GunBot: Design Concept of a Semi-Autonomous UGV with Omni-directional Mobility and Auto-Target Tracking

Cardenas Irvin, Shao Leo, Jong-Hoon Kim
Discovery Lab, School of Computing and Information Science
Florida International University, 11200 SW 8th St, Miami, Florida 33199
icard005@fiu.edu, lshao002@fiu.edu, kimj@cis.fiu.edu

Abstract

Modern day firefights during military operations in the Middle East have resulted in a high number of casualties and wounded soldiers due to the exposure of deadly attacks. However, those highly risky activities are inevitable for military operations.

Unmanned robots will lead to a new era of reduced casualties. To perform dangerous activities without those casualties, unmanned robotics is a valuable approach. We have developed a semi-autonomous Unmanned Ground Vehicle, named GunBot, which is designed for battlefield operations as well as police patrol.

GunBot has two superior features; Omni-directional Mobility based on the mecanum wheel mechanism which provides Gunbot with quick response to movement in any direction and an auto-Target Tracking system based on image processing techniques which enables one operator to drive GunBot and to track a target simultaneously. In this paper, we provide a prototype of GunBot and show the feasibility of the design of GunBot.

Keywords: UGV, Robotics, Autonomous Target Tracking, Image Processing, Mecanum wheel.

1. Introduction

During the current military operational time, many efforts are placed in reducing the life-risk factor for United States service members. Unmanned Ground Vehicles (UGVs) are the most sought option to reduce the presence of our military men and women in hostile areas.

Unmanned ground vehicles are used in important military applications, which include surveillance, unarmed/armed reconnaissance, and explosive device inspection and disposal [5]. As unmanned ground vehicles keep on becoming ever more prominent, to maximize their effectiveness in field operations more advanced methods of guidance and targeting keep on being implemented.

This has led to the global UGV market to become a growing marketplace that is providing government contract opportunities to major defense contractors and robotics research institutions [5]. As the market for UGVs grow. To distinguish ourselves we are forced to implement a more agile, more versatile and more efficient robot.

1.1 Background

Early Research Efforts

As early as the late 1960's, mobile robotics has been on the move, starting with one of the first major mobile robots named *Shakey*. *Shakey* was created to serve as a platform of experimentation for DARPA's funded artificial intelligence research work at the Stanford Research Institute. Although Shakey was not considered a success in its day because it never achieved the desired autonomous operation, it was the starting point for other mobile robot projects and AI research in areas such as vision. [3], [6], [7], [10], [11].

Other projects such as Hans Moravec's Stanford Cart project, a robot used to plan an obstacle-free path to its destination, at Stanford University AI Lab from 1973 to 1981 led to further involvement of the government and private agencies such as DARPA. And in the early 1980's *Shakey* was reborn as the DARPA *Autonomous Land Vehicle (ALV)*, which focused on military applications [2].

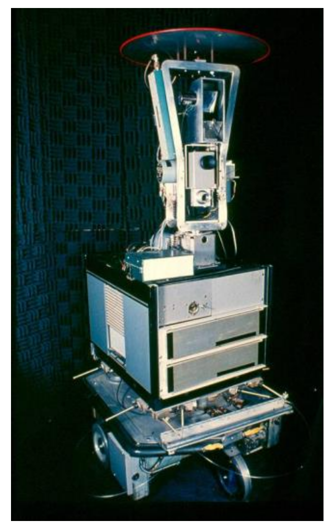


Figure 1. *Shakey* [14]

Reconnaissance, Surveillance, and Target Acquisition (RSTA)

The idea of RSTA application always drew the attention of UGV developers since it would offer non-human military battlefield "personnel" with sensing capabilities on the battlefield.

In 1990, in response to Congressional concerns, a number of Department of Defense (DoD) advanced development projects related to ground vehicle robotics were placed under the Joint Robotics Program (JRP) directed by the Office of the Secretary of Defense (OSD)

The Joint Robotics Program Master Plan (JRPMP) is prepared annually and provided to Congress. This plan provides an integrated Department of Defense document that describes the strategies for acquiring first-generation UGVs and for developing technologies critical to these systems.

