Machine Design and Vision Based Control for Agro-Robot

Field Robot Event 2014-Robot Fun & Creativity

HAMK
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ABSTRACT

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ABSTRACT

This study covers the design of an autonomous robot and its testing process on an artificial maize field constructed for an indoor environment. However, the ultimate goal of this project was to participate in the Field Robot Event 2014 organized by the University of Hohenheim in Germany. This project was commissioned by HAMK University of Applied Sciences. And was fabricated and tested in the automation laboratory of HAMK UAS valkeakoski.

The test result obtained by plotting the signal from wheel encoder, sonar sensor, gyroscope, magnetic compass was used as a primary source of information. Different scientific literature published on four wheel differential drive and vision based navigation was well examined for background information. Beside literature, rules and the regulation of the FRE 2014 were used as a source of information as well. In addition to these a working video on a previous field robot event provided a good reference for planning and designing an autonomous robot.

A four-wheel differential drive chassis with a suspension system was designed and fabricated. Sensors such as a magnetic compass, gyroscope, sonar sensor, wheel encoder and camera were used to sense the environment. A suitable control algorithm was developed to meet the requirements of the competition. An indoor test field was designed with the artificial maize plants made up of paper and plastic tube. This test field was used to examine the control modules designed for different level. After a series of testing and tuning, a smooth navigation through row of corn was achieved. Oscillation was dropped down to nominal level; obstacle was identified from a safe distance and weed plants was successfully detected.

The findings suggest that the performance of the robot is satisfactory. However, there are several possibilities for improving it. These include: replacing a sonar sensor with laser range scanner for detecting maize plants. Simultaneous localization and mapping can also be introduced. The author strongly recommends implementing a laser range scanner and stereo vision in to a future project.

Keywords: Field Robot Event 2014, precision farming, autonomous robot navigation, NI vision assistant

Pages **30** p. + appendices 5 p.

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1 INTRODUCTION

The aim of this thesis was to design field robot and to participate in Field Robot Event 2014 "Robot Fun and Creativity" (later FRE 2014). FRE 2014 is unique from other type of robot competition because proto type model must be build with an ability to perform its task in real world environment. This was the most challenging task as proto type model works well in simulated or in a controlled environment. Whereas in an outdoor and especially in agricultural field most of the parameters changes with respect to time and it is impossible to track or predict entire trend using any known mathematical model. Because of which designing a proto type robot with a higher degree of stability, robustness and disturbance rejection feature is still a huge challenge for engineers and designers. Hence, several theories, research papers and previous FRE videos were carefully studied for better tracking and sensing such trends. To precisely control, to achieve better and quicker response to changing environment, different controllers were designed and was switched accordingly for example; navigation, avoid obstacles, turning mode and reverse drive.

A team of five members worked together in this project to take part in FRE 2014. Tasks were divided among members. Task one: designing agro-robot, task two: designing follower robot for irrigation, task three: navigation based on image captured from camera, task four: navigation based on RTK GNSS, task five: navigation based on distance measurement from sonar sensor and task six: wireless communication between two robots. Among these tasks the author had a responsibility to build agro robot; calibrate the sensor and develop the control algorithm for navigation based on image captured from camera.

Before starting to fabricate robot several sensors were tested and analysed for example; IR sharp Sensor, Sonar Sensor, wheel encoder, magnetic compass, digital gyroscope and camera. As robot has to drive on loose muddy terrain four wheel differential drives with skid-steered chassis (each wheel with separate motor drive) was fabricated. Arena of FRE was in outdoor environment so there is a possibility to fluctuate the disturbances such as; intensity of sun light; temperature and humidity. This fluctuation could affect the stability and robustness so best two different algorithms were used for the final event. This was verified by conducting several tests in simulated maize field build from paper and plastic inside the room and by adding possible disturbances.

Among different sensors vision based sensor was found to be best and cheapest to sense maize row when lightning condition was good enough. However, data acquired from vision sensor contained a lot of noise and was relatively large. Processing such a large amount of data was quite challenging and required better controller. So computer was used to process data acquired from vision sensor and two Arduino Mega microcontrollers was used to interface other sensors and actuators.

Working in a multicultural group is always a fun. Different activities carried out in a team to complete this project resembles like a lab works conducted to understand hard core theory.

1.1 Introduction of Field Robot Event 2014

FRE is an open robotics platform in which, students from different countries come together with their best designs of field robot to compete with their opponent teams on a common discipline. This event is conducted with a view to achieve precision farming in agriculture by means of completely autonomous robot. This event is organized every year; however the place and the organizing committee/university are varied. In 2014, 12th edition of FRE was announced and the organizing team for this year was the University Hohenheim together with the DATENSCHUTZERKLARUNG DER (later DLG). The event was held at the international Crop Production Centre in Bernburg-Strenzfeld, Germany. (FRE, 2014.)

In this event autonomous robot designed by the students performed its task in maize rows. There were altogether five different tasks. In which robot should be able to perform task such as: sensing crops field, navigating in between the crops rows and precisely controlling actuators without destroying crops.

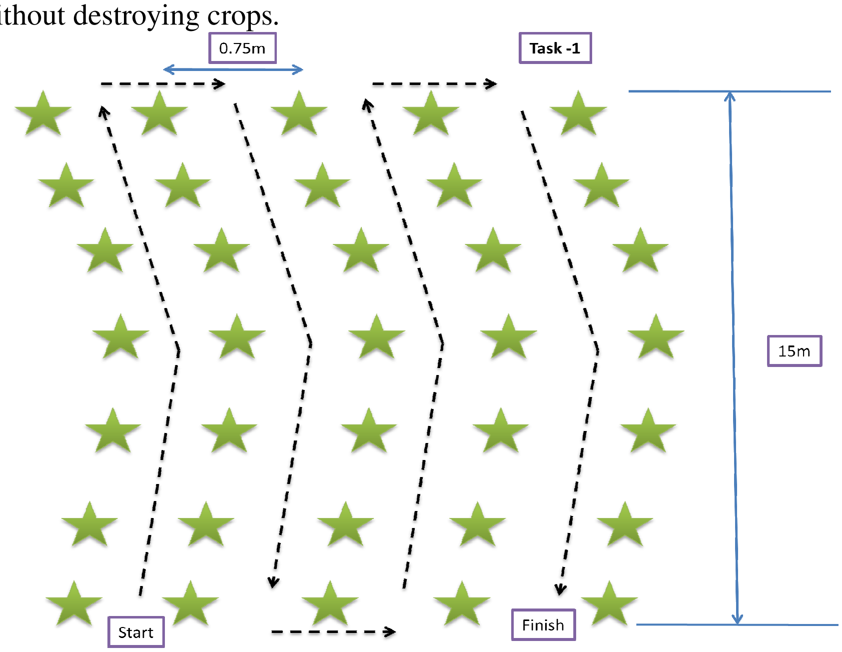

Figure 1 Test field for task 1(Gautam, 2014)

As shown in figure1, task 1 was termed as basic navigation and in this task robot must navigate in between long curved rows of maize plant as fast as possible without damaging crops. (FRE, 2014.)

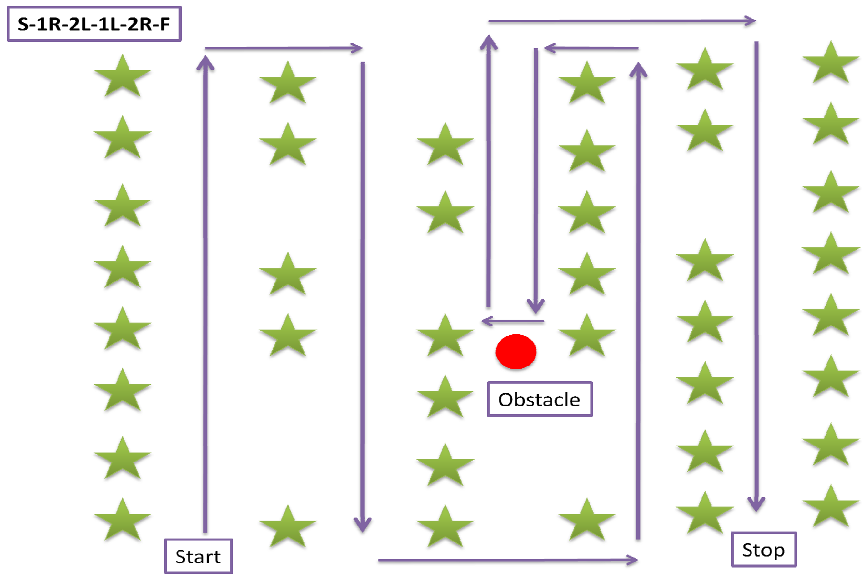

Figure 2 Test field for task 2 (Gautam, 2014)

As shown in figure2, task 2 was termed as advance navigation and in this task robot had to follow pre defined paths which is a long straight maize row. To add complex ability in navigation and to create a real world scenario size of maize plant is uneven; there were missing plants in rows with a maximum distance of 1 meter and obstacle in undefined location. This obstacle blocked the way so that the robot should have the ability of reverse driving. (FRE, 2014.)

