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# INTRODUCTION

## Problem Background

Navigation has been an essential part of human experience and has been highly developed in sea exploration. One major method for navigation is dead reckoning. Dead reckoning involves taking careful measurements of movement to determine current location. Future positions can be found by knowing an absolute starting point, and measuring from that location. Dead reckoning was initially used primarily in sea vessels, it now has moved to mobile robots. There are several methods implemented to measure movement including odometry and inertial navigation.

Localization is defined to be the process of determining the robot's location within the environment. This is achieved with the aid of maps and sensors readings. The ability for a robot to know exactly where it is located in reference to a map is vital in the real world. Robots can be used in search and rescue missions in response to natural disasters or various other catastrophes. Sensor readings from either optical encoders or accelerometers could be translated into a known location in the physical realm. This can then be compared to its actual location to determine a percent error so that future discrepancies can be accounted for.

Odometry is measuring axle rotations to determine the distance traveled. There are several types of sensors that can measure axle rotations. They include brush encoders, potentiometers, synchros, resolvers, optical encoders, magnetic encoders, inductive encoders, and capacitive encoders. Optical encoders have been popular in mobile robotics. They have a relatively simple design and have the added benefit of having a digital output.

Accelerometers work by measuring the acceleration of the object they are placed on based on either a tilt in gravity or an inertial acceleration that is then turned into an electrical signal. Using this acceleration, velocity and position can be found by doing integration operations. In this project, we will be using MEMS accelerometers that are analog. MEMS, standing for Micro-Electro-Mechanical Systems, is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. These Microelectronic integrated circuits can be thought of as the “brains” of a system. It allows Microsystems to have sensors, to be able to measure information from their environment. After collecting this information, the electronics then process it and come to a conclusion by a decision-making capability which in turn causes them to react to the environment. MEMS accelerometers are quickly replacing the conventional accelerometers due to their extra sensitivity and small sizes. One example is in crash air-bag deployment systems. The older accelerometers were bulky in size and mounted on the front of the car with separate electronics near the air-bag. The costs were around \$50 per car, which the MEMS accelerometer has changed completely. MEMS accelerometers are not only smaller, but the whole system is within one silicon chip including the electronics. They are smaller, much more reliable, and only cost \$5 to \$10 per car. MEMS accelerometers have greatly changed the way accelerometer applications were used before.

## Problem Statement

We are to build a mobile robot to follow a pre-specified path using different navigation methods. We will execute trial runs and record actual versus specified paths. We will analyze the results to determine the most accurate system.

## Objective

Construction: We plan to build a robot consisting of a chassis, power supply, servo motors, and a micro controller. We will use accelerometers and shaft encoders as our movement sensors. We will write drivers for the robot using software compatible to the micro controller. We will interface between a personal computer and the robot using serial ports.

Experimentation: We will load a path for the robot to follow. We will layout a path on the experiment surface. We will then be able to measure the deviation in the paths.

Analysis: The experiment surface is a grid. We will be able to measure the area of deviation produced by different trials. We will then be able to make error distributions for the different navigation methods. From the error distributions, we will be able to see which method is more accurate.

## METHOD OF SOLUTION

### Literature, Market, and Existing Solutions

The OOPic is a single board microcontroller. The OOPic board can be easily programmed using Java, C or VB. Software is available for no cost from the manufacture to compile and download programs to the OOPic board via a parallel interface.



Fig 1: OOPic Board

The OOPic board has enough EEPROM storage onboard to accommodate 4096 instructions. An additional EEPROM can be added expanding this storage an additional 32,768 instructions. All hardware necessary for writing the EEPROM is integrated into the OOPic. The processor is capable of executing 2,000 instructions per second.

The OOPic has 31 I/O lines available and two additional lines available for networking multiple OOPic boards using an I2C network. Four of the OOPics I/O lines can be used for analog input. The board has an integrated A/D converter.

The OOPic board's power requirements can be satisfied with a standard 9V battery. A 5V power regulator is present on the OOPic board.

