College of ENGINEERING

VILLANOVA UNIVERSITY

# Villanova University
# Autonomous Surface Vehicle Competition
# ‘Captain Planet’

*Abstract*

The Villanova Autonomous Surface Vehicle has been modified for the 2011 Autonomous Surface Vehicle competition. Building off of the same frame, original hull, and original drive train systems designed by previous year's teams, the 2011 ASV team has modified the vehicle to more effectively navigate through obstacles in water and to complete most of the 2011 competition tasks. The ASV weighs about 117 lbs and is approximately 2.75 feet in height, 5.5 feet in length, and 2 ft in width. This year's ASV, shown in Figure 1 below represents the collaborative efforts of the Villanova University Team to create the most efficient vehicle possible without sacrificing effectiveness given the limited amount of time for development.

**Figure 1: 2011 Villanova ASV**

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**Introduction**:

This year's ASV team consists of undergraduate and graduate students from Villanova University. The 2011 team is composed of the following students:

- ●Ralph Sullivan (*graduate mechanical engineering student)*
- ●Joseph Denny, Nicholas DiLeo, Ryan Holihan, and Lester McMackin (*undergraduate mechanical engineering students*)
- ●Shahriar Kahn (*undergraduate electrical engineering student*).

This year's team is lead by Dr. Helen Loeb and Dr. Dongbin Lee. Team *Captain Planet* is advised by Dr. C. Nataraj, chairman of the mechanical engineering department at Villanova University.

**Mission**:

The 2011 competition contains two categories of tasks. Mandatory tasks must be completed first. The first mandatory task is a propulsion test in which the ASV must demonstrate the maximum thrust it can produce. Next, navigation is tested when the ASV locates and proceeds through the starting gate. The time it takes *Captain Planet* to enter and exit the speed gates will make up the speed test. The final mandatory task is navigating through a channel marked by red and green buoys. Throughout this task, Captain Planet must also avoid yellow buoys, which will be placed within the navigation channel.

Once the four mandatory tasks are completed, the challenge stations may be attempted. These challenges consist of four different "elemental" stations where the ASV can find and record the location of a hot target, turn off an artificial waterfall, extinguish an artificial fire, and retrieve a treasure located on land. After attempting all four challenge stations, a bonus task may be completed by returning to the dock back through the navigation channel. The course layout may be seen below in Figure 2.

