Duke University Robotics Autonomous Underwater Vehicle: "Gamera"

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Many designs exist for AUVs, however, most only lend themselves to cruising type operations. The Duke University vehicle, Gamera, departs from this trend. It is capable of performing large accelerations, paving the way for high underwater maneuverability.

The students at Duke University AUV team are continuing the use of four flexible fins (Nektors™) arranged in an X-pattern as the main method of propulsion. This technology, developed from a joint venture with Duke University and Nekton Research, LLC, provides the necessary 6-DOF control with only four actuators. With this arrangement, Gamera is capable of imparting large forces to the water very quickly, thereby providing high maneuverability in order to effectively adjust and maintain depth, heading, position, and speed.

Gamera also employs a suite of sensors in order to perform the mission tasks including a RDI Doppler Velocity Log (DVL), a MSI depth sensor, a Tritech altimeter, an acoustic sensor array, and a digital web camera. These sensors can all provide data as to Gamera's location within the environment, thus allowing redundancy and accuracy in calculations for position and orientation of the AUV.

An Ampro PC/104 module running Linux Slackware, 8.0 uses the sensor data along with fine tuned navigation algorithms in order to maneuver the AUV through the environment and accomplish the specified tasks.

1. HARDWARE

1.1 Propulsion motivation:

The means of propulsion for Gamera is by using "…large forces generated from unsteady fluid flow around large pitching flexible foils."[1] Nektors™ [Figure 1] allow a certain level of flexibility that conventionally controlled, propeller based vehicles do not. By arranging these fins into a horizontal X, the vehicle can translate for-aft, side to side, up and down, yaw pitch and roll. This results in the full six degrees of freedom controlled motion from only 4 actuators. Gamera is only the second vehicle to employ this configuration, and the first to do so autonomously.

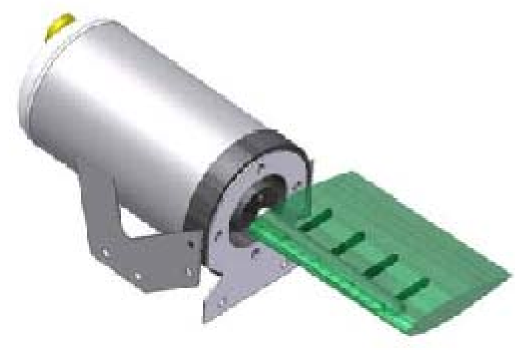

Figure 1: CAD drawing of a Nektor™

The imaginary line drawn between the motor shaft and the midpoint of oscillation is the thrust vector. Thus, the fin can change the force vector by simply rotating to different angles and oscillating about that center point. Because of this, Gamera can perform precise movements and rapid accelerations much more effectively than other conventional vehicles. Tasks that would otherwise seem quite difficult to control, such as hovering or sudden changes in direction, can now be performed with relative ease.

1.2 Main Chassis:

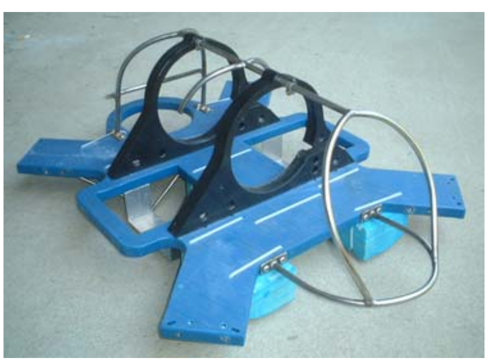

Figure 2: Vehicle Exoskeleton

The base plate [Figure 2] is made of ¾" ultra-high molecular weight (UHMW) polyethylene. It is easy to bolt to, and very rigid. The main electronics pressure vessel is secured to the base plate with two UHMW clamp straps. The main electronics pressure vessel has double O-ring seals at both end caps.

A stainless steel crash frame is used to protect all sides of the housing. The battery pods, located on either side of the electronics pressure vessel, are protected on the bottom by another stainless steel crash frame. Each motor and the batteries are completely separate from the main electronics housing, so that if one of them should leak, the electronics suite would remain protected.

1.3 Electronics Pressure Housing:

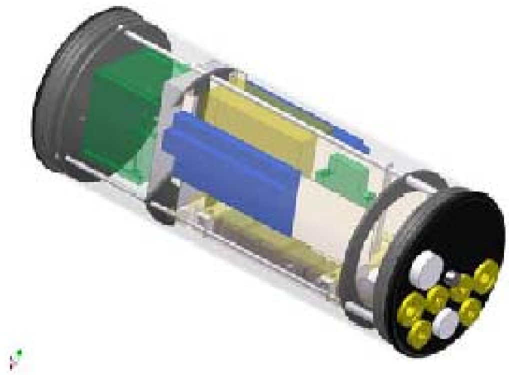

Figure 3: CAD drawing of Electronics Housing

The electronics pressure housing [Figure 3] is one of the most critical parts of the whole vehicle. Donated by McMaster-Carr, the inner diameter of the acrylic tube measures to be 6.25". Clear material was used for this housing in order to simplify troubleshooting, leak detection, and allow the camera to be mounted inside the electronics housing.