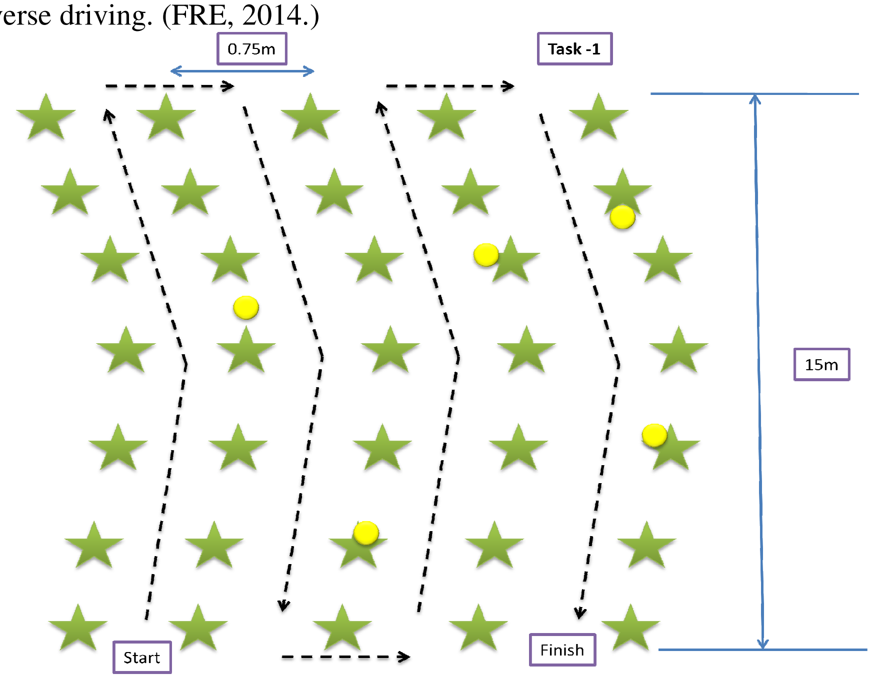

Figure 3 Test field for task3 (Gautam, 2014)

As shown in figure3, task 3 was termed as Professional Application and in this task, to create a real world scenario 5 weed plants were randomly placed within crops row. An absolute geo-referenced weed map had to be generated of these weeds by using an RTK GNSS. Task 4 was termed as Cooperation; in this task two-team could perform cooperative task by establishing some kind of communication between robots while performing some activities related to farming. Task 5 was termed as Freestyle; in this task team could show their own idea and creativity related to agriculture. (FRE, 2014.)

1.2 Research Question

The research questions moreover focused to address the task assigned by event committee of “Field Robot Event 2014- Robot Fun & Creativity”. However, the author tried to address general question which was suggested during Research and Development lecture:

- What is the importance of vision in mobile robot?
- What are the ways of controlling the robot?
- What would be the accuracy of robot and how to improve it?
- What type of controller/controlling device is used to perform computational task based on vision?
- How a vision based mobile robot control superior then other type?
- Why you choose this topic?

1.3 Research Approach

This was probably the first project; in which an autonomous robot was built to take part in robot competition by a group of students of bachelor’s degree programme in Automation Engineering of HAMK University of Applied Sciences (later HAMK UAS). However, the author had participated in national and international robot competition during his Diploma in Mechanical Engineering studies. Experiences gained through previous competitions and experiment based approached followed by theory were used to solve challenges of this competition. From the sensor selection to the chassis design each module was selected after conducting deep research on its mathematical model, design constrains, working principle and cost limitation and those modules were tested in labs of HAMK UAS.

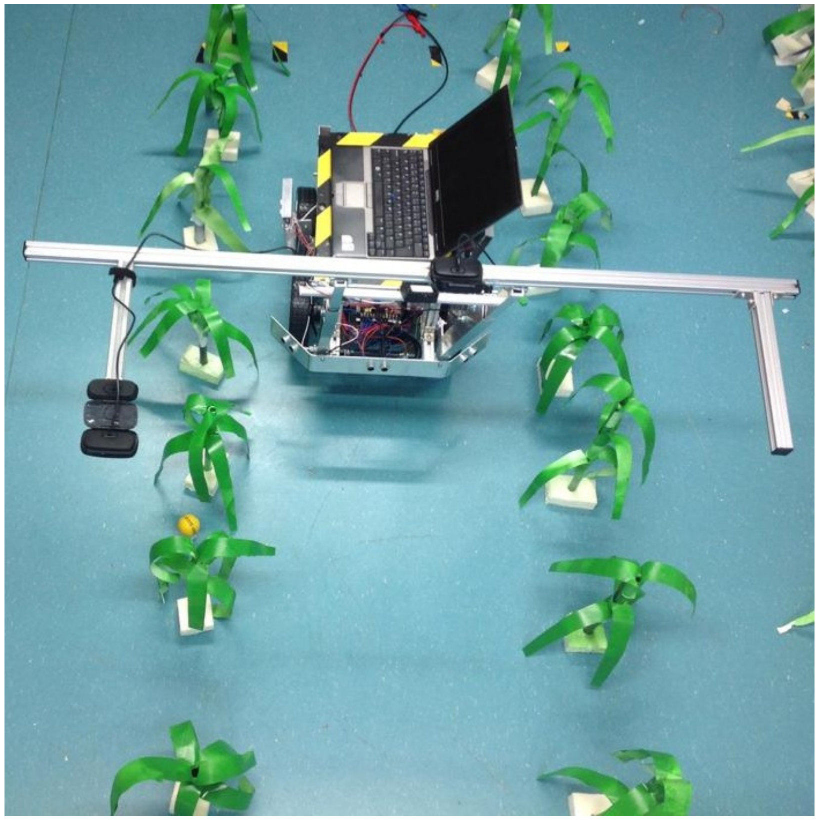

Figure 4 Indoor testing of robot (Gautam, 2014)

Research papers published in online media were examined to understand theory behind those modules. Working videos of previous team in FRE from You Tube were taken into consideration. As shown in figure 4, plants made up of paper and plastic were used to create real maize field scenario and to test all possible algorithms. National Instrument Data acquisition device was used to acquire data from sensors and those data was digitally simulated and tested using LabVIEW graphical programming software. Two best algorithms were selected for FRE after a series of tests and tuning. Indoor test field is shown in appendix 2.

2 MECHANICAL DESIGN AND TESTING OF ROBOT

This section is aim to introduce theory based on differential speed steering control for four wheel independent drive electric vehicle by (Wu, Xu and Wang, 2013) and practical implementation of it in FRE. Among several types of drive system 4WD skid steering was chosen, as robot had to perform its task on loose muddy terrain. Knowing the fact that, increase in power and torque results in larger lateral slip.It was design to be able to produce enough torque and power to overcome such a large friction. To ensure good contact between each wheel and the ground, an appropriate suspension system was designed. Chassis was designed and fabricated using aluminum bar in HAMK UAS workshop.

2.1 Differential speed steering for 4-Wheel Drive Electric Vehicle

Research paper on differential speed steering control for four wheel independent drive electric vehicle by was preferred to examine because dynamics of our model was best described on it. As shown in figure 5, in case of skid steering four wheels were fixed. Hence, to turn robot in a desired direction suitable lateral slip must be developed in inner wheels. Control strategies for lateral slip could be achieved in three different ways.

Control strategies one: in this control mode, only outer wheels velocity is increased without changing the inner wheels velocity. This was easy to carry out but the radius of turn was found to be bigger. It was because the inner wheels velocity may be at higher value (Wu, et al. 2013).

