ARIZONA STATE UNIVERSITY

Presents

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Guided By: Dr.Armando Rodriguez, Dr.Kostas Tsakalis

Special thanks to Ananth Viswanathan

1. Introduction

Arizona State University is proud to present its first entry to the Intelligent Guided vehicles challenge called the ‘MoViT’, which stands for **Mo**bile **Vi**sion based **T**ank.

It is a platform intended to be used in the development and modeling of Vision based robotics. MoViT uses a skid steer mechanism with Tank Treads to give it off-road capability. It is the result of an endeavor to a create a low cost but highly competitive, intelligent vehicle using a combination of vision capabilities, optimal decision making policies, and reinforcement learning.

2. Team Organization

The Team members are

- **Kapil Sekhar (Graduate Student,MS):** Team Leader, Mechanical design, Embedded systems, Controls, Sensors, Logic and Navigation
- **Harikrishnan Raghunathan(Graduate Student,MS):** Vision system, mechanical design , Logic and Navigation

A lot of technical and moral support was given by Dr.Armando Rodriguez and Dr.Kostas Tsakalis.

3. Design procedure and problems

The design paradigm that we followed was to build the vehicle in stages and trouble shoot it as it was being built and integrated. The essence of our design was to keep it as simple as possible. This enabled us to ensure that every part worked well, was easy to maintain, and could be fixed if it developed problems. Another important design policy we followed was to use as many parts or building blocks as we could from readily available off-the-shelf components and custom make very few parts. This has allowed the robot to be modular in nature allowing us to play with the configuration as well as find easy replacement for parts that did not integrate well. Additionally, this has enabled us to keep the costs down. One of the key features of our design and building was that a number of test rigs as well as tests were thought of, designed along-side, and then used to test the validity of the design we had implemented. This has helped us eliminate potential problems, especially those of a mechanical nature, as we are not mechanical engineers and would suffer greatly if there are severe mechanical problems on-site.

Some of the challenging problems we encountered were with bad gear ratios, mounting motors and gears in an ideal configuration and choosing a camera.

4. Innovations

MoViT is a culmination of a number of novel ideas. To build the physical system we are one of the first robot team in the IGVC to extensively use the Vex robotics components. This was a direct implementation of the COTS principle and is truly cost effective as well as being a highly compatible system.

A remarkable innovation is the lightness of MoViT, which was a direct result of a conscious decision to keep its weight within 50 lbs making it lighter than most robots in its class. This has given MoViT, the desired maneuverability alongside making it easily portable.

Use of tank treads is another rare adaptation to the IGVC robots that we have implemented as this would give true off-road capability as well as good traction.

An original idea realized within MoViT's software framework, is the use of robot learning to improve MoViT's performance as the competition progresses. This enabled us to incorporate machine intelligence into MoViT and making it truly worthy of being a “Learning System”. We are implementing this using a reinforcement learning algorithm.

5. Mechanical System:

5.1 Chassis

MoViT is based on a Tank Design. The robot chassis has been designed and built to satisfy the following criteria

- Capable of going over grass and off-road terrain
- Predictable and easily measurable turning mechanism
- Allowing good integrability and amenable to future changes in design
- Easy to repair in case of damage
- Must be made from inexpensive COTS products or materials

Hence to satisfy these constraints we made the chassis using slotted cold rolled steel rails and angles bolted together with screws and keps nuts. The overall dimensions of the vehicle are contained within a box 3’2”x1’6”x2’6”.

The chassis is a 6 level design, where the lowest level is for the bogie wheels that facilitate the contact between the track and the ground. The next stratum is where all the power sources are kept .The third level is the propulsion level. which also houses the motors and drive trains. This is also where the payload would be kept. The fourth level is the electronic system level where the microcontroller and the motor controllers will reside. The fifth level is for housing the computer that will process information and issue commands to the microcontroller and the highest level is for mounting the camera and GPS. The Camera has an adjustable plate that allows for adjusting the height and angle of depression so as to provide the best view to the camera in different scenarios.

