Land Mine Detecting Robot Capable of Path Planning

MUHAMMAD ZUBAIR, MUHAMMAD AHMAD CHOUDHRY
Department of Electrical Engineering,
University of Engineering and Technology,
Taxila,
PAKISTAN.
zubairaw@alum.ceme.edu.pk, dr.ahmad@uettaxila.edu.pk

Abstract – The purpose of Landmine detecting robot is to cover maximum possible area, presentation of landmines and the left over area on a visual map with accuracy in millimeters. This paper presents a prototype model of land mine detecting robot that is powerful yet low cost, easy controllable, having the required accuracy and is equipped with visual interface for landmines plotting, PID tuning and cameras alignment. Emphasis is placed on the control of the differential drive robot in auto mode, semi auto mode and the manual mode. The image processing is used to find the accurate position of robot which provides the live reckoning feedback to the dead reckoning servo control of the robot. Balance Beat metal detector is the sensor used to detect landmines. The use of graphical user interface for the remote terminal computer to control the robot provides the user a simple but powerful control. The overall aspiration of system is to provide the user a powerful, cost effective and the same time intelligible to an average user.

Key-Words: - Land Mine detection, robot path mapping, image processing, Graphical user interface, PIC microcontroller

1 Introduction

The catastrophe of war destroys societies in a short time. In order to restore war hit societies, land mines must be eliminated. Land mines elimination is a major time taking and costly process. Science can help the world to become a safer place to live. Robots can detect and map land mines.

Mapping of land mines after detecting them is the initial step in de-mining. Many automatic and semi-auto robots [3, 4, 5, 6, 7] have been developed to do the job. These robots used the GPS, optical encoders with GPS or image processing for the localization of the robot. High accuracy is needed for this job. Offset of few inches can prove to be deadly.

The success of landmine detecting robot is to be invisible to the landmine which is only possible by reducing the weight of robot. To find the start point of land mine field as [3, 4] is not a practical approach toward solving the problem. Researcher [3, 4] has used heavy equipment which is always porn to be a victim of landmines.

Demining is problem of poor countries, whose economies is down by wars. They do not have funds for costly demining equipment. Researcher [3, 4] has used engine power vehicles, control room vehicles which makes the countries stick to manual methods of demining.

Poor literacy rates demand user friendly systems for land mine detection in affected countries. The user interface should be simple enough for novice users to operate the robot. Researcher [3, 4] has the system that need proper training to operate it.

Repair and maintenance of robot [3, 4, 6, 7] in land mine fields is difficult. Local manufacturing of these systems, in form of transfer of technology to land mine affected countries, is difficult due to lack of infrastructure.

The design of demining robot presented in this paper is light weight and virtually invisible to land mines. This is a low cost robot. All parts used in this robot are easily available in local market. The user interface developed for this robot is very simple, making its novice user to control the robot easily. The aim of this research is to detect and plot the land mines and the area visited by the robot accurately so that the demining crew can easily locate and remove the landmines.

Dead-reckoning techniques cause the error to increment so with improved dead-reckoning, periodic absolute position updates are necessary. GPS does not provide the accuracy as well as its weak signals in buildings and thick vegetation makes it unfeasible for mapping however it can be used beside any other positioning sensor to get a global map of mine field. Position of robot can be found by Image processing and active beacons system [8]. In both of these cases the clear line of sight is required for calculation of actual position of robot.

This paper presents the use of image processing to find the position of robot. A stereoscopic vision system is used to find the position of robot in which the two cameras are placed at specified angles. Using the laws of trigonometry the actual position of robot is calculated. For the alignment of cameras a visual environment program is created. This program helps to place the cameras at exact required angles.

Basic design is light weight, differential drive robot. Both wheels are coupled with DC geared servomotors. Two caster wheels are added to ensure stability and to reduce the weight on each wheel. PID control is implemented on both wheels for the motion control of robot. Speed of robot is reduced to minimize the slip of wheel. A PID tuner program is created in Visual environment to ease the process of PID tuning. The values of K_p, K_i and K_d are saved in the electrically erasable, programmable, read-only memory (EEPROM) of the microcontroller.

PIC 18F4550 microcontroller [9] is used to control servomotors and read metal detector values. A LCD on robot shows the metal detector values and motor control commands. Microcontroller communicates with the computer using RS232 serial protocol at the baud rate of 115200. This serial communication is done with the help of wireless serial communication modules. The computer calculates the next feed for the drive motors and microcontroller preforms the tasks given by computer.

Beat Balance Metal detector is used to detect land mines which is a hybrid between beat frequency operation and induction balance. This detector is more sensitive and its immunity to voltage, temperature variations and ground mineralization is better.

