Summer Project 2013

ANAHITA

AUTONOMOUS UNDERWATER VEHICLE

IIT Kanpur, Robotics Club

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ABSTRACT

ANAHITA is an effort to create a basic autonomous underwater vehicle capable of obstacle avoidance and path planning.

The dimensions of the robot are about 40 cm*15 cm*20 cm and weighs around 9 kg .It comprises of two compartments, one carrying a six syringe piston assembly as ballast system, and other one carrying all the electronic components. The bot is capable of performing heave and pitch motion (using the same ballast mechanism) and surge and yaw motion (using two propellers on the sides).

A Li-Po battery powers the bot. Arduino MEGA single board microcontroller acts as the basic brain. A 10 dof IMU is being used for AHRS (Attitude and Heading Reference System). There are four motors, two controlling the pistons and two being used as propellers. Motor drivers control the propellers according to signals received. A good sensory system implementation still remains a job to be done.

The paper describes various design features including mechanical, electrical and computational aspects.

INTRODUCTION

The project name ANAHITA is the name of Iranian Goddess of Waters. This reminds us of the enormous power of exploration in deep waters for which AUV’s have become a hot topic of research everywhere in the world.

The team consists of first year passed out undergraduate students from different branches of the institute brought together under the Robotics Club. In this short period of 40 days the team was able to design and build up a robust mechanical functional body for the vehicle, achieve controlled motion and try out a basic implementation of IMU in the form of direction following, though a lot remains to be done to make the robot completely autonomous.

The team approached the project by exploring various aspects of AUV technology one by one. The team researched about all the technologies easily available and generally used to make AUV’s and developed a mind-set on how the team is going to use them to accomplish different tasks. Designing of the mechanical model was taken up and the designs of various parts were sent for fabrication. The team then started working on various electronic components, learning how to use them. Finally, the electronics were embedded in the mechanical systems and codes were fed to get the form of an AUV.

At present the robot is capable of changing its depth and pitch through a remote control. Once the depth is fixed the bot can perform the programmed task by manoeuvring its propellers. The robot as of now moves in the same direction once it is settled at any particular depth. This has been achieved using an IMU and a motor driver to control the movements of propellers according to the signals sent by an Arduino Mega micro-controller.

MECHANICAL SYSTEMS

1. Basic Structure

The robot is basically made up of two separable cuboidal boxes made up of 4mm thick aluminium metal sheet that can be attached one on top of the other. The upper compartment consists of the ballast mechanism while the lower one contains the electronics. Both boxes have rectangular lids. The upper box has it on top surface while the lower box has it on the bottom surface. The upper box has six holes with plastic syringes coming out of them. The syringes have plastic flanges around them to give them support to handle the large pressures underwater. The lower box has a polycarbonate window in the front and one clamp on either sides with three varying levels to attach the propellers.

Separating the mechanical and electrical stuffs has multiple advantages. One that the accidental leak of water from the ballast system doesn't damage the electronics. Two, the two systems can be separated and repaired independently. And third, the ballast system can be attached over any other robot to make it submersible if weight is carefully trimmed.

In order to remain stable the centre of buoyancy and centre of mass need to be on the same vertical line. Any tilt of the bot produces sideward shift of the centre of buoyancy and this produces counter torque which stabilise the bot again. So, while designing the body and adding trimming weights it has been tried to increase the separation of centre of buoyancy and centre of mass to the maximum.

2. Ballast Mechanism

The principle of buoyancy come here. The ballast system provides a variable buoyancy to the robot by sucking in and releasing out water. Here a total of six, 60 ml syringes have been used, three on the front and three at the back. The pistons of the triplets are connected to each other inside the box and move together.

A robust mechanism was required to push and pull the pistons, as the water pressure increases tremendously with depth. Firstly rack and pinion mechanism was proposed, but was rejected due to too much apparent mass movement inside, which could change the centre of mass in an unknown manner and could cause problems with the motion of AUV. Secondly sail winch mechanism was proposed, but was once again rejected due to its poor reliability as the string used to move the pulley might break easily at larger depths.