The OOPic board is available from Savage Innovations, Inc.<sup>1</sup>

To use the OOPic to control DC motors a second board is required. The recommended board would be the Dual Channel PWM (Pulse Wave Modulation) DC Motor Driver Board from Magnevation<sup>2</sup>. This product is available in a bundle with an OOPic. Each channel on the PWM board uses 5 I/O ports on the OOPic. The board amplifies the PWM signal from the OOPic board to drive the DC motors. The board uses the 5 I/O lines for the following signals to and from the OOPic board.

- Speed
- Direction
- Brakes
- Thermal Flag
- Analog Output (to indicate motor current)

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<sup>1</sup> <http://www.oopic.com/>

<sup>2</sup> <http://www.magnevation.com/>

The project requires four interfaces for sensors. The sensors necessary are two shaft encoders to measure revolutions of each wheel and one accelerometer with outputs for two axis. Both of these sensors are capable of digital output so A/D conversion is not necessary. There are sufficient digital I/O ports available on the OOPic to interface with the motors and all sensors.

The chassis for the robot would be constructed using Plexiglas. A three wheel design, with two powered wheels each having a shaft encoder and a third caster wheel will be used.

An alternative solution to the OOPIC based device uses the MIT Handy Board microcontroller. The MIT Handy Board is a Motorola 68HC11 based microcontroller designed for use in both small scale educational projects and industrial control systems. In general the reference material for the Handy Board project is much less organized than that of the OOPic solution. The Handy Board is also considerably more expensive than the OOPic based solution.

The programming interface for the Handy Board is also not as refined as that of the OOPic. The Handy Board uses a subset of the standard C language called Interactive C. This is the only high level language available for the Handy Board. The board can also be programmed using Motorola's assembly language for the 68HC11 chip.

The Handy Board has 32 kilobytes of SRAM available on board in addition to the 256 bytes on the 68HC11 chip. There is no EEPROM available but the SRAM is battery backed so data should be saved. The processor runs at 2 MHz and most instructions take 2-4 cycles.



The Handy Board has 9 digital and 7 analog inputs. A nice feature of the Handy board is that it has two integrated motor headers. These motor headers can supply 1A at 9.6V.

An integrated rechargeable battery comes with the Handy Board system. The battery supplies 9.6 V at 600 mA. The battery consists of 8 AA nickel cadmium cells.

The Handy Board has two integrated motor drivers able to supply 1 A at 9.6 V. Motors can be connected directly to the board on these ports.

The Handy Board has 9 digital and 7 analog inputs available. Our sensors require only four digital inputs.

There are many robots that are equipped with dead reckoning systems with the use of optical encoders. The Trilobot made by Arrick Robotics comes shipped with optical encoders already installed. They control the distance and speed to allow the robot to move down a specified path. It has been involved in numerous navigation research projects and also a few automatic guided vehicle simulation experiment.

The Pioneer 2-DX8 robot has exceptional navigational capabilities. It uses 500 tick encoders to keep up with its top speed of 1.6 meters per second. The robot offers upgrades such as inertial correction systems which greatly enhances the standard laser mapping and navigation the robot comes with standard. The robot can map an entire room rapidly which then allows the user to

point to a location on newly created map, and the robot will travel there. Unfortunately, this robot is discontinued.

There are many publications concerning odometry and its role in dead reckoning systems. They cover topics including design solutions, technical difficulties, and error correction.

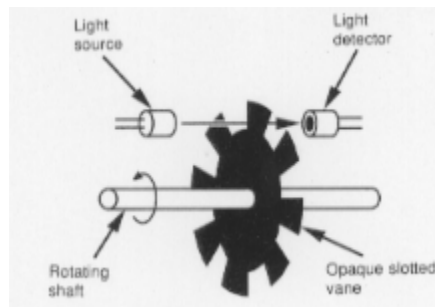


Fig 2: Optical Encoder

Design solutions include using different kinds of shaft encoders to determine the axle rotations. The encoders involve attaching a disc to the shaft that will interrupt a flow of light into a detector. Each disruption creates an output signal. Further, there are two types, incremental and absolute. Incremental encoders provide a continuous square-wave signal and measure the axle velocity with the frequency of the wave. An addition to the incremental encoder are called the phase-quadrature incremental encoders. They add a second disc and rotate it to be 90 degrees out of phase of the first disc. This allows for determination of the direction of the axle rotation by analyzing which wave form is leading. The absolute encoders provide a disc with a specific pattern on it and a parallel output. The specific patterns allow for greater precision and the ability to maintain that precision when there are vibrations and jolts.

