Prairie View A&M University AUV Robotics: Transitioning from the PV Inspire I to PV Inspire II

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Abstract— **The Prairie View A&M Autonomous Underwater Vehicle (PV AUV) Robotics Team is a team comprised of mechanical, and electrical engineering students under the advisement of respective professors from within the Roy G. Perry College of Engineering. Innovations in autonomous subsea robots have been extremely valuable. To the oil and gas industry, these robots perform several underwater functionalities such as, but not limited to, mapping underwater terrain for potential oil reservoirs or monitoring and quickly fixing piping leaks. Through the exploitation and reimaging of existing technologies and methods utilized to manufacture current autonomous underwater vehicles (AUVs), the team designed, engineered, and programmed the *PV Inspire II* to compete in the 2019 International RoboSub Competition.**

Entities that employ AUVs to do subsea work desire a robot that is intelligent and equipped to respond to a variety of underwater challenges quickly without any external assistance. Aiming to satisfy competition goals and provide solutions to industry matters, the *PV Inspire II* is fashioned to exceed its predecessor the *PV Inspire I* in overall functionality, capable of interpreting and following visual cues, manipulating the environment, maintaining control under harsh underwater conditions, and executing desired tasks efficiently. The standard four thruster arrangement and ballast tank design ensures a high level of maneuverability and increases the vehicle's overall modularity. A forward-facing camera allows the AUV to scope out and follow the pool floor while a servo-operated, also to navigate the vehicle through its surroundings. The vehicle's navigation system, computational boards, and main power source are sealed within a large egg shape hull, creating a simplistic, yet intricate and lightweight design.

I. INTRODUCTION

Established since 2011, PV AUV is a yearly senior design project structured to challenge a collaborative team of engineers of various disciplines to design and build a fully autonomous underwater vehicle, capable of competing in the AUVSI RoboSub Competition. This year students were originally asked to redesign a new

AUV, *PV Inspire II*. While the *PV Inspire I* vehicle proved to be structurally sound, the overall deterioration of the vehicle's frame, electrical connections, and unresolved water leakage inspired the 2019 PV AUV team to push the boundaries and design a completely new sub. Hence, the *PV Inspire II* was engineered not only to surpass its predecessor in the technical aspect but to serve as a turning point for the engineering program at Prairie View, inspiring students to go beyond self-imposed limits and aspire to produce products of excellence.

II. DESIGN STRATEGY

The *PV Inspire II* is designed to satisfy four main project objectives: functionality, convenience, safety, and economic consideration. Restricted to primarily in-house fabrication, a limited budget, and a yearly time constraint, the team focused on creating a simple and effective, yet cost-efficient sub. A successful design that incorporates a high degree of modularity and maneuverability, target tracking capabilities with stereo cams, and a fully integrated navigation system will hypothetically allow the AUV to meet the basic navigational goals and leave room for future teams to develop the vehicle for additional task items. In retrospect, previous teams designed a hull to fit a rigid frame and subsequently manipulated the weight and buoyancy according to the addition and placement of external housings. The open-frame design, for example, has a thin cross-sectional frame for easy movement in the forward and backward directions. The selected composite material, fiberglass and carbon fiber, meet the high strength to low weight ratio, no corrosion effect, and is overall considered "excellence" [1] for underwater vehicle structures. In comparison to earlier variations of the AUV, the compact frame make it easy for transportation. However, the rigid structure configuration, which was designed to fit the hull in its entirety while remaining within the AUVSI maximum size constraints, limited the versatility for other, potential components and left little to no room for any major adjustments along the frame. Focusing primarily on increasing stability and reliability without sacrificing capability, this year's team opted to move most of the electronics inside a single hull. The final design of the PV Inspire II, shown in Fig. 1, emphasizes simplicity and functionality and easily accessible components allowing for the adjustment of current parts and the retrofitting of any additional parts.

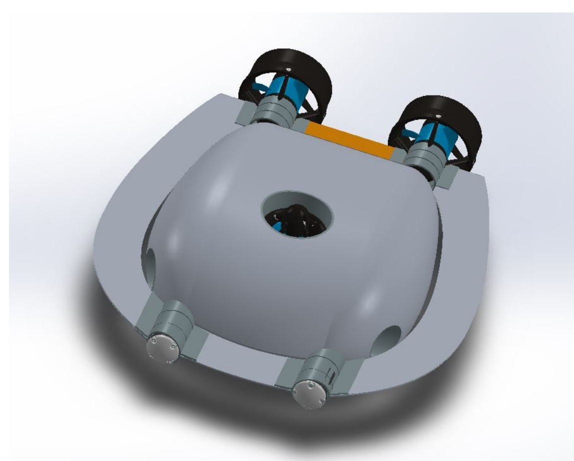

Fig. 1 Solidworks rendering of the finalized *PV Inspire II*

III. VEHICLE DESIGN

The purpose of the 2018-2019 AUV design, *PV Inspire II*, is to allow students to grasp the basics of underwater control, be exposed to the RobSub competition for the following year, and have a capable model for further improvement. To keep within the four major self-established statutes, the sub was designed in mind with a simple, robust and unique framework.