Finally acme screw - drive mechanism was accepted. It consists of a screwed rod attached to the rod connecting the three pistons of a triplet. The screwed rod is moved linearly using a cylinder which has screw threads on the inner surface and gear teeth on the outer surface. The cylinder is bound between two clamps and free two move. A 100 rpm motor rotates this cylinder which in turn moves the pistons linearly. Although even this mechanism involves mass movement, it was accepted as it was later realized that movement of a few grams won't affect the motion too much but rather provide much higher reliability. Opening the piston triplets equally would cause the AUV to sink in straight, while variably opening the triplets can be used to change the pitch of the AUV.

3. Propellers

Large surface area of propellers provides large torque. But at the same time it increases the drag force. So thinner blades are better for higher top speeds while larger, flatter blades are essential for better acceleration. As the objective was not to maximize the speed but to improve handling, we decided to go on with 7 blade propeller fans (3 inches diameter) taken from CPU exhaust systems. 300 rpm high torque motors are used to run the fans attached to the motor shaft using couplers. Using the propellers the bot can achieve forward backward (surge motion) and yaw motion.

Ideally one propeller must be right handed while the other one must be left handed and they must rotate in opposite sense in order to cancel the counter torque produced by motors. But due to unavailability of counter rotating propellers, propellers with same sense of rotation have been used here. Due to the large counter torque produced by the 3kg dead weights at the bottom the tilting caused by the counter torque due to motors is highly diminished.

4. Waterproofing/Anti – rusting

To make the boxes waterproof, the lids have a rubber lining around the edge on the contact surface and are fixed using Allen screws into rivet nuts to make a complete water tight seal. The boxes have gone through CCC (Chromate Conversion Coating) to make them anti – rusting. Some holes were required to be done on the boxes for wires of sensors and motors to come out. The water proofing around these holes and around plastic flanges has been done using m-seal, araldite, fevi quick and hot glue. The propeller motors have been encased in aluminium casings especially made for them for waterproofing purposes.

5. Weight Trimming

The approximate volume of AUV is around 9 litres, while it only weighs around 6kgs with all the components put together. In order to just submerge the AUV underwater, additional 3kgs had to be put on. This was done by attaching rectangular iron plates in the form of 4 stacks below the lid of the lower box. This enabled easy weight trimming, by shifting the weights in various stacks. Attaching weights on the lower surface is advantageous as it increases the separation between centre of mass and centre of buoyancy, which adds to the stability of the bot.

The final tilting of the bot was corrected by attaching small weights on the top surface of the bot using double sided tape.

ELECTRONICS

1. Inertial Measurement Unit

An **inertial measurement unit**, or IMU, is an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes.

The term IMU is widely used to refer to a box containing three accelerometers and three gyroscopes. The accelerometers are placed such that their measuring axes are orthogonal to each other. They measure inertial acceleration, also known as G-forces. Three gyroscopes are placed in a similar orthogonal pattern, measuring rotational position in reference to an arbitrarily chosen coordinate system.

The IMU is use for navigational and orientation purposes and data collected from the IMU's sensors allows a computer to track a craft's position, using a method known as **dead reckoning**. In navigation, dead reckoning is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time.

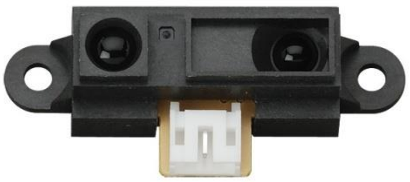
The robot uses a 10-DOF IMU (3-axis accelerometer ADXL345, 3-axis gyroscope L3G4200D, 3-axis magnetometer HMC5883L and a barometric pressure sensor BMP085). We used the unified reading of yaw through accelerometer, gyroscope and magnetometer to work on our algorithm to move in the same direction.

IMU-GY80 (credits: http://www.arduiner.com/it/)

The barometric pressure sensor has not been used in this prototype of the robot but we plan to use it once we get in the process of developing this vehicle and it turns bigger. We then plan to use it keep a check on the pressure inside the vehicle and thus monitor water leakages.