The Joint Robotics Program Master Plan describes the individual projects and the management framework for their execution. It is considered an OSD management tool for fulfilling its responsibility to oversee the Joint Robotics Program [5].

Teleoperation

Teleoperation capability, or the ability for an operator to manipulate and control a UGV remotely from a safe location, is what attracts UGV developers the most. At the moment it is the most mature control technology available and therefore is an area of emphasis for all Services in developing first generation robotics programs.

Teleoperation capabilities are important to the military because they enable standoff operations and thereby reduce or remove operator risks in highly stressful and dangerous environments, such as minefields and in areas of potential explosive hazards [5].
A variety of potential UGV applications to land operations can increase mission performance, combat effectiveness, and personnel safety. These applications include assistance of military personal, mapping of unknown areas, disaster rescue, and visual identification. In these areas it is important for an UGV to have an advanced visual interpreter and agile mobility. Advanced visual interpreter is defined here as visual mapping which will allow the mapping of unknown areas during disaster recovery and also to identify between friend and foe targets during hostile encounters. This advanced visual technology combined with agile mobility, which we define as being able to move, and change directions quickly and efficiently will create a dynamic UGV that is better equipped for a wide variety of situations.

The majorities of UGVs are designed to traverse various terrains and avoid obstacles but lack agile mobility. There is plenty of research on UGVs that operate on slow speed. There have also been experiments on higher speed performance in small sized robots; but there is not much research devoted to the turning and mobility of a UGV. The majority of UGVs designed to be agile are either Ackerman or skid-steered. Their design prevents them from being extremely agile. There are also omnidirectional UGVs such as an Active Split Offset Caster (Figure 2.), which while having 360-degree movement are lacking in speed.

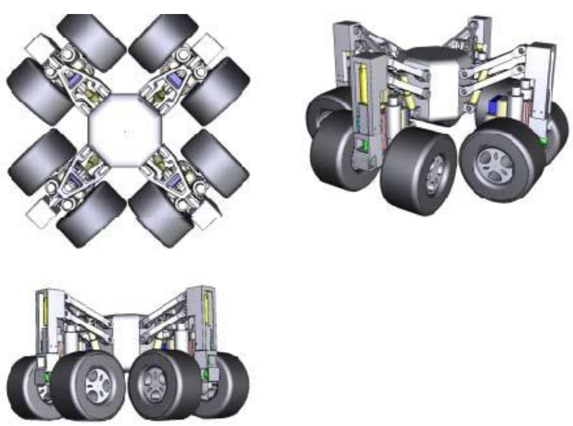


Figure 2. Active Split Offset [9]

In addition to mobility other features are taken in consideration, especially that of a UGV's teleoperation Interface. Despite advances in autonomy, there will always be a need for a human involvement in vehicle teleportation; in particular for tasks such as exploration, and reconnaissance, and surveillance where human interference is required for monitoring and control of the vehicle [4].

There four main categories of teleportation interfaces that we take in consideration: direct, multimodal/multisensory, supervisory control, and novel [4].

The direct interface is the most common interface, which relies on the operator using hand-controllers such as 3-axis joysticks, while watching video from vehicle-mounted cameras. Although it is the most simple form vehicle teleoperation it is the most problematic due to the operator's loss of situational awareness, inaccurate attitude judgment, and failure to detect obstacles" [4].

On the other hand multimodal and multisensory interfaces provide for efficient command tools and strong information feedback between the operator and robot. This is needed when a vehicle is operated during a complex or highly dynamic situation such as those of military operations, where it may be difficult for the operator to rapidly and accurately perceive information from the vehicles surroundings, to make correct control decisions [4].

Then we have supervisory control, which is an interface where the operators divide a problem into parts that he/she can perform and that the robot can execute, needless to say, this means that the robot should have some level of autonomy.