Technical difficulties are present in all designs. For incremental encoders, false readings can be generated when direction is changed at certain positions. For absolute encoders, there is a problem with the number of wires required to implement the parallel output that they generate. There is also the difficulty of mounting the encoders. They should not weight too much for the axle and have to be properly aligned with that axle.

Error correction is necessary in odometry navigation because of problems with the system assumptions and non-ideal environments. Problems with the system include poor measurement of robot dimensions, wheels not aligned properly, and encoder resolution and sampling limitations. Non-ideal environments include wheel slippage and uneven floors. Error correction includes adding encoder wheels, trailing encoders, calibration adjustments, and mutual referencing (this requires two robots).

Market solutions include encoders included in robots, separate encoders, and building our own encoders. Robots that include encoders are generally expensive. Separate encoders come in a variety of shapes and types. Building our own encoder will take time, but will not have a precision or accuracy comparable to manufactured encoders.

Due to the requirements in the project, we had to use MEMS accelerometers which did not leave us many choices in which accelerometer to use. However, we did research past accelerometers that have been used and came to the conclusion that MEMS were the best ones to use due to their small size and extra sensitivity. Past accelerometers have always been larger and involved extra electronics to be placed around it. Within the MEMS accelerometers, the first choice was a dual

axis versus a single axis. The dual axis has many different types in different acceleration values ranging from  $+2g$  to  $+100g$ . In this project, the robot will be very slow, so we decided to look at only the  $+2g$  accelerometers. At  $0-2g$ , you can measure the acceleration of a human walking which will be enough for our slower robot. We ordered a kit that included the accelerometer itself, two resistors, and three capacitors. Instead of also ordering the sensor board kit, which is required to program the chip, we are instead going to attach the chip to the OOpic board that we will already have with the MARK III robot we are ordering. This saves space on the robot, and it also utilizes what we already have. In the end we decided on using the ADXL202E, which is a digital output  $\pm 2g$  accelerometer with  $200\text{ mg}$  resolution.

## Project Phase Summary

The proposed solution for the project involves three stages. The first stage is robot construction. A robot is needed which can follow a predefined course using either odometers or accelerometers as its source of navigation information. After the robot has been constructed a period of experimentation will take place to record data concerning the accuracy of each navigation method. Once all trials have been completed during the experimentation phase of the project an analysis of the recorded data will be completed to provide numerical data comparing the results of the different methods of navigation. The three phases of the project will be:

- Construction
- Experimentation
- Analysis

## Construction

The primary goal of this project is not to construct a robot. Construction of a robot is a critical phase of the completion of the project, but not the goal of the project. Because of this the teams choose not to create a completely custom robot. The proposed robot will be based on a kit robot available. The kit will be modified as necessary to meet the requirements of our robot.

The kit chosen will be a Mark III Complete Kit (OOPic Version) which is available from the Mark III Robot Store.<sup>3</sup> The kit comes with all the parts and instructions necessary to create a mobile robot. The team will modify the kit to include shaft encoders on each wheel and accelerometers. Also a The following items are included with the Mark III kit:

- Mark III Chassis Kit
- Mark III Controller Board Kit (OOPic Version)
- Sharp GP2D12 Distance Measuring Sensor
- Set of two Injection Molded Wheels
- QRB1134 IR Photo reflector
- Standard Torque Servo Motors

In addition to the kit the team will purchase the following items to complete the robot.

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<sup>3</sup> <http://www.junun.org/MarkIII/Info.jsp?item=27>

- (2) Incremental Optical Shaft Encoders Model 600CS-ND
- (1) Serial Cable
- (1) Accelerometer Kit (includes MEMS accelerometers)
- (1) 2 Count 9V Battery Pack
- (1) 12 Count AA Battery Pack
- (1) Marker

Another modification that will be made to the robot is that the “scoop” which drags behind the robot will be removed. In its place will be an attachment so that a marker can be dragged behind the robot recording its path on butcher paper.