5.2 Drive Train

The drive train for the robot consists of a 2 Johnson HC683LP motors with the following specifications as given in Table 1

Model	Voltage		No Load		At Max Efficiency					Stall		
	Operating Range	Nominal	Speed (r/min)	Current (a)	Speed (r/min)	Current (a)	Torque		Output (w)	Torque		Cu
HC683LP	6.0 ~ 12	12V	22,300	1.84	19,600	12.99	69 mN-m	NA	142	560 mN-m	NA	9

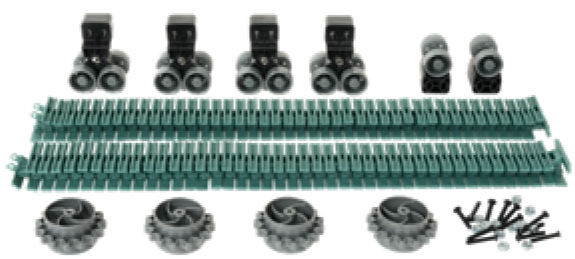
Table 1: Specifications of Motors used for MoViT

Fig 2 : Motor Controller and Vex Gears

The gear reduction used is a 77:25. A linear gear arrangement did not yield the optimum reduction in speed and increase in torque so as to drive the vehicle. To fix this 3 compoundings were done with a ratio of 36:60 per compounding . The driving gear was a 12 tooth gear and the final driven gear was an 84 tooth gear. This brought about a generous increase in torque .The gear train is a compound gearing made from gears available in the Vex robotics systems. The motor power is directed by two Victor 884 motor controllers that switch polarity of the motors depending on the desired direction.

5.3 Mobility

Fig 3: Vex Tank Treads



The steering mechanism used in the control of MoViT is a skid steer. This was a deliberate decision as skid steers are easy to control, allow for more accuracy in turning and at the same time make it easy to measure the turning through encoders. This has also given MoViT, a zero turning radius with the accompanying agility in moving and turning.

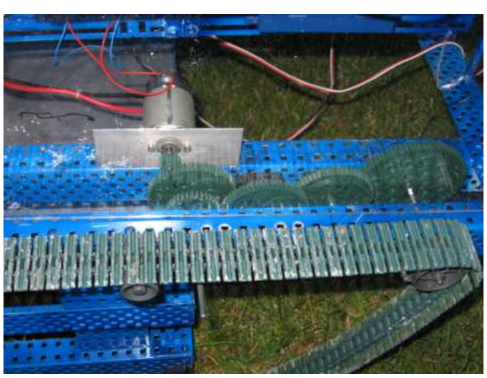


Figure 4: Gear System used in MoViT

MoViT uses a set of plastic tank type treads to enable it to move. These treads are part of the Vex robotics system and are made of Delrin plastic.

6. Electrical System

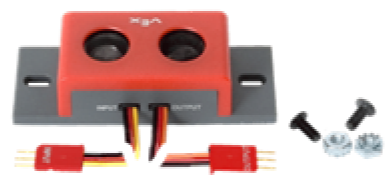
The electrical system has been a phased development of designing, building and testing. The idea of reliability has be paramount in the design.

6.1 Sensors

MoViT has 4 sensors to help it visualize and interact with its surroundings . They are

- **Camera:** For the vision system, a Sony Handycam (DCR-TRV22E) was used to obtain visual images. Besides being compact, the Handycam obtained high resolution images using wide angle lens. The camera is housed in a plexiglass structure to protect it from inclement weather.

- **Ultrasound:** This allows us to detect obstacles from 3cms to 3 metres or 10 feet. This sensor works on the principle of sound echo-location. It sends out a ultra-sonic frequency sound wave and measures the time taken for it to return and finds out the distance of the obstacle. The sensors are mounted on the front beam of the vehicle so as to give an accurate estimation of the obstacles in case the vision does not pick them up of incorrectly estimates them. The ultrasound modules are made by VEX.



- **Encoders:** Encoders are sensors used to get data on how much the motor or wheels have traveled and in what direction. MoViT has two encoders mounted on either shaft, thus giving feedback to the controller on how much of the commanded motion had taken place.