Lastly we have Novel interfaces, which refer to unconventional interfaces such as the hands-free remote driving interface based on brainwave and muscle movement analysis [4].

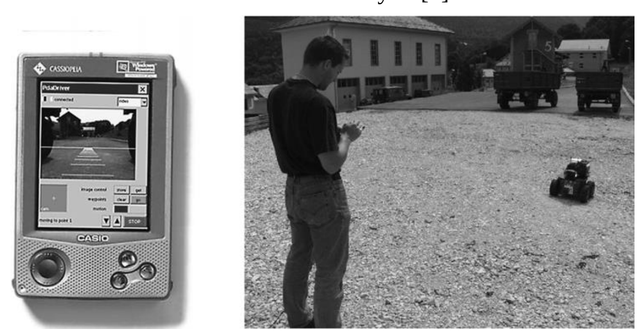


Figure 3. Digital modal sensory Interface [4]

2. State of the Art

Gladiator Tactical Unmanned Ground Vehicle is a high tech vehicle developed by the US marines. They have an array of vision devices that allow the user to see as well as if he were on the battlefield. We believe that utilizing our technology we can improve this machine. The heavily armed gladiator could greatly benefit from an auto tracking mechanism. It already has high definition vision and weapons so this implementation will allow a fully autonomous machine, which will be able to better help the US marines [5].

Figure 4. Gladiator Tactical UGV [12]

Remote Ordnance Neutralization System (RONS) is a high level machine that was designed to dispose of waste and get rid of explosives. To increase its functionality the RONS is equipped with a specialized driving system that allows it to change its elevation and provides various other maneuvers. Unfortunately, their special drive system also limits them in their directional drive movement. If we were to implement Gunbots omnidirectional movement with RONS then we could achieve a more agile waste and explosive disposal machine, which would be beneficial in different terrains. The RONS could be further improved with the addition of a face tracking and visual interpreting mechanism. This would allow the RONS to be able to communicate with onsite workers without them having to explicitly give the commands [5].

Figure 5. RONS UGV [13]

The TALON is a lightweight versatile robot that is useful in reconnaissance and combat situations. In the development of Gunbot we took into consideration the abilities of the TALON and realized that we could improve upon it. The TALON like the Gunbot can be fitted with weapons and provides a good gun mount to shoot targets. Unfortunately the TALON only has Tele-Operational abilities and lacks the sensing and the mobility of Gunbot. Gunbot has a face detection system that allows for a more autonomous and variable robot. The face detection will take away the clumsiness of having to train a user to track a target and allow a user to operate multiple vehicles. The TALON also uses caterpillars to drive. We believe that our use of mecanum wheels to provide Omni-directional movement adds to the survivability and efficiency of the combat robot [5].

Figure 6. TALON UGV [1]

2.1. System Overview

GunBot will be programmed in C and will run on an embedded computer inside GunBot. The computer will receive signals through various detectors attached on GunBot including high definition cameras. After being interpreted by the GunBot program, the computer will transmit serial signals to GunBot's microcontroller, which will be programmed in C and will act accordingly. The computer will also have 4G cellular network modules, which will allow remote control of GunBot from anywhere.

3.Architecture

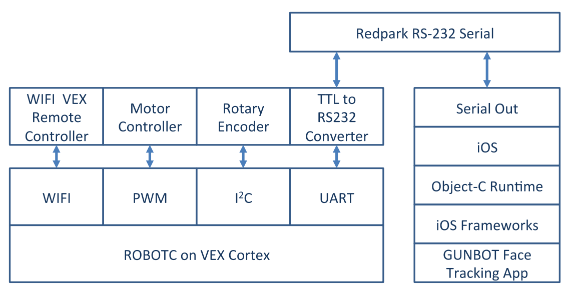


Figure 7. Architecture

GunBot has two main control components, the vex microcontroller, and the iPhone. The microcontroller has our code loaded into it and receives wireless signals to control the Gunbot via a VEX controller. The iPhone has a built in face tracking software, which we modified to send serial signals via an UART connection.

