Senior Project Proposal

Design Progress, Direction and Budget

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Executive Summary

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, propellers integrated into the rear will allow the robot to move with speed and efficiency. Two caster fins will be placed on the back of the turtle to protect the propellers and reduce surface friction.

Given the design criteria's above, the functionality of the robot can be broken into smaller parts. These parts includes, motors for moment, GPS/compass for navigation, cameras for vision, wireless router for communication, and main board for interfacing all the hardware components into one unit. Each of these parts is then researched by the members of the turtle development team. The research objective is to find the 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.

Introduction:

Nekton research has presented a unique design challenge. The challenge is to design and build a robot. This robot should posses' 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 be able to move and observe the terrain as well as other objects. To design such a robot a team of student were assembled to complete this task. This paper outlines progress made towards and direction of the project.

Design:

Before any designs could be considered the main requirements of the project must first be defined. Nekton research gave basic traits of the robot and the target weight. From this information it was determined the final design must meet the following requirements.

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

The target size was determined using Archimedes principle. Which states the buoyancy force is equal to the weight of the displaced water. Thus, using the target weight and the known weight of water the total volume of water displaced was determined. To get a basic idea of the design size the robot was considered to be a sphere. Therefore, yields a diameter of approximately 11.67 inches or in water surface area of 213.68in^2.

Target Size:

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

Movement Experiment:

After determining the size of the design how it would move was considered. The team acquired two motors and flippers from Nekton. These motors were mounted to a plastic frame approximately the same size as the target design. Power was supplied to the motors 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. Therefore, resulting in the following findings.

Results 1: Voltage controlled the RPMs of the motor
Results 2: Current controlled the Torque of the motor

Once the requirements were determined and experiments were preformed the design process could start. 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 are unique to the world. Their uniqueness stems from their amphibious ability. Additional traits of Sea turtles are a 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.

Alternative Designs:

A total of four designs were considered for the final product. Additionally, all designs resembled a turtle. Therefore, had a hard hollow shell ideal for storage of all electronic components necessary for operation. Sea turtle's also posses a broad belly, which will provide better buoyancy. Each design is listed below.

Design 1:

This design has four flippers total. Each flipper would be used for movement on land and in the water. Therefore, the design would require 4 motors and enough batteries to handle the power requirement.

Design 2:

Design 2 replaced the flippers 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.

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 these flippers would only be operated by servos. These flippers would be used for turning in water. Therefore, this design would require less power than design 1 & 2 and also weight less because of fewer motors. Conversely, movement on land would be affected due to the loss of rear flipper motion.

Design 4:

Design 4 is similar to design 3 however removes the two rear flippers. Thus, this design suffers from the main drawback. However, the design adds casters to the rear of the robot for reduced friction when moving on land. Therefore, effectively reduces the land motion drawback.

Each design has its own advantages and disadvantages. Therefore, to help in the decision making process a decision matrix was used. Because, 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 is the decision matrix for determining 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.

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 is the CAD drawing of the turtle.