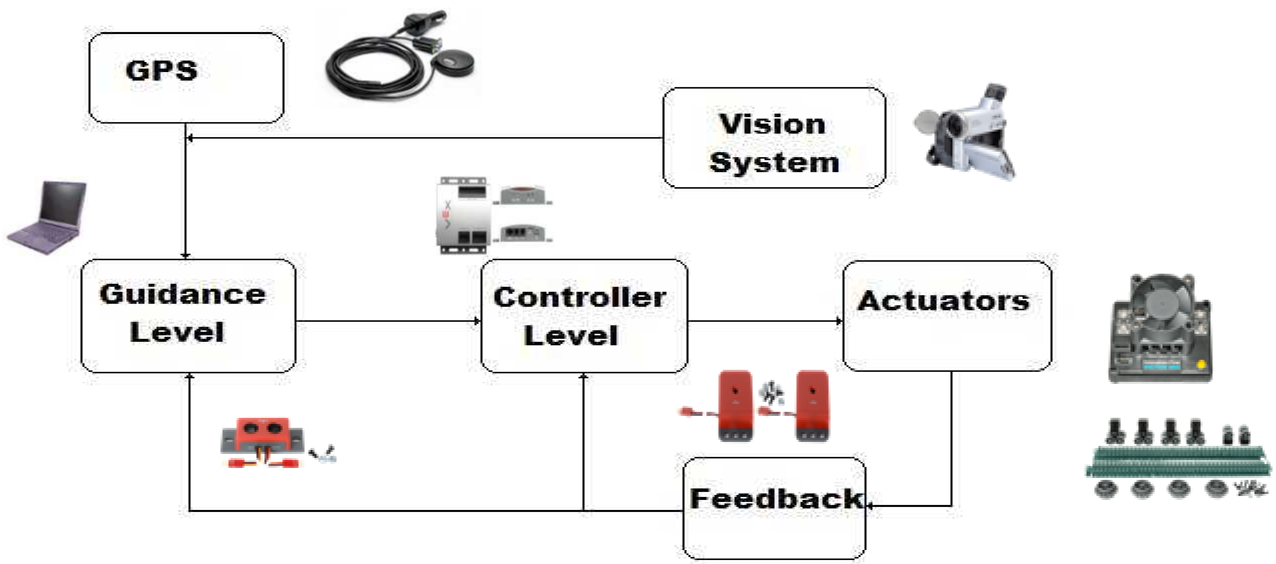
- **GPS:** A Global Positioning System receiver has been used to obtain real time position information. This helps us to know where we are and if we are moving in

the right direction and not in circles. We have used a Garmin 18 PC, RS232 i/o port type GPS receiver which has an error range of 10feet or 3metres.

6.2 Processing and system integration:

MoViT uses a hierarchical system of processing information. There is a higher level or guidance level processor which is a Dell Latitude 610 laptop that interfaces with the GPS and the Vision System and then the controller level that interfaces with the encoders, Ultrasound and the motors and controls them.

Figure 5: System Integration Block Diagram



This system is designed so as to allow the motor controls to operate independent of the vision processing time and thus optimizes the time in motion to process the vision.

6.3 Power

MoViT is powered by a combination of DC sources:

- A single 12V lead acid battery that supplies power to the motors and the GPS
- A 7.2V battery supply to the Vex Microcontroller module
- The laptop and camera are powered by their own battery sources

This distributed power supply scheme was thought of to give each device to perform to their maximum and to give the robot a longer overall operational life. This also eventually helped MoViT perform efficiently during trials as the devices were able draw enough current to perform their task without flaw or compromise.

7. Software System:

The robot's software has been written using three different programming languages, namely

- Visual C++ (the Vision Algorithm)
- Visual Basic 6.0
- Easy C (Vex programming language and MPLAB , Microchip compiler)

The Vision algorithm has been developed using a toolbox know as OpenCV , created and distributed by Intel for the purpose of Image processing.

Visual basic is a great tool for creating front end interfacing tools and thus was chosen to help us integrate all the disparate pieces of software into one .

7.1 Vision

The visual algorithm was developed using Intel's OpenCV, an open source computer vision library. With OpenCV, a high-end real time computer vision library, the algorithm was made highly sophisticated and robust.