3.1 Programming Algorithm

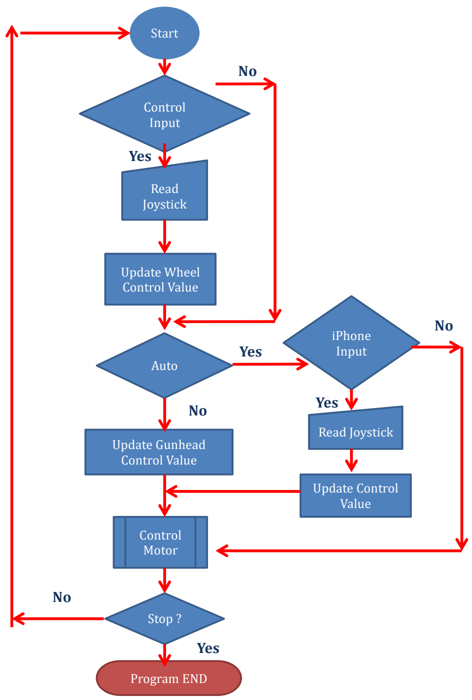


Figure 8. Control Flow

The code is set in an infinite loop to continually accept commands from the controller. The cycle starts by the microcontroller checking if the user has sent any commands for wheel motor movement. If there are commands, the relevant motors will be activated else no motors will be activated. The next step is to check whether or not the Boolean for auto-targeting has been activated. If it has been activated then the microcontroller checks whether or not a signal has been sent. If one has been sent then the Gun mount motors will activate. If no signal has been sent the microcontroller will not wait for the signal and instead continue the cycle and check again the next time it reaches this step. In the event that the Boolean for auto-tracking has not been activated the microcontroller will check what commands has been inputted in the controller for the gun mount. If commands have been inputted then the gun mount motors will act accordingly otherwise the motors won't act accordingly.

4. Implementation

The prototype design considered in this paper is of a battery powered UGV with omnidirectional mobility via the mecanum wheel mechanism and auto target tracking capability made from iPhone's API.

4.1. Implementation Plan

The Implementation Plan consists of the first phase of GunBot. Phase one consists of the proof of concept of an auto target tracking system based on image processing and the proof of concept of omnidirection mobility based on the mecanum wheels.

The next phase consist of a proof of concept of an advanced auto target tracking system using image processing and depth perception technology based on the Xbox Kinect sensor, and a proof of concept of an improved omnidirectional mechanism suitable for outdoor environments with less terrain constraints. In this paper we implement Phase one.

4.2. Major Structure of GunBot

A reduced scale prototype was built using VEX parts, smart phone device (mainly iPhone), and serial communication hardware.

The structure of the prototype is divided into four major parts:

- Mechanical Structure
- Electrical Structure
- Image processing and face detection.
- Logic Design and Architecture.

Mechanical Structure

GunBot has an aluminum structure that measures 15.32" x 11.61".

The base

The base is composed of four 3x3x25 cm. angle rails, two slotted angles rails that make the structure that holds the gears and mecanum wheels.

Place on top is the first part of what makes up the base for the gun mount. It is composed of four C-Channel rails, two on each side, which hold the four *2-wire 393* motors.

The final part of the base is a 1x5x1x25 cm. C-Channel rail, which connects the gun mount, and a *2-wire 393* motor for the gun mount's horizontal movement.

Gun mount

The gun mount is composed of a two Turntable gear system. The Turntable gears provide us with low friction turning which in turn provides us with more accurate reading from the encoders.

Electrical Structure

We connected 6 motors to the Cortex microcontroller. Four of the connections were for the wheels. The two others were for horizontal and vertical gun movement. The gun also has its own internal motor, which is connected to the microcontroller.

Gun Movement

The two gun movement motors were fitted with quadrature encoders connected in daisy chain. The encoders allow us to measure the movement of the motors.

Controller

WIFI connection provides communication between controller and microcontroller manual control.

iPhone and UART Connection

The UART Serial Connection allows communication between the microcontroller and iPhone.