Control strategies two: in this control mode, the turning was obtained by locking the rotor of inner wheels and introducing suitable velocity on outer wheels (Wu, et al. 2013). This type of control mode was suitable when small radius of turning was required. However, it has one disadvantage which was: for a jerk free motion robot had to stop before steering.

Control strategies three: in this control mode steering radius was achieved by introducing differential speed in inner and outer wheels (Wu, et al. 2013). Provision of individual wheel velocity control of inner and outer wheels had added additional flexibility to control steering motion. Robot need not to be stopped for steering sharp turn.

As suggested by Wu, Xu and Wang (2013) and an experiment carried out by the author in a controlled environment third control strategy was used: increasing the outer wheels velocity and reducing the inner wheels velocity as desired. However, in our case point of contact was loose soil and predicting precisely the radius of turning by a controller was quite challenging. It is because lateral slip also depends upon coefficient of friction developed between the wheel and floor contact point.

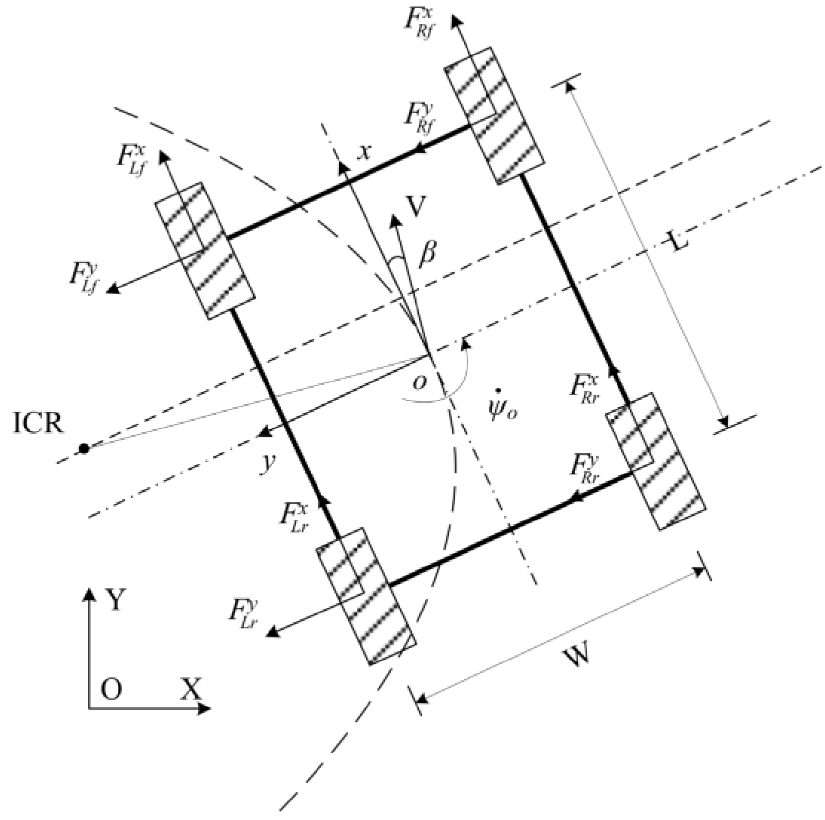

Figure 5 Skid-Steered Vehicle (Wu, et al. 2013.)

A kinematic model of a differential-steered vehicle moving at constant velocity about an instantaneous centre of rotation (later ICR) is shown in figure 5. In this model following assumption was made to simplify mathematical modelling: centre of mass was at geometric centre of robot chassis, robot runs at slow speed and two motor on same side were provided with an electrical power producing same speed. The kinematic relationship between the whole vehicle and the wheel speed can be expressed by a mathematical formula, which is shown in equation 1 (Wu, et al. 2013.)

$$\begin{pmatrix} Vox \\ Voy \\ \psi o \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{ICRx}{W} & -\frac{ICRx}{W} \\ \frac{1}{W} & \frac{1}{W} \end{pmatrix} \begin{pmatrix} Vl \\ Vr \end{pmatrix} \tag{1}$$

Where, W is width of robot
Vl is left wheel velocity
Vr is right wheel velocity
ICR is instantaneous centre of rotation

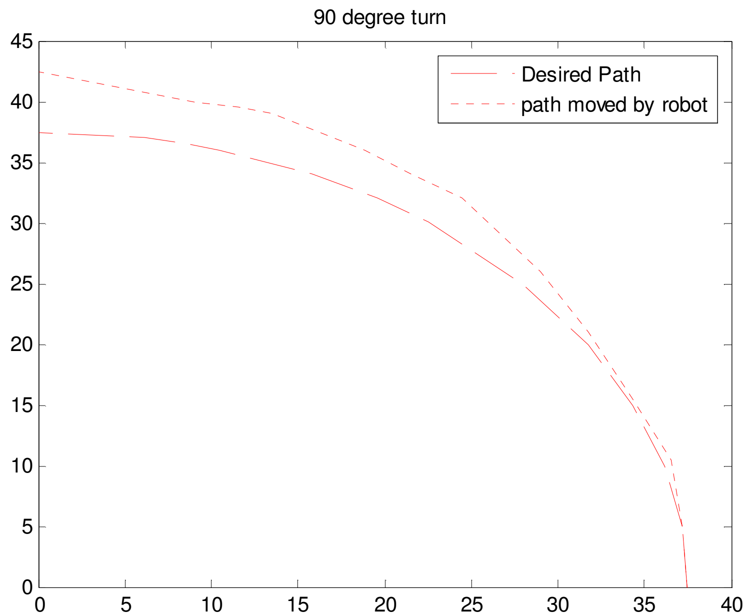

Figure 6 Graph of robot 90 degree turn. (Gautam, 2014)

Suitable algorithm was developed to execute the formula derived from Wu, et al. (2013.) model. As shown in Fig. 6, the robot's path was deviated with small amount. It was because of poor wheel coupling, as there was slip between wheel and shaft. Though same power was supplied to all the wheels, yet there was some difference in speed. This had lead to deviation of robot's path. Despite mechanical inefficiency, the result from graph demonstrated that the differential speed steering control for four wheels independent drive electric vehicle model best suits this project.

2.2 Suspension System

After conducting several tests with 4WD chassis it was found that the wheel looses a contact if terrain was uneven or loosely packed. In order to overcome this issue, suitable suspension was developed and implemented. In order to reduce jerk produced by high torque motor and to establish flexible connection between wheel and chassis, each wheel was fitted with suitable suspension system.

Figure 7 Suspension system for Skid-Steered Vehicle (Gautam, 2014)

As shows in figure7 a helical spring was used with central rod. This rod was used to prevent spring from buckling effect. The total mass of robot was 12kg. Approximately 20 kg of counter mass was required to compress the spring fully.

2.3 Agro-Bot

Agro-Bot was the name given to robot by the author. In this section the author will discuss general aspect of robot. Robot chassis was designed in Autodesk inventor 2012 and fabricated using aluminium AW 6063 T5 rectangular bar of size (100x20x2, 40x20x1.5 and 20x15x1.5) mm. Image of CAD designed Agro-Bot is attached on appendix number 3. Each wheel was separately powered by electric motor and featured with suspension system to ensure that all the wheels touch the ground. Robot chassis holds everything attached to it and has a provision to hook follower.

Figure 8 Agro-bot (Gautam, 2014)

As shown in figure 8, it has one magnetic compass which is denoted by ‘M’, it has four sonar sensors whose position is defined as -90, -45, 0, 45, 90. It has a computer on the top which controls outputs through Arduino. 12V 15Ah battery is placed just below laptop. Motor H-bridge, power adapter and Arduino are placed inside a junction box which is underneath laptop. There are two cameras; one in the middle and other on right hand side. Rare wheels are equipped with wheel encoder. Camera placed on the centre is used to capture image for detecting yellow colour ball. And the camera placed on the right hand side is used to synchronize robot path. . Figure of mechanical system modelling in AutoCAD is attached in appendix 1.

3 SELECTION OF PERCEPTION AND CONTROLLER

This section is aim to explains about the sensors used in this robot. Different types of sensor modules were developed and tested in normal, medium and worst case scenario in a controlled environment. Results obtained from test environment and basic working principle of commonly used sensors is explained in this unit. Along with the sensors different electrical and electronic modules used in this project is explained.

