# Robotic Turtle Project – Design for Review

| Date | Revision | Author | Comments |
|---|---|---|---|
| 2005-12-05 | A | Watts | Original Document |
| | | | |
| | | | |
| | | | |

Table of Contents

# 1 Overview

The goal of this project is to design and build a robot. This robot must be autonomous, amphibious, and appear indigenous. When in operation, this robot will be designed to navigate through land and water terrains to reach a predefined destination. Once the robot has reached its target location, internal cameras, constructed into the robot will be utilized to capture the surrounding environment.

The design and appearance of the robot will be modeled after the sea turtle. The robot also has a given target weight of 15 lbs. Two front flippers will be utilized for movement on land. When operating in water, a propeller in the rear will allow the robot to move with speed and efficiency. Two casters will be placed in the rear underneath the turtle to protect the propellers and reduce surface friction.

Given the design criteria above, the functionality of the robot can be broken into smaller parts. These parts include: motors for movement, GPS/compass for navigation, cameras for vision, wireless router for communication, and main board for controlling all the hardware components. Each of these parts was researched by the development team. The research objective is to find the best and most reliable hardware device for the lowest price.

Once the technology research is completed, a budget and development plan is formulated. The robotic design team is split up into two sections, this way hardware and software applications for the robotic turtle will be developed in parallel. Hardware development will focus on building the robot frame and mounting hardware devices. Software development will focus on interfacing the hardware devices and developing the brains/artificial intelligence of the robot.

# 2 Overview of the Robotic Turtle Project

Nekton research has presented a unique design challenge. The challenge is to design and build a robot. This robot should possess traits that are autonomous, amphibious and appear indigenous. The basic functionality of the robot is to self navigate to a predefine location. After arriving to the destination it must be able to observe the terrain as well as other objects. To design such a robot, a team of engineering students was assembled to complete this task. This paper outlines the progress and direction of the project.

# 3 Design

Before any designs could be considered, the main requirements of the project must first be defined. Nekton research set the basic traits of the robot as well as the target weight. From the information presented the following main requirements were set. Any design consider must have met or exceed main requirements.

## 3.1 Project main requirements:

1. Target weight ~ 15 lbs
2. Target size ~ 11.34 inches diameter
3. Amphibious
4. Indigenous appearance
5. Autonomous (self navigating, image recognition and capture)
6. Capable of communicating with "base" wirelessly

## 3.2 Target Size:

The target size was determined using Archimedes principle, which states the buoyancy force is equal to the displaced water. Thus, using the target weight and the known weight of water, the total volume of water displaced was determined. To simplify the equation the robot was considered to be a sphere. This yielded a diameter of approximately 11.67 inches or in water surface area of 213.68in$^2$.

Weight of water: $62.4\frac{lbs}{ft^3}$

Weight of turtle: 15 lbs

Equation 1: Volume of Displaced Water = $\frac{DesignWeight}{WeightofWater}$

Equation 2: Volume of Sphere: $V = \frac{4}{3}\pi r^3$

r = 5.83 in or diameter = 11.67 in

Water surface area = 213.68 in$^2$

## 3.3 Movement Experiment:

After determining the size of the design, the movement of the robot was considered. To fully understand robotic motion an experiment had to be conducted. For the experiment two motors and flippers from Nekton were used. These motors were mounted to a plastic frame, approximately the same size as the target design. Power was supplied and the experiment was observed. At high voltage (20V) but low current (500 mA) both motors turned at a high RPM but could not produce enough torque to move the plastic frame along the lab floor. However, lowering the voltage (6V) and raising the current (1500 mA) the plastic frame was able to move across the floor but at a low RPM. The experiment produced two results and is as follows.

Results 1: Voltage controlled the RPMs of the motor

Results 2: Current controlled the Torque of the motor

After the requirements were determined and experiments were preformed, the design process began. During this process several ideas were considered. However, one possible design template kept coming to the forefront. The particular design idea was to mimic a sea turtle. Sea turtles have been around about 150 million years, and very unique to this world. Their uniqueness stems from their amphibious ability. Sea turtle's also posses a broad belly, which will provide better buoyancy. Additional traits of sea turtles are the hard shell with four fins protruding from each corner. Based on the sea turtle's amphibious ability and the indigenous requirement, the turtle is a good basis for all designs considered.

## 3.4 Alternative Designs:

A total of four designs were considered for the final product. All of the proposed designs resembled a turtle. Therefore, each design had a hard hollow shell for storage of all electronic components necessary for operation. As well as a broad underbody for increased buoyancy and good looks. Each of the designs is described below.

### 3.4.1 Design 1:

This design has four flippers, which would be used for movement on land and in the water. Therefore, the design would require four motors and enough battery power to handle the power requirement.

### 3.4.2 Design 2:

Design 2 replaced the flippers described in design 1 with paddle wheels. These wheels would provide easy movement on land and in water. However, this design is still susceptible to the high power requirements as design 1. Additionally, the paddle wheels deduct from the indigenous appearance.

### 3.4.3 Design 3:

Like design 1, this design had two flippers in the front for movement on land. However, a propeller for movement in water was introduced to the design. This design also retained the two rear flipper but operated only by servos. These flippers would serve as directional control in water. Therefore, this design would require less power than designs 1 and 2. This would also decrease the weight because fewer motors are needed. Conversely, movement on land would be affected due to loss of rear propulsion.