Battery

A 7.2-volt main battery and a 9-volt backup battery power the CORTEX microcontroller.

Image processing and face detection.

Our auto-target tracking system is based off an app developed for the iPhone.

The iPhone sends serial signals to the microcontroller, which allow the gun motors to move until the target has been reached.

Logic Design and Architecture.

GunBot has two main control components, the VEX Cortex microcontroller and iPhone.

GunBot's ROBOTC code is loaded onto the VEX Cortex microcontroller. The microcontroller receives WIFI signals from the VEX remote controller to allow movement.

Our app makes use of the iPhone's face detection API, and an external hardware and software implementation that allows serial communication between the iPhone and the CORTEX microcontroller.

5. Prototyping

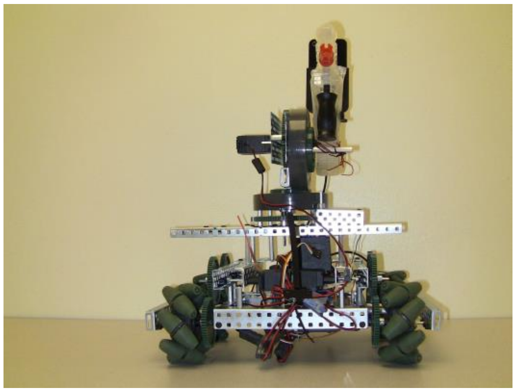
In this paper the prototype of GunBot was built from VEX Robotics parts to allow efficient and inexpensive prototyping.

Figure 7.a) shows the front view of GunBot where the gunmount design could be seen. One Turntable is laid horizontally, while another is placed vertically ontop. The gun is attached to the vertical Turntable gear.

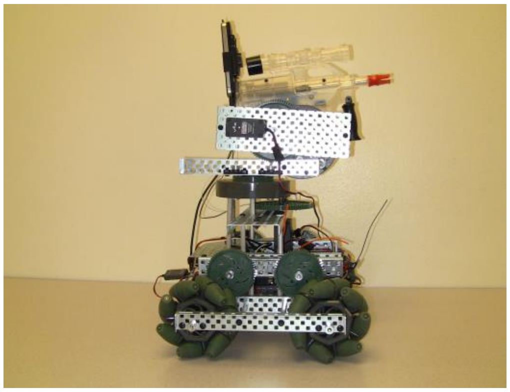
Figure 7.b) show the side view of GunBot. On this image the side of the gunmount design could be seen. Under the horizontal table gear a 12-tooth to 84-tooth gear system is arranged along with the Turntable gear to reduce speed and increase torque in the gun's movement.

Figure 7.c) shows the top view of GunBot's prototype. On this image we can see a vertical view of the 12-tooth to 84-tooth gear system connected to the vertical Turntable gear.

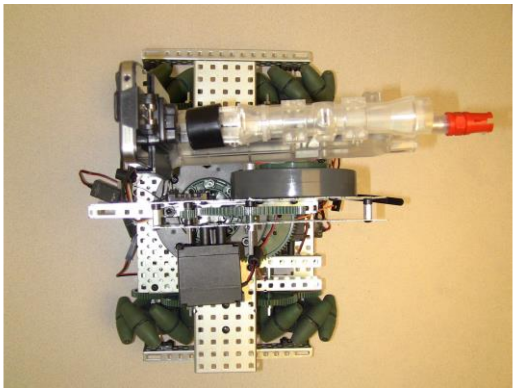
Figure 7.d) shows the bottom view of GunBot's prototype. On this image we can take an in depth look at the microcontroller and wiring.