3.1 Sensors

Selection was based on the test result and cost. First test was carried out with infra red sharp sensor and it was found out that this type of sensor works well only in normal lightning or in absence of ambient light. For second test Sonar Sensor was coupled on Servo motor to mimic laser range scanner. It was because laser range scanner was very expensive. Results from this design were good but for a single scan of 180 degree with a resolution of 5 degree per step it took more than 5 seconds. With this delay value it was impossible to complete even the first task in FRE. So we had only one option remaining that was to make skirt of sonar sensor on the chassis. For this purpose five sensors was placed at an angle of -90, -45, 0, 45 and 90. Main problem of sonar sensor was that soft materials absorb considerable amount of signals because of which, receiver failed to detect this eco.

3.1.1 IR Sharp Sensors

Infra red (later IR) sharp sensor for Arduino is a commercial sensor produced for educational project. It consists of infra red emitter and a photo diode which are separated by a small distance. IR rays projected by emitter will be reflected back to receiver if an object is introduced within its range. It is moderately accurate for measuring short distance under normal ambient light. We cannot see IR rays by our necked eyes but we can use camera to verify presence of light. The IR-sharp sensor used for test purpose is shown in figure 9 (a) and pin configuration is shown in figure 9 (b).

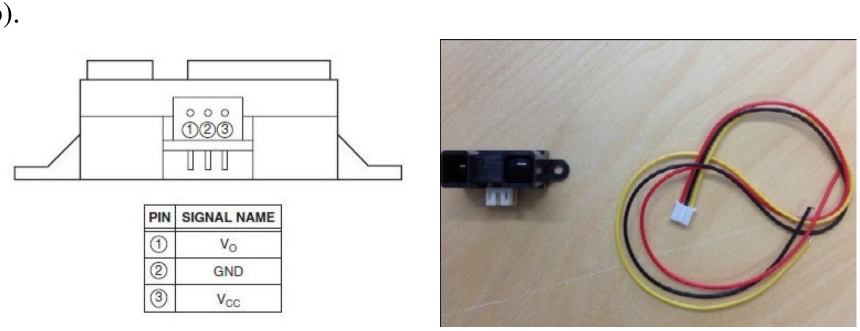

Figure (a) Figure (b)

Figure 9 IR sharp sensor (Gautam, 2014)

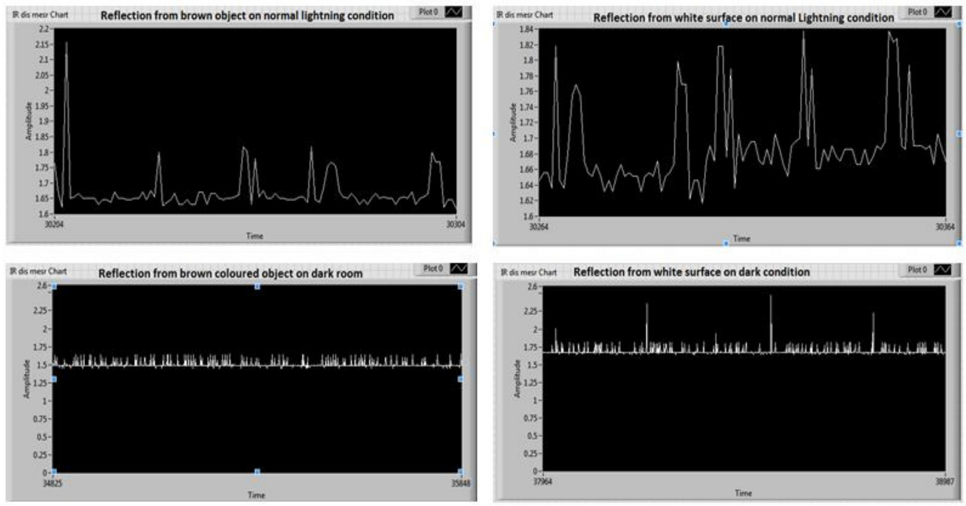

Figure 10 IR sharp sensor disturbance measurement in real time (Gautam, 2014)

Experiment carried out in four different conditions is shown in figure 10. Amplitude of signal was plotted on x-axis and time on Y-axis. Amplitude of signal ranges from 1.6-2.2 volt. Top left graph shows IR signal received from brown surface on normal lightning condition. Signal is affected by noise. Top right graph shows same signal from white surface in normal lightning condition. Signal thus obtained is highly affected by noise. Bottom left figure shows same signal from brown surface but no light condition. This signal is quite good. Bottom right corner shows same signal from white surface and no light condition. Hence, it was clear from graphs that IR sensors were mostly affected by light intensity. So as an alternative of this sensor, sonar sensor was chosen.

3.1.2 Ultrasonic Sonar Sensor

Ultrasonic sonar sensor is a type of active sensor which has a transducer and a receiver. When an electric signal is supplied to a transducer made of thin membrane of piezoelectric ceramic then mechanical distortion occurs; emitting ultrasonic waves. These waves travel through air and produce an echo if a foreign body is introduced within it range. The reflected waves (echo) were picked by receiver producing mechanical vibration on a thin membrane of piezoelectric ceramic creating an electrical signal. Ultrasonic wave has sorter wave length which means better accuracy can be achieved on distance measurement. The speed of ultrasonic waves mainly depend on temperature, but the amplitude of the echo waves depend on the area and surface properties of reflecting materials (Foessel, 2000).

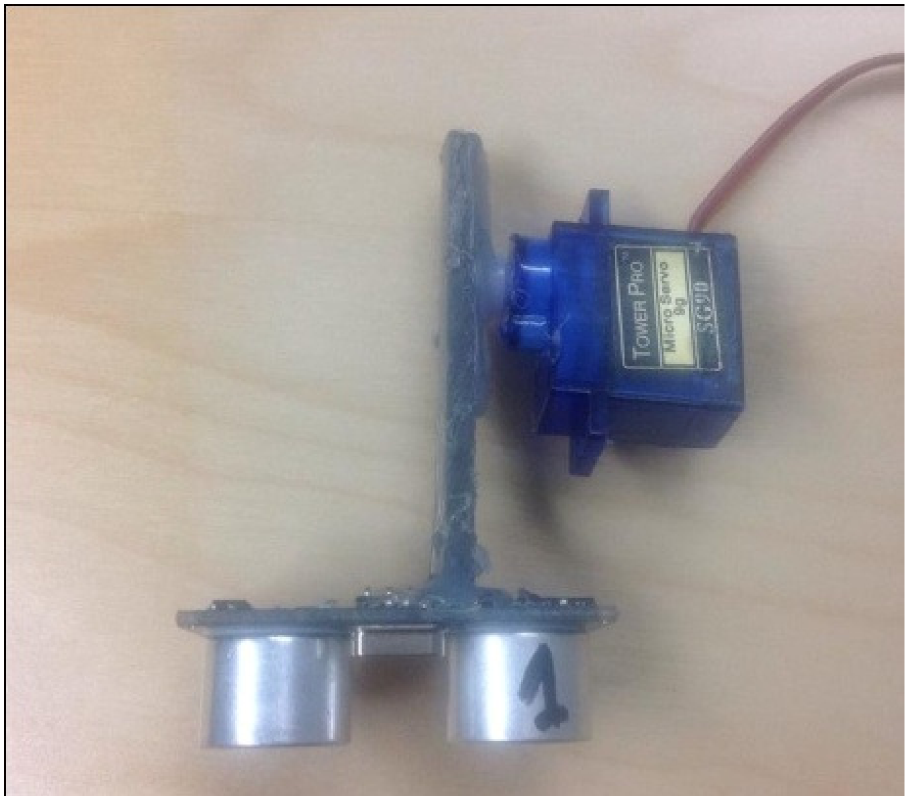

Figure 11 Sonar sensor and servo module (Gautam, 2014)

First of all an experiment was carried out with a sonar sensor and a servo motor (as shown in figure11) to mimic laser range scanner. In this experiment a sonar sensor of range between 0.04-4m was mounted on a shaft of servo motor. The resolution of 5 degree per step and a scan angle of 180 degree were chosen. A trigger was send to transmitter at every step and distance corresponding to eco was stored in 2D array before taking new step. The outcomes of this type of combination were found to be satisfactory if the object size was relatively bigger, sampling time was longer and scan area was small.

But in this project stem of maize plant was no more than 0.04m, the distance between two successive plants was 0.133 m and distance between two rows was 0.75m (FRE2014, 2014) and sonar sensor used in this event had an aperture angle ranging from 30-45 degree as shown in figure 12. Two or more than two plant can be enclosed within effective region. And another major drawback was long sampling time.

