Prairie View A&M University Autonomous Underwater Vehicle (PVAUV): Development and Design

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***Abstract*— Team PVAUV Panthers consists of undergraduate mechanical and electrical engineering students from Prairie View A&M University in Prairie View, Texas. The purpose of designing and manufacturing an autonomous underwater vehicle is to create a cost effective, efficient autonomous underwater vehicle that will be able to perform and complete all of the designated AUVSI AUV competition tasks. Underwater explorations and recent tragic accidents with aircraft carriers all submitted to a rising concern for the current limitation of unmanned underwater vehicles. In order to design and manufacture a fully functioning AUV, the AUV team followed the design process: problem definition, literature review, concept generation, analysis, and manufacture, test, and refine design. The Panther system design includes software architecture, electrical infrastructure, and mechanical design.**

I. INTRODUCTION

The Association for Unmanned Vehicle Systems International (AUVSI) Autonomous Underwater Vehicle (AUV) competition is designed to provide a unique challenge to engineering students among different schools around the world. This will help guide students in understanding the applications with AUVs and its impact in the world. The vehicle has to complete different tasks performed underwater that are implemented into our AUV through the hardware and software. Each team will need to integrate several different engineering areas into their final design. Some of these areas include vehicle hydrodynamics, underwater propulsion, sensing, mechanical systems, integration and testing. Considering the complexity of each mission tasks, a systems engineering approach will be critical to a successful vehicle design.

II. PROJECT GOALS

The goal is to design a working model of an Autonomous Underwater Vehicle to complete the following tasks: gate pass through, guide path segments (line-follow), and color recognition and touching the buoy. Additional tasks for development to be considered for assurance of an exceptional performance in the competition are as follows: navigating through an additional gate and adding a hydrophone attachment to complete the remaining competition tasks (hydrophone listen and surface).

Objectives

The following are the competition design specifications. These design specifications are broken down into a task tree shown in Figure 1-1:

1. RoboSub should maintain at least 0.5% buoyancy (Buoyancy)
2. RoboSub should be balanced underwater (Movement)
3. RoboSub should be able to move forward and reverse: passing through gate qualifying round (Movement)
4. RoboSub should be able to steer left and right (Movement)
5. RoboSub should be able to navigate to competition site (Movement)
6. RoboSub should be able to operate through the 30 minutes time slot for the competition (Performance)
7. RoboSub should be waterproofed (Performance)
8. Robosub should be able to operate with minimal electrical interference (Performance)
9. RoboSub should be able to recognize underwater color distinctive objective through the sonar and visual signal data feed (Tasks)
10. Robosub should be able to pass through the initial Gate stage (Tasks)
11. Robosub should maintain competition weight (Tasks)

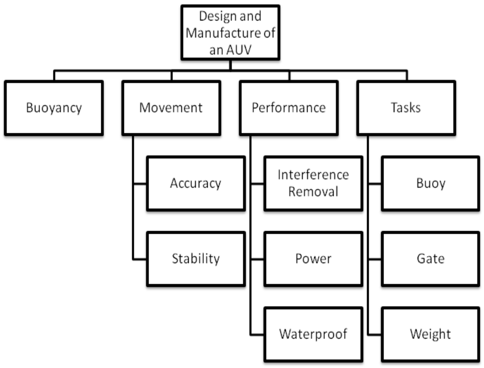

Figure 2-1 Objective Tree

III. PROJECT PLANNING

The team stayed on task by using Microsoft Project. This program helped us stay on time with our deliverables and objectives. Timelines and Gantt Charts were used to keep track and check off things as they got done. Table 3-1 shows a small sample of a timeline that was used for keeping tabs on the project.

Table 3-1 Testing Task for Spring 2016

12. Testing	12.1 Pre-Testing	To prepare the sub for various testing	A familiarity with the subs parts and structure breakdown	7	10/1/2015	10/7/2015	Long
	12.2 Structure Leak Test	To test the sub for any cracks or leaks in the structure	A structure test of the sub without the cpu system connected	1	10/8/2015	10/8/2015	Tunde
	12.3 Test last years UAV	To test previous years UAV as is to determine the failures	A failure analysis of previous years UAV	7	10/1/2015	10/7/2015	Amy
	12.4 Thruster Test	To correct thruster placement	The test to enusre thrusters are placed in a consistent position	14	10/7/2015	10/21/2015	Ha
	12.5 Interference Test	To test wiring and cpu reliability of the sub when submerged	The reliability test of the cpu to eliminate interference	14	10/7/2015	10/21/2015	Amy
	12.6 Time Change Battery Test	To test battery compartment adjustment and modification	The modification to the battery compartment to reduce time delay	14	3/15/2016	3/29/2016	Jeff
	12.7 Balance Calibration	To test UAV submerged to gather sensoring data	The test to gather sensoring data	14	3/13/2016	3/27/2016	Ha