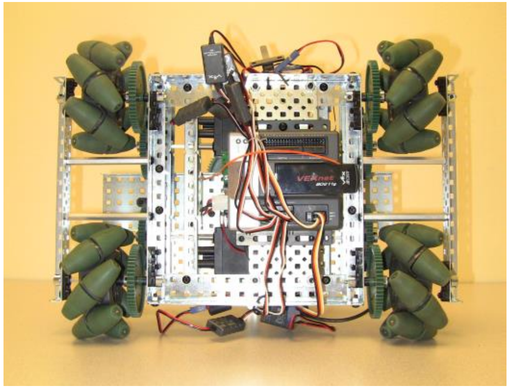
a) Front view



b) Side view



c) Top view



d) Bottom view

Figure 7. Multiple views of GunBot

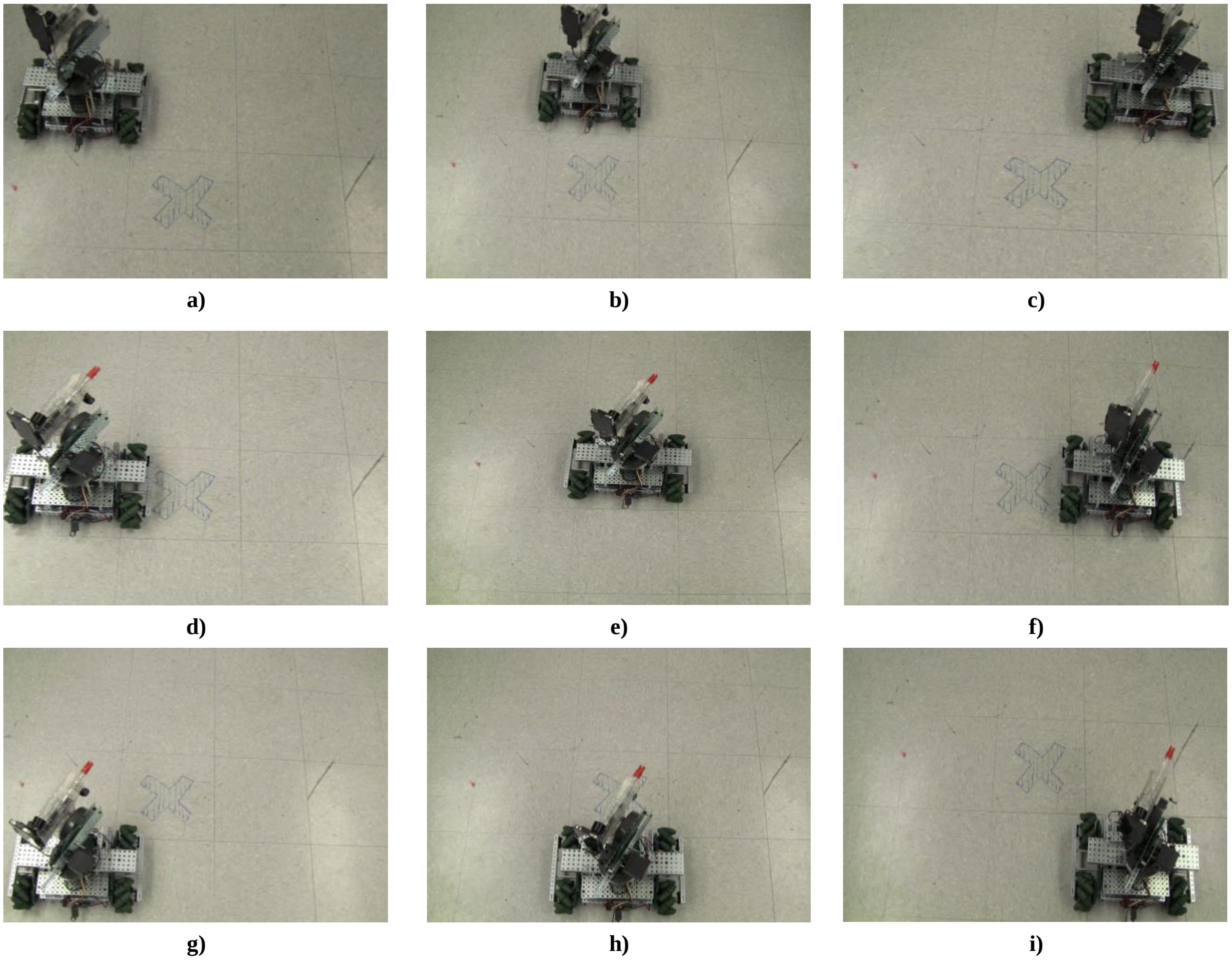


Figure 8. GunBots Omnidirectional Movement

Movement	Velocity	Percentage/Power
Forward/Backwards	1 foot/6.40 sec	100%
Horizontal	1 foot/7.30 sec	88%
Diagonal - 45 Degree	1 foot/11.55 sec	55%

Table 1.