The electronics housing is sealed at both ends by two endcaps, both with O-ring protection. One endcap is made out of aluminum for the main purpose of heat dissipation. The other endcap is composed of 1" thick UHMW polyethylene. Any cable that is required to go from within the electronic housing to the outside environment goes through this polyethylene endcap. It also holds the switch that turns on the robot, as well as a purge plug. The purge plug allows a vacuum line to be attached to the front endcap. Therefore, the endcaps can be secured into place by the difference in air pressure. Once the endcaps are in place, the vacuum line is removed and the housing is allowed to refill with air. It is important to let the housing refill with air so the electronics can transfer heat by convection instead of relying on radiation in a vacuum.

Since the tube is located on top running down the long axis of the vehicle, it contributes to the righting moment of the robot. Because of this, the vertical orientation of the robot is very stable. As a result, the acrylic tube helps counteract unwanted torques produced by the fins when changing center positions. [2]

1.4 Motors and Motor Amplifiers:

Figure 4: Brevel Motor

TMI Robotics donated the motors and motor amplifiers [Figure 4]. The motors are Brevel motors, and have been used by Dr. Jason Janét in the past on terrestrial robots with great success. These motors were used primarily because of the cost restraints on this vehicle. Since the motors are designed for 360^{o} motion, it was imperative to mount encoders onto the motor. These encoders are HEDS-5500 G06 optical encoders made by Hewlett Packard with a resolution of 360 counts per revolution and a ratio of 70 revolutions per motor turn. The encoders mount onto the motor using a small setscrew that runs in against the shaft and sticks out of the top of the motor. The setscrew holds the slit wheel in place with respect to the motor shaft.

The amplifiers are based on the National Semiconductor LMD18201 H bridge chip. Each of the amplifier boards has four of these chips on it. These chips can be run separately to run four motors per amplifier board, or all four chips can be paralleled into a single output with increased current capacity. Each chip has a current capacity of 3A continuous. For this application, two of the chips are placed in parallel so that two separate motors are running from one amplifier board. As a result, the maximum current draw per motor is 6 Amps.

1.5 Power Electronics:

Four 12V lead acid batteries provide the power for this vehicle. They are located in the battery pods on either side of the vehicle. One pair of batteries provides 12V for the four amplifiers/motors (two motors per battery). These batteries share a common ground, and are sent into their own independent 12 Amp breaker. These breakers protect all of the equipment on the vehicle. In the event of a fault, they are much easier to reset than a fuse.

The other two batteries are set in series, resulting in a 24V supply. This 24V runs into 3 DC-DC converters. One converts the power to +/-12V, another to converts the power to +5V. These two share a common ground. The last DC-DC converts the power to an isolated +24V that is used to power the DVL and altimeter.

The vehicle is turned on and off by a switch on the front endcap. The switch connects the batteries to the motor amplifiers. The switch also places 12V on the signal side of a solid-state relay. This relay closes and provides 24V to the power board, which distributes the power to the rest of the electronics. Bryan Schulz, a Nekton Electrical Engineer, designed and made the PCB for the power board. The components that run from the power board are listed in table 1.

Table 1: Vehicle Components Running from Electronics Powerboard

Component	*Ground*	*+5V*	*+12V*	*-12V*	*Current Draw (A)*
Motor Encoders (1, 2)	X	X			0.050
Motor Encoders (3,4)	X	X			0.050
Acoustic Array	X	X			0.100
Depth Sensor	X	X			0.050
104-pin Stack	X	X	X		3.000
Microdrive	X	X	X		1.000
Optoisolators		X			0.050
DVL			X	X	0.250
Altimeter			X	X	0.100

1.6 The 104-Pin Stack

With this highly mobile AUV, it was necessary to have a CPU with a fast processor speed but remained small enough to fit into an AUV. Ampro Computers donated a 32MB CoreModule P5e PC/104 that was less than 6 inches across. The CoreModule connects with an IBM 1GB Microdrive, running Linux Slackware 8.0. It also connects to an I/O board, where the majority of our sensors interface with the PC/104. The DVL and altimeter have RS-232 connections, and the camera connects via USB.

A 104-pin connection ensures high-speed communication between devices in a compact and modular system. Also interfacing into the 104-pin stack [Figure 5] is: a data acquisition card, wireless ethernet card, and 4-axis motion control card.

The Diamond MM-32 Data Acquisition Card processes the remaining sensors that do not go through the I/O board. It performs an A/D conversion for the depth sensor, and reads 16 data bits from the acoustic array.

The wireless Ethernet card was added to this year's robot in order to facilitate data acquisition/analysis. With real-time data streams from the wireless Ethernet, it is now possible to quickly and effectively tune mission algorithms.

Gamera is now using the Galil, DMC 1240 Motor Controller Card. The previous card, though adequate, was not suited to effectively produce the flapping motion. The old card produced rigid triangle wave flaps, and was very demanding on processor time. The Galil card, however, has its own processor onboard, and motion commands are downloaded onto the card. Therefore, it can produce smooth sine wave oscillations, and is not as demanding on the PC/104.