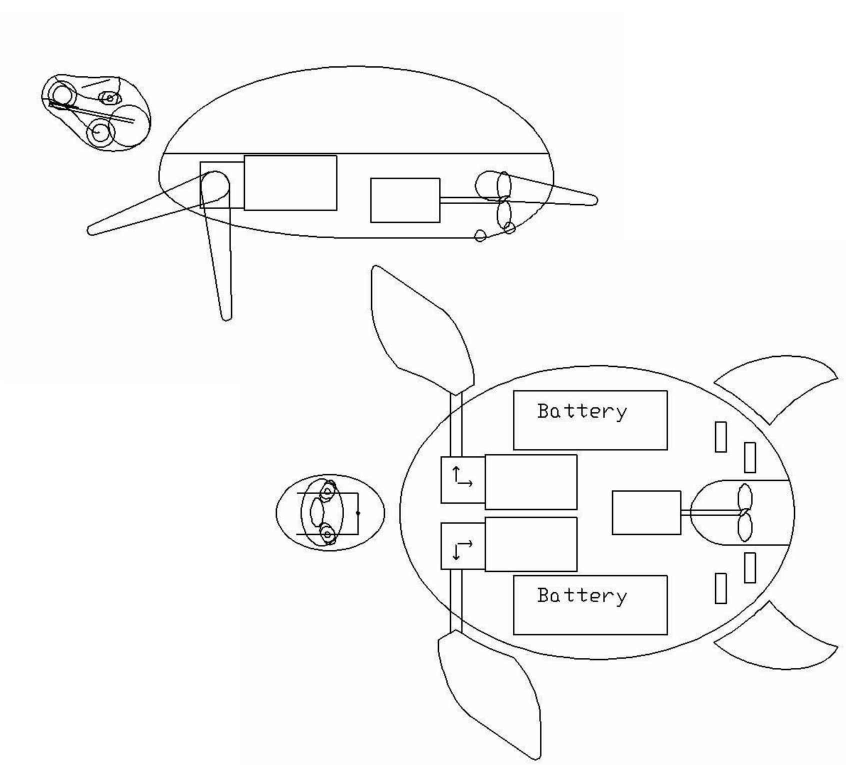

Figure 01: Final Design Schematic

Peripherals

Now that the final design has been determined how the turtle will operate was analyzed. The final design will require three motors for movement. The motors for the front flippers must provide adequate torque for land movement. The motor for the propeller must provide enough RPMs to propel the turtle through water. Yet, these motors would need to be controlled as well as over higher cognitive control. After careful consideration of the design, the cognitive controls were determined and divided into 4 sub-categories. Each sub-category is essential to the proper operation of the design. These sub-categories are listed below.

Cognitive Devices:

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

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 it's power-efficient design. A TS-7200 SBC has a standard power consumption of 2Watts, 5Volts at .4Amps. Embedded boards built with a 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 operate in a fanless 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 application 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.

Internal Navigation System

The project must be able to self navigate to the destination. In order to accomplish the task the turtle must be able to determine its location. Sea turtles direct there 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 deemed a viable solution. GPS derives geographical coordinates accurate to less than 4 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, based on current design criteria the turtle will not have to submerge. Thus, GPS will be 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 an 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.

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 its environment 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 QuickCam 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.

Wireless Communication:

The amphibious and picture capturing requirements require fast communication to a computer. Thus, to cut down on unneeded ports to the interior, which is a source of leakage. It was decided that the best recourse is to communicate to the main board VIA wireless connectivity. Therefore, 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 surfaced Linksys and DPac. Both were comparable and provided means of communicating at fairly low power consumption. Because of their similarity a stringent comparison was required to determine the best product for the project. Equation 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

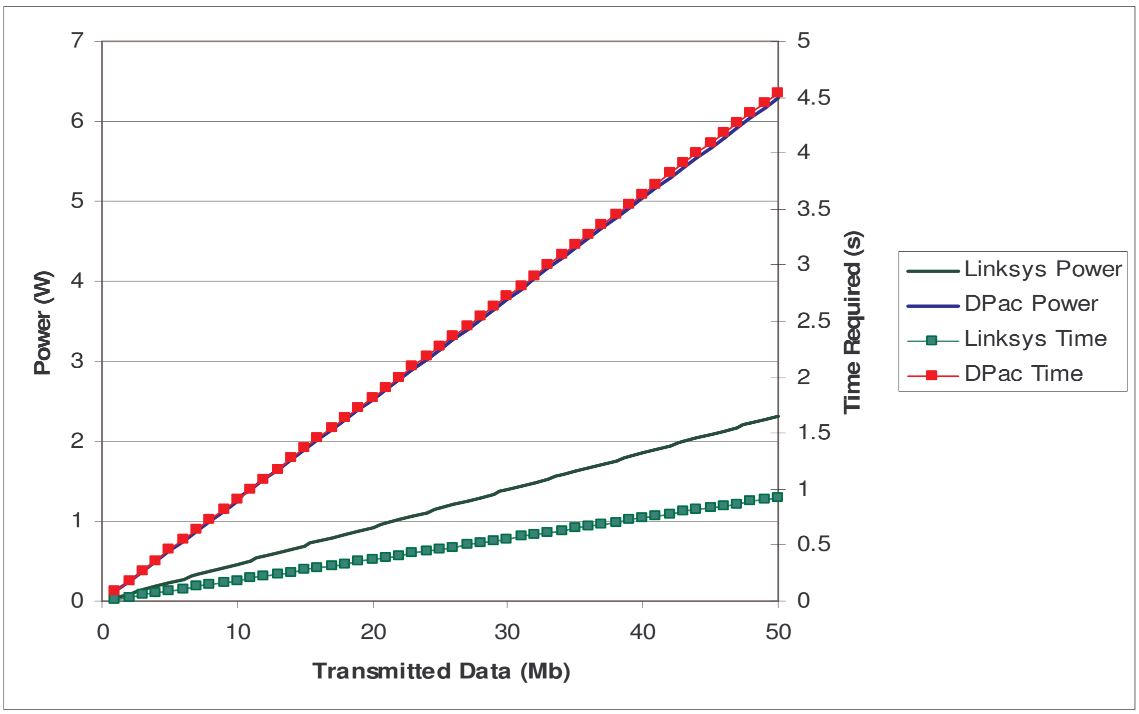

Figure 02: Comparison of Power Requirements

The wireless device will only be operated when the turtle needs to communicate with a monitoring computer. It can be seen 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.