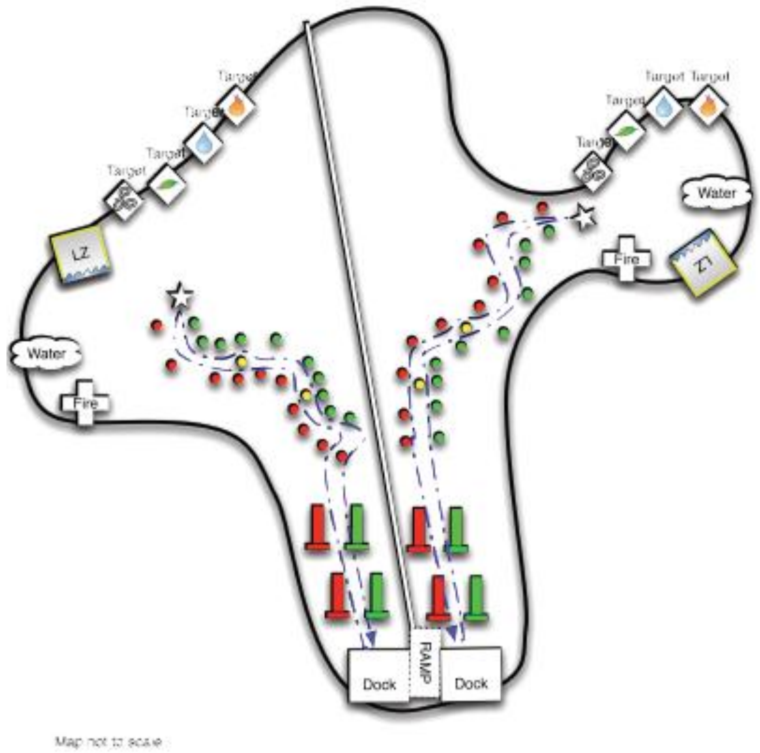


**Figure 2: 2011 Competition Map**

*Captain Planet* will opt to attempt the fire, air, and possibly water challenges. The team evaluated the earth task and proposed solutions such as using a suction device (e.g. handheld vacuum) to pull the ball from its position onto the ASV. Although feasible, this task will not be attempted by *Captain Planet* due to time constraints. The fire test, which includes shooting water through a target, will be accomplished by finding the target with the vision system then properly positioning the water pump (mounted on servos) to shoot a specified amount of water through the identified target. In the air task, *Captain Planet* must identify one target (out of four) that is 20°C hotter than the ambient air and the other targets. The ASV must subsequently report the hot target's GPS position and elemental symbol to the competition network. This task will be accomplished by using an infrared temperature gun to record differences in temperature. The symbol of that hot target can then be identified by the video algorithm. *Captain Planet* may attempt the water challenge in which the ASV must travel under a waterfall to press a stop button. It has been determined that the craft may not go completely under the waterfall since there are several instruments (e.g. camera and lidar) that must be kept dry. If this task is accomplished, it will be in the form of an arm that extends from the boat, through the waterfall, and turns the button off. If these tasks can be accomplished, it will be a successful mission for *Captain Planet*.

**Mechanical Systems**:

*1) Shell and Frame:*

The shell of the ASV is a Thule 682 Sidekick, car-top carrier, with a custom fabricated fiberglass cover. Due to the fact that the shell is too thin and flexible to restrain the ASV's internal components, an internal frame was constructed out of $1/20^{th}$ inch thickness aluminum to form a hollow 1" by 1" frame. Figure 3 on the following page shows a SolidWorks model of the shell and frame of the ASV.