Visual Algorithm:

The visual algorithm identifies lines, potholes and obstacles and prepares a map of the path ahead. In order to do the identification efficiently, the images obtained from the camera are preprocessed to remove noise using techniques such as Gaussian pyramidal decomposition and thresholding. Using pyramidal decomposition, downsampling and upsampling are done, which ensures good noise removal. Thresholding also greatly aids identifying lines and brightly colored obstacles and potholes. The noise filtered image is then passed through a canny filter that obtains all the edges from the image. The lines in the preprocessed image are then located using the Hough Transform. The existence of obstacles and potholes are detected using contour finding functions. Both solid and dashed lines can be are found accurately by simply varying certain thresholding parameters within the Hough Transform

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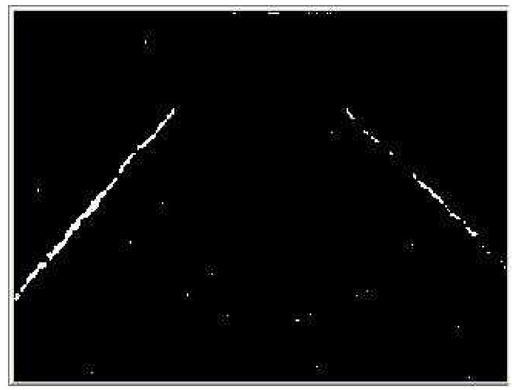


Figure 6: Source and Processed image using OpenCV

7.2 Control

The controlling algorithm is implemented through a Visual Basic program. The control algorithm is where the whole process comes together. The control program interfaces with the vision software, connects to the GPS and interfaces with the Vex controller. The control program first initializes all the ports and variables it needs. Then it calls the vision software to invoke the camera and process the image it receives. It receives from the vision software the most optimal path to follow within the constraints of the boundaries set out on the course. The program then checks with the GPS with the next proposed coordinates are not tending to be trap or leading to a circle. It commands the VEX in the direction of motion suggested by the vision software. The Vex uses the ultrasound, when ever is starts or stops the motors, to detect any obstacle upto 15 feet in front of it. On detecting, it sends a hold command to the control program, takes over navigation and navigates around the obstacle. When it sees no other obstacle in front of it, it returns command to the control which uses the vision software to navigate further.

7.3 Microcontroller

The software for the microcontroller has been written in MPLAB C18 assembly language as the microcontroller is a PIC18F8520 as in the VEX controller. The microcontroller software controls the motor direction and speed, checks for obstacles using the Ultrasound sensors, keeps tabs on the wireless emergency stop as well as communicates with the guidance level controller. The software on command from the control program probes the ultrasound and gets the result, and on command from the control program runs the motors in the desired direction. The microcontroller also keeps a tab on a signal from the wireless e-stop and all the emergency e-stops are wired to physically cutoff power as well as make the controller issue a stop command to the motors.