### 3.4.4 Design 4:

This design is similar to design 3, however the two rear motors are removed. Design 4 adds casters to the rear of the robot for reduced friction when moving on land.

Each design has its own advantages and disadvantages. Therefore, to help in the decision making process, a decision matrix was used (Table 1.0). The more motors a design has the more cost is incurred from the motors, as well as the batteries required to operate the motors. It was determined that cost, weight, and power consumption were major factors for the final design.

**Table 01:** Design Decision Matrix

| | Light weight | Power Consumption | Speed | Directional Control | Distance | Cost | Aesthetics | Worth |
|---|---|---|---|---|---|---|---|---|
| **Design 1** | 2 | 2 | 7 | 8 | 6 | 3 | 8 | **38** |
| **Design 2** | 3 | 4 | 8 | 9 | 7 | 3 | 4 | **47.75** |
| **Design 3** | 5 | 6 | 4 | 5 | 5 | 5 | 7 | **52.75** |
| **Design 4** | 7 | 7 | 4 | 3 | 6 | 6 | 5 | **60** |
| % Weight | 30 | 30 | 12.5 | 10 | 5 | 7.5 | 5 | |

The decision matrix yields design 3 and 4 as the better designs. Thus, the final design is a hybrid of both design 3 and 4.

### 3.4.5 Final Design:

The final design will keep the two front flippers for movement on land. Additionally, the design will retain the rear propeller for movement in water. Added to the design are two non-motorized rear flippers. These flippers will contribute to the overall surface are in the water adding to stability. Figure 01 displays the CAD drawing of the turtle.

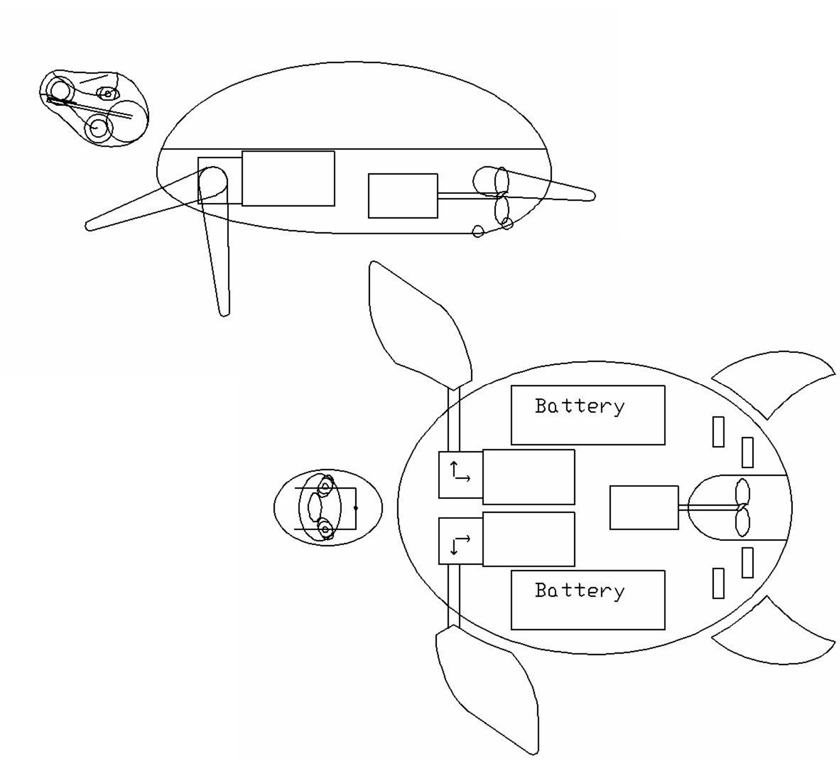

**Figure 01:** Final Design Schematic

# 4 Peripherals

After the final design was determined, the next step was to analyze how the turtle will operate. The challenge calls for the robot to be able to self-navigate and survey its surrounding. Therefore, the robot would need several peripheral for higher cognitive control. Careful consideration of the design's cognitive responses resulted in four sub-categories. Each sub-category is essential to the proper operation of the design. These sub-categories are listed below.

## 4.1 Cognitive Devices:

1. Mainboard
2. Internal Navigation System
3. Optical Sensor
4. Wireless Communication

### 4.1.1 Mainboard:

This projects main requirement is to be autonomous. To achieve this requirement a computer board must be used. However, this board must be versatile enough to control the basic motor functions as well as higher cognitive functions. Therefore, several candidates were researched and the TS-7200 was selected.

Board Candidate:
TS-7200 Single Board Computer:

- ARM9 Processor with MMU
- 32 MB SDRAM
- 8MB Flash Disk
- 10/100 Ethernet
- Compact Flash
- 2 USB Ports
- 2 COM Ports
- 20 DIO
- PC/104 Expansion Bus

The TS-7200 Single Board Computer (SBC), produced by Technologic Systems, will become the heart and brain of the robotic turtle. This SBC runs on a 200MHz ARM9, 32-bit, processor. The ARM, Advanced RISC Machine, architecture is ideal for embedded applications due to its power-efficient design. A TS-7200 SBC has a standard power consumption of 2Watts, 5Volts at .4Amps. Embedded boards built with an x86 processor, AMD or Pentium can consume up to 4.5Watts, 5Volts at .9Amps. This low power feature will allow the processor to generate less heat, and can operate in a non-temperature controlled environment. Since the embedded board will be enclosed in a water sealed infrastructure, a processor generating less heat would be ideal.

