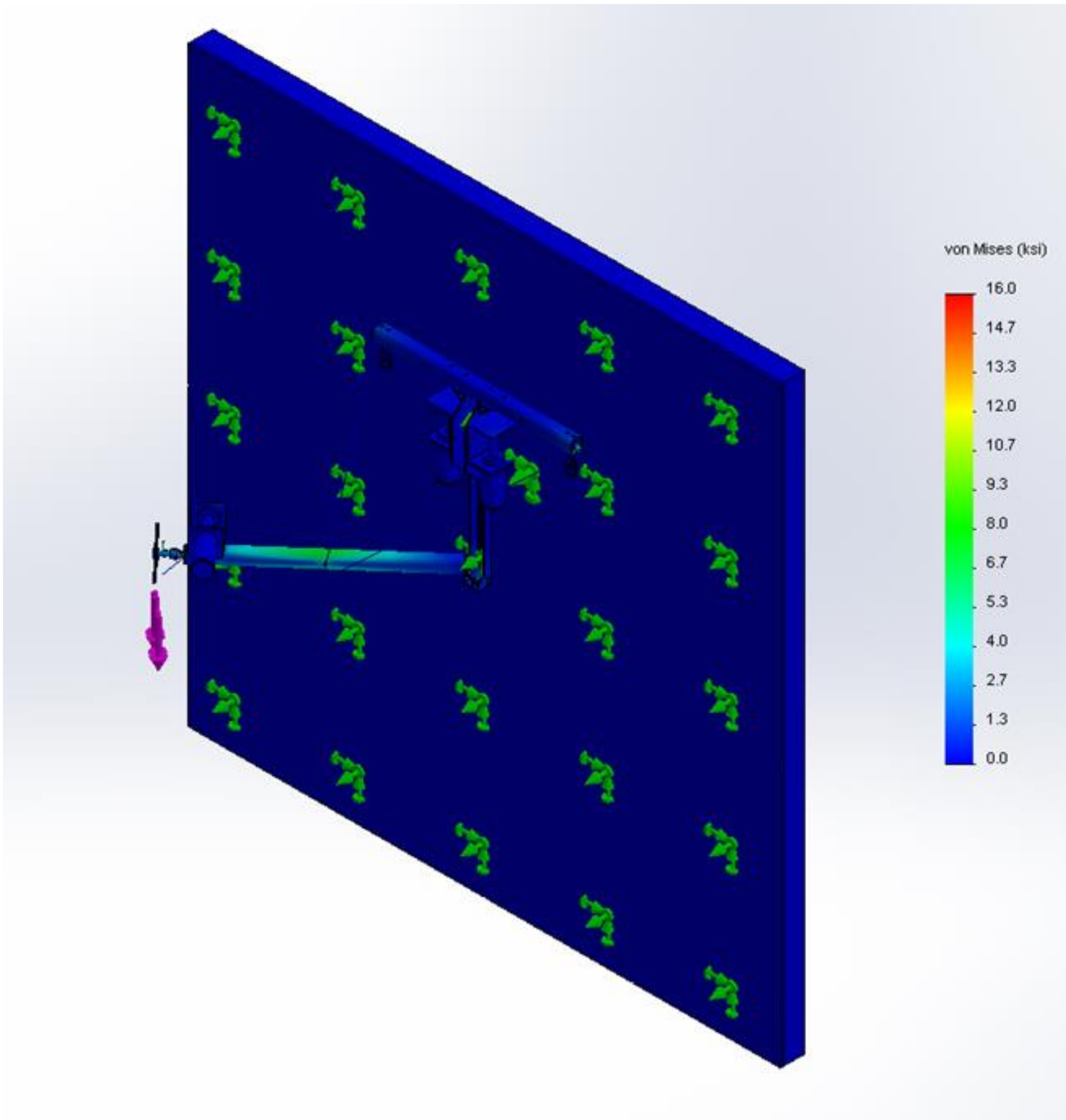

Figure 11: Static FEA

After FEA testing it was determined that great stresses were concentrated in the lower joint. The arm stresses (the green region in Figure 11) are calculated in the calculations section of this report. The original plan was to design a custom joint that would optimize movement and stability. After careful consideration, it was concluded that an off-the-shelf caster would suffice despite its lack of ability to dampen vibrations. The chosen caster has a capacity of 300 lb. which exceeds the design requirements.