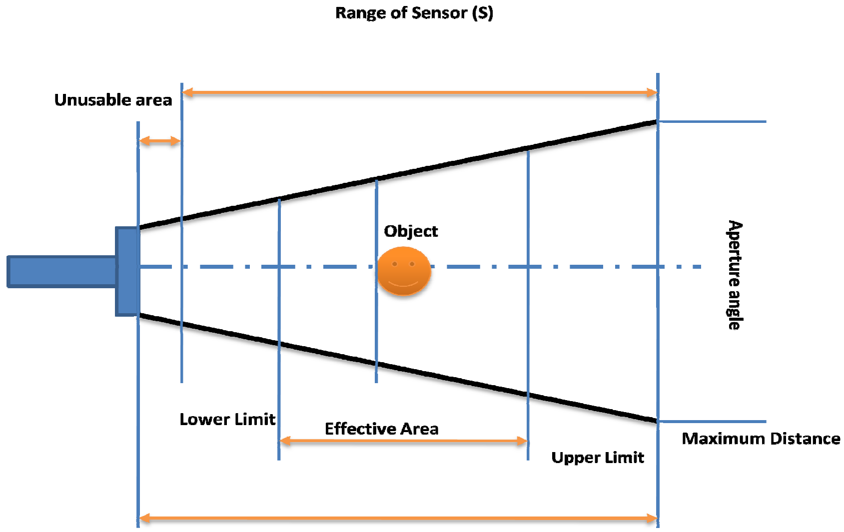

Figure 12 Sonar sensor effective area (Foessel, 2000)

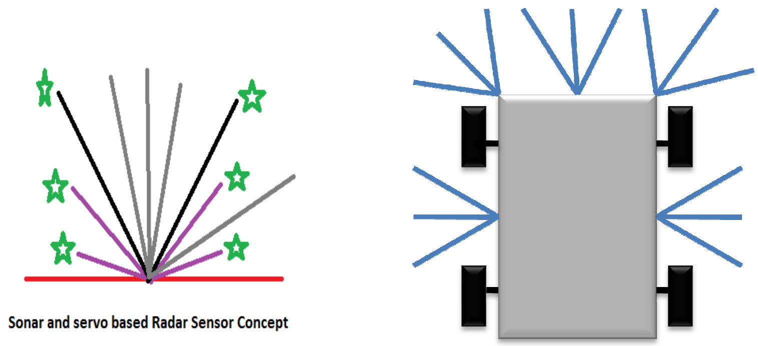

Figure (a) Figure (b)

Figure 13 Sonar sensor position in robot chassis (Gautam, 2014)

For a single scan of 180 degree (as shown in figure 13 (a)) with a resolution of 5 degree per step size; sampling time was more than 3 second. Hence, array of 5 sensors (as shown in figure13 (b)) were used to acquire distance in order to reduce sampling time. Schematic of sonar and servo module is attached in appendix 3

3.1.3 Wheel Encoders

Wheel Encoders used in this robot was hand fabricated. It is an internal sensor which provides angular velocity of the motor. Equally distributed strip of black pattern is printed on transparent plastic and glued between two circular disks to strengthen it. Diameter of circular plastic template exceed by 6 mm. Sensor is made up of optical transmitter emitting very narrow beam of light and a receiver which is facing each other. Very narrow optical beam is blocked by this small and equally distributed pattern when shaft attached to the wheel is rotated. As a result square wave is produced at output terminal of the encoder. Square wave received from the encoder is enough to determine revolution per minute. However, it failed to provide direction of rotation. Therefore, two optical encoders were used at 90 degree phase shift to each other to determine direction of rotation (Olson, 2009). The schematic of wheel encoder with sensors is shown in figure 14 (a), determining direction from quadrature phase wheel encoder is shown in figure 14 (b) and the actual wheel encoder output is shown in figure 14 (c).

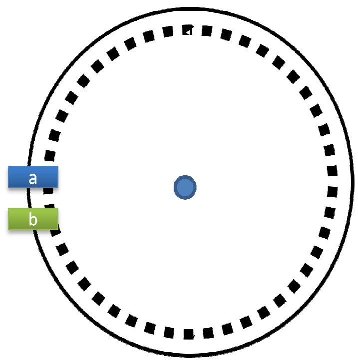

Figure (a): wheel encoder

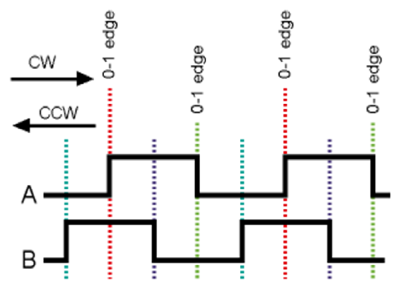

Figure (b): Direction signal

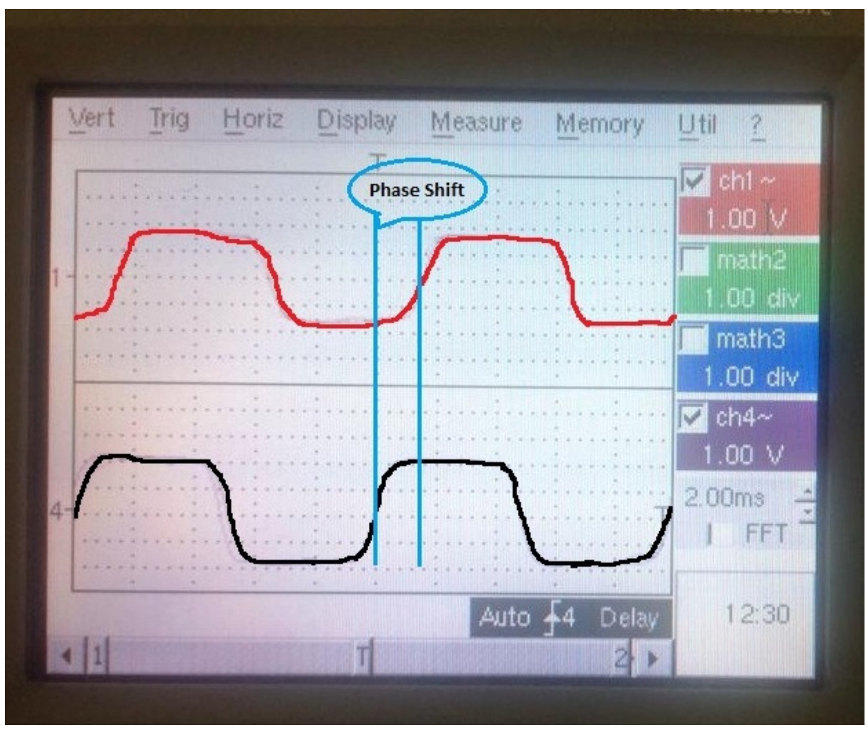

Figure (c)

Figure 14 Quadrature Phase wheel encoder (Gautam, 2014)

$$Resolution = \frac{total\ pulse}{360^0} \quad (2)$$

Based on the equation (2), in one rotation it produces 64 ticks, resolution is 0.177 per degree and smallest angle it can detect is 5.62 degree. Output signal of wheel encoder fabricated for this project deviates significantly from an ideal wheel encoder. Phase difference between two channels in an ideal wheel encoder is exactly 90 degree. Because of design constrains, the author was able to achieve maximum of 55 degree phase shift. However, it was sufficient to distinguish clockwise and counter clockwise direction. Figure of wheel encoder used in this robot is attached in appendix 3.

3.1.4 Magnetic Compass

Magnetic compass is a digital sensor which is made of thin strip of magneto resistive element (NiFe). It is constructed in such a way that its resistance changes with change in its orientation with respect to earth magnetic north. Morden magneto resistive sensor has sensitivity below 0.1 and a sampling time is less than 1 microsecond (Caruso, 1997). For the better heading direction magnetic compass must be placed far from magnetic substance and also from ferrous metal like iron and steel. Figure 15 shows detail schematic of heading angle.