The ARM9 processor of the TS-7200 SBC also offers a MMU, Memory Management Unit, which supports the Linux OS, Operating System. The embedded Linux OS has been chosen as the development environment for the robotic turtle. The Linux OS offers a free and stable environment for application development. This environment will allow the programmers to work closely with the embedded hardware, creating more optimized code. Code optimization will allow the applications being developed to consume less system resources and offer better functionality.

Although the ARM processor provided is the main strength of the TS-7200 SBC, this embedded board also offers expansion slots for peripheral devices. Peripheral devices such as motors, GPS, cameras and wireless routers can be interfaced with the TS-7200 SBC. The ability to interface peripheral devices with the main board will allow the development team to expand the robotic turtle's functionality.

The only negative feature of the TS-7200 SBC is the lack of COM ports, in which only two are available. The lack of COM ports can diminish the embedded board’s ability to add additional peripheral devices. However, this problem can be easily solved by purchasing an expansion board with additional COM ports.

Overall, the TS-7200 is a well rounded embedded board with plenty of processing power and expansion capabilities. This embedded board will enable the turtle development team to effectively design and create a powerful and robust robot.

### 4.1.2 Internal Navigation System:

Sea turtles direct their locomotion based on two categories of position: global and local. They use a magnetic map for there general location and vision and smell for their relative location locally. However for this design current position indicating technologies will be used to determine the position of the turtle.

After researching several technologies, GPS was deemed as a viable solution. GPS derives geographical coordinates accurate to less than four inches by means of satellite signals in conjunction with differential positioning and other techniques. These sensors are reasonably priced but cannot work under water. However, the current design criterion does not require the turtle to completely submerge. Thus, GPS was selected as the technology for rendering position.

GPS Candidates:
Garmin, OEM GPS Engine, Model: GPS 15
San Jose Navigation, OEM GPS Receiver / Antenna Module, Model: FV-18

The two models above were compared for selection based on various GPS requirements. Both boards are comparable with the exception of WAAS and the integrated compass. The cost difference for models with these capabilities was prohibitive; therefore, these requirements were not fulfilled as an integrated unit. Both units are extremely compact, accurate, and lightweight. The distinguishing factor between the boards was the type of antenna needed. Both units work with an active antenna, but only the San Jose Navigation FV-18 has an onboard active antenna. Additionally, this unit has onboard memory which would add flexibility to the final product. To maximize benefit for the final turtle design, our team chose the FV-18.

Since the functionality of a compass would greatly enhance the team's design solution, the Willow V2Xe compass module will be utilized. This component provides accurate direction data, and it is accomplished in a lightweight, compact, and efficient unit. The addition of this unit will give the turtle the ability to perceive direction while remaining stationary.

### 4.1.3 Optical Sensors:

In the area of autonomous devices, having a real time sensor is critical. The most useful and dynamic sensor is the optical. An optical sensor will allow the turtle to dynamically react to changes in the surroundings like tidal changes and fallen trees as well as aid in data gathering.

Camera Candidate:
Logitech Camera: QuickCam
Still image capture: Up to 640 x 480 pixels
Video capture: Up to 640 x 480 pixels
Color Quality: 16 bit
Frame rate: Up to 30 frames per second
Power Rating: Under 5V and under 500 mA
Communication: USB
Cost: This model costs anywhere from $30 - $50 on the web and in stores.

Due to cost constraints, professional cameras like a Photonfocus Hurricane 40 were not a viable option. However, a non-professional camera like the Logitech camera could be used at one-fifth the cost and will provide the functionality to meet the project requirements. Additionally, the Logitech camera is easier to implement with sample Linux drivers available on the web.

### 4.1.4 Wireless Communication:

The Amphibious and picture capturing requirements require fats communication to a computer. However, ports to the interior are a potential source of leakage. Therefore, it was decided that the best recourse is to communicate to the main board VIA wireless connectivity. The trade off is a 15% reduction in speed from a standard 100Mbps Ethernet speed (if 54Mbps transfer speed is used). However, the biggest concern for this project is power consumption, not speed of transmission.

Wireless Candidates:
Linksys: WET54G
DPac: 802.11b

During research two technologies that surfaced were Linksys and DPac. Both technologies are comparable and provided means of communicating at fairly low power consumption. However, because of their similarity a stringent comparison was required to determine the best product for the project. Equations 3 and 4 were used to determine the amount of power required to transmit the same information. Figure 02 is a graph of these equations.