8. Strategy

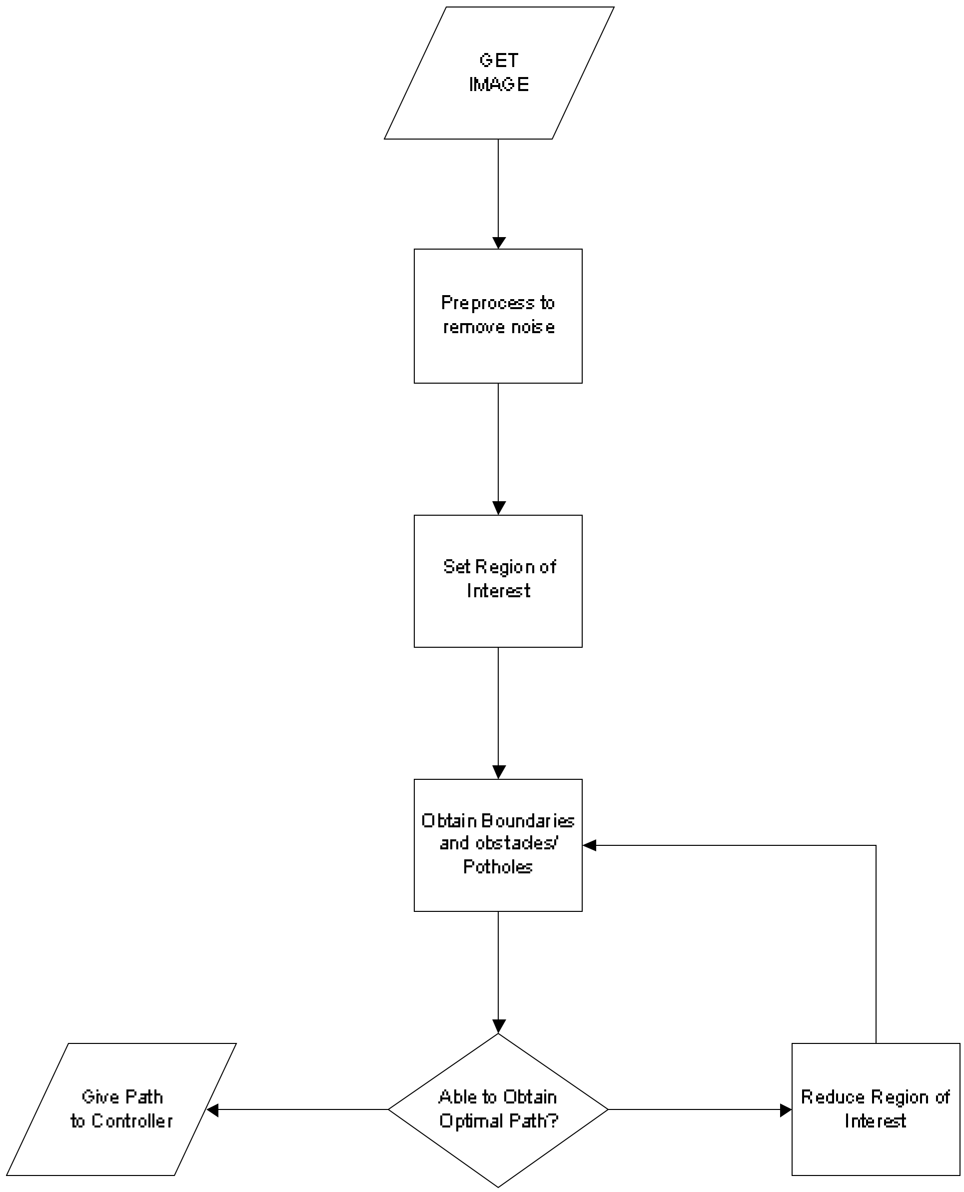
The strategies for autonomous and navigational challenge were of a slightly different nature as demanded by the differences between the challenges.

8.1 Autonomous Challenge Operation

The path to be taken by 'MoViT', is determined once the boundary lines and potholes or obstacles (if any) identified by the algorithm. The region of interest (ROI) is iteratively reduced from an half the image size till an optimal path is obtained. The path planning strategy is a generic two-fold action. If the algorithm detects the absence of obstacles or potholes, then 'MoViT' is oriented along the line and made to follow the line. When either of an obstacle or potholes is detected, then regions of approachability are identified by the path navigation algorithm and the most optimal path in terms of distance from obstacles or potholes and the boundary lines is identified. When such an optimal path cannot be obtained without necessitating a collision or crossing over potholes, the ROI is reduced and the vision algorithm is called to identify boundaries and contours in this changed ROI. After this, the path navigation algorithm is applied again to determine an optimal path.

Once an optimal path is determined, the polar coordinates of the path are fed to the controller which makes MoViT to follow this path accordingly. The advantage with using such a generic strategy is obvious, as procedural programming involving all probable cases of choices to be made by MoViT is simply too tedious.