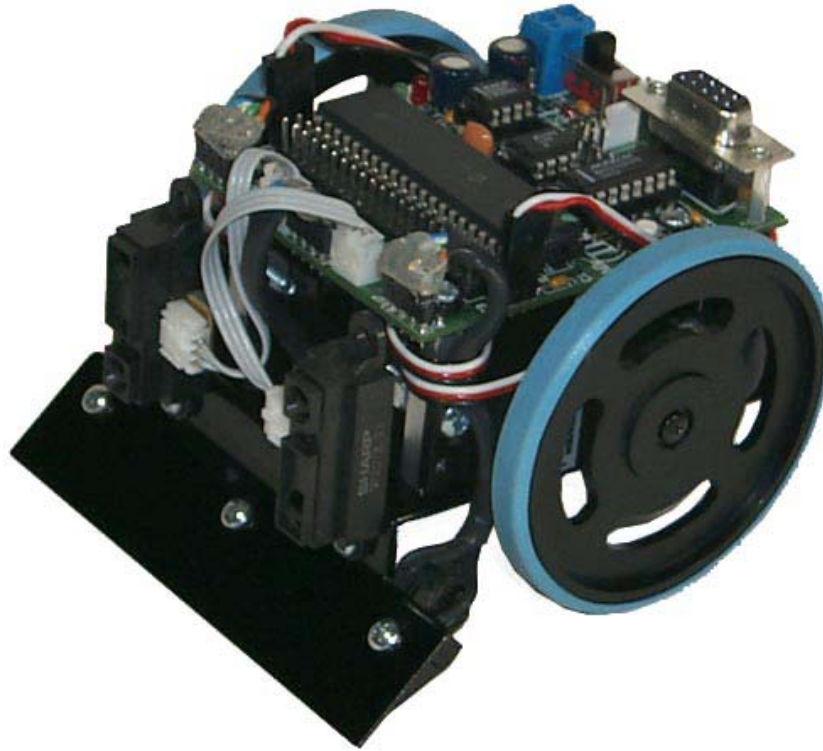


Fig 3: Mark III Robot

## Experimentation

The team has a unique idea for recording data in each of the trials. First a path will be programmed into the robot. The team will then draw this path out onto a piece of butcher paper. The robot will be told to begin following the path. As the robot moves along the path it will be dragging a marker which will denote what its actual path was in relation to the target path. The robot will repeat each path a certain number of times using odometry for navigation and again a certain number of times using accelerometers for navigation.

## Analysis

After all experimentation has been completed a grid will be drawn on the butcher paper. The area between the actual path and the target path will give us a numerical values of how close the robot was to its target path. This data is the goal of the project - to compare the accuracy of the two different navigation methods.

## Design Constraints and Feasibility Study

With either of the proposed custom build robots the same constraints apply. The primary constraint is time. The project must be completed within this semester. Because of this constraint the team feels it is appropriate that products which will be the easiest for us to assemble and develop applications for are the best choice. The OOPic based solution clearly has an advantage in this area because of its well defined programming interface.

In general, a completely custom robot would not be in the best interests of the team. The primary goals of this assignment are not to build a robot but to test different navigation methods using a robot. Because of this constraint it is in the interest of the team to find an existing robot platform or kit which can be modified to meet our requirements.

Because one of the requirements of our project is that we use odometry to determine the robots position our robot will require shaft encoders. Most existing kit robots do not include shaft



encoders. Because of this limitation the almost any existing kit robot will need to be modified to include the shaft encoders.

For this project, feasibility of encoders will be limited mainly by price, availability, and mounting styles. (Fill in with info from online. I don't know which encoder we plan to use.)