Equation 3: $T = \frac{D}{S}$

T = Data transmission time
S = speed of transmission
D = data to be sent

Equation 4: $Pc = P * T$

Pc = Power Consumed
P = Typical Operating Power
T = Data transmission time

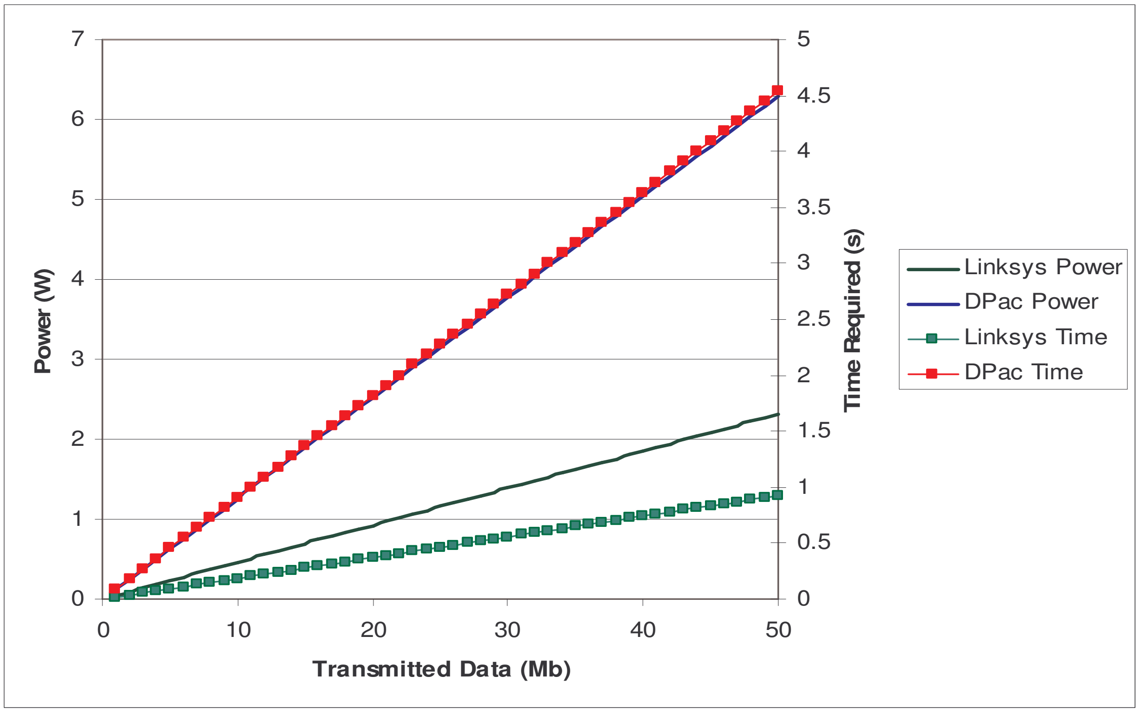


**Figure 02:** Comparison of Power Requirements

The wireless device will only be operated when the turtle needs to communicate with a monitoring computer. Additionally, from figure 02 it can be concluded that the Linksys requires less power for the same data transmitted. This can be contributed to the faster transmission speed requiring less operation time, resulting in a 36.7% reduction in power consumption. Based on this operation criterion the Linksys WET54G wireless Ethernet Bridge was chosen.

# 5 Movement: (Motors)

In order for the project to move from point A to point B on land or in water, motors and logic to control them will have to be used. Since, the robot turtle will be battery powered, DC motors will be utilized. An additional consideration for the robot is its amphibious requirement. Thus, motor considered must provide adequate torque for movement in both mediums. . Before any motors can be chosen, the torque required to move the turtle must be determined.

## 5.1 Torque Calculations:

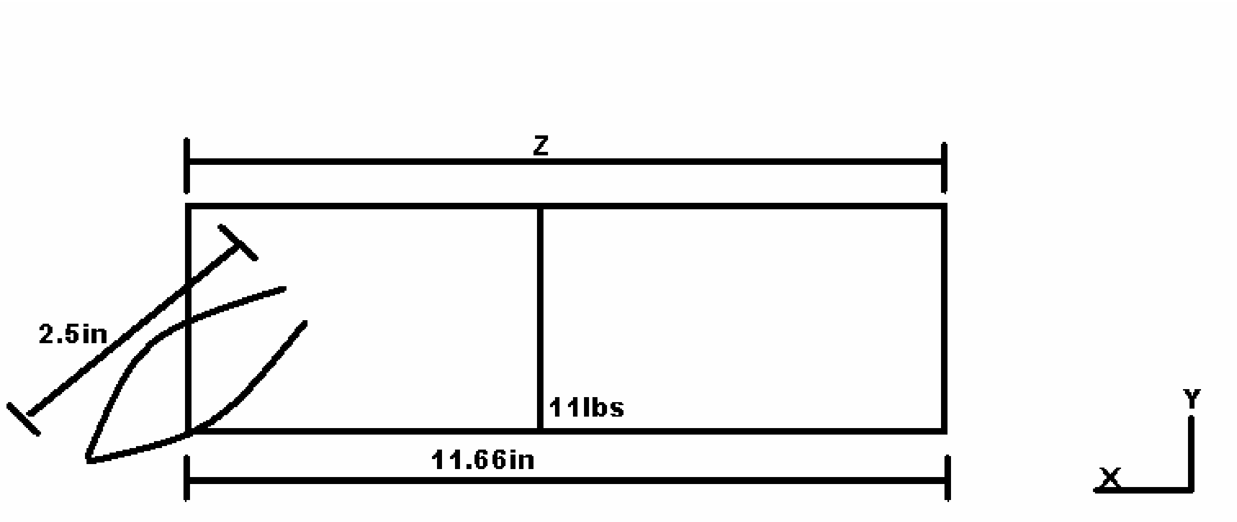


**Figure 03:** Torque Example

Equation 5: $$\tau = \frac{COG * FL * WT * 16}{DIS * MN}$$

Where:
**COG** = Center of Gravity
**FL** = Flipper Length
**WT** = Weight
**DIS** = Distance from Center
**MN** = Number of Motors used
16 = Unit conversion from lbs to oz.