Graphical user interface is created by which the user has the options to control the robot in auto mode, semi auto mode or the manual mode. These modes give the user a powerful system for the detection of landmines.

Map of the area covered by robot and the landmines detected are shown in the visual environment of Microsoft C# [10]. The control scheme is shown in the figure 1.

In 2001 army of Pakistan laid land mines on the eastern border, due to the escalation of tensions with India. This border of Pakistan with India is 2912 Km long [1]. The land mines were laid as a defensive strategy of Pakistani army [2]. These land mines are made in Pakistan and have some metallic parts. With start of peace talks the demining process started. As no global landmines field maps were made so 100 percent demining is not achieved. Those areas are still marked as landmine field. Nearby areas have high population density so those landmine fields should be cleared as a high priority job. The land mines are laid manually. The terrain of these areas is mostly dry, have low vegetation and surface layer is dusty. The terrain makes the robot wheels skit sometime which makes the dead reckoning servo system inefficient. A mobile robotic system is required by the Pakistani army to clear the numbers of present mine fields in terrain. This system should be of low cost, fast, accurate and having easy user interface.

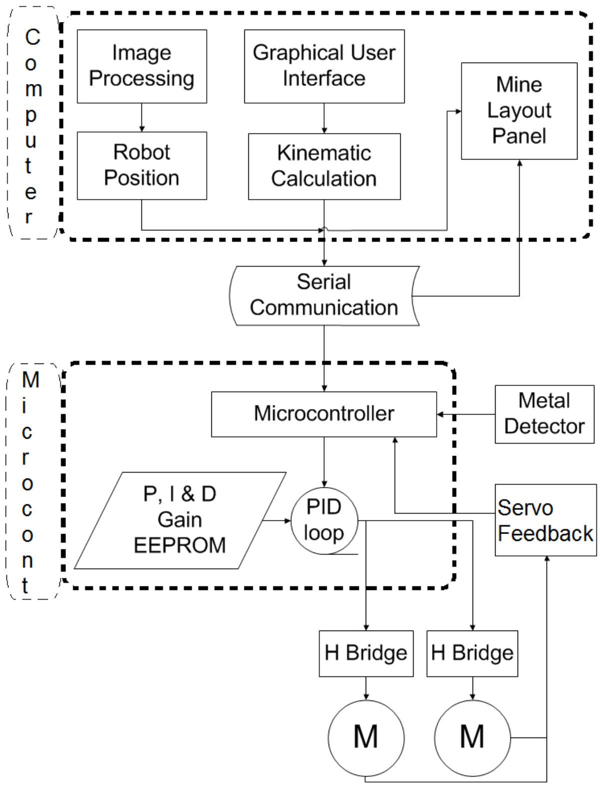

Figure 1: Programming Scheme of Robot and remote terminal showing serial interface between them

Taking this as a case study at hand a prototype mobile robot is fabricated which can detect and plot landmines. The other features of this robot are that it is low cost, differential drive and has easy user interface.

To cater with the slip of wheels, image processing is used to find exact position of robot. Various aspects of this system are discussed in this paper; stress is given on the easy user interface and the position location of robot using image processing. The control and communication of robot with remote station is discussed. The overall feel of work is to provide a cost effective but powerful system.

2 The Robot

Fibre glass is used to fabricate the robot that makes it light weight. The robot has differential drive system that both wheels are coupled with 12V DC geared servomotors. Motors have incremental encoders. The encoders have resolution of 504 pulses per revolution.

This robot scheme with differential drive, two caster wheel and metal detector, is shown in figure 2. One caster wheel can serve the purpose of stability of robot but instead two caster wheels are used to reduce the weight on wheels [11]. The weight of robot is about 10 kilograms and the distribution of the weight is over four wheels which help in making the robot to move in landmine field without triggering the landmines. Antipersonnel landmines are usually tuned to trigger at a minimum weight of 25 to 40 kilograms. Metal Detector is connected in the front of robot to detect landmines.

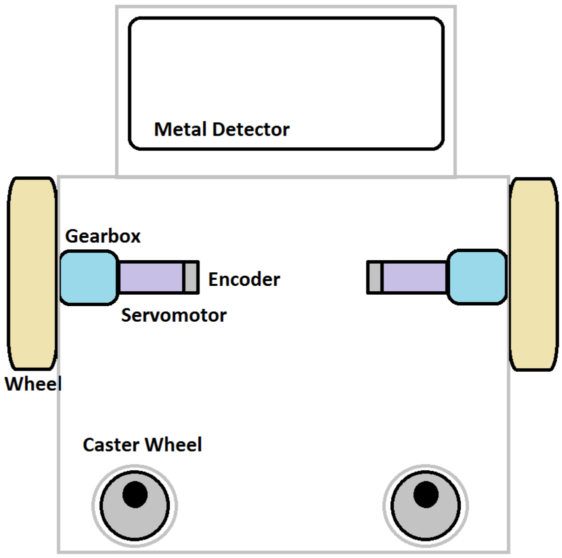

Figure 2: Differential Drive Landmine Detecting Robot scheme

3 Robot Control

PID control is implemented on the motors in PIC 18F4550 Microcontroller and the robot movement commands come from computer. This scheme is shown in Figure 3.