The concept design process took longer than expected, but helped us in the long run because we had something to base our final design on. Each part of the project was broken down and evaluated separately. We were able to use the drawings that each member had and came up with an overall drawing which we later created a CAD model that is shown in Figure 3-1.

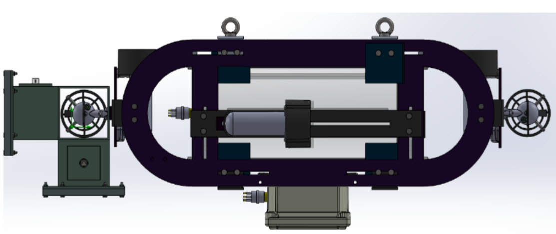

Figure 3-1 CAD Assembled Drawing Model

IV. MECHANICAL SYSTEMS

Panther's structure system consists of a clear acrylic hull, aluminum caps, aluminum side and cross frames. Our main goal was to improve last year's waterproofing. We achieved that by adding O-Rings to the caps. The entire assembly was then drawn up in NX 7.5 CAD software and analyzed with Abaqus CAE 6.12 and Hypermesh 13 software for structural rigidity. The AUV also was analyzed for flow simulation with Solidworks Computational Fluid Dynamics.

A. Hull

The hull of the AUV was sized to fit and protect all the internal electrical components. The main hull is designed with cylindrical acrylic tube that has aluminum caps. These caps provide the waterproof ability with the help of O-Rings that are sized and fitted to Parker's O-Ring handbook. Figure 4-1 shows the CAD Model of the Hull with the Acrylic material.

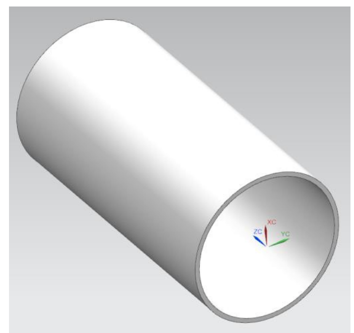

Figure 4-1 CAD Model of Acrylic Hull

B. Frame

The structure for the AUV needs to be sturdy, light weight, and smaller than or equal to the maximum size constraint of 6' x 3' x 3'. Part of the constraints for this year includes reusing as many components from the previous year's AUV as possible; therefore, the structure of last year's AUV will be used. The structure is made of 3/16" aluminum 6061 and it is 2' x 1' x 1' in size. The shape of the structure is also compatible with the concept cylindrical hull that is roughly 18" long with an outer diameter of 8.5". The structure selected will satisfy the size requirements and will be compatible with the concept hull design, further detailed analysis will be performed to ensure that the thickness of the aluminum will endure the forces the structure will have to endure. Figure 4-2 shows the CAD Model of the Right Frame

Figure 4-2 CAD Model of Right Frame

C. Battery Box

This year the team decided to implement a new feature on the AUV. We added a battery box to the bottom of the AUV to help reduce cycle time during competition. We know that time is very valuable, so we wanted to make sure that the delivery to set. Figure 4-3 shows the CAD model of the Battery Box that we created.

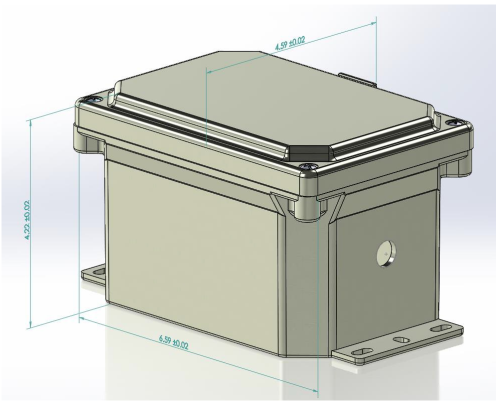

Figure 4-3 CAD Model of Battery Box

D. Analysis

To verify if the structural integrity and load force on the components are capable of withstanding the applied loads and forces, a Finite Element Analysis (FEA) was performed. This is to ensure that no components would undergo excessive stresses while the AUV is operating. Figure 4-4 shows the Solidworks simulation analysis completed on the AUV. This analysis was done to determine the total volume of 1581.091 in^3 which was completed including the solid of the hull.