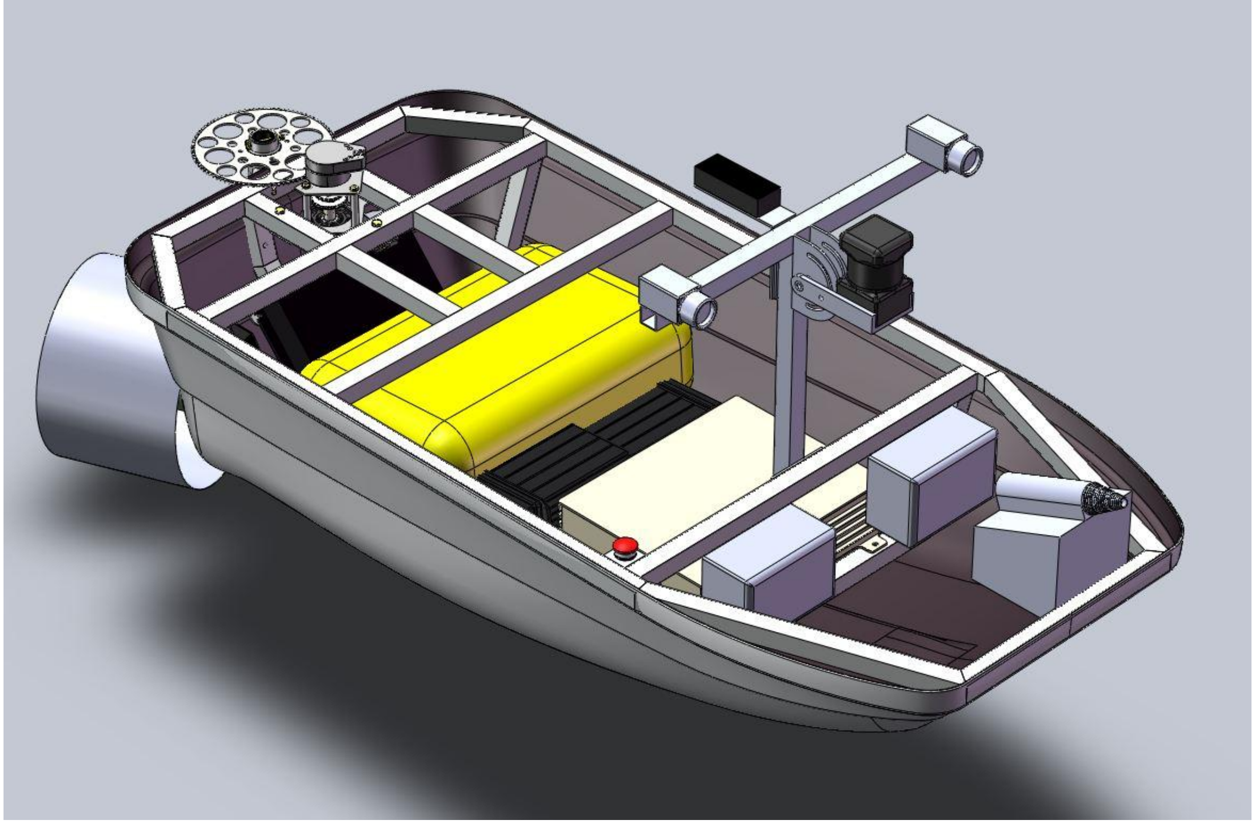

**Figure 3: Model of *Captain Planet***

*2) Propulsion and Steering:*

Providing the ASV with propulsion is a 40 lb-thrust Minn Kota trolling motor. The motor has a capability of 3000 RPM and a maximum speed of about 5 knots. Surrounding the propeller of the trolling motor is an aluminum shroud, put in place for safety purposes as a rule listed in the competition manual. The steering system of the ASV is a gear system powered by an AME-series 12-volt RH gear DC automobile window motor. The gear ratio of the trolling motor shaft to the steering motor is 6:1.

*3) Water Pump:*

The ASV is equipped with a Flojet 24V DC Water pump capable of 40 psi and a flow rate of 4.2 gallons per minute to provide the ASV with the ideal water jet to put out “fires.” To direct the water jet in the right direction, 2 HITech Servo motors are used to control the pan and tilt of the water jet. This will allow *Captain Planet* to accurately pump water through the target during the fire task.

**Electrical Systems:**

*1) Main Electrical System:*

The electrical system serves to supply power to all systems on *Captain Planet*. The ASV is powered by two 12 Volt *Odyssey* batteries. This was chosen because the ASV's motor controllers work off a 24 Volt power supply that can be obtained when these batteries are wired in series. Additionally, the batteries are already waterproofed, which meets competition guidelines.

Two DC/DC converters- a 5 and 12 Volt- hook up to the electrical system in order to give different devices on the ASV the correct amount of voltage. The video processor, GPS, INS, encoder, and compass connect to the 5 Volt regulator, while the control box, cameras, and lidar connect to the 12 Volt regulator. In order to turn the boat on, both manual and wireless emergency stop switches need to be set in the on position. Finally, the power switch located on the outside of cover must be flipped to the on position.

*2) Navigation System:*

This year's ASV has several options for navigation. The GPS, compass, IMU, video cameras, and lidar all serve as inputs for navigation. The GPS seems to be fairly reliable with an error of approximately ± 2 meters. The GPS alone, however, is not able to be used for navigation of the course. This is especially true in the buoys navigation channel since the channel may shift position a bit and the yellow buoy (which is to be avoided) can move. For navigation of the buoys, *Captain Planet* relies heavily on a video algorithm that can detect buoys in water and can distinguish colors. The video algorithm, which will later be discussed in more detail, is used in conjunction with the output readings from the lidar.

*3) Communication Systems:*

The control box on the ASV communicates with the host computer and downloads its code through xpctarget, a toolbox built into Matlab. Source code is loaded onto the control box via TCP/IP connection. This year, rather than running an Ethernet wire under the boat cover, a wireless router will be used to wirelessly communicate with the control box. Video code must also be transmitted to the control box via TCP/IP connection, so an Ethernet switch was added to switch between the control box and either the video board or the wireless router. This enables the *Captain Planet* team to wirelessly download code to the control box then connect to the video board without having to spend unnecessary time connecting wires under the boat cover.

*4) Video System:*

The vision system is responsible for analyzing the video data that is pertinent to the mission tasks. The video processing is executed on a Texas Instrument DSP processor platform, using the Matlab and Simulink programming environment. The Texas Instruments 642 video card is shown on the following page in Figure 4.