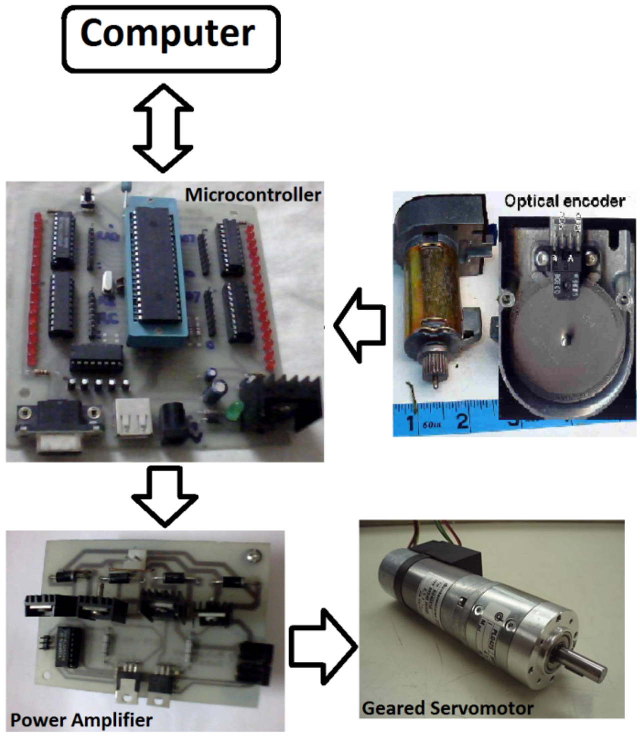

Figure 3: Computer interface with Microcontroller, controlling Drive of servomotor and encoders used for feedback

3.1 Microcontroller

Motion commands come from the remote station computer using serial communication. PID is implemented by changing the pwm of channels build in microcontroller. In manual mode the motor runs in open loop. Incremental encoders are used as feedback of the close loop system. One pwm channel is used to control one motor so a mux is added in the power amplifier cards.

Microcontroller displays the mode of operation of robot, motion commands and reading of metal detector on LCD (liquid crystal display) on robot. Microcontroller communicates with remote computer preforming the commands and sending the metal detector values to remote computer. This communication and control scheme is described in the figure 4.

3.2 PID Gains Storage

The values of proportional, integral and derivative gains of both motors are stored in EEPROM (Electrical erasable programmable read only memory) of microcontroller.

3.3 Communication Protocol

The communication between microcontroller and computer is done using RS232 serial protocol at a baud rate of 115200.

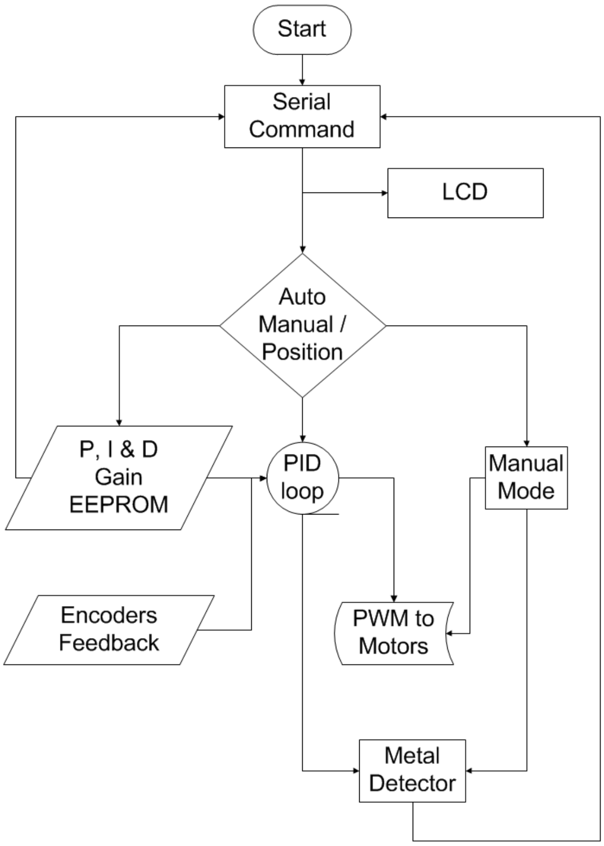

Figure 4: Microcontroller Program Scheme

3.4 Wireless Serial Communication

Wireless serial modules are used for serial communication between the robot and computer. These modules make the robot mobile thus cables free.