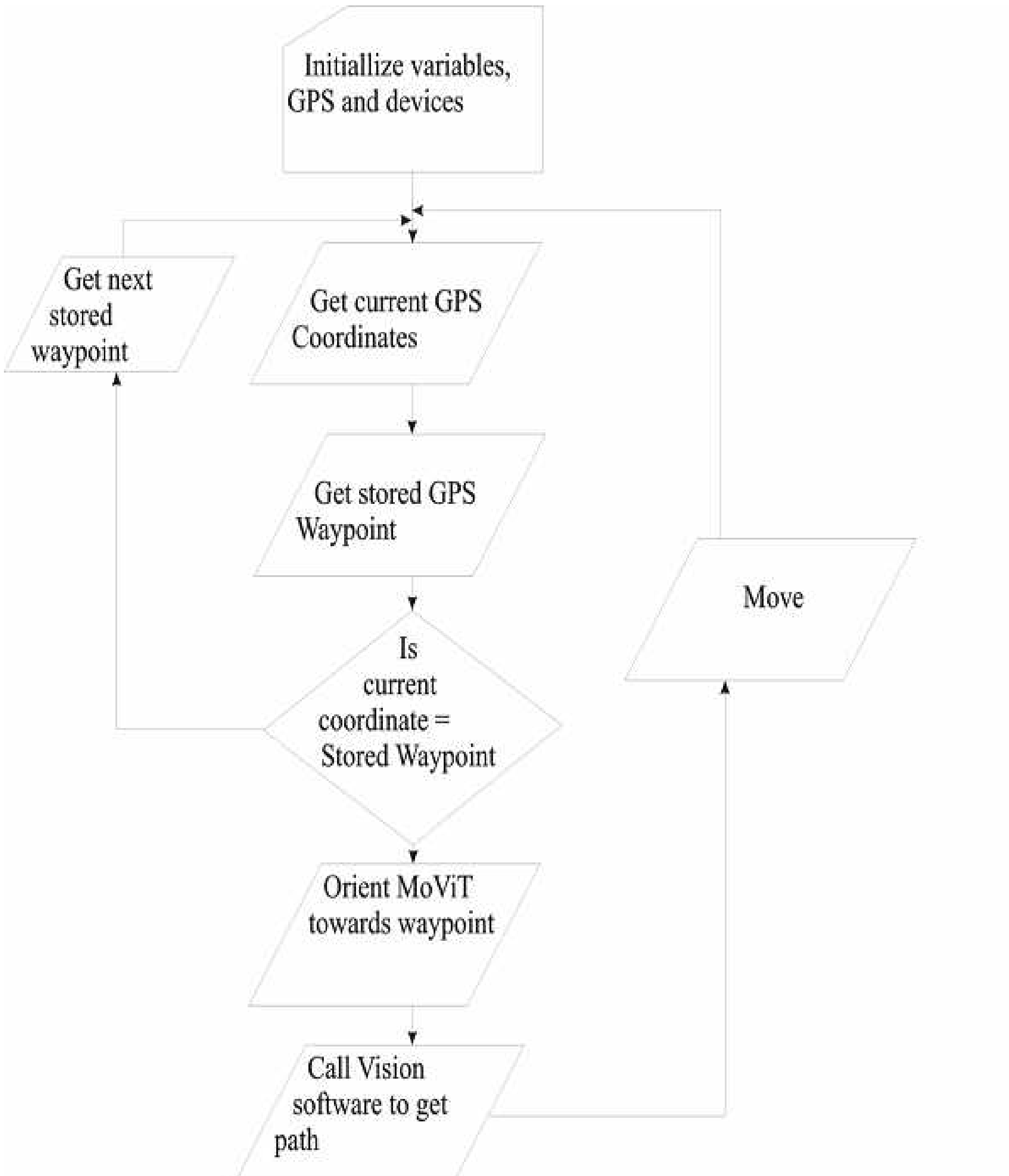
Fig 7 Flow Chart depicting autonomous algorithm



8.2 Navigational Challenge Operation

For the navigational challenge, small changes from the path planning operation followed for the autonomous case are in order. Using the GPS receiver, MoViT's current position is identified. The next target position is obtained from the given waypoints from which a general path to be followed is determined and MoViT is oriented in this direction. The actual path that MoViT needs to take is determined by a path finding algorithm. The path finding algorithm identifies any obstacles or potholes on MoViT's path and accordingly finds an optimal path around the obstacle as was done in the autonomous operation.