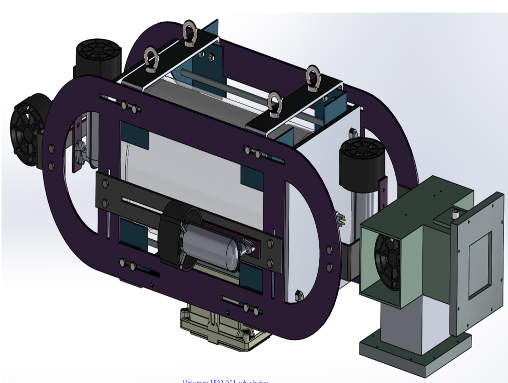

Figure 4-4 Sub Partial Volume Analysis

Figure 4-5 and Figure 4-6 show the Solidworks Flow simulation analysis completed on the AUV. The moving speed of the sub based on the calculations is 6.0 in/s. This analysis was done to determine the maximum velocity flow of 6.72 in/sec.

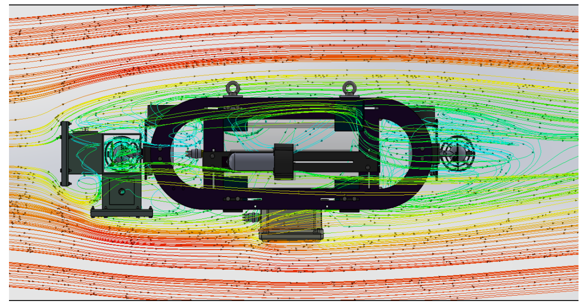

Figure 4-5 Velocity Flow Analysis 1

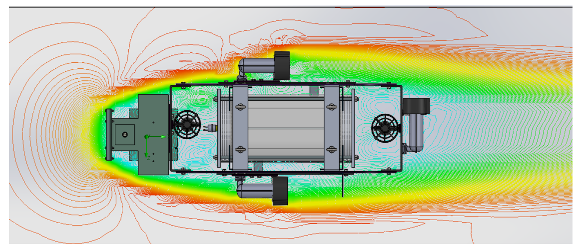

Figure 4-6 Velocity Flow Analysis 2

Using some equation from Fluid Dynamic, the maximum pressure at maximum depth 38 ft (11.58 m) during dive operation is P= ρ · g · h= 11.58*9.81*1000 = 113599.8 Pa = 113.6 kPa=16.389 psi. Based on the calculations, the maximum pressure at a depth of 38 feet acting on the hull is 16.389 psi.

Figure 4-7 shows the Solidworks simulation analysis completed on the hull of the AUV. This analysis was done to determine the amount of pressure the hull can withstand when the AUV is in diving mode. The maximum pressure the Hull can withstand when diving at 16.389 psi was determined to be 315.9 psi.

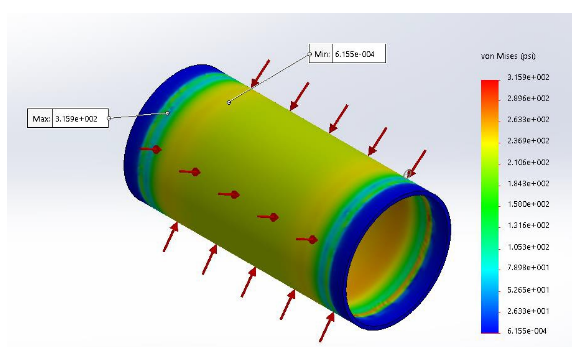

Figure 4-7 Hull Analysis Dive Pressure

Figure 4-8 and Figure 4-9 shows the ANSYS analysis completed on the AUV. This analysis was done to determine the Maximum amount of Stress the AUV can withstand. The maximum Stress was determined to be 5924.9 psi. This is highlighted in red. Figure 4-8 shows that as the applied force on 4 bolts the stress on the brackets are still in the green zone, and light blue, so the max stress is around 1316.6 psi.