Below is a picture of the finished prototype in Figure 12. The white component is the pre-existing weight machine part that was utilized because it had a sturdy joint already in place. The red ribbon replaced what was supposed to be a double ended I-Bolt to help alleviate the jerkiness.

Figure 12: Actual Prototype

The product performed as expected and provided the full range of motion as specified in the product objectives. The stability, integrated remote system, and the visual appearance are the only shortfalls of this project.

Calculations

Bolt Shear: Frame-Wall, Caster

Bolt Diameter = 3/8 inch

$$\tau = \frac{4 \cdot V}{3 \cdot A} = \frac{4 \cdot 200\text{lb}}{3 \cdot 0.5625} = 2.414 \text{ ksi}$$

Yield Strength = 32 ksi
Shear Yield Strength = 16 ksi
Factor of Safety = 6.626

Cable Tension:

Cable Diameter = 5/32 inch

Position: Straight Out, 45° Side

$\Theta = 22.6°$
$\text{Cos } \Theta = \frac{240\ lb}{tension} \rightarrow$ tension = 130 lb. (extreme cable)

Position: Full Retracted

$\Theta = 66.1°$
$\text{Cos } \Theta = \frac{120\ lb}{tension} \rightarrow$ tension = 296.1 lb. (per cable)

Cable tension is under maximum allowed value as winch has maximum load of 2000lb.

Arm Force:

Buckling

$\Theta = 14°$
$\text{Cos } \Theta = \frac{120\ lb}{force} \rightarrow$ $force_{buckling} = 123.7$ lb.

Bending Force

$$\sigma = \frac{M \cdot C}{I} = \frac{(240lb \cdot 18\ inch) \cdot 1\ inch}{\frac{(2\ inch)^4 - (1.625\ inch)^4}{12}} = 5{,}743 \text{ psi}$$

$\sigma_{\text{yield strength}} = 31{,}994$

Factor of Safety, N = $\frac{31{,}994}{5{,}743} = 5.57$

Refer to Appendix F for more calculations and drawings.

Components

Frame
- Square steel tubing
    - 2 x 2 x 3/16 inch
- Weight machine part

Winch
- 12V DC
- 0.85 HP
- Gear Ratio = 153:1
- Max Load = 2,000 lb.

Pulley Assembly
- Off Shelf
- Max Load = 400 lb.

Electronics
- Included with winch
- Wireless Accessory
- Automotive Jump Box

Bolts
- 3/8 inch
- Size W Hole = 0.3860 inch
- VESA screws

Joints
- Caster (300 lb. capacity)
- Weight machine part

Bill of Materials

Table 3: Bill of Materials

Item #	Part	Quantity
1	Square Tube	2
2	Arm	2
3	Vesa	1
4	Caster	1
5	Caster Screws	4
6	Pulley	2
7	Winch	3
8	3/8 Bolt 5 in	2
9	3/8 Bolt 2.5 in	9
10	3/8 U-Bolt	2
11	Vesa Bolt	4
12	Electronics	3

FABRICATION & ASSEMBLY

Upper frame is composed of square steel tubing that required cutting to proper length and drilling of holes for mounting: frame to wall, winches to frame, and pulleys to frame. Lower frame, made of same tubing, also required cutting to appropriate length then drilling holes for mounting: frame to wall, and caster to frame. The arm (white part) was originally a part of a weight lifting machine that was modified. It was cut to length, and holes were drilled to connect: arm to caster, winch to arm, and VESA plate to arm. The upper winches supported the arm, once fed through their respective pulleys, via a strap that was attached to both upper winch cables that ran underneath the arm and then held in place by a bolt. A hole was drilled in the VESA plate and a strap attached to the arm winch cable to achieve desired tilt. Electronics were installed by connecting them as detailed by the winch manufacturer.