3.5 Synchronization

Since the computer execution is faster than the motors of robot, the computer must be synchronized with the microcontroller. The computer program is synchronized [12, 13] with the microcontroller such that computer waits for the controller to execute the commands and microcontroller send verification signal that the task has been completed. After that, the computer sends the next command.

3.6 Visual Tuning Interface

For the PID tuning of motors graphical user interface is created in visual environment of Microsoft Visual C#. "Connect" button is used to read the gain values from EEPROM of Microcontroller thus verifies the serial connection between the robot and computer.

The values if P, I & D gains can be saved in EEPROM using the "Save EEPROM" button. Step response of P, PI, PD and PID for user specified Error and Steps can be viewed by "Run" button after selecting the motor from the left or right motor checkbox and selecting the appropriate P, I and D checkboxes.

The graphical interface shows the curve representing the values of encoder along y-axis and number of steps along x-axis. The user can see the overshoot, rise time, settling time, error band of the system. This user interface is shown in the figure 5. The tuning of servomotors is made very easy with this graphical visual interface.

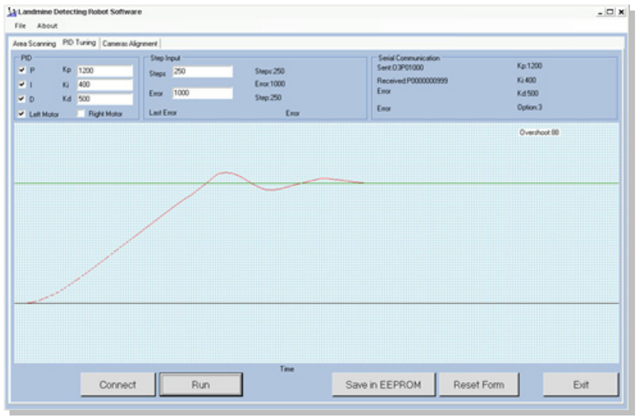

Figure 5: Visual C# PID tuning Graphical User Interface for Servomotors

4 Robot Kinematics

The software uses following type of kinematics [14] for the motion of differential drive robot.

4.1Forward Kinematics

Forward kinematics of differential drive robot consists of calculating the end point of robot, while knowing the start point and velocities of both wheels.

Following equations are used to calculate the final point of robot.

$$x' = \frac{v_l + v_r}{2} \sin\theta \quad (1)$$

$$y' = \frac{v_l + v_r}{2} \cos\theta \quad (2)$$

$$\theta' = \frac{v_r - v_l}{B_w} \quad (3)$$

Where x', y', θ' are the linear and angular velocities of robot. V_r and V_l are the velocities of the wheel of differential drive. B_w is the distance between the two wheels. θ is the orientation of robot.

4.2 Inverse Kinematics

Inverse kinematics is the calculation of motion of wheels to reach specified robot motion. Since this is a two degree of freedom problem, two parameters are specified as the velocity in x axis (x') and the orientation of robot (θ') Following equations are used to solve the velocity of left wheel (V_l) and velocity of right wheel (V_r).

$$= \frac{x'}{\sin\theta} + \frac{B_W}{2}\theta' \qquad (4)$$

$$= \frac{x'}{\sin\theta} - \frac{B_W}{2}\theta' \qquad (5)$$

4.3 Error of Differential Drive

The differential drive mobile robot kinematics is based on the following assumptions [15, 16] which in real world causes odometry errors.

The error in differential drive robots are due to following reasons. Unequal wheel diameters, average of both wheel diameters differs from nominal diameter, misalignment of wheels, uncertainty about the effective wheelbase (due to non-point wheel contact with the floor), limited encoder resolution, limited encoder sampling rate, travel over uneven floors, travel over unexpected objects on the floor, wheel-slippage due to: slippery floors, over-acceleration, fast turning (skidding), external forces (interaction with external bodies, internal forces (e.g., castor wheels), non-point wheel contact with the floor, control loop gain differences.

The caster wheel axis should be vertical to ground but due to constructional inaccuracy there is an offset error which is shown in figure 6.