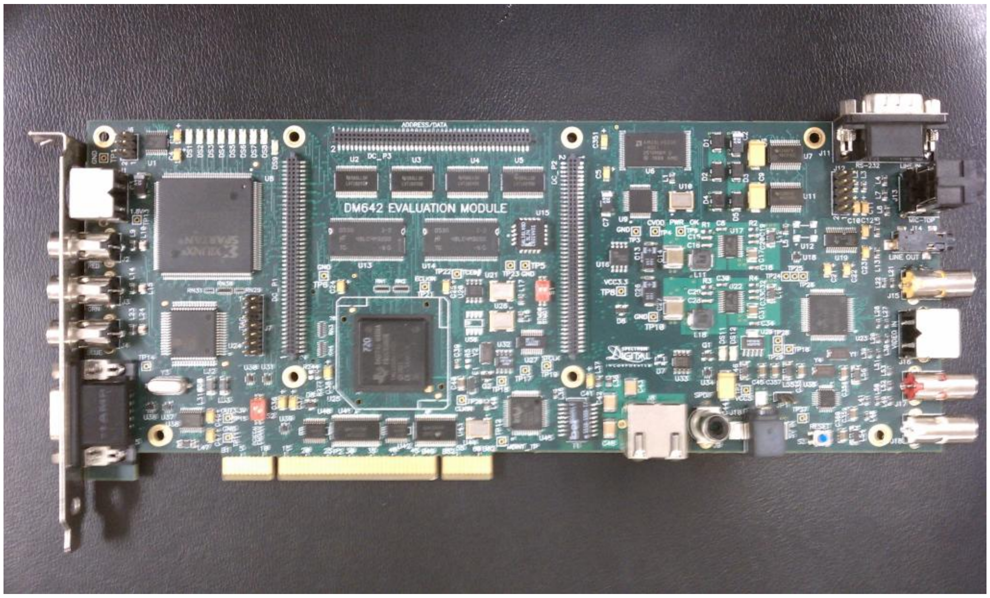


**Figure 4: Texas Instruments 642 Video Card**

The video algorithm mainly focuses on buoy navigation. Buoy detection is completed by processing the YCrCb color space within a given frame. Each pixel within this color space is made up of three values from the three matrices that make it up; one from Y, one from Cr, one from Cb. Since a specific color will have a distinct color combination within these three matrices, three separate processes are used to find where these values exist in a given matrix and these results are logically combined together. This successfully extracts the desired color from the given image. From this output, one the algorithm can compute important data. For example, because the size of the buoys is known, the distance to the buoy can be found by analyzing the number of pixels it takes up on the screen. In the case of the buoy navigation channel, the buoys that are lowest on screen are used for navigation. This correlates to the fact that the lowest buoy in a given frame would be closer to the ASV and must first be processed by the navigation system. Video processing must again be used in the hot task portion of the competition wherein an elemental symbol must be recognized and reported.

*5) Lidar:*

A lidar (light detection and ranging) device uses laser pulses dispersed around the sensor to measure the distance to any objects within the range of the beam and on the plane of the scan. A lidar typically consists of a laser source, receiver, and a rotating mirror that is used to direct the pulses outward in a plane around the source/receiver hardware. The receiver can precisely measure the time it takes for a given pulse to return to the lidar after being reflected from the first object in the line of sight, and from that determine the distance to the object.

The lidar device used by the *Captain Planet* is a Hokuyo UTM-30LX (shown below in Figure 5), which scans a 270 degree semicircular plane with 0.25 degree resolution.

**Figure 5: UTM-30LX Lidar**

This lidar only supports USB output, due to the rate of data output, however the xpc control box is only compatible with serial communication since it does not support hardware interrupts. The Villanova ASV team purchased a Beagleboard to communicate between the lidar and the control box, as the Beagleboard supports a full Linux operating system and has both USB and serial interfaces. The lidar sends data to the Beagleboard over USB, where the raw data is analyzed to extract the location and color of obstacles; this reduced data is then sent over a serial connection to the control box.

*6) Software Development:*

*Captain Planet's* software was developed using Matlab 2008b and Simulink 7.2 for navigation and data acquisition. This code is executed in the xpctarget control box. The video processing code was also developed in Matlab and Simulink, but is executed on the Texas Instruments 642 card. The lidar is interfaced through USB and C++ code was developed with gcc tools under linux.

For project development, source control tools were used both on Windows and linux. SVN was chosen because of its wide support and ease of use. The team's code and documents database is hosted online at www.assembla.com. This allows every member of the team to easily stay in touch with the source code and make changes that can easily be tracked.

**Conclusion**

*Captain Planet* demonstrates the 2011 ASV team's experience in the classroom as well as their experience in practical engineering applications. Building upon the ASV of past years, *Captain Planet* has been remodeled and is expected to perform very well in competition. The additions of this year's team have ensured that *Captain Planet* will complete the mandatory tasks and will perform admirably in the challenge stations.