TESTING & PROOF OF DESIGN

The product prototype performed as expected. It achieved 45° side-to-side and 30° up-and-down tilt. The velocity and acceleration were never of concern, but it must be noted that it moves relatively fast for a TV mount. All components are rated at greater capacity than their respective operational load requirements. Physical resistance was applied to the mount during operation to prove its lifting capacity, but a TV was never installed. Overall, the mount was easy to set up, but lacks a clean visual appearance.

PROJECT MANAGEMENT

Schedule

Design Report to Faculty:	January 28th
Building & Testing:	March 2nd
Project Completion:	March 29th
Public Unveiling:	April 4th
Project Report to Faculty:	April 7th
Final Report Submission:	April 22nd

See Appendix D for detailed schedule.

Budget

The project came out significantly under budget due to utilization of pre-existing components and the use of off-the-shelf components. Budget estimates and actual costs can be seen in further detail in Appendix E.

CONCLUSION

Optimizations were brought to light during the manufacturing phase and modifications were applied where necessary. These include the switch from a vertical center frame, a customized lower joint, and a double ended I-Bolt on the arm. The project never progressed to the integrated controller phase, which was optional from the start. The project lacks stability, a clean visual appearance, and an acceptable operational noise level. Other than these few undesired characteristics the product safely performs its intended functions with a small price tag.

There are many modifications that could improve the prototype. Dampening of the lower joint would greatly reduce the arm vibrations. This problem could also be minimized by slowing down the winch speeds with a voltage regulator. All electronic wires could be routed through the frame itself to improve the visual appearance. Having casings to hide the winches and to make the product appear as a unified system would also improve the visual appearance. The ideal future improvement would be to create a controller that integrates all three separate winch controllers into one, to allow for simple operation.

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APPENDIX A - RESEARCH

Interview with John of Best Buy

08/25/12 4:00PM
650 Eastgate South Drive
Cincinnati, OH 45245
(513) 753-7062

John explained the differences between the three types of flat screen wall mounts that his company sells (all manual); low-profile, tilt, and full-motion. Their full motion mount is similar to the Chief wall mount pictured below in that it is a swing arm design. He stated that he had heard of automated wall mounts but that they do not carry them. He also provided information regarding the VESA mounting interface standards, explaining that mounts and TVs have standards which allow for one mount to work with many different TVs of similar size. The dimensions and specifications for the VESA mounting interface standards can be found at the following link: http://en.wikipedia.org/wiki/Flat_Display_Mounting_Interface.

Interview with gamer Ryan Codding

09/07/12 8:00PM
1065 Ty Dr.
Medina, OH 44256
(330) 635-7547

Ryan's main concern was with his video gaming experience between his chair and bed in the same room. He expressed that the tilt requirements were small, but that a rotation of at least 45 degrees each way would be needed. He said he would prefer a remote that could be programmed to control his TV as well, thus eliminating the need for a separate remote. Possible integration of the mount and the gaming system were discussed to allow for the TV to always aim itself at the game system controller or any remote control. Ryan also expressed his concerns with a "jumble" of cords coming down from under the mount. He stated that this product would need to be under $500 for him to consider purchasing it.

Chief - Wall Mount
http://www.chiefmfg.com/Series/PXR

Rotation: 45 Degrees (L&R)
Tilt: + 0/ -12 Degrees
Weight Capacity: 150 lbs.
Screen Size: 32 - 65"
Extension: 4.5 – 27’’
Mounting: 16’’ studs
Controller: IR remote (4 presets)
VESA Compliant
Price: $1999.99

Inca - Glider Lift Mount
http://www.inca-tvlifts.com/

Rotation: 90 Degrees (L&R) (Glide)
Tilt: None
Weight Capacity: Unknown.
Screen Size: Unknown
Mounting: Custom
Controller: Touch Screen
VESA Compliant
Price: Unknown
This is also a lift system.