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 be implemented. Because the robot turtle will operate autonomous therefore battery powered, only DC motors can be used. An additional consideration for the robot is the amphibious requirement. Thus, all motors considered must provide adequate torque for movement in both mediums. Yet, before any motors can be chosen, the torque required to move the turtle must be determined.

Torque Calculations:

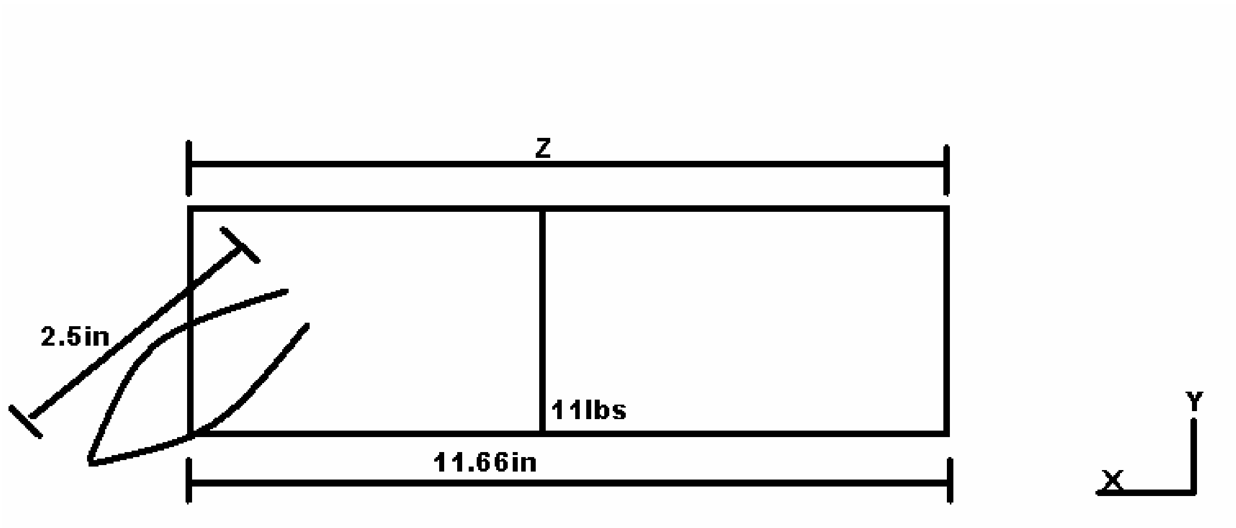

Figure 03: Torque Example

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

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 is the graphical representation of the torque equation across all possible values of the robot starting at center with respect to the rear.

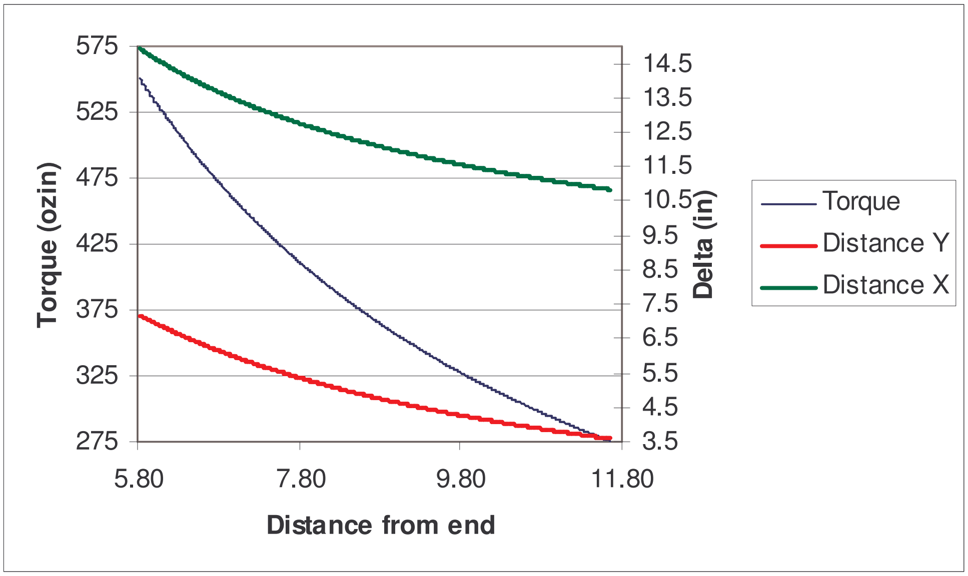

Figure 04: Torque required and Distance traveled

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 4, 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. Thought cost is one of the big obstacles.

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 length. Because of the high quality of motor the Maxon line is also very expensive. To help reduce cost a shorter arm length and pushed the paddles forward, this will help reduce the amount of torque required and a smaller motors can be used. On the downside though, it also reduces the efficiency of our design, there will be less distance per rotation of the flippers. It was decided to go with the Maxon Motor 118889. With a 49 to 1 gear ratio this will give us 120 RPM and 2665 nNm of torque. This might change based on the weight and size of the turtle. The back propeller will be powered by the same kind of motor.