Figure 8. shows GunBot's omnidirectional movement. Figure 8.e) shows the starting point marked by an "x". GunBot can move at a 45 degree angle forward as shown by figure a) and figure c). It can also move forward and backwards as show by figures b) and h), and side-to-side as shown by figure d) and f).

Table 1. shows GunBot's ground velocity on a smooth surface. 100% of GunBot's velocity is achieved throughout forward movement. During horizontal movement, with the same amount of power, GunBot achieves 88% of its maximum velocity. While moving diagonally, GunBot achieves only 55% of its velocity.

Because of the mecanum wheel mechanism, which only allows the usage of all four-wheel motors for forward and reverse movement, and only the usage of two wheel motors for diagonal movement, there is almost a 50% drop from GunBot's maximum velocity during diagonal movement. This drop in velocity is inevitable to achieve omnidirectional movement.

Movement	Velocity
Vertical	90 degrees /9 sec.
Horizontal	90 degrees/7 sec.

Table 2.

Table 2. Displays the average velocity achieved by GunBot's gun mount movement.

GunBot's auto target tracking system can be seen in action in Figure 9. As the target move from the middle (Figure 9b) to the left (Figure 9a) then to the far right side, (Figure 9c). Gunbot at all times is able to localize the target and lock into it.

a) GunBot tracking target's left movement **b) GunBot locked into the target** **c) GunBot tracking target's right movement**

Figure 9. GunBot's Auto Target Tracking System

6. Discussion

The alpha type bot had a caterpillar drive system that had a gun mount with movement only in the vertical position. The two-motor drive robot lacked adequate mobility in that it could not strafe in multiple directions. The main problem was of the lack of mobility of the gun mount. To solve this we proceeded to the beta type Gunbot

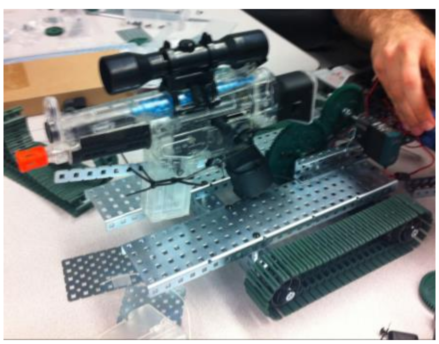


Figure 10. Alpha Type GunBot

The beta type bot was very similar to the prototype Gunbot. To increase the mobility we switched out the two-wheel drive and changed it to four-wheel mecanum drives. We also used two Turntable gears to give 120-degree horizontal and 90-degree vertical movement. We then created our iPhone face detection software that allowed us to have our first semiautonomous Gunbot.

There were also many improvements on the microcontroller software side of Gunbot, which allowed the microcontroller to utilize the improvements to the gun mount and make use of the iPhone application.

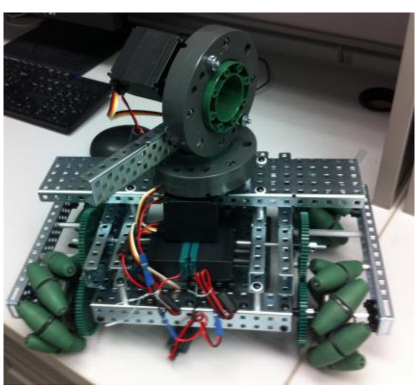


Figure 11. Beta Type GunBot

At the time there was also a critical problem which was the lag caused by the slow processing speed of the iPhone, which prevented the Gunbot from zooming in on its target.