CLO Systems - Wall Mount

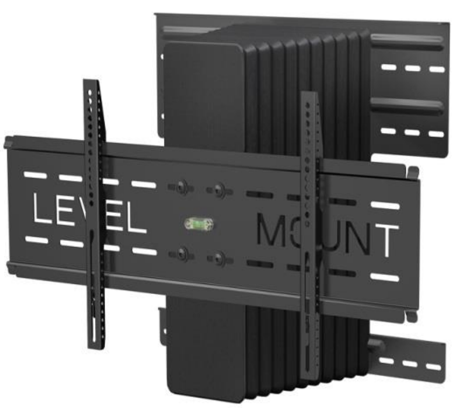
http://www.smarthome.com/43220/CLO-Systems-X-Arm-Automated-Fully-Articulating-Motorized-Mount-for-a-TV-Display/p.aspx

Rotation: 56 Degrees (L&R)
Tilt: + 7/ -20 Degrees
Weight Capacity: 180 lbs.
Screen Size: 37 - 63"
Extension: 4.6 – 12’’
Mounting: 16’’ studs
Controller: IR remote (universal)
USB port for ControlWand
- Wall Wizard App for iPhone

VESA Compliant
Price: $799.99

Level Mount - Wall Mount

http://www.standsandmounts.com/LEVELMOUNTMotorizedFullMotionWallMountfor37to85inchScreensDC65MCL.aspx



Rotation: 30 Degrees (L&R)
Tilt: + 15/ -15 Degrees
Weight Capacity: 150 lbs.
Screen Size: 37 - 85"
Extension: 4 – 15’’
Mounting: 16’’ studs
Controller: RF remote (3 presets)
Built in level
VESA Compliant
Price: $439.50

OmniMount - Wall Mount

http://www.omnimount.com/products/motorized_products/power55/

Rotation: 20 Degrees (L&R)
Tilt: + 15/ -0 Degrees
Weight Capacity: 110 lbs.
Screen Size: 37 - 55"
Extension: 2.9 – 7.6’’
Mounting: 16’’ studs
Controller: IR remote (3 presets)
Safety Stop
Side-to-side adjustment
VESA Compliant
Price: $407.76

Sanus - Wall Mount

http://www.sanus.com/us/en/products/visionmount/other/VLMF109#

Rotation: 30 Degrees (L&R)
Tilt: None
Weight Capacity: 110 lbs.
Screen Size: 37 - 60"
Extension: 2 – 9’’
Mounting: 16’’ studs
Controller: IR remote (presets)
Side-to-side adjustment
VESA Compliant
Price: $429.99

Future Automation - Wall Mount

http://www.wallmountworld.com/Electric_180_deg_Swivel_TV_Wall_Bracket_p/fa-motorized-180.htm

Rotation: 90 Degrees (L&R)
Tilt: None
Weight Capacity: 110 lbs.
Screen Size: 37 - 65"
Extension: 5 – 30.7’’
Mounting: 16’’ studs
Controller: IF remote (presets)
VESA Compliant
Price: $439.50

APPENDIX B – SURVEY WITH RESULTS

AUTOMATED TV WALL MOUNT – CUSTOMER SURVEY

An "Automated TV Wall Mount" is a wall mount that allows the viewer to remotely control the angle that the TV is facing in both up-and-down and side-to-side directions.

Please rate the following product features by customer importance. Circle response.

	Not Important	→			**Very Important**		**AVG**
Affordable	1	2	3	4(2)	5(28)	N/A	**4.93**
Stylish	1(1)	2	3(8)	4(10)	5(11)	N/A	**4.00**
Safe	1	2	3(2)	4(3)	5(25)	N/A	**4.76**
Easy to Install	1	2(2)	3(5)	4(5)	5(18)	N/A	**4.30**
Easy to Integrate & Program	1	2	3	4(3)	5(27)	N/A	**4.90**
Easy to Use	1	2	3	4(1)	5(29)	N/A	**4.97**

How much would you be willing to purchase one for?