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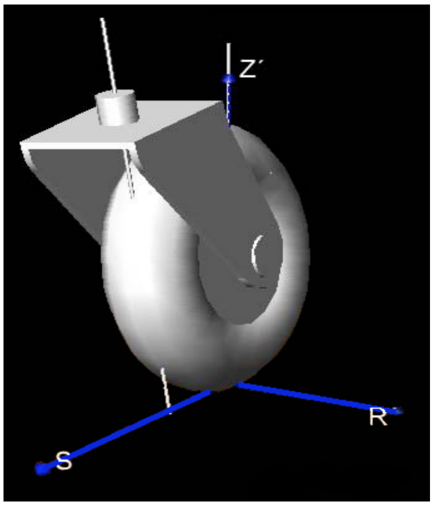

Figure 6: Constructional inaccuracy of caster wheel

The robot can be calibrated to reach a minimum accepted error as described by [15] in a laboratory environment but in field small pebbles or little steep of soil can cause a change in the direction of robot. Land mines plotting need accurate position system so odometry system is not dependable.

The errors in control loops, electrical characteristics and mechanical construction inaccuracies described above shows that the differential drive odometry need a live reckoning feedback for eliminating the errors in robot position.

Image processing is used for finding the location of robot.

5 Image processing

Image processing [17, 18] using stereoscopic vision system is developed to eliminate the error in mapping land mines. A stereoscopic vision system is the single perception of a slightly different image from each camera, resulting in depth perception.

5.1 Scheme

Front view cameras scheme is used to detect the position of robot. This scheme is shown in figure 7. Both cameras see the robot in front of them.

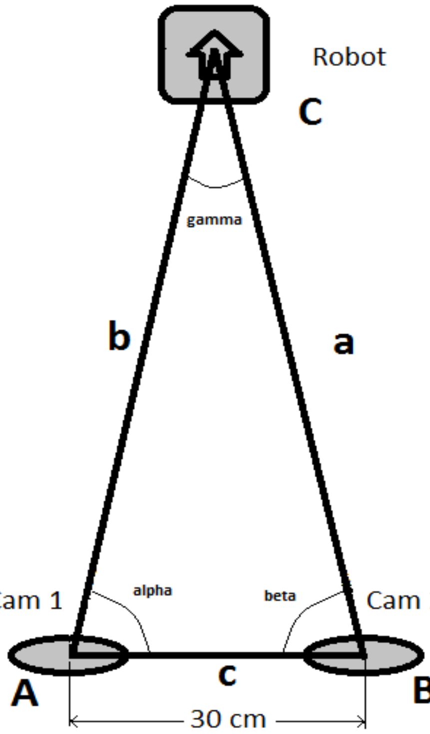

Figure 7: Stereoscopic Cameras Arrangement Scheme for the Robot Location

The cameras are placed at a pre-specified distance between them. The cameras are aligned to the target robot at fix angles. To calculate the distance that is using cameras as measuring sensors the field of view of cameras and their resolution should be known.

The resolution of cameras is noted from the image taken by them. The field of view of both cameras is calculated by measuring the maximum vision of camera at a specific distance. The scheme is shown in figure 8. Using the following trigonometric relation the field of view (FOV) is calculated.

$$V = 2 * \tan^{-1}\frac{measured\ distance}{2 * 30} \quad (6)$$

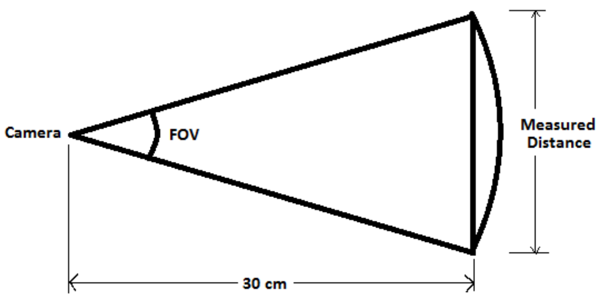

Figure 8: Field of View of Camera Measurement Scheme

Right Camera

Horizontal Field of View	= 42.25 degree
Vertical Field of View	= 35.79 degree

Left Camera

Horizontal Field of View	= 41.73 degree
Vertical Field of View	= 34.92 degree

The distance between the cameras is specified. The cameras are aligned at specific angles. The coordinates of the robot are processed by both cameras then using trigonometric laws position of the robot is calculated.