Figure 8: Flow Chart depicting navigation algorithm:



9. Performance Estimations

9.1 Speed

The top speed boasted by MoViT is about 2.5 MPH on-road and 2 MPH off-road. This was obtained by reducing the no load speed of 22000 rev/min using compounded gear system. In addition to this, speed can also be varied with software using Pulse Width Modulation.

9.2 Ramp Climbing Ability

MoViT can negotiate any slope with a gradient of less than 50 degrees with ease. This steep ramp climbing ability of MoViT can be attributed to its stable structure and the use of tank treads.

9.3 Battery life

Battery life for the respective sources are:

- Lead Acid: 1 hours of continuous operation
- Laptop battery : 1hour 30 minutes of continuous operational time
- Vex power source of 5AA batteries is about 2 hours
- Camera battery is about 300 minutes of continuous operation time

9.4 Distance at which obstacles are detected

The average distance at which distance at which obstacles are detected is 5 meters by the camera and 3 meters by the ultra sound .

9.5 How the vehicle deals with dead ends, traps, and potholes

When MoViT encounters a dead end, it is programmed to do a 360 degree turn and go back the way it came till it finds a junction or alternate path. When it encounters obstacles, either the vision would have accounted for the obstacle in the path planning and thus the robot will choose an obstacle free path planning or if the vision fails to account for it , the ultrasound will safely navigate the robot around it by physically checking the obstacles presence and position relative to MoViT’s path at every move. When the MoViT encounters a trap, it will learn it and in future avoid or discount that path from its planning. . The GPS system will also track the path followed by MoViT and ensure that it never goes in the wrong direction

9.6 Accuracy of arrival at navigation waypoints

Predicted accuracy of arriving at navigation waypoints is about +/- 10feet as the GPS receiver picks up DGPS signals from the US Coast Guard Transmitting beacons.

10. Safety and Reliability

MoViT has a manual E-Stop that can be used to switch it off instantaneously. The hardware governed speed system has guaranteed that MoViT can never go faster than 2,5 mph, making it safe for operation even in obstacle dense areas. To make MoViT electrically safe, all connections were encapsulated in conduit pipes. Corners and sharp edges were rounded thus giving MoViT an enhanced user interaction capability.

MoViT's reliable operation even in difficult weather conditions was assured by housing all electronic parts and the camera in shatterproof plexiglass structure. Contingency plans such as, using Ultrasound as a backup for obstacle detection and GPS to make sure that MoViT does not reverse its direction, have given a high degree of reliability. Addition of encoders has resulted in accurate implementation of path commands given to the controller.

11. Costing

The creation of MoViT was funded by a variety of sources. We are thankful for a generous donation from **MTL Standard Automation**. Arizona State University through Dr.Tsakalis has kindly sponsored our trip to attended the IGVC. Ananth Vishwananthan has loaned his camera to give sight to MoViT and we are very grateful to him. Table 2 Lists the particulars of total cost spent on the robot and the cost to the team.

Number	Particulars	Value	Cost to team
1	Chassis	$200.00	$0.00
2	Vex Kit	$150.00	$0.00
3	Drive Train	$90.00	$90.00
4	Garmin GPS receiver	$95.00	$95.00
5	Camera	$360.00	$0.00
6	Victor 884 Motor Controller x 2	$260.00	$260.00
7	Dell Latitude C 610	$1,300.00	$0.00
8	Ultrasound sensors x2	$60.00	$0.00
9	Encoder x 2	$20.00	$0.00
10	Vex Tank Treads x 5	$60.00	$0.00
11	Paint	$50.00	$50.00
12	Battery for laptop	$165.00	$165.00
13	Plexiglass cover	$70.00	$70.00
14	USB hub	$30.00	$30.00
15	Registration Fees	$200.00	$0.00
	Total	$3,110.00	$760.00

Table2: Total cost details

12. Conclusion

MoViT is a culmination of novel ideas and organized effort over a period of 6 months that aimed at creating an intelligent vision based platform and has succeeded. It is a good example of low cost design and fabrication achieved by phased design and development process. It looks poised to perform favorably in the 14th Annual IGVC competition.