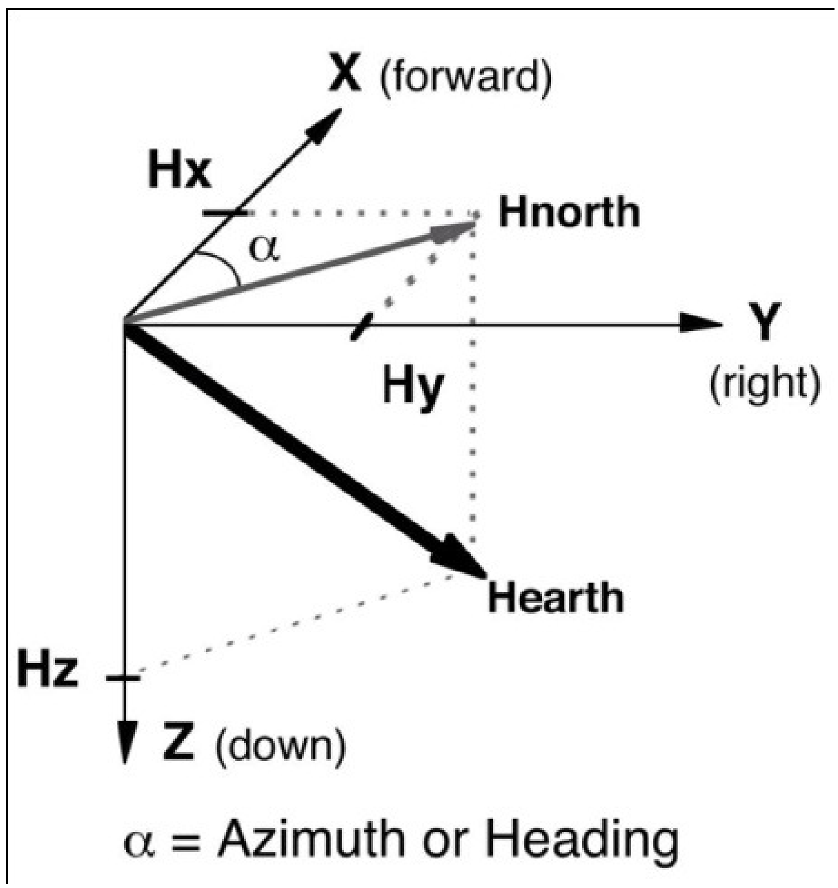

Figure 15 Heading in X ,Y- plane

Based on figure 15, a formula to calculate magnetometer heading is shown in equation (3):

$$\alpha = arctan\left(\frac{Hy}{Hx}\right) \quad (3)$$

Where α is heading

Magneto resistive compass module was used in this project to determine the heading angle of robot with respect to earth's magnetic north. Data acquired from magnetic compass was used for navigation and turning. I2C communication was established between magnetic compass and microcontroller

3.1.5 Inertial Measurement Unit

Inertial measurement unit (later IMU), consist of accelerometer, gyroscope and manometer. Accelerometer is used to measure linear acceleration, and gyroscope to measure rotational velocity. Figure 16 shows the integration process of these two sensors in a sequential block. Combination of this two sensing element on one package helps to sense motion type, rate, gravitational force and direction (Hazry, Sofian, Azfar, 2009). It is used in real time navigation to calculate the acceleration, velocity and position of moving system. This is obtained by integrating the acceleration and rotational rates signals from IMU.
Measurements of the direction of Earth's gravitational and magnetic field vectors along with the angular rates allow estimate of orientation of the sensors module. This sensor is mounted on the frame of robot. These orientations in turn are used to transform acceleration measurement from the moving body coordinate frame to an earth fixed reference frame. The total acceleration is subtracted from gravitational acceleration. The remaining acceleration is double integrated to estimate position relative to the starting point as shown in figure16. (Vincent, 2013)

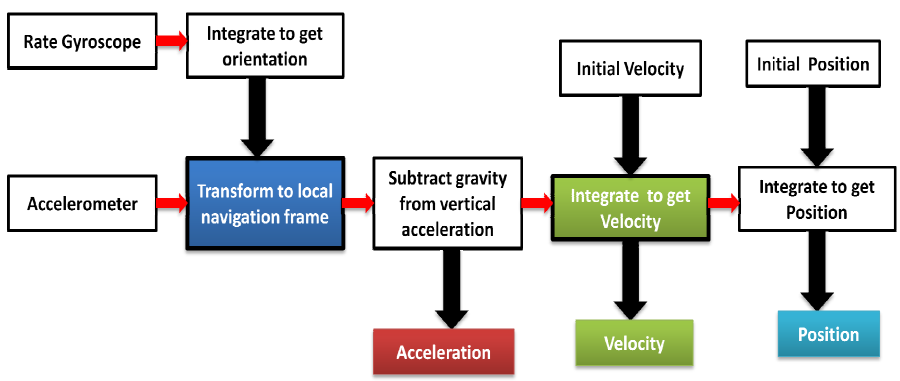

Figure 16 Linear acceleration and orientation (Gautam, 2014)

IMU was used in our application because the resolution was good and data from wheel encoder was affected if any slip occurs on the wheel. It was also helpful to navigate in between crops rows as the array of data contains orientation about the reference, linear acceleration, and a rotational velocity of the robot. However, data from IMU was found to be affected by drift, accumulative error and sine error.

3.1.6 Real Time Kinematics Global Navigation Satellite System

Real Time Kinematics Global Navigation Satellite System (later RTK GNSS) is a complex system used for global navigation. The working of this system can be simply defined as following: position of any point on the space can be defined if the location of three satellites on space and the distance from that point to the satellite is known. However in real system satellites (as shown in figure 17) are moving and the signal is disturbed by different layers of earth's atmosphere. GNSS system consists of mainly three stations: space station, control station and a user interface station. Space station is located outside the earth and used to correct the orbit of the satellite. Control station is located on ground base network which is used as a master control station for uploading the data. Main function of master control station is to update the satellite's orbit parameters. And user's station consists of a receiver which processes the satellite signal to retrieve time and location information. (Introduction to GNSS, 2014.)

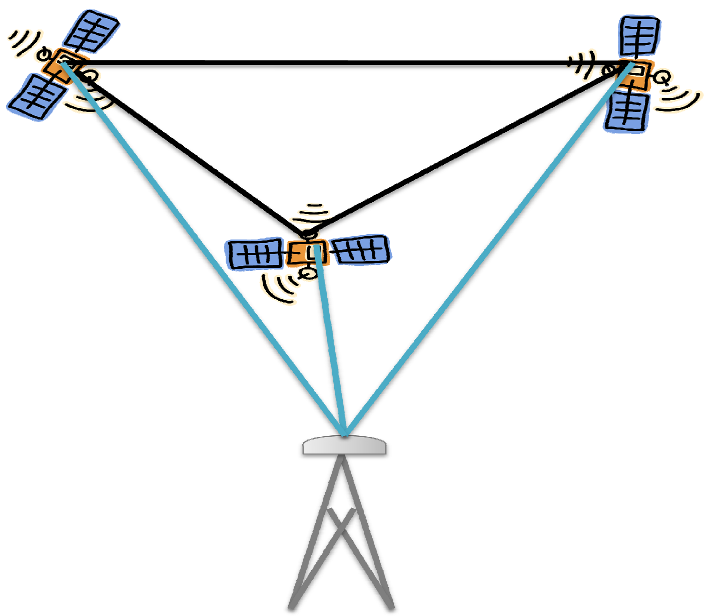

Figure 17 RTK GNSS Working Model (Gautam, 2014)

Precision farming was possible with the advancement of Global Positioning System. The accuracy of such devices was improved from few meters to centimetre level. Morden farming machine was equipped with RTK GNSS positioning system to improve precision farming. In this system a base reference station provide real time correction of signal and this was achieved by the use of carrier phase measurement. The cost of such devices is very high and depends upon the accuracy level. RTK GNSS system was only used in task 3. It was provided by the FRE organizing team. This system was used to determine absolute coordinate of the robot frame centre. A resultant vector was calculated to map the coordinates of weed plant centre to robot frame centre coordinate.

3.2 Computer

Large amount of data needed to be computed when vision was used as primary source of data. Microcontroller such as Arduino cannot handle such a large amount of data; hence personal computer was used for extracting features from vision sensors. Computer running on windows 7 was used by disabling unwanted features of windows 7 for this task. Very few programs were operated on this computer. So that optimum performance was achieved to perform real time computation. Two Logitech USB cameras were directly connected to computer. National Instruments LabView 2010 was used to compute data acquired from two cameras. Sensors data was acquired from Arduino Mega 1 suitable control output was send to Arduino Mega 2 to energize the actuators'.