The above equation was used and plotted. Figure 04 below is the graphical representation of the torque equation across all possible values of the robot starting at the center with respect to the rear.

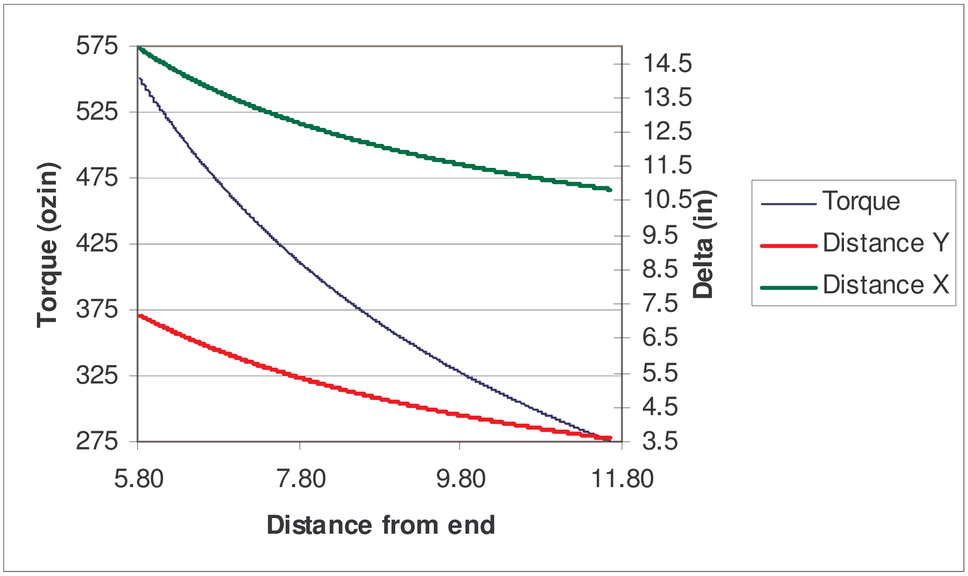


**Figure 04:** Torque required and Distance traveled

The distance Y is the height the robot will lift itself every rotation of the flipper. The distance X is the forward distance the robot will move itself with every rotation of the flippers. This assumes no loss in movement based on surface conditions. A larger Y distance will allow for the robot to clear larger obstacles and the larger X distance increases the efficiently of the robot. These are gained though at the cost of a higher torque, which will add to the overall cost of the design. From the figure 04, it can be seen that the torque x and y distance is mostly linear resulting in no sweet spot. Therefore, no point exists to provide better performance, though cost is one of the big obstacles.

## 5.2 Motor Research:

Research has shown that the Maxon line of motors had very little current usage for the amount of torque they produced. This was very critical for the battery life. The Maxon motor line is high quality however, very expensive. To help torque the flippers could be shorten and moved to the front of the turtle. This in turn reduces the amount of torque required and a smaller motor can be used. The trade of is a reduction in efficiency due to less distance per rotation of the flippers. It was decided to go with the Maxon Motor 118889, geared to a ratio of 49 to 1, which yields 2665 nNm of torque at 120 RPM. These figures may change based on the final weight and size of the turtle. The back propeller will be powered by the same kind of motor.

# 6 Power Supply

Important considerations for the batteries are weight, cost, and at least 30 minutes of operation. To choose the best battery for the design, all battery types were carefully researched and considered. In general there are two main types of batteries, wet cells and dry cells. Since wet cells are very heavy and distribute too much power, they will not be considered as an option thus, leaving only dry cell batteries. Dry cell batteries can be further broken down into two categories rechargeable and non-rechargeable. Only rechargeable batteries will be considered for the design. The different dry cell rechargeable battery types are listed below.

## 6.1 Battery Candidates:

1. Ni-Cd (Nickel Cadmium)
2. Ni-MH (Nickel Metal Hydride)
3. Li-ON (Lithium Ion)
4. Li-PO (Lithium Polymer)

Each type has it own advantages, disadvantages and similarities. Therefore, each type's characteristics were weighed and a decision matrix was used. Based on requirements for the project cost, weight, and current supply were the most vital. An additional criterion such as availability was important for possible replacement.

**Table02:** Battery Decision Matrix

| Type | Cost (20%) | Weight (30%) | Availability (10%) | Batterylife Per Use (15%) | Current (25%) | Total |
|---|---|---|---|---|---|---|
| NiCD | 6 | 3 | 6 | 5 | 5 | 47.0 |
| NiMH | 5 | 6 | 7 | 8 | 9 | 69.5 |
| Li-ON | 1 | 8 | 4 | 9 | 2 | 48.5 |
| Li-Po | 3 | 10 | 3 | 10 | 10 | 79.0 |

## 6.2 Battery Selection:

After a review of the characteristics, Li-Po batteries seem to be the best candidate. However, this type of battery is highly flammable and as a higher cost. Addition, the Li-Po batteries require extra accessories that will effect the overall cost. Therefore, Ni-MH will be the battery type to supply power to the turtle. This battery provides other desirable characteristics such as reduced connection space area.

# 7 Implementation

After all the parts were chosen, a plan of how they would be integrated was devised. The team decided the best recourse would be to split the build into two separate entities. Thus, both entities could be executed simultaneously resulting in better efficiency. One entity deals with the hardware build of the project and the other with the software development of the project. Both entities are elaborated further below.