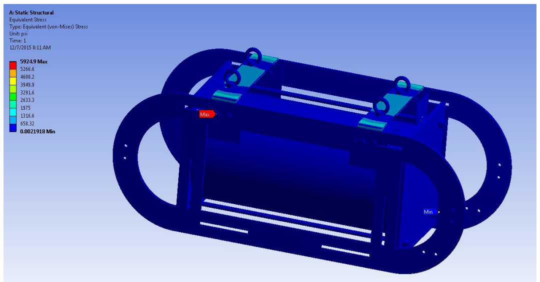

Figure 4-8 Stress Analysis on Cross Members

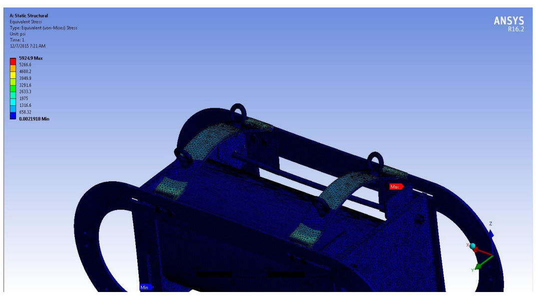

Figure 4-9 Stress Analysis on top brackets of AUV

Figure 4-10shows the Solidworks analysis of the battery box of the AUV. Based on the calculation, the original weight of the battery box is 1.67 lbs. In addition, the total weight of 2 packs of battery are 360g*2= 720g=1.588 lbs. So the total weight of the box and the battery is about 3.258 lbs. Use the same weight, and assigned material for the box, applied the total weight on the battery mount, we can find the von Misses of the mount is 520.529 psi shown in the Figure below.

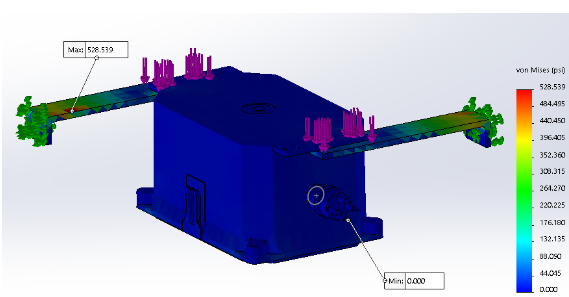

Figure 4-10 Solidworks analysis of the battery box

From the result of the Figure above, using Solidworks we can find the minimum of factor of safety for the battery mount is about 41.388 is shown in the Figure 4-11.

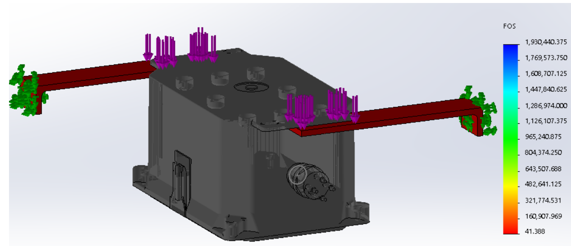

Figure 4-11 Solidworks analysis of the battery box

E. Buoyancy and stability

To keep the AUV from rolling and swaying underwater, the center of mass was calculated and used for finding the center of buoyancy. From these calculations the differences between the positions of mass center of gravity acting on the body were determined and the locations were noted. From the center of buoyancy location, PVC tubes were added. The sizes and lengths of the pipes were based on the data obtained from buoyancy calculations. Figure 4-12 shows the added PVC tubes.

Figure 4-12 PVC Tubes for stability

F. Thrusters For propulsion,

Panther has 6 Seabotix BTD150 thrusters. This is one of the main components that was reused from last year's AUV. These thrusters have been reliable in the past and have endured all the testing that the AUV has done. This thrusters at half power provide the AUV with a speed of 6 inches per second. This is the speed that was used for the CFD as explained above. Figure 4-13 shows the vertical thruster

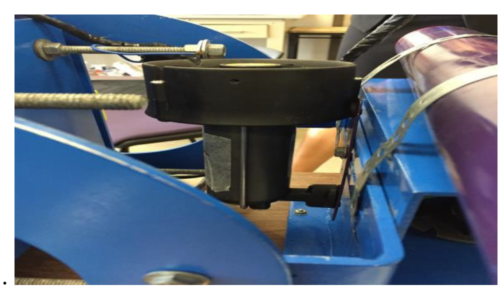

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Figure 4-13 Vertical Thruster

G. Connectors

Connectors are a very important component to the AUV's communication system; Connectors from SubConn were used due to the reliability and connect-ability. These SubConn connectors are Wet-Connect which mean that they can be connected or disconnected underwater. The connectors were installed directly to one of the end caps. Figure 4-14 shows the connectors being installed to the cap.