To correct these challenges we updated the Gunbot to its present version, the prototype. The prototype attempted to solve the problems by improving the software through designing a more efficient algorithm. We also tried to solve this problem by greatly improving the gun mount. We lowered the gear ratio of the mounts to improve the accuracy. The improvement to the gun mount also maximized its movement, giving it 360-degree horizontal movement and 120 degree vertical movement.

6.1 Limitations

We decided to limit our Gunbot by focusing our Gunbot as a strictly anti-personnel vehicle. Due to size and our desire to maintain agility we will not equip our Gunbot with anti-armor weaponry nor equip it with vehicle detection and identification technology. We will not equip Gunbot with anti-ship weaponery. We will also not equip our Gunbot with anti-air weaponry; however, the user could always attempt to shoot at those targets.

In order to maintain mobility we will not design GunBot to have a heavy load capacity. We will also not greatly increase the size of Gunbot to enable it to have a heavy load capacity, as this will make Gunbot to easy of a target to be worth using. We will not optimize Gunbot's carrying ability nor will we give Gunbot multifunctional tools like arms.

Gunbot will not be designed for advanced human interaction. While Gunbot will be equipped with a wide array of sensor technologies we will not implement technologies that will allow Gunbot to communicate and interact with immediate humans. In other words, the only way to send commands to Gunbot will be through Gunbots command console.

Gunbot will not be designed for aquatic movement. The definition of aquatic movement in this case is any movement that requires moving through water of a depth greater than 1 inch or moving under water. Gunbot will also not be designed for flight capabilities. The purpose of Gunbot is to accurately obtain target information and track them. If Gunbot were flying such accuracy would not be possible and the target tracking would be less effective.

6.2 Future Works

Our next goal is to prove the concept of an advanced auto target tracking system using image processing and depth perception technology base on the XBOX Kinect sensor. Utilizing the Kinect we will be able to take advantage of the built in camera and depth perception ability. Using the Microsoft's Kinect SDK we will build upon our knowledge of image processing and development a smarter and more flexible face detector. To process the Kinect and interpret the data we will use a fast computer to run our software, which will greatly reduce the runtime of the image processing. Our software will be designed to allow for smooth transition between multiple targets and a Graphical User Interface (GUI) that will simplify and improve user experience. We will also work on developing an entirely original frame for GunBot. All of our parts will be designed with the idea of optimizing GunBot's ground movement, gun movement, and auto-target tracking system.

In our final design through continuously improving upon Gunbot we will develop a truly avant-garde machine. In an effort to optimize the already highly mobile mecanum wheel, we utilize encoders to align the power output of each of the motors for the four-wheel drive. In recreating our design we will also improve the quality of our parts i.e. wheels, motors, and frame.

These improvements will provide immediate and impressive results, including massive improvements in agility and coordinated directional movement. With the continuous development of the GunBot AI, we will develop our own software that will improve user experience and reliability when handling GunBot.

The software will also take care of sensor inputs. Our sensors will consist of multiple high definition cameras and lasers to provide 3d mapping and 360 degree monitoring of all situations. GunBot's facial detection and image detection abilities will enable it to differentiate between friend, foe, and civilian targets, turning GunBot into the ultimate soldier.

7. Conclusion

In this paper a design of a semi-autonomous UGV with omnidirectional movement and an auto target tracking system has been presented. Our prototype has showed that this is indeed feasible. The omnidirectional movement has been implemented with the mecanum wheels and the auto target tracking has been implemented via apple face detection software. Our inexpensive design of an UGV will provide the military with the capabilities to accomplish critical missions more rapidly and successfully. This UGV will also be applicable in many other fields such as mapping out disaster territories and supporting police officers. There are however limitations with our current prototype. The lack of coordination with the mecanum wheels and the delay from the face tracking will be solved by later models of our Gunbot. Future Gunbots will use higher quality motors to balance the wheels and more advanced face-tracking technology, which will greatly reduce any lag in target auto-tracking.

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