## 7.1 Hardware Build:

Due to the environmental operating conditions of our autonomous vehicle, the housing and chassis must above all be impervious to water seepage. It also must provide a reliable platform for the electrical system and for the components necessary for locomotion. This will be accomplished through a variety of innovative hardware combinations. In order to realize the necessary implementation, the project planning GANTT chart Figure 05 shows an entire development sequence dedicated to the hardware construction of the unit. Progress in this area will be effectual only if sedulous hardware design choices are made. This section of the paper will elaborate on the plans and parts necessary as a preliminary basis for such an endeavor.

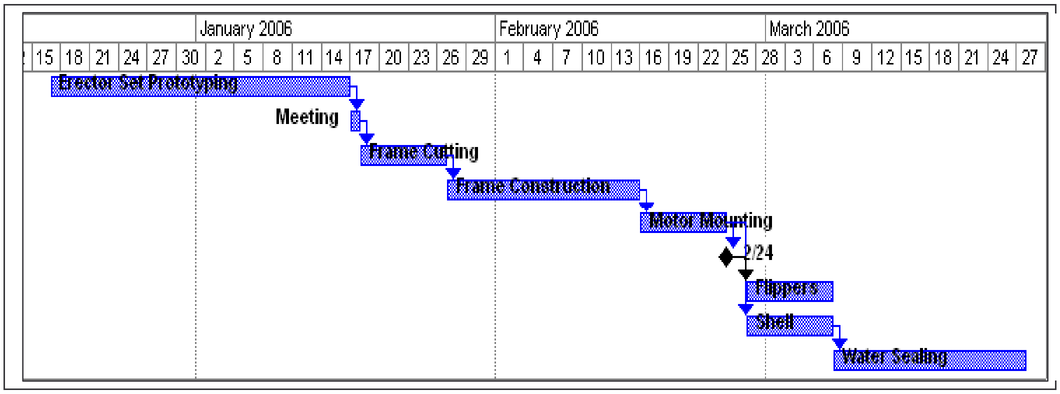


**Figure 05:** Hardware Timeline

### 7.1.1 Mockup:

The first step of the hardware design will be to build a chassis mockup. To complete this stage a rudimentary assortment of components will be used to construct a full scale model of the chassis. The dimensions of the chassis overall are approximately14”x 8”. The construction of the skeleton will start from the conceptual draft of the chassis made using AutoCAD, as seen in Figure 06. This step will ensure that all selected components will have sufficient space for mounting and operation to eliminate the need for modification to the external shell of the turtle.

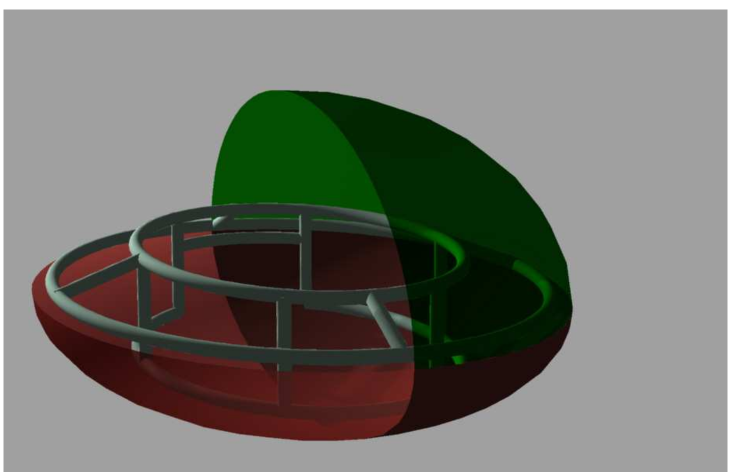

**Figure 06:** Frame Concept Model

### 7.1.2 Frame Build-up:

The second step of the hardware design will be completed after several iterations of chassis modeling and testing have been completed. In this step the team will prepare the frame materials for assembly. Due to uncertainty concerning the tooling facilities that will be available at the University of North Carolina at Charlotte, details will be finalized concerning the material for the frame construction in early January. The material choice will be either aluminum frame and hardware or a high density plastic such as acrylonitrile butadiene styrene (ABS) with aluminum hardware.

### 7.1.3 Chassis Construction:

Once the components have been manufactured, the team will begin assembly of the unit. The structural elements will be assembled first, followed by the main component platform, and finally the flipper and propeller motor mounts. The components will be dry fitted and then the external mold will be created. This mold will be made of floral foam and will be used for the production of the feel beast's watertight hull. Once this foam mold has been sized the components will be returned for use in software development. The goal for this stage will be to have a completely assembled chassis and a mold for use in hull production.

### 7.1.4 Flipper Construction:

From this step the team will be completing two design objectives concurrently: flipper manufacturing and hull construction. The flippers will be completed by constructing a wooden mockup of the flipper with an anatomically correct appearance. This mockup will be used in producing the finished flipper by rubber injection molding. The turtle's hull, comprised of a dorsal shell and a ventral shell, will be constructed of fiber glass. The dorsal shell will have a single penetration for the head, while the ventral shell will have three penetration points: the two flippers and the propeller.

### 7.1.5 Water Sealing:

The final hardware step will be water sealing and submersion tests. During this stage the ventral shell will be permanently affixed to the chassis. This will allow the flippers and propeller to be mounted in the final configuration. The dorsal shell will be capable of being sealed to the ventral shell and unsealed upon demand in order to provide access to the sealed compartment.