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 divided 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.

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. Hence, each type's characteristics were weighed and a decision matrix was used. Based on requirements for the project cost, weight, and current supply were of the most vital. An additional criterion such as availability was important for possible future 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

After a review of the characteristics, Li-Po batteries seemed 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 increase 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.

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.

Hardware Build:

Due to the environmental operating conditions of our autonomous vehicle, the housing and chassis must above all be impervious to water seepage but also 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 Ghant chart shows an entire development sequence dedicated to the hardware construction of the unit. Since the team is also devoid of mechanical engineering students progress in this arena 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.

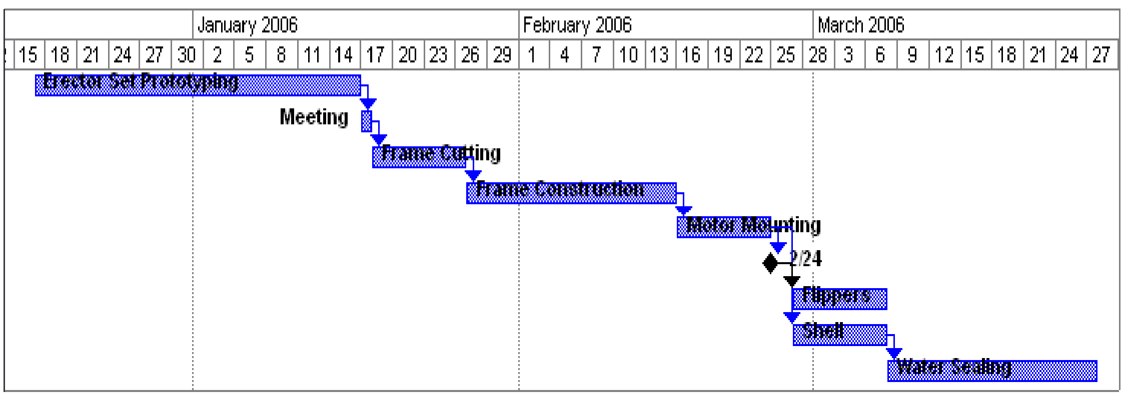

Figure 05: Hardware Timeline

Mockup:

The first step of the hardware design will be to build a chassis mockup. Although this stage is labeled as Erector Set Prototyping, the team will be using an assortment of rudimentary components to complete a preliminary full scale model of the chassis. The dimensions of the chassis overall are approxamitly14"x 8". The construction of the skeleton will start from the conceptual draft of the chassis made using AutoCAD, as seen in Figure 05. During this step the team 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.

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. Do 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.

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 fell 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.

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 making 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.

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.

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.

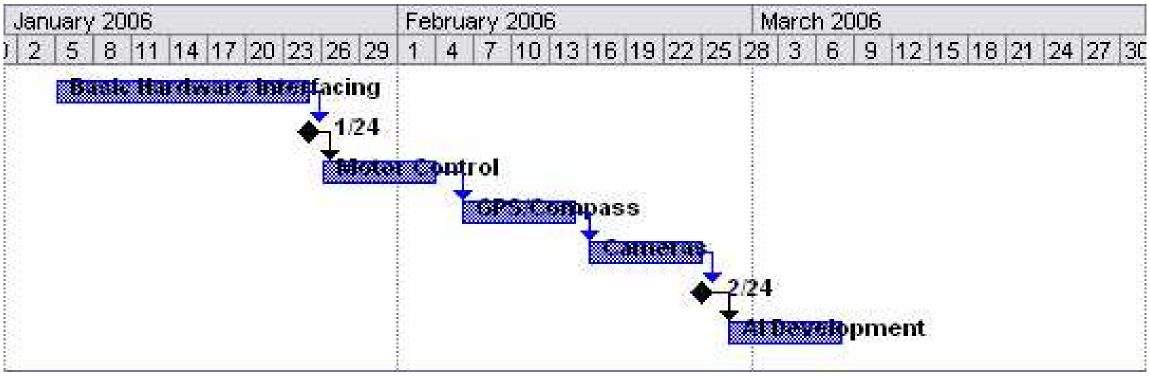

Figure 05: Software Development Timeline

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 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.

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's currently pointing to. The information provided by the GPS and compass will enable the turtle to travel to a location, predefined by the user. After the GPS and compass applications are complete, the last peripheral device to be interfaced is the camera.

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.

Budget:

The total budget to build two prototypes was determined. Table 3 is the budget for this project. As can be seen from table 3 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					
Ecoder	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 wirless 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**

Conclusion:

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