A. Preliminary Design

By dissecting and grasping the failures and successes of previous design concepts applied to the *PV Inspire I*, the team acknowledged common mistakes and incorporated effective techniques and ideas into the current design. The preliminary design of the *PV Inspire II* began with a functional decomposition flowchart that specified the main function the AUV needed to accomplish and sub-functions that explicitly define how the team would enable the vehicle to deliver. Given the difficulties experienced by previous teams in navigation and sensory tasks, the main function consisted of the AUV completing three specified competition tasks. Enabling the vehicle to move to a specified destination and integrating the electronic components served as the two major sub-functions which shaped the ideas that populated the concept generation chart. Ideas were collectively evaluated and either denoted as a “GO” or a “NO-GO” based on general efficiency, effectiveness, and reliability. From there, ideas denoted as “GO” were discussed at length based on a more detailed set of criteria, considering additional factors such as how much time and funding the team would have to incorporate the concept, manufacturability, longevity, and whether the concept would keep the vehicle lightweight.

The design displayed in Fig.2 demonstrates the initial compilation of the resulting “GO” concepts' and ideas from the decision-matrix selection process. This original design was implemented as the redesign of The Inspire I of 2018. The previous year model did not implement any additional lighting to aid the camera systems and needed a tremendous amount of weight added to counteract the buoyancy. As shown in Fig 1, those notable drawbacks have been corrected with coated steel beam weights permanently attached to the side frame support (code name Halo) and underwater front beam lights.

Table 1: The Overview of the PV Inspire II

Specification	**Dimensions**
Length	24 in
Width	16 in
Height	7.5 in
Weight	20.1 lbs/ 9.12 kg
Max Depth	30 ft.
Thruster	4 x Blue Robotics T100
Cameras	USB Camera

Inertial Navigation System	Inertial Measurement Unit
Operating Frameworks	Arduino Mega, Intel Celeron

**The listed weight in the table doesn't include any ballasts or additional weights needed to obtain .5% buoyancy*

B. Mechanical Systems

Detailed process and design analysis equations and simulations were applied and conducted on all the AUV's major components. The gathered results further determined the reliability as well as the robustness of the vehicle and gave deeper insight into hidden failure points. Solid Works, ANSYS, and Siemens NX were all utilized to run analyses on various parts of the Inspire. Much of the structure has changed from the previous year's mechanical systems. Which is the result of refinement from leaks, that ended up decommissioning previous models, and other the lack of safeguards to protect electronics from water damage.

1) The Hull

Last year a cylindrical, acrylic hull was used, which served as the main housing unit for all the electrical components (including the battery), was the reused component from the *Panther* [2]. As a transparent material, it allows to quickly diagnose and identify problems even while sealed and submerged underwater, but consequently weaker than other materials such as aluminum, polycarbonate, and fiberglass. A thorough hydrostatic analysis was simulated in Solid Works to ensure structure failure due to increased water pressure would not cause the hull to fail, the design was limited due to its cylindrical structure.