## Alternative Solutions

Many various prefabricated robots were researched to be the basis of the project. Robots such as the Pioneer 2-DX8 and the Trilobot made by Arrick Robotics were considered since they already have encoders built into the robot. They both have limitless possibilities in terms of expansion, unfortunately their costs would have greatly exceeded the budget provided. Another robot, the Khepera II made by K-Team, met the minimum technical specifications, but its size was a negative attribute. At a height of 3 centimeters and a diameter of 7 centimeters, the option of not using this robot was an easy decision. The Magellan Pro made by iRobot poses a different problem. The wheels are located completely beneath the robot. This would lead to difficulty attaching encoders to the wheels. Finally, 2 robots manufactured by Applied AI Systems, Inc. were considered. Inquiries to the cost of the LABO-1 and Koala robots were made, but a response was not received in time to suit the schedule of this proposal. Overall, ten prefabricated robots were looked upon to be the foundation of the project. Based on the objective and group preferences, the number was narrowed down to the one we feel best meets our required needs. Because of the constraints placed upon the project a completely custom robot is not the ideal solution. As an alternative to a custom robot the team has chosen to use an existing kit robot which uses an OOPic microcontroller. The kit robot will be modified to include shaft encoders

and accelerometers. The kit robot uses modified servos so a PWD DC Motor board is unnecessary.

Doppler encoders, magnetic encoders, potentiometers, tachometers, resolvers, and synchros. These solutions provide similar outputs to optical encoders, with the exception of the doppler encoders and potentiometers. Doppler encoders calculate the axle velocity based upon the doppler effects on the energy waves it generates. Potentiometers produce varying voltages based upon the axle position. The other sensors produced sine or square-waves and the axle velocities are calculated using the frequency of the signals. We decided to just buy an accelerometer without a board by just placing the accelerometer on the OOpic board.

## Validation

Before the experimentation phase of the project can begin there must be some confidence that the two navigation methods are actually working. It would be impossible to generate the data needed if the robot for example went in continuous circles when using accelerometers for navigation.

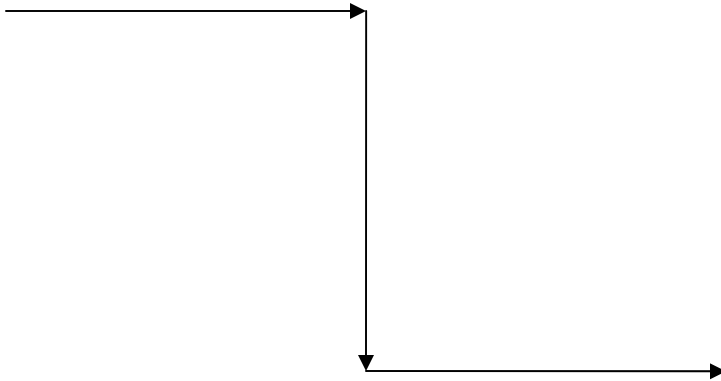


Fig. 4: Path of Robot

For the validation of our robot we are going to ensure it can follow the path of a simple trial which will involve a right and left hand turn and three straight segments. Experimentation cannot begin until the robot is able to complete this simple circuit using both methods of navigation.

## **ANALYSIS**

### **Cost**

The cost of our project is significantly lower than the budgeted \$1000. The following chart gives a break down of expected costs associated with the Construction, Experimentation and Analysis phase of the project.

Part	Supplier	Phase	Quantity	Price	Shipping	Cost
Incremental Optical Shaft Encoder	Digikey	Construction	2	\$ 46.14	\$ 15.00	\$ 107.28
Mark III Complete Kit	Mark III Robot Store	Construction	1	\$ 98.00	\$ 15.00	\$ 113.00
Serial Cable	Mark III Robot Store	Construction	1	\$ 4.00	\$ 4.00	\$ 8.00
Accelerometer Kit	Mark III Robot Store	Construction	1	\$ 23.00	\$ 4.00	\$ 27.00
Urethane Tires	Mark III Robot Store	Construction	1	\$ 6.00	\$ 4.00	\$ 10.00
2 Count 9V Battery	Eckerds	Construction	1	\$ 6.79	\$ -	\$ 6.79
12 Count AA Battery	Eckerds	Construction	1	\$ 7.99	\$ -	\$ 7.99
Materials for Chassis Modification		Construction	1	\$ 40.00	\$ -	\$ 40.00
Material for Experimentation Recording	OfficeMax	Experimentation	1	\$ 40.00	\$ -	\$ 40.00
						\$ -
Total Cost:						\$360.06

Table 1: Cost Analysis

## Societal

Dead-reckoning robots can change society by becoming a big part of our everyday lives. These robots can be used to become housekeepers, servers at parties, workers, flight simulators and many other basic human jobs. Robots can also be used to perform dangerous human operations such as investigating hazardous and dangerous environments.