4.4 Specifications

Distance between cameras is 30 cm. Length of line from robot perpendicular to the line connecting the cameras is 250 cm. This means that at the distance of 250 cm both cameras are aligned and the robot is in the center of their images. This equates to be the alignment angle for cameras is 86.5663 degrees.

$$= \tan^{-1}\frac{250}{15} \quad (7)$$

Blob from the image of both cameras is processed out. The change in angle is calculated as the field of view and the resolution of cameras is known.

$$= \tan^{-1}\left(\frac{250}{15}\right) - \left(\frac{res}{2} - x1\,cood\right) * \frac{fov1}{res} \quad (8)$$

$$= \tan^{-1}\left(\frac{250}{15}\right) - \left(\frac{res}{2} - x2\,cood\right) * \frac{fov2}{res} \quad (9)$$

Where res is the resolution of camera, fov1 and fov2 are the field of view of camera 1 and camera2 respectively, x1 cood is the blob x coordinate in image of camera 1 while the x2 cood is the blob x coordinate in image of camera 2. Now we know the all three angles and length of one side so using law of sine calculate the other sides.

$$\frac{b}{\sin\beta} = \frac{c}{\sin\gamma} \quad (10)$$

The position of robot is calculated by using trigonometric equations. Results obtained are in accordance with our application. Error is in millimeters. Error can be decreased by increasing resolution, by decreasing predefined angle of cameras and by increasing distance between optical centers of cameras.

5.4 Graphical User Interface for Cameras Alignment

In order to align the cameras at the prescribed angles a graphical user interface is created in Microsoft Visual C#. This interface helps in placing the cameras at exactly 86.5663 degrees.
Figure 9 shows the working of this interface.

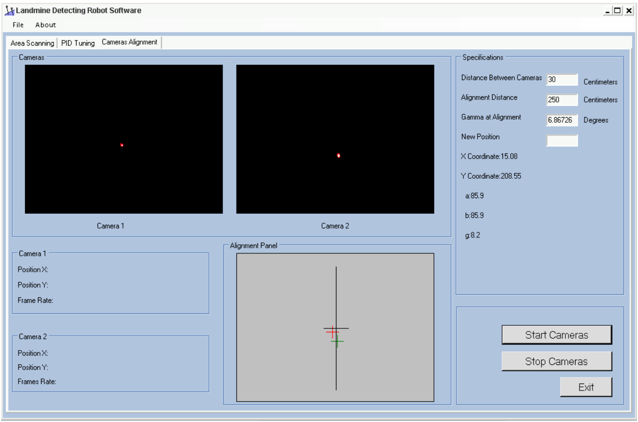

Figure 9: Graphical User Interface for the Alignment of Cameras

In this interface both cameras are placed at distance of 30 cm form each other, and then robot is placed at 250 cm on the line perpendicularly bisecting the line between the two cameras. So, the both blobs of robot in image should appear in the center of image. In a panel the center is marked and the cameras output marks are also visible. The task of aligning cameras is to rotate cameras so that their crosses are aligned with the center cross keeping the distance between two cameras equal to 30 cm.

6 Landmine Detection

To detect land mines balance beat metal detector is used. This is a new genre of metal detector. It is a hybrid between beat frequency operation (bfo) and induction balance (ib) by dubbing it "Beat Balance" (bb) thereby giving a nod to each of the two principles which underlie it. The result is a very simple design that is capable of greater sensitivity than that of a bfo detector whilst offering a high level of immunity to voltage mineralization, together with good discrimination


Figure 10: Landmine Detecting Robot Scanning area for landmines

7 Motion Commands

Following are the robot motion commands that are used in Graphical user interface for the computer station integrated with cameras:

7.1 Auto Mode

In auto mode the robot covers the field autonomously.

7.1.1 Scan Area

In this case robot moves in a rectangular path to scan the area. This scheme is shown in the figure 11. This scheme is to cover maximum area for the detection of landmines. Any signal from the landmine detecting sensor is transmitted to the computer using serial protocol where the location of landmine is stored and presented on a visual map.

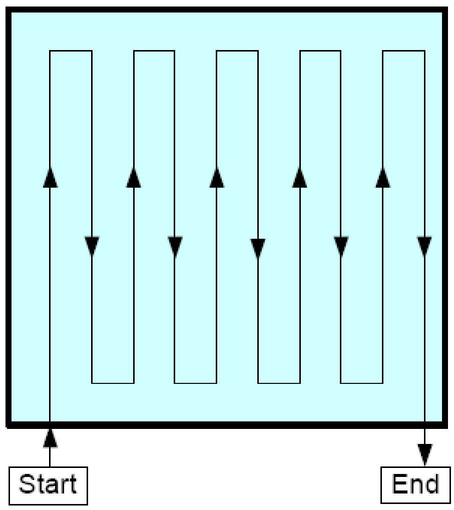

Figure 11: Scanning path of robot in scan area command

7.1.2 Go to point

Using the equation of inverse kinematics discussed earlier, robot moves to the new position. The differential drive robots are imposing what are called non-holonomic constraints, the robot cannot move laterally along its axle.

7.2 Semi Auto Mode

In semi auto mode the PID control makes the robot move in the user specified path. The user has the following options

7.2.1 Move in straight line

Moving in straight line is achieved by this command. The direction of motion depends on the checkbox forward or reverse. This motion is important for demining crew for making a clear straight path in land mine field.