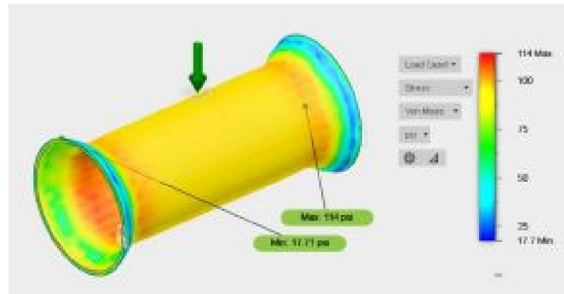

Fig. 2 Stress Analysis for the Hull

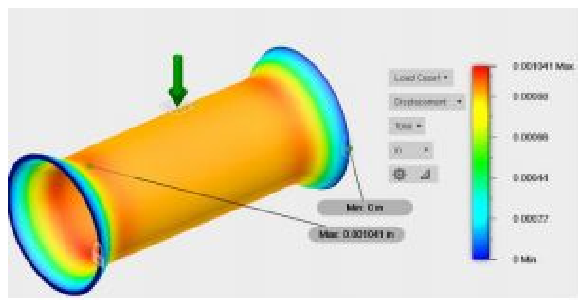

Fig. 3 Displacement Analysis for Hull

The new housing design in Fig. 4 composed of fiberglass for its lightweight characteristics and the shape allows the team to utilize the entire space inside the housing. At a competition depth of 16 feet, the pressure induced on the tube would be estimated to be 6.94 psi (pounds per square inch) as displayed in Fig. 2. Compared to the acrylic yield strength of 7092 psi, hull failure due to increasing water pressure was determined to be ineffective. A deflection analysis was also conducted, resulting in a theoretical displacement of no more than

.001 inches, which was determined to be insignificant in affecting the inner electronics as well as any detriment to the seals from the acrylic caps.

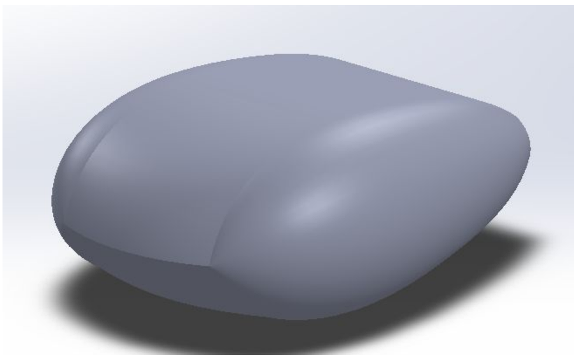

Fig. 4 PV Inspire II Housing

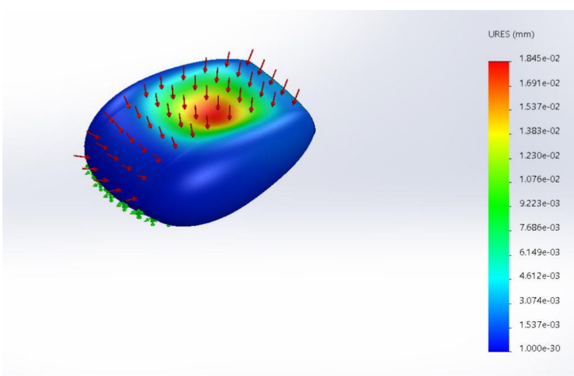

Fig. 5 Housing analysis

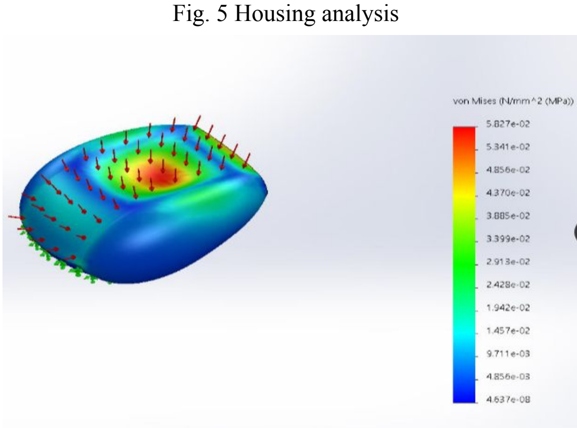

Fig. 6 Housing analysis II

IV. Electrical System

The greatest lesson the team learned in the development and integration of the electrical system was contingency. Given the experiences of the teams in previous years, navigation and system control has continually been a problem for the PV AUV team. The second system was designed to complete the basic functionalities needed to carry out the aforementioned, navigational tasks, leaving room for expansion building towards the competition and future endeavors.