## Environmental

One aspect of the environment that must be taken into account is the surface that the robot will travel. Due to the constraints aforementioned, the robot will only be tested on a 2 axis plane. A smooth, flat surface will be required to perform the experiments that have been designed to test the robot. In order to achieve maximum results, traction of the wheels is an important attribute.

Instead of using the standard rubber band around the wheel for basic traction, an upgrade to the urethane based band was chosen since it will greatly improve traction. Due to the size of the robot and for better viewing purposes, an area of at least four square meters will be necessary for testing and demonstration purposes.

The MEMS accelerometer best operated between -55C to 125C and its storage temperature range is from -65C to 150C. If the accelerometer is placed in temperature conditions that go beyond these ranges, then permanent damage may occur and device reliability will be affected.

## Risk

Risk analysis must take into account a variety of concerns. Among our concerns are resources being limited, resources breaking, teammates, time limitations, and incompatibility. Our resources could be limited by the computer science department. Orders for expensive products could be rejected or they could be asked to be reduced in cost. Our resources could break in several ways: circuitry breaking, faulty robot parts, sensors breaking. Our teammates could be undependable or end up dropping out of the class. We have time limitations imposed upon us by mail delivery, due dates, and the end of the semester. We will have to manage all of these times and produce a deliverable. Incompatibility issues may exist between hardware parts and between the software and the sensors.

## Safety

Safety of the group members and of the surroundings will be a concern. All work on the robot will be done in a controlled setting which will be the designated lab room. Here the proper tools will be used to follow the instructions provided to construct the robot. Modifications to the original specifications of the robot will be handled with extreme care. Adding on to the frame, soldering connections, and handling batteries are all actions that have the potential to lead to injury. Any additions to the frame of the robot must be securely attached so that nothing can become dislodged and possibly be projected to cause damage. Overheating and electrical shorts are also problems that can occur. All efforts will be taken to prevent these mishaps from happening. Control of the robot is another key safety issue. The robot must travel in a predetermined path or else the safety of environment can be threatened.

## Management, Scheduling, and Team Work

Scheduling for the project is a key component in order to achieve success. A decisive schedule must be prepared but at the same time needs to have some flexibility in order to accommodate any unforeseen circumstances. With this in mind, we created a schedule that we believe is feasible to complete. Key activities include ordering and receiving the materials, formula derivations, software development, hardware construction, testing of the robot, and analysis of the results and findings. Each activity is allotted a certain amount of time to be completed within. Refer to the Gantt and PERT Charts that are attached to this report for more details.

In order to complete the project objective, the team will need to meet many times to discuss and work on the project. Lab time that is already scheduled for the class will be primary time during

which work will be accomplished. Since this is the last semester of all the group members, each respective member's class load is not too demanding. This allows for the group to have additional meetings on an as needed basis without much trouble.

Documentation and feedback will be closely reviewed throughout the duration of the project. Each member of the group will maintain a notebook in which any and all project related information will be recorded. Weekly meetings with the advisors are planned each Monday at 5:45 so that they can be aware of the status at the current time. Bi-weekly reports are also another requirement and another form to relay the current state of the project.

Specific activities such as software development and hardware construction will be worked on in pairs. This will allow for concurrent work and more efficient use of time. Testing of the robot will require all the members to be present.

<i><b>Task</b></i>	<i><b>Week</b></i>									
	First	Second	Third	Forth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
Order Components	■									
Components Arrive		■								
Odometry algorithm	■									
Accelerometer algorithm		■								
Putting robot together			■	■						
Coding the OPIC			■	■						
CDR					■					
Debug						■	■			
Analysis								■	■	■

Fig 5: Gantt Chart of Project Tasks

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