7.2.2 Turn 90 Clockwise

This command rotates the robot 90 degrees in clockwise direction. The PID control is implemented on this command. Both wheel turns but in opposite direction to perform this task.

7.2.3 Turn 90 Anti Clockwise

This command rotates the robot 90 degrees in anti-clockwise. The PID control is implemented on this command. Both wheel turns but in opposite direction to perform this task.

7.3 Manual Mode

User has the power to move the robot in manual mode. The manual mode has following options.

7.3.1 Left Motor

By clicking the left motor button, left servomotor starts depending on the direction checkbox, it continues till the button is kept pressed.

7.3.2 Right Motor

By clicking the right motor button, right servomotor starts depending on the direction checkbox, it continues till the button is kept pressed.

7.3.3 Robot

By clicking the robot button, both wheels servomotor starts depending on the direction checkbox, it continues till the button is kept pressed. So we can move the robot forward and reverse using this button.

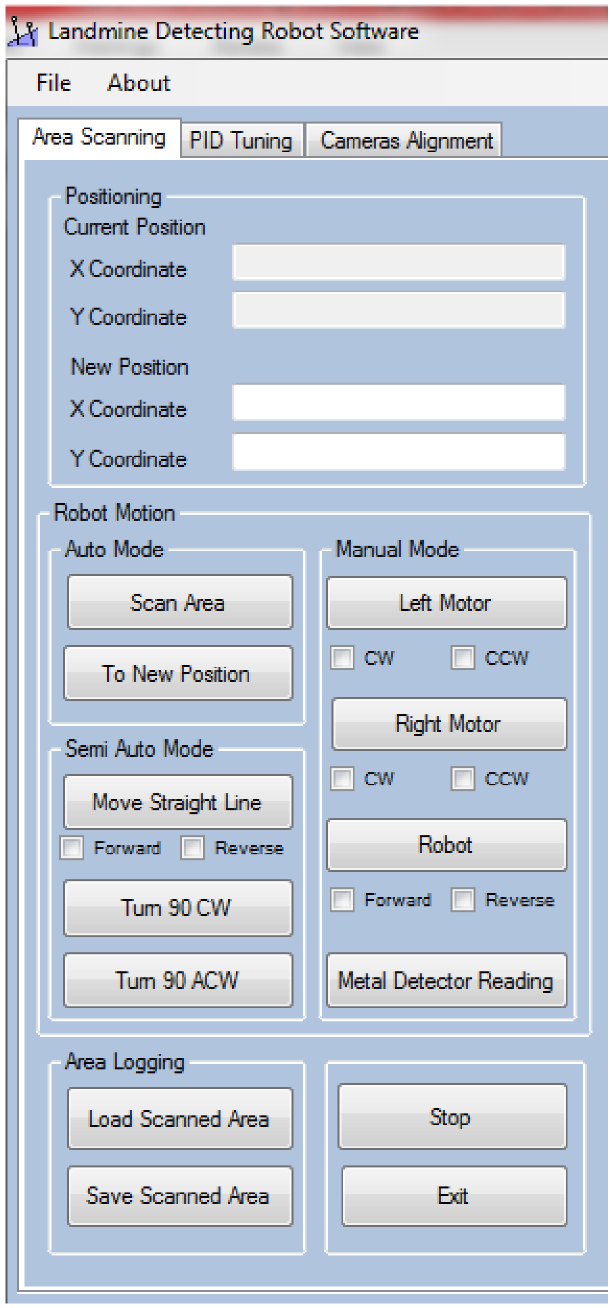

Figure 12: Robot Control Graphical User Interface

8 Mapping of Landmines

The land mines detected during the motion of robot are mapped on the visual environment of Microsoft C#. Figure 13 shows the scan of a 60 x 90 cm square area.

In the map a small square shows a centimeter square area while the big square shows the 10 centimeter square area. Green area is the one scanned by robot while the landmines are represented by the red circle. In these test trials only two land mines were placed which were successfully detected and plotted by the robot.