Figure 5: 104-pin cards

2. SOFTWARE

2.1 Operating System

Linux Operating Systems have become a standard in mobile robotic applications. The user is given the freedom to manipulate the system in ways not as easily found in Microsoft Windows Operating Systems. Such manipulation is important when developing an autonomous platform from scratch. Multithreading is also very important in controlling the many tasks required for the AUV. Thus DOS, which does not easily support multithreading, was ruled out as an optimal Operating System. Threads are very easy to control and manipulate in Linux.

Slackware was chosen over other Linux operating systems because of its more modular nature. It is flexible in its install options, allowing more unnecessary packages to be removed from the install and thus creating a stable Operating System capable of fitting onto an IBM Microdrive. An advantage of using a regular distribution of Linux is that there are no questions about missing libraries or unsupported features. A Beta version of Linux is not guaranteed to have all the features necessary to run our AUV. Slackware also fulfilled the major requirement of supporting POSIX threads, a simple multithreading system. With a greater focus on vision, a web camera was added to the system. In order to handle a USB interface, the OS was upgraded to Slackware 8.0.

2.2 Control Software:

The software was designed with two major factors in mind: simplicity and modularity. The system was broken into low, middle and high levels of control. High level of control reads sensor data, builds the environment, and sends out a movement vector for the robot. Middle level of control takes the movement vector and converts the request to specific motor movements (amplitude and center position for each of the four motors). The low level of control executes these motor movements. Each sensor and level of control runs off its own process. If sensor or part of control fails, the entire system is not taken down and the remaining parts can continue the mission if possible. High level sensor fusion was developed in such a way that if one of the sensors stopped performing properly (environmental factors, hardware/software failure, etc.) the other sensors could continue to build an accurate environment for control.

3. SENSORS

3.1 RD Instruments Doppler Velocity Log:

Figure 6: RDInstruments DVL

In order to perform the precise movements that the fins and the motor controller cards are capable of producing, we need to be able to determine our position with a given degree of accuracy. This cannot be accomplished with simple accelerometers in the unstable environment for which the AUV is designed. To suit the needs of our system, a Doppler Velocity Log (DVL) [Figure 6] was needed. RD Instruments loaned a Workhorse Navigator currently fitted on the AUV. With the DVL mounted rigidly to the frame of the vehicle, the AUV can navigate by tracking its velocity relative to the bottom of the lake. Tracking using bottom velocity is optimal because it takes into account any current or drift that could change the AUV's course. A major advantage with this DVL is that it independently calculates position by integrating the velocity data. As a result, processor time is freed, and position data becomes more accurate since the DVL filters data outliers. With accurate data for position and orientation in the environment, the AUV can navigate with great precision.

3.2 MSI Depth Sensor:

Rated for 50psi and a stainless steel chassis, the MSP-600 depth sensor [Figure 7] combines accuracy with simplicity. It requires only 5V and is low power. It has a single analog output, which is read by the data acquisition card. From there, a simple mathematical conversion provides us with depth information.

Figure 7: MSI Depth Sensor

3.3 Digital Web Camera

A generic digital web camera has been added to this year's robot. The camera interfaces to the PC/104 though USB, thus speeding up the acquisition of the image matrix. Through various filtering algorithms such as edge detection and histogram equalization, the barcode can be extracted and read.

3.4 SensorTech SQ06 Hydrophones; DesertStar MAXIM 275 ACWP filters:

A clean acoustic signal must be detected to successfully determine the location of the pinger. Using hydrophones bought from Sensortech, and filters/amplifiers donated by Desert Star Systems, the incoming signal is filtered and amplified at the correct frequency. By placing the hydrophones in various locations on the AUV, a bearing on the beacon's location, which is at the center of the environment, can be calculated and used to estimate position. Thus, allowing another method of navigation.

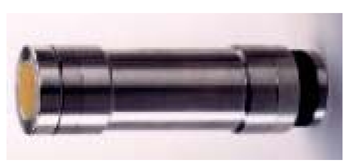

Figure 8: TriTech Altimeter

3.5 TriTech PA500 Altimeter

An altimeter is also a new addition to Gamera II. Since the DVL only returns depth at angles from vertical, it was imperative to add a rangefinder with a narrow beam.

The 6-degree conical beam produced by the TriTech PA500 [Figure 8] is the ideal sensor to determine the depth of each barcode. By placing the altimeter closer to the camera, it allows the depth of the barcodes to be determined without having to randomly sweep throughout the surrounding area.

4. CONCLUSION

Gamera is proof towards the effectiveness and maneuverability of Nektor™ propelled vehicles. With this innovative method of propulsion, Gamera can perform precise maneuvers, and impart large forces in order to remain stationary when hovering over objects (such as barcodes). With the addition of more sensors, we now have a suite that provides accuracy and redundancy as to the orientation and position of the robot.

With the wealth of incoming data, a superior vehicle design, and rigorously tested high-level algorithms, we feel that our robot is most suited in accomplishing the specified tasks in the 2002 AUVSI Underwater Competition.

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6. REFERENCES

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