Figure 4-14 SubConn Connectors

V.ELECTRICAL SYSTEMS

Panther's Electrical System includes both power and controls. The controls system saves processing time by interfacing a data acquisition and processing module and a desktop computer in a server/client configuration. Splitting the processing work allows for heavy lifting and quick response times to make the best of the 30 minute time limit of runs. The power system consists of easy to find, modular, and replaceable components, leaving room for upgrades and effective repair.

A. Power System

The power consists of multiple electrical components that are assembled in the electronics cage. The electronics cage houses all the major electronic components that allow the sub to run autonomously. This cage is stationed in the inner hull and in its current stage there is a lot of clutter. There are gold plated audio plugs, which are excessive in weight. The placement on the wires may disconnect or break when removing the cage from the hull to operate. Currently the batteries are staged at the bottom of the electronics cage but it would be ideal to remove them to their own housing. Figures 5-1 displays the electronics cage.

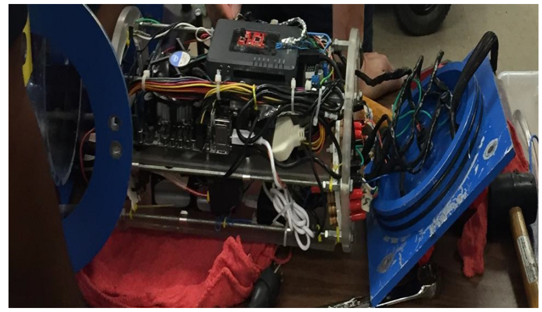

Figure 5-1 Electronics Cage

B. Computer System

The computer system is a mini-itx motherboard using an m2 solid state drive, a single DDR3 8GB RAM module, and the Intel I-7 4790S low power processor with onboard graphics. It is powered using the M4- ATX power supply by Minibox. The computer system interfaces using USB connectors with the motor controllers, the NI MyRio, and the Logitech C920 webcams.

In measurement and control applications, programming is just one task of a system designer. Engineers often don't have time to keep up with or rewrite old software to support the advancements in computing and measurement hardware, operating systems, and so on. They add value by figuring out how to acquire, manipulate, and present real-world data—not by coming up with new ways to handle memory allocations and thread pools. By using LabVIEW, you can build on top of tested, supported, and maintained libraries of lower level code from NI. Choosing C means you'll need to implement, support, and maintain your own lower level libraries or purchase them from a vendor (NI offers NI LabWindows ™/CVI software and NI Measurement Studio for this use case) [30].

Syntax-wise, C is optimized for sequential execution of instructions as fast as the CPU can handle them. This is perfect for pure computation, when only one task is being executed and instructions are more basic. The graphical syntax in LabVIEW, on the other hand, is optimized for the parallel execution of tasks that have real-world timing constraints [30]. The current Sub already have LabVIEW implement.

C. Data Acquisition System

Data acquisition simply means taking the input from various sensors and preprocessing that input for use by the computer. The sensors include a Sparkfun 9DOF razor IMU, three Aquarian Audio H1c hydrophones, and a Honeywell MLH050PGP06A depth sensor. Each of these interfaces serially with NI MyRio which then handles pre-processing of the data by applying sensor fusion and an extended Kalman filter. All of these devices are powered from interfacing with the NI MyRio, which itself is powered through a voltage regulator connected to the power rail. The filtered values are then sent to the computer system which will use the values to create outputs to the control system.

D. Controls System

6 Pololu SMC 24v12 are interfaced using USB with the computer. These motor controllers take in voltage from the parallel power rail and throttle voltage to the Seabotix BTD150 thrusters. The amount throttled is determined by values sent serially over the USB connection. These controls are determined by which task the AI has selected based on inputs from the environment. Nessie uses only IMU and depth sensor data in order to complete the gate task. It does this by recording the original orientation and stopping forward thrust to make adjustments to orientation. Once the gate task is completed, Panther switches to visual data and its relative position to the center of the respective camera to control itself. The completion of line following tasks creates a counter which is used to determine the current task.