## 7.2 Software Development Plan:

The software development for the robotic turtle is segmented into three main sections or goals. From designing device drivers to artificial intelligence, each section focuses on a specific software task. This breaks up the robot software into smaller and more manageable parts. A programmer would not have to worry about higher layer applications when designing lower level device drivers. This method would also allow each section to be divided among the software development team, which would increase productivity.

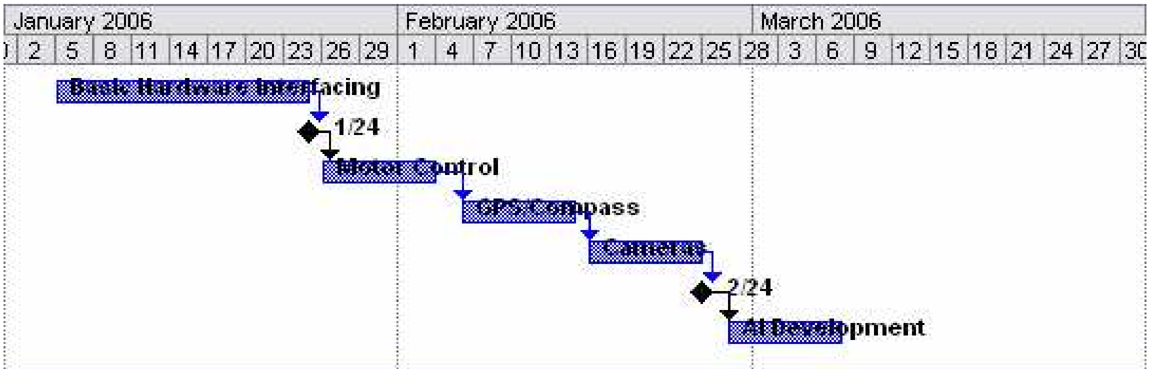


**Figure 07:** Software Development Timeline

### 7.2.1 Basic Hardware Interfacing:

The first goal of the software development team is to design and create device drivers. The drivers created will open up the capabilities of the peripheral devices. User applications, developed later, will utilize the capabilities offered by the drivers. The drivers for the peripheral devices will also be modularized. This means the software code will become part of the Linux Kernel. A modularized driver can operate at the highest level of a CPU, where functions like interrupts and direct memory access are enabled. Simple user applications, or test codes, will also be developed along side the device drivers. These applications will test the drivers, and the functionalities of the hardware components. Once all device drivers are written and tested, the test codes will become the base for more robust user applications.

### 7.2.2 Hardware Applications:

The second goal of the software development team is to design and create user applications to take advantage of the hardware devices. The objective of this section is to improve and increase functionality to the test codes. Since movement is a very important feature to any robot, the motor application will be created first. This application will allow the robotic turtle to move forward, change directions, and increase/decrease speed. After the motor application is complete, the GPS and compass applications will be created. This will give the robotic turtle a sense of direction, where it is located on the earth and what direction it is currently pointing to. The information provided by the GPS and compass will enable the turtle to travel to a predefined location. After the GPS and compass applications are complete, the last peripheral device to be interfaced is the camera.

### 7.2.3 Autonomous Interaction:

The third and last goal of the software development team is to design and create the artificial intelligence, AI, of the robotic turtle. The code for this section will include and utilize all hardware applications created earlier. The AI will be designed to wait for location coordinates from the end user or base. Through the information given, the AI will use the data provided by the GPS and compass to calculate which direction to move. The motor functions will then be utilized to move the turtle to its target location. Once the target location is reached, the camera will be used to take pictures.

# 8 Budget

The total budget to build two prototypes was determined. Table 3 is the budget for this project. As can be seen from table 03 the total cost is $3535.00. Majority of the cost is incurred from the movement of the turtle. Therefore, cost of the project could be reduced if an inexpensive motor replacement can be found.

**Table 3.0:** Budget

| Item | Description | Unit Cost | Per | Quantity | Total |
|---|---|---|---|---|---|
| **MOVEMENT** | | | | | |
| Encoder | Land Propulsion | $88.05 | Each | 4 | $352 |
| Gear head | | $177.80 | Each | 4 | $711 |
| Motor | | $259.10 | Each | 4 | $1,036 |
| Propeller | Water propulsion | $3.00 | Each | 2 | $6 |
| **Total For** | Motion | | | | **$2,106** |
| **PERIPHERALS** | | | | | |
| Compass | Digital Compass chip | $75 | Each | 2 | $150 |
| FV-18 | GPS unit | $58 | Each | 2 | $116 |
| TS-7200 | Single Board Computer with 32MB RAM | $149.00 | Each | 2 | $298 |
| PC/103 Board | Peripheral Board, Provides 4 Serial Com Ports | $89.00 | Each | 2 | $178 |
| 64mb Flash Card | 64MB Compact Flash Card | $51.00 | Each | 2 | $102 |
| Logitech Quickcam | Camera | $50.00 | Each | 2 | $100 |
| Linksys wireless | Linksys WET54G wireless Ethernet bridge | $75.00 | Each | 2 | $150 |
| **Total For** | Brains | | | | **$1,094** |
| **POWER SUPPLY** | | | | | |
| 4.8V Battery | 4.8V @ 2200mAH | $12.95 | Each | 2 | $26 |
| 12V Battery | 3000mAH = $69.90 | $34.95 | Each | 2 | $70 |
| **Total For** | Power | | | | **$96** |
| **CONSTRUCTION** | | | | | |
| Fiberglass | For Shell | $12.96 | yd | 6 | $77.76 |
| Hardware | Screws, bolts, etc. | $100.00 | N/A | 1 | $100.00 |
| Wires | Connection | $0.30 | ft. | 12 | $3.60 |
| Aluminum | 0.014" Walled for frame | $0.66 | ft. | 12 | $7.92 |
| Misc. | Miscellaneous Items | $50.00 | EACH | 1 | $50.00 |
| **Total For** | Build | | | | **$239** |
| | Per Turtle | | | | $1,767.44 |
| | **Gross Total** | | | | **$3,535** |