2. Sensors

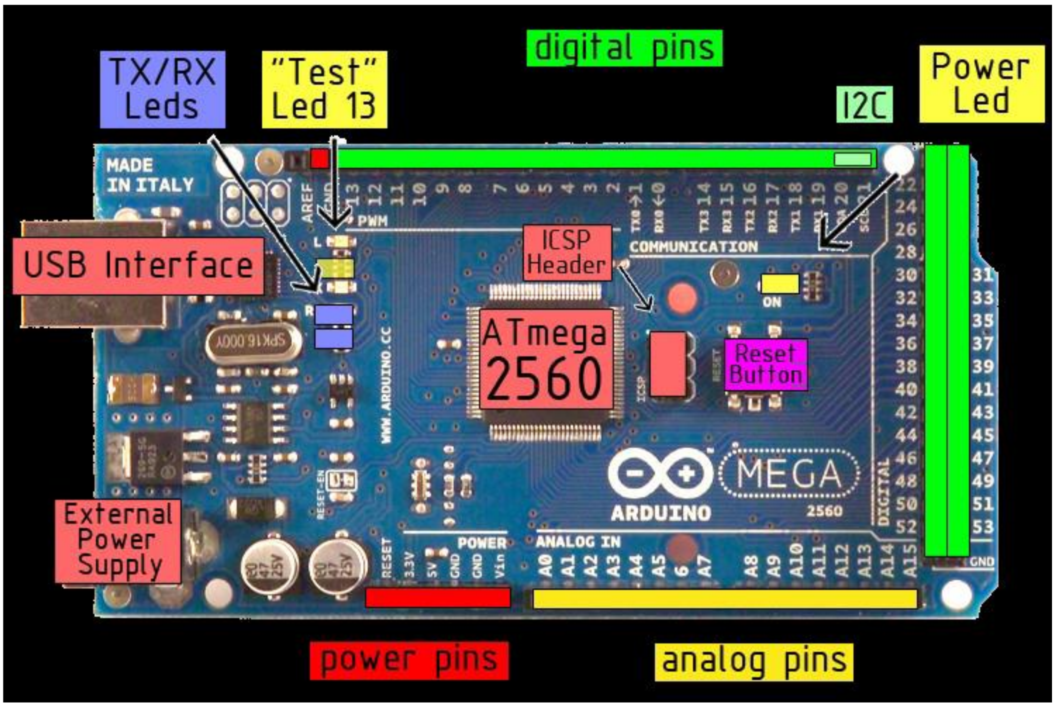
Besides IMU, no others sensors have been used. Initially, the vehicle was supposed to avoid obstacles in its path using Infrared sensor. This could not be implemented due to sudden failure of the sensors before project submission.



IR Sensor (GP2Y0A21YKOF) (credits: http://www.jameco.com)

3. Micro-Controller

The proposed vehicle used six IR sensors, four motors controlled by two motor drivers and an IMU. This required six analog pins, eight digital pins, SCL and SDA pins apart from power pins and 3.3V pins. Taking into account the functions our vehicle was to perform, and the number of pins required, we chose Arduino mega.



Arduino Mega (credits: http://arduino.cc/)

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs),16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Features

Microcontroller	- ATmega2560
Operating Voltage	- 5V
Input Voltage (recommended)	- 7-12V
Input Voltage (limits)	-6-20V
Digital I/O Pins	- 54 (of which 14 provide PWM output)
Analog Input Pins	- 16
DC Current per I/O Pin	- 40 mA
DC Current for 3.3V Pin	- 50 mA
Flash Memory	- 256 KB of which 8 KB used by bootloader
SRAM	- 8 KB
EEPROM	-4 KB
Clock Speed	-16 MHz

4. Motor Driver

We ended up using a single motor driver to control the propellers. The motor driver has a current rating of 20 A. This takes into account the current rating of the two motors which control the propellers (7.5 A. each).

(source: http://www.robokits.co.in/shop/)

Features

• Simple connectivity to IO pins of any MCU.