E. Networking System

Preliminary research of the networking system showed that a USB device could be powered with up to 15 feet of cable. In practice, only low voltage devices such as computer mice will work. The voltage drop over such a length of cable proved too much distance for the powering of a USB wi-fi card. As such, a separately contained system for networking was implemented by using a waterproofed box which will float on the surface. The system uses a powered USB hub and a voltage regulator with nickle rechargeable batteries as the power source. Since this power source was narrowed down to causing interference, it was grounded on the negative terminal of the batteries to the endcap. PVAUV: Panther – Prairie View A&M University 7 The wi-fi card connects to any wireless router which allows a programmer to connect to the computer via LAN. Windows remote desktop software is used to inspect code as it updates in real time and allows for quick readjustment. This system is not required to run the robot, it is only for testing purposes.

F. TESTING

For the first water test of the sub, many challenges were faced. The challenges included being able to connect to the AUV through the tether line, opening/closing the hull of the sub, running the existing LabView program, and controlling the sub through the LabView program. After resolving all connection issues with the tether, the sub was lowered into a pool and the existing program was ran. From this test, the group concluded that there was an issue regarding the thruster power output because the sub would only run in a circle instead of straight. The group checked all of the motor controllers to rule out the cause of the problem being malfunctioning.

VI.CONCLUSION

The Prairie View A&M University Mechanical and Electrical AUV team were able to fully assemble, program, and test the designed AUV. Right now we are preparing for competition that will take place in July 25th-31st, 2016. Good luck to all the participates.

VII. ACKNOWLEDGMENTS

The Autonomous Underwater Vehicle senior design team would like to thank Naval Sea Systems Command (NAVSEA), for continued support and sponsorship of this design project. We would also like to acknowledge Dr. Xiaobo Peng and Dr. Paul O. Biney for reviewing and providing feedback on our reports, and advising us throughout the process of completing this senior design project. We give special thanks to Mr. Riaz and Mr. Lee for sharing information and tips from their experiences with the Autonomous Underwater Vehicle Senior Design Project from the previous years. Appreciation is also extended to the members of the electrical engineering team for working with us to fulfill this project. Electrical engineering team members are: Alexus Hall, Ali Shahzad, Jessica Keys, Spencer Holman, and Quaviz Owens.

VIII. REFERENCES

[1] "Structural Engineer: Description." | Prospects.ac.uk. N.p., n.d. Web. 30 Sept. 2015- “Design of Ship Hull Structures”: A Practical Guide for Engineers By Yasuhisa Okumoto, Yu Takeda, Masaki Mano, Tetsuo Okada

[2] Statement, Regularly Required, When Releasing Navy Documents To Public, and Domain. AUVSI Foundation and ONR (n.d.): n. pag. Web. 9 Oct. 2015-

[3] Paper Submitted to the ”Science and Defence Conf”, Brest, France, 19 October 2004 Power Sources for AUVs (n.d.): n. pag. Web. 9 Oct. 2015-

[4] Web 15- Oct. 2015 http://www.cuauv.org/vehicles/nova/mechanical/heat-transferuhpv

[5] "Properties of Aluminium." Aluminium Design RSS. Web. 15 Oct. 2015

[6] "Poly(methyl Methacrylate)." Wikipedia. Wikimedia Foundation. Web. 04 May 2016. <https://en.wikipedia.org/wiki/Poly(methyl_methacrylate)>.

[7] "Buoyancy." Pressure. Web. 04 May 2016. <http://hyperphysics.phy-astr.gsu.edu/hbase/pbuoy.html>. 130

[8] Wikipedia. Wikimedia Foundation. Web. 7 Dec. 2015- <https://en.wikipedia.org/wiki/Electromagnetic_interference>.

[9] Wikipedia. Wikimedia Foundation. Web. 7 Dec. 2015- <https://en.wikipedia.org/wiki/Twisted_pair>.

[10] "Wire Gauge and Current Limits Including Skin Depth and Strength." Web. 7 Dec. 2015-

[11] "Experience the Best in Action Video." Web. 7 Dec. 2015- <https://www.isawcamera.us/>.

[12] "CMUcam5 Pixy." Overview. Web. 7 Dec. 2015-

[13] "Kalman Filter Recipes for Real-time Image Processing." Kalman Filter Recipes for Real-time Image Processing. Web. 04 May 2016. <http://www.sciencedirect.com/science/article/pii/S1077201403000640>.