3.3 Interface Board

Computer couldnot directly communicate with sensors and actuators'. In order to establish basic communication between these devices an interface board was needed. Hence, to connect sensor and to control actuators, microcontroller was used. Two units of Arduino Mega microcontroller were used as an interface board to computer. First and for most reason to choose Arduino was that: it is open source, variety of sensors and other module was available in the market and next, it is reliable compared to self built microcontroller circuit. All the inputs were connected to Arduino Mega-1 and all the outputs were connected to Arduino Mega 2. However, in Arduino Mega-2 signals from wheel encoder was connected. It is because in Arduino Mega-2 PID controller were used to drive motors in desired velocities. All the raw sensors value from sonar, gyroscope, compass, wheel encoder were processed and delivered to computer on its request. Figure 18 shows the actual Arduino mega board.

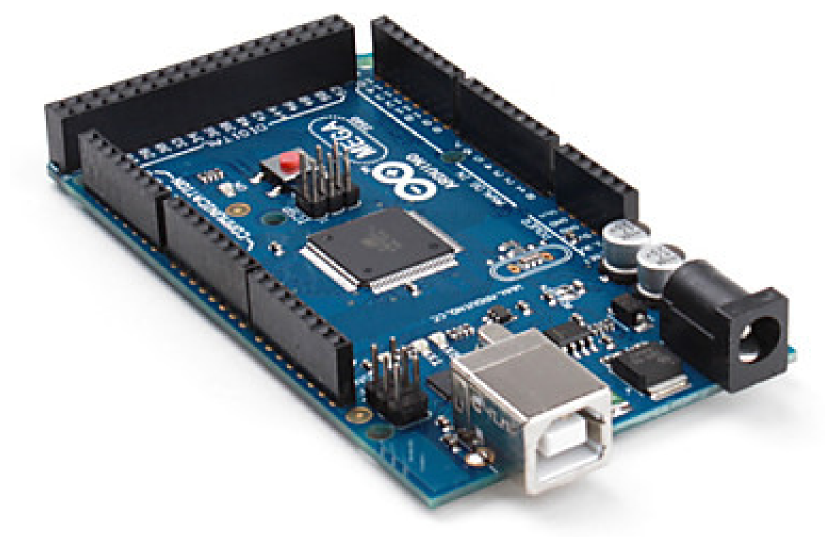

Figure 18 Arduino Mega Microcontroller (Gautam, 2014)

3.4 Inter-Integrated Bus

I2C stands for Inter-Integrated circuit. It is quite popular in embedded system because of its simplicity, built in addressing and multi drop functionality. Pair of wires; one containing data and other containing clock is used to establish two way communications between multiple devices. Data transmission rate up to 400Kbps is supported by modern I2C device. Fig.19. shows devices that were connected using I2C bus in this project.

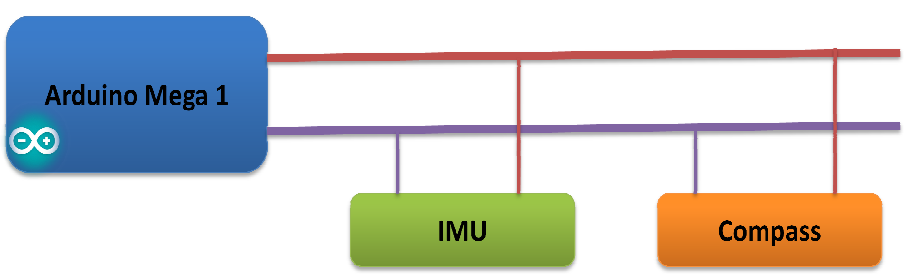

Figure 19 I2C bus device (Gautam, 2014)

As shown in figure20 data was transmitted in a packet and each packet contains: start condition, slave address, slave acknowledgement, actual data, master acknowledgement and stop condition.

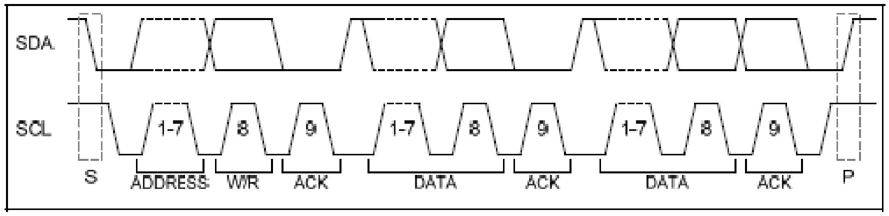

Figure 20 I2C bus protocols (Land, 2012)

Whenever, master device want to acquire information or wants to perform some tasks through slave device connected to its bus. Then, master sends rising pulse on SDA which drops exactly at the middle of SCL and SCL clock is rising at start condition. Then slave address along with read bit or write bit is transferred. If slave device receives this piece of information then it sends acknowledgement whether it is ready for new task or not. It slave device is ready then actual piece of information was transmitted otherwise process will resume with start condition. When all the data is transmitted, master device will send an acknowledgement to slave informing that the data transmission was successful. Finally master device will send stops condition to slave. If that is the last piece of information otherwise data transmission will be continued until next stop command, from master device. (Land, 2012 Lecture.)

3.5 Motor Drive Circuit

Motors used in this project consume relatively high current that is 2 ampere per motor. The output of microcontroller cannot supply such a large amount of current. Therefore, readymade motor H-bridge made of a pair of metal oxide field effect transistor was used. Primary function of H-bridge is to switch high power device into low power or vice-versa. Besides switching application, it is also used to change direction of motors and circuit isolation.

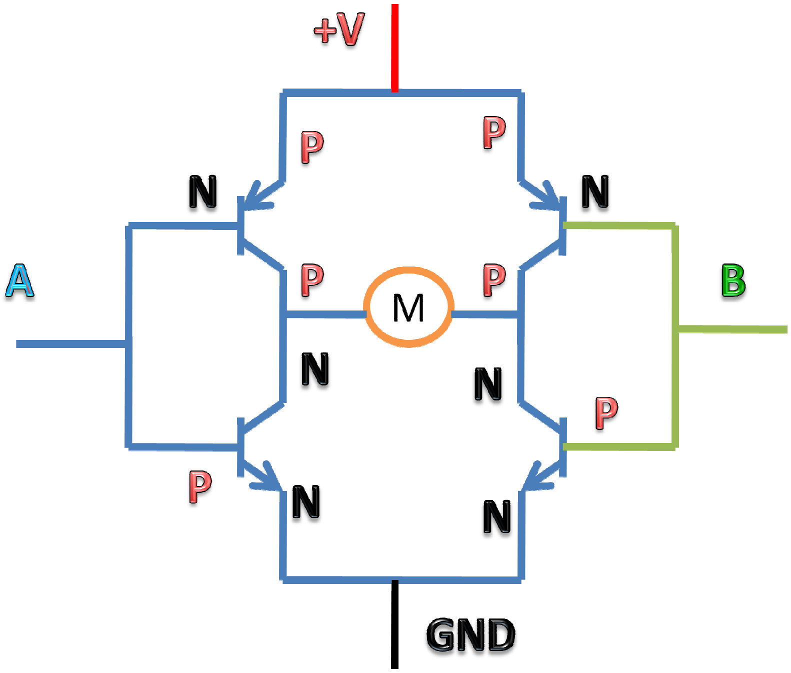

Figure 21 H-Bridge Schematic (Gautam, 2014)

Figure 21 shows the basic schematic of MOS FET H-bridge.

3.6 DC Motor

Power window motor of a car was used to drive wheels of robot because it has relatively large torque in a compact size. It is a type of permanent magnet direct current motor (later PMDC motor) with a rotor shaft connected to worm gear. By the definition PMDC motor consists of radially magnetized permanent magnets, which are attached on the wall of motor housing forming a stator core to produce field flux and a rotor having dc armature with a commutator segments and brushes (Electric Motor, 2014). Figure 22 (a) shows the actual motor used in this robot and the torque relation.

Figure (a): Power Window Motor

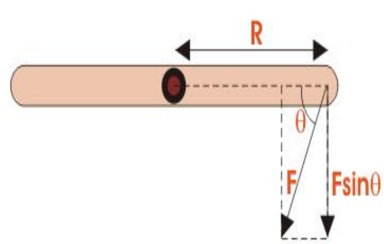

Figure (b): Torque relation

Figure 22 PMDC motor (Electric Motor, 2014)

According to figure 22 (b), the equation of torque is given in equation (4):

$$T = FRSin\theta \qquad (4)$$

Where F is force in linear direction, R is a radius of rotating object and θ is the angle made by force F with radius R vector.