1) Hardware

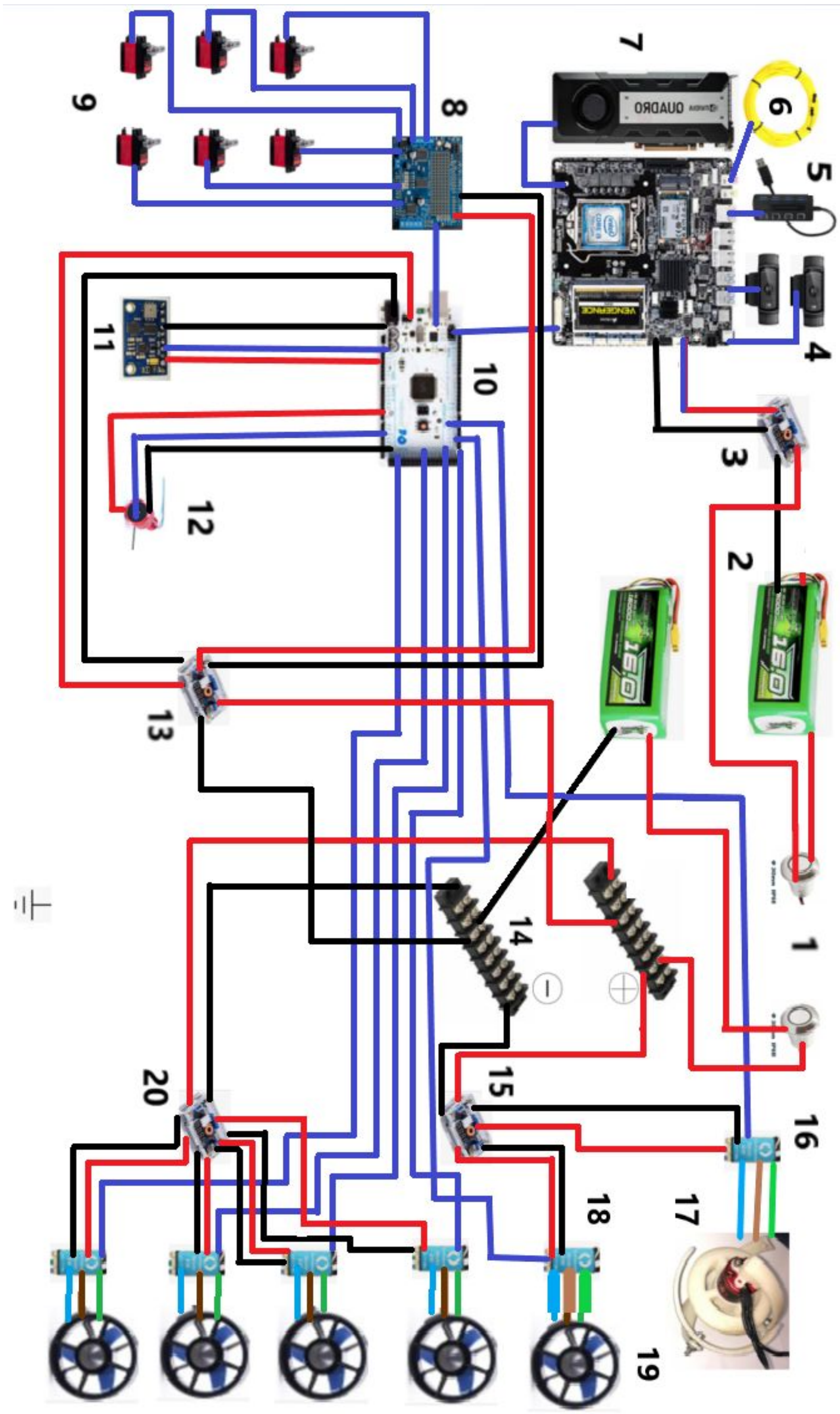

Fig 7. Hardware Architecture

Table 2: Hardware Components

Number	**Component**
1	Switches
2	Multi-Star Batteries
3 , 13 ,15,20	DC-DC Converters
4	Cameras
5	USB Hub
6	Tether
7	Motherboard
8	Motor Controller Shield
9	Servo Motors
10	Arduino Mega
11	Gy-80 Sensor
12	Bar 30 Pressure Sensor
14	Terminal Hubs
17	Mechanical Gyro
18	Electronic Speed Controllers
19	T-100 Thruster

2) Power System

The *PV Inspire II* is powered by two 14.8V, 20Ah or two 16aH Li-Po battery, located on the second tray of the electronic control system rack (ECSR). The battery's capacity is sufficient to provide run time of at most 2 hours based on testing and observation from last year testing and trial runs of which far exceeds the fifteen-minute time limit for actual and practice run segments of the competition.

The power supplied by the battery is conditioned by way of two heavy duty waterproof switch. When individually enabled the switch distributes power through 2 branches within the electronic control system rack (ECSR). Switch one sources power through SSR-1, through to a LM2596 Buck Stepdown DC voltage regulator which conditions the voltage to the recommended input operating parameters for the microcontroller boards. Switch two sources power through SSR-2, directly to a twelve-gang terminal block (TB-1), wired to individually power each of the electronic speed controllers (ESC) that operate its associated connected thruster. Uniquely assigned (addressed) output pins on the Arduino microcontroller is wire to each ESC, providing enabling control signals to the thrusters. The camera(s) are operated and controlled from a mini STX motherboard

3) Computer and processing

Each functional component of the *PV Inspire II* is operated by two primary processing components: the Arduino Mega 2560 and Intel Celeron. The Arduino is responsible for utilizing the Inertia Measuring Unit (IMU) in order to adjust the thrust based on orientation of the vehicle. The motherboard is for graphics processing of the camera for Originally, each board was responsible for one major component or functionality of the Inspire. However, based on limited time and complexity of the programming, most functionalities will be run using the Arduino Mega 2560. This will not include the camera which is working with the Intel Celero not include the camera which is working with the Intel Celeron.