• Compatible with motors rated up to 18V
• Can easily deliver 20A of current during normal operation
• Braking feature included without affecting the performance of an MCU

Applications
• Simple DC motor applications that require forward and backward driving of motors
• DC motor applications requiring speed control via PWM input
• Halting or braking a DC motor during operation

Electrical Characteristics
Input Voltage: 7V minimum to 18V maximum
Continuous Current (< 1seconds) ~ 20A
Continuous Current (< 10seconds) ~ 10A
Continuous Current (> 10seconds) ~ 5A (without heat sink on MOSFETS)
Absolute Maximum Peak Current ~ 50A
No short circuit protection on output of the driver

5. Power

The 4 motors used have a maximum current usage of 7.5 A. So motors could at max drive 30 amp current at any instant. Arduino, Motor Driver and IMU use a maximum of 20mA.So the total power calculations turn out to be 20 Watt. According to these calculations we finally decided to use a single Net Botix 11.1 Volt 5000 mAh battery.

(source: http://www.nex-robotics.com/)

This would give us between 45 min to 1 hour of continuous bot usage (taking factor of safety 3).

PROGRAMMING

1. PID Controller

Overview: PID (Proportional, Integral, and Derivative) control is a widely-used method to achieve and maintain a process set point. The *process* itself can vary widely, ranging from temperature control in thousand gallon vats of tomato soup to speed control in miniature electric motors to position control of an inkjet printer head, and on and on. While the applications vary widely, the approach in each case remains quite similar. The PID control equation may be expressed in various ways, but a general formulation is:

$$\text{Drive} = kP*\text{Error} + kI*\Sigma\ \text{Error} + kD * dP/dT$$

where Error is the difference between the current value of the process variable (temperature, speed, position) and the desired set point, usually written as
Error = (Value-SetPoint);
ΣError is the summation of previous Error values;
dP/dT is the time rate of change of the process variable being controlled, or of the error itself.
The proportional coefficient kP, the integral coefficient kI, and the derivative coefficient kD are *gain* coefficients which *tune* the PID equation to the particular process being controlled.
Drive is the total control effort (often a voltage or current) applied to actuators (heater, motor, and valve) to achieve and hold the set point.

Coding a PID control algorithm:
Code for a PID system can be rather simple. The following is an example of some *pseudo code* to do PID:

```
PID:
        Error = Setpoint - Actual
        Integral = Integral + (Error*dt)
        Derivative = (Error - Previous_error)/dt
        Drive = (Error*kP) + (Integral*kI) + (Derivative*kD)
        Previous_error = Error
        wait(dt)

GOTO PID
```

2. Motion in the same direction

The final prototype of the vehicle moves in the same direction (-10 degrees to +10 degrees) despite any forced or accidental change in direction. This is achieved using a simple algorithm as produced below:

i. Record the initial yaw as soon as the motion starts.
ii. Read the yaw at instant and check if it is in the given range of 9 (-10 to +10 degrees from initial yaw).
iii. In case it is not, change the direction of rotation of motors such that the vehicle returns to initial direction. To ensure smooth rotation of motors, proportional term from PID controller is used.
iv. Continue moving.

This simple algorithm produced the required results.

FUTURE STRATEGIES

- Presently the testing hours for the bot have been very less. So focus would lie on making the bot's motions more robust and calculated. Experiments need to be done on how the bot varies its depth at various levels of water in the syringes and also on how the bot responds to various adjustments of propellers.
- Secondly, implementing a robust sensory system would be the aim which might include video processing using video cameras, IMU, SONAR module, depth sensors and water sensors. This would enable much accurate obstacle detection and avoidance.
- Then path planning algorithms could be tested. Firstly the problems would remain two dimensional, and later an extension to three dimensional world can be made.

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????? All the components required have been listed below:

Mechanical

- Aluminium cylinder (to fabricate water proof casing of the motors)
- 60 ml syringes (6,for controlling pitch and depth)
- Silicon sealant, m-seal and many other water proof adhesives
- Rubber parts (again for water proofing)
- Many other small parts needed in fabrication

Electronics

- 10 DOF Inertial Measurement Unit
- Arduino Mega board
- A 20 AMP Motor driver
- General purpose board
- Wires of various current rating
- 2 motors- 100 rpm
- 2 motors- 30 kg-cm torque
- A Lithium Ion battery