# 9 Conclusion

Given the design specifications and the component break down specified in this document; the proposed design will meet the requirements set forth by Nekton. Additionally, the timeline suggested is reasonable and attainable.

# 10 References

[1] Daisuke Iijima, Wenwei Yu, Hiroshi Yokoi, and Yukinori Kakazu. "An Acquisition of a Narrow Path Going Through Behavior for a Distributed Autonomous Swimming Robot," *Systems, Man, and Cybernetics, 1999, IEEE SMC '99 Conference Proceedings, 1999 IEEE International Conference*, Toyko, Oct. 1999, p. 602-607.

[2] Gangatheran.N, Rajasegaran G., Zahari Taha, S.Ramachdmn. "Design and Development of an Underwater Vehicle with the Structure Mounted on Spheres," *Seventh International Conference on Control*, Automation, Robotics, and Vision *(ICARCV'02h),* Singapore, Dec. 2002, p. 1470-1474.

[3] Moser, Ed. "Industry Shorts -Security: Pentagon Pouring Funds Into a Host of Land and Sea Robots." Robotic Trends, 6 Sept. 2003 <http://www.robotictrends.com>.

[4] Martian J. Dudziak, T. Renee Fields, Kenneth C. Youngman. "AI Programming vs. Conventional Programming for Autonomous Vehicles – Trade-Off Issues," *Unmanned Untethered Submersible Technology, Proceedings of the 1985 4th International Symposium*, June 1985, p. 284 – 296.

[5] Kimon P. Valavanis, Denis Gracanin, Maja Matijasevic, Ramesh Kolluru, Georgios A. Demetriou. "Control Architectures for Autonomous Underwater Vehicles," *Control Systems Magazine*, IEEE, Dec. 1997, p. 48 – 64.

[6] Gat, Erann. *Conditional Sequencing for Land, Space and Sea. "*Autonomous Underwater Vehicle Technology," *Proceedings of the 1996 Symposium*, Monterey, CA., June 1996, p. 216 – 222.

[7] Hamilton Kelvin, Lane Dave, Taylor Nick, Brown Kieth. "Fault Diagnosis on Autonomous Robotic Vehicles with RECOVERY: An Integrated Heterogeneous-Knowledge Approach," *Robotics and Automation, Proceedings 2001 ICRA. IEEE International Conference*, Vol. 4, 2001, p. 3232-3237.

[8] Daisuke Iijima, Wenwei Yu, Hiroshi Yokoi, Yukinori Kakazu. "Adaptive Behavior Acquisition for a Distributed Autonomous Swimming Robot Based on Real-World Learning," *Proceedings of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Kyongju, Mar. 1999, p. 230-234.

[9] Naomi Kato. "Control Performance in the Horizontal Plane of a Fish Robot with Mechanical Pectoral Fins," *IEEE Journal of Oceanic Engineering*, Vol. 25, No. 1, Toyko, Jan. 2000, p. 121-129.

[10] Naomi Kato. "Application of Swimming Functions of Aquatic Animals to Autonomous Underwater Vehicles," *OCEANS '99 MTS/IEEE. Riding the Crest into the 21st Century*, Seattle, WA, Mar. 2000, p. 1418-1424.

[11] Toshio Fukuda, Atsushi Kawamoto, Fumihito Arai, Hideo Matsuura. "Steering Mechanism and Swimming Experiment of Micro Mobile Robot in Water," *Micro Electro Mechanical Systems, MEMS '95*, Feb. 1995, p. 300 – 305.

[12] Gregory Dudek, Michael Jenkin, Chris Prahacs, Andrew Hogue, Junaed Sattar, Philippe Giguere, Andrew German, Hui Liu, Shane Saunderson, Arlene Ripsman, Saul Simhon, Luz-Abril Torres, Evangelos Milios, Pifu Zhang, Ioannis Rekletis. "A Visually Guided Swimming Robot," *Intelligent Robots and Systems (IROS 2005),* 2005 IEEE/RSJ International Conference**,** Montreal, Aug. 2005, p. 3604-3609.

[13] Bails, Jennifer. "CMU robot walks on water.", Pittsburgh Tribune-Review, Pittsburgh, 6 April 2006. <http://pittsburghlive.com/x/tribune-review/print_440639.html>.

[14] Anonymous. "Technologic Systems – PC/104 Single Board Computers and Peripherals for Embedded Systems" *Technologic Systems*, Feb 2006. <http://www.embeddedarm.com>.

[15] Xhaard Michel. "SPCA Video for Linux Drivers." <http://mxhaard.free.fr/>.