4) Thrusters

The Blue Robotics T100 thrusters supply the necessary force to propel the vehicle and allow it to navigate in a desired direction (forward, backward, left, right, up, down). The design of the PV Inspire allows each of the eight thrusters to be moved to relatively any position along its respective axis (Fig. 8).

Fig. 8 Example of Thruster Modularity Along Past Platform Base

A hydrostatic pressure contour was conducted to determine the best positioning for the thrusters. The side-thruster configuration displayed in Fig. 9, allows for the best equal distribution of the pressure along the front of the vehicle, rather than in one area. Although the positioning of the side-thrusters appears to perform best at a higher altitude, keeping them aligned with the center of pressure will always yield favorable results.

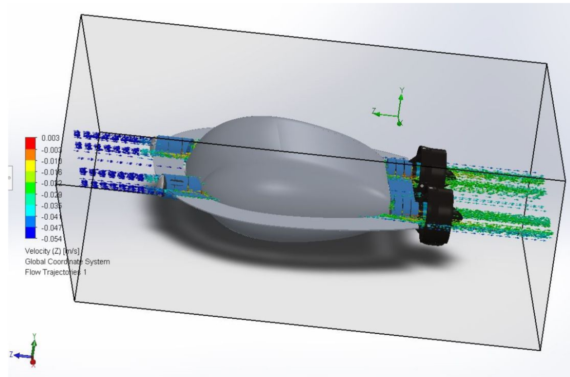

Fig. 9 ANSYS rendering of a Pressure Contour Analysis

5) The Halo

The Halo serves as brackets for the thrusters to attach to the AUV. Another important purpose of the Halo is to protect the housing of the AUV from any unwanted contact. The Halo is also in foldable design for ease of carrying and practicality. The analysis is done on the front fin depicted in Fig. 8.

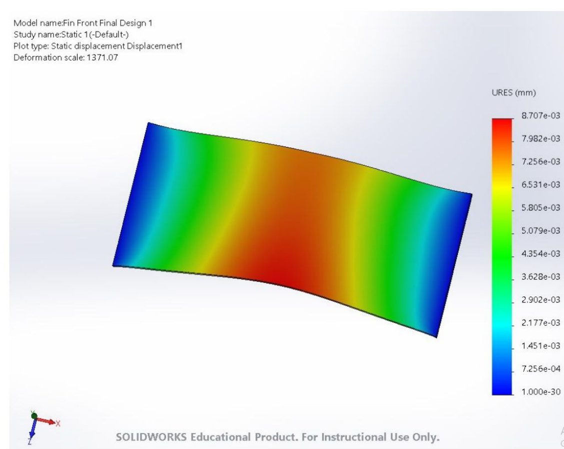

Fig.10 Static displacement on front fin

IV. EXPERIMENTAL RESULTS

Primary testing was directed to thoroughly waterproofing the hull. After using lubrication, petroleum jelly to silicon grease, waterproofing was no longer an issue and allowed for the integration and implementation of the electronics. Plasti-dip was also used at the front of the hull to seal any small leaks the inevitably presented itself. During this phase of testing, the team observed and confirmed that while the AUV maintained balance and was statically and dynamically stable, and by adding several removable dead weights presented a problem. Adding large preset that become a part of the main structure permanently where less removable weights were needed. Currently, certain components of the vehicle are being modified to help reduce buoyancy and add weight. For the camera system, the lighting was added in order to improve color recognition underwater, but at the cost of larger voltage draw from the main electrical system. Coding was eventually added to reduce brightness or control the brightness based on the task pursued. Although the thruster configuration has been completed, the programming for the camera processing, as well as the IMU and depth sensor is still being calibrated. Additional functionalities of the PV Inspire II will be incorporated based on time. In the future, testing of the electronic components should begin during the first semester to minimize unforeseeable mishaps such defective or unnecessary parts. Extra consideration to minor details as well as improved accountability from individual teams, mechanical, electrical and computer engineering, will allow the collaborative team to arrange more testing time and less contingency options.

V. Acknowledgments

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