$200-$300(19) $400-$500(8) $500-$600(1) $600-$700(2) $700-$800

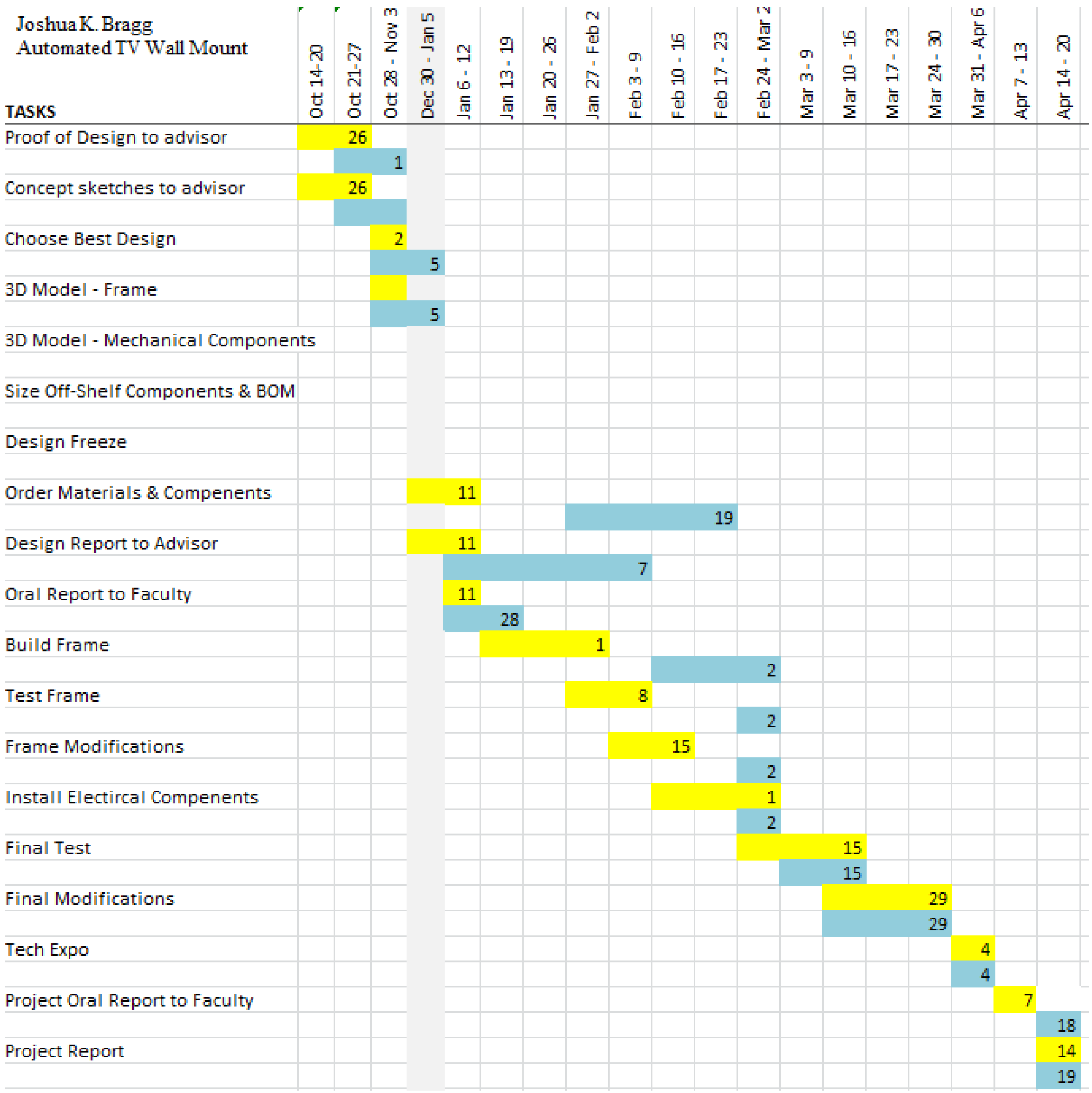
AVG = $290-$390

Thank you for your time.