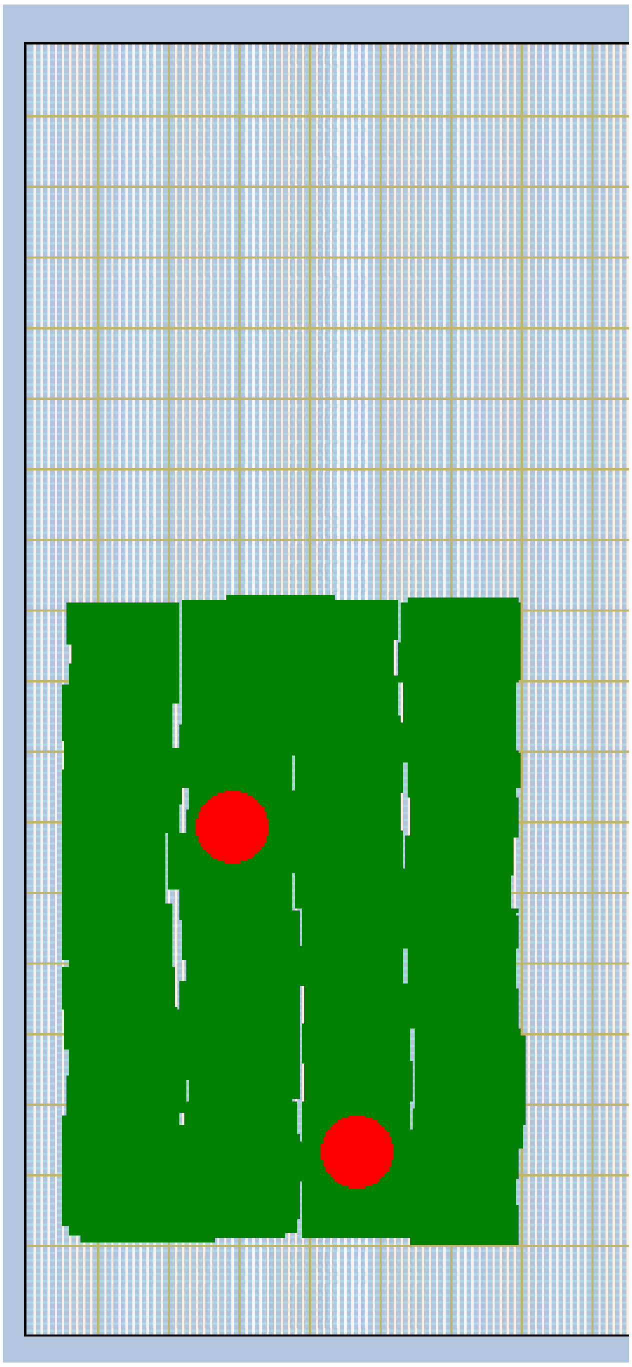

Figure 13: Mapping of Robot visited area and location of landmines

9 Results

The aim of this research was achieved by detecting and plotting the land mines and the area visited by the robot accurately so that the demining crew can easily locate and remove the landmines.

The success of this landmine detecting robot is to be invisible to the landmine which is only possible by its low weight. This robot is low cost. This robot has very simple graphical user interface and mapping system. Novice users can operate the robot easily. The parts of robot are easily available in local market.

Robot was successfully operated in all three, auto mode, semi auto mode, and manual mode. All three control modes present on one graphical user interface provide a very powerful system to the user.

Image processing made the dead reckoning error compensation so, landmines can be accurately plotted. This is the essential feature required by the user of this research to compensate for the dusty areas prone for the skidding of robot wheels. The landmines plotted on visual map have error in just few millimeters. The balance beat metal detector did a fine job of detecting landmines. With the help of visual map the landmines can be located easily.

PID was successfully implemented using PIC microcontroller on servomotors. The tuning of servomotor is done in visual environment. The visual environments for the PID tuning saved time. The response of control shown in visual environment quickly enables the user to change the value of any parameter to get the desired response.

The visual environment program for cameras alignment helped in quick setup of system in any remote area. To test the intelligibility of the robot, novice users operated the robot and found the controls very easy to use and learn.

Wireless serial interface handshaking was successfully implemented between the PIC microcontroller and remote terminal computer. This communication remained secure and reliable at all times.

10 Conclusions and Future Work

The interface developed is a powerful tool for the control of differential drive robot. The control modes along with the mapping make the system a useful demining robotic system. The ideas and techniques mentioned in this paper can be used to make better landmine detecting robots. To increase the speed of work many robots can be used, at the same time, updating the map.

Land mines detection can be improved by using more than one sensor on robot. High resolution servos can be used to turn the cameras to track the robot. This will help to increase the working space of the robot. GPS can be added to the remote station to get a global map of landmines. Modern robotic systems provide graphical and simulation facilities. The simulation of this system can provide a training facility for the users.

Mechanical design of robot can be improved by making rugged robot made of composite material to reduce weight. Light weight robot has many advantages including invisible for the landmine; less torque is required to move the robot and batteries last longer. Obstacle avoidance scheme can be another upgradation to the system. This can help the robot to find its way in any environment. Camera mounted on robot or with help of proximity sensors this can be achieved.

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