APPENDIX C – HOUSE OF QUALITY

Joshua K. Bragg **Automated TV Wall Mount** 9 = Strong 3 = Moderate 1 = Weak -1 = Inversely Weak -3 = Inversely Moderate	Black Finish	Component Concealment	Wire Concealment	Supports 55in. 120 lb. TV	Fatigue Loading	30 Minute Install	Basic Tool Install	Single Stud Mounting	Designated Remote	Existing Remote Compatible	Always Powered On		Customer importance	Designer's Multiplier	Modified Importance	Relative weight	Relative weight %
Affordable		-1	-1	-3	-3		1		-3	3	3		4.93	1.2	5.9	0.20	20%
Stylish	9	9	9										4.00	1.1	4.4	0.15	15%
Safe				9	9			-1					4.76	1	4.8	0.16	16%
Easy to Install		-1	-1			9		3					4.30	1	4.3	0.15	15%
Easy to Integrate & Program									9	3			4.90	1	4.9	0.17	17%
Easy to Use									9	9	3		4.97	1	5.0	0.17	17%
Absolute Importance	1.35	1.00	1.00	0.86	0.86	1.32	0.20	0.28	2.43	2.64	1.12	13.1			29.2	1.0	1.0
Relative Importance	0.10	0.08	0.08	0.07	0.07	0.10	0.02	0.02	0.19	0.20	0.09	1.0					

APPENDIX D – SCHEDULE

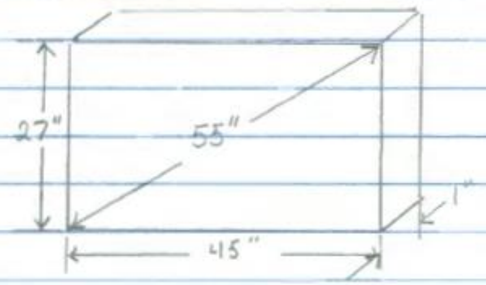


APPENDIX E – BUDGET

Component	Description	Estimated Cost [$]	Actual Cost [$]
Frame	Steel Tubing	100	68.60
Pulleys	Pulleys, Housings	25	9.99
Joints	Bearings, Hinges	30	7.99
Winches	Assembly, Cables, Mountings	250	209.97
Control System	Remote, Controller	100	56.32
Fasteners	Bolts, U-Bolts, Screws	15	22.89
TOTAL		**520**	**375.76**

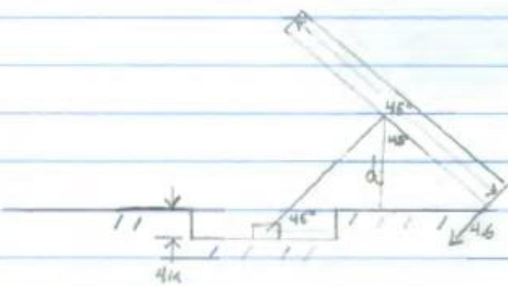
APPENDIX F – SAMPLE CALCULATIONS

55" TV Dimensions:



Worst Case:

- TV larger than recessed box
  - aprox 4 inches deep



$d = 22.5\cos 45 = 15.91''$

$d_{w/retreat} = 15.91'' + \underbrace{4.6\sin 45}_{\text{retreat in } y} = 19.16''$

$d_{actual} = 19.16'' + 4'' - \underbrace{d_{\text{box to joist corner}}}_{\text{assume } 1''}$

$d_{actual} = 22.16''$

Side View:

$l_{rod} = \dfrac{22.16''}{\sin 45} = 31.34''$

$\sin 20° = \dfrac{\text{retreat}}{13.5''} \Rightarrow \text{retreat} = 4.6''$