4 MACHINE VISION

This section is aim to explain the basic of image acquisition, image processing and image features extraction. Dependency of image quality on different factor is explained with an aid of figure. Digital image contains very large amount of information, handling such a large amount of data need a very large computational power. However, all the information contained in a digital image is not necessary. A very small portion of information is enough to extract meaning full information from it. The practical aspect of extracting image features is explained in different subs-headings.

4.1 Image Acquisition

An image acquisition is a process of capturing scene and representing it in a user defined format. Nowadays, images are stored digitally. It is possible to capture an image digitally if an object reflects light energy received from sun or any light emitter (Moeslund, 2012). As shown in figure 23, a suitable optical system was used to capture scattered rays and an array of photoreceptors (photo diodes) were used to measure light intensity of reflected light energy from that object.

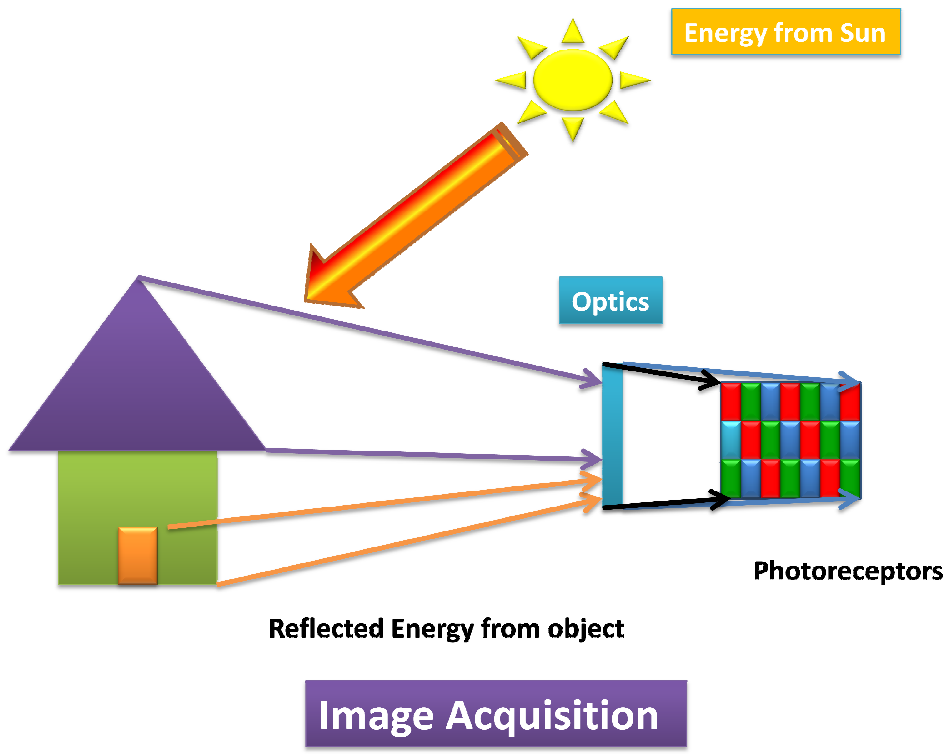

Figure 23 Image Acquisition (Gautam, 2014)

Smallest element of digital image is called as a pixel. Each pixel stores the intensity of electromagnetic waves. If an image is a gray scale type then its intensity value is represented from 0-255 where 0 represents black region and 255 represents white region (Moeslund, 2012). And in case of colour image, original image is filtered using red, green and blue filters. Each receptors measure the intensity of light which has passed through specific colour filter. Combination of these three basic colours is used to represent all other colours. Digital images largely depend on optics type, pixel value and reflected light from objects. In an outdoor environment the intensity of light changes unexpectedly. So an extra precaution must be taken to filter this noise.

4.1.1 Optics

When light falls on any object, some of the lights are absorbed by the object and some are reflected. The reflected rays gets scattered most of the time that drops off the quality of image so, to get better quality image a suitable lens must be used. It is because lens can focus multiple rays of light coming from same point on a single point (Moeslund, 2012).

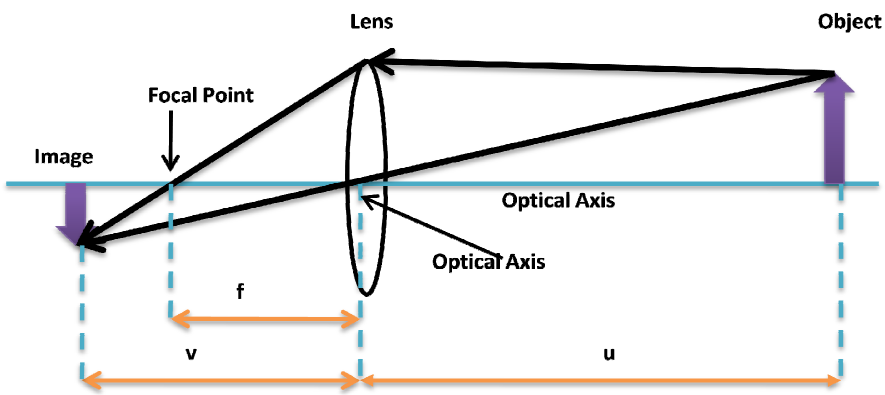

Figure 24 Fundamentals of Optics (Gautam, 2014)

Focal length and the aperture are the basic parameters of lens. As shown in figure24, focal length play key role in magnification of image and the intensity of light is regulated through aperture. The main disadvantage of using optical system is that it deforms images. However, it can be corrected using suitable algorithm.

4.1.2 Illumination

Illumination is an important factor in machine vision because the quality of an image depends on the intensity of light energy received by photo receptors. If the intensity of reflected light is less than the minimum threshold then the image will be of poor quality where as if the intensity of light is above the maximum threshold then the image will be very bright (Moeslund, 2012). Hence, suitable lightning must be used for better image resolution. But the light source should not be behind the image otherwise it will capture dark image.

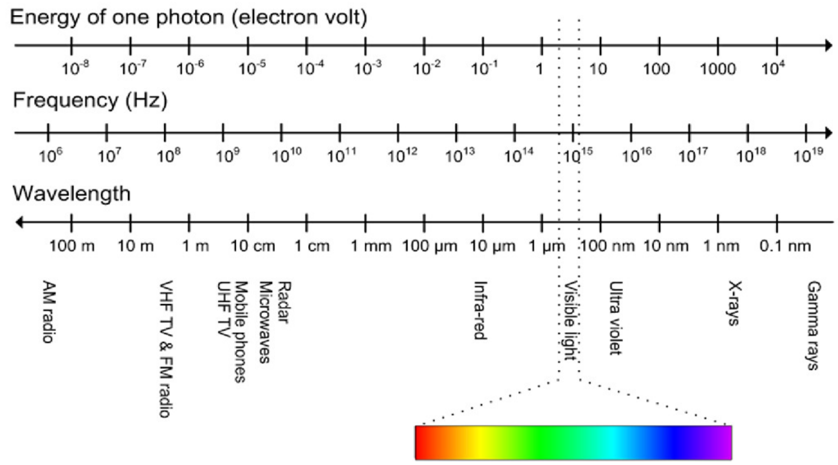

Figure 25 Electromagnetic Spectrum (Moeslund, 2012)

Figure 25 shows the light spectrum. In an outdoor environment the intensity of light changes unexpectedly. To improve image resolution in poor lightning condition, suitable lightning must be added. As we know that defuse lightning system can illuminate an object from every directions so, that the photo receptors can capture very tiny details. Hence, it is a good idea to use deffuses lightning system. When the intensity is very high then a suitable filter must be used to regulate the threshold and to prevent an image from being glared. In our application we had used polarised glass to improve image quality.

4.2 Digital Image Processing

Digital image is a two dimensional representation of scene and it has certain intensity value. Mathematically, it is represented as function of f(x, y) where, x and y represent position of pixel in 2D plane (Young, Gerbrands and Vliet, 2007). Image acquired from any sensor are subjected to disturbances. It is important to filter those disturbances as it affects computations which are based on these data. There are several known methods to minimize those disturbances. The process of minimizing disturbances and extracting useful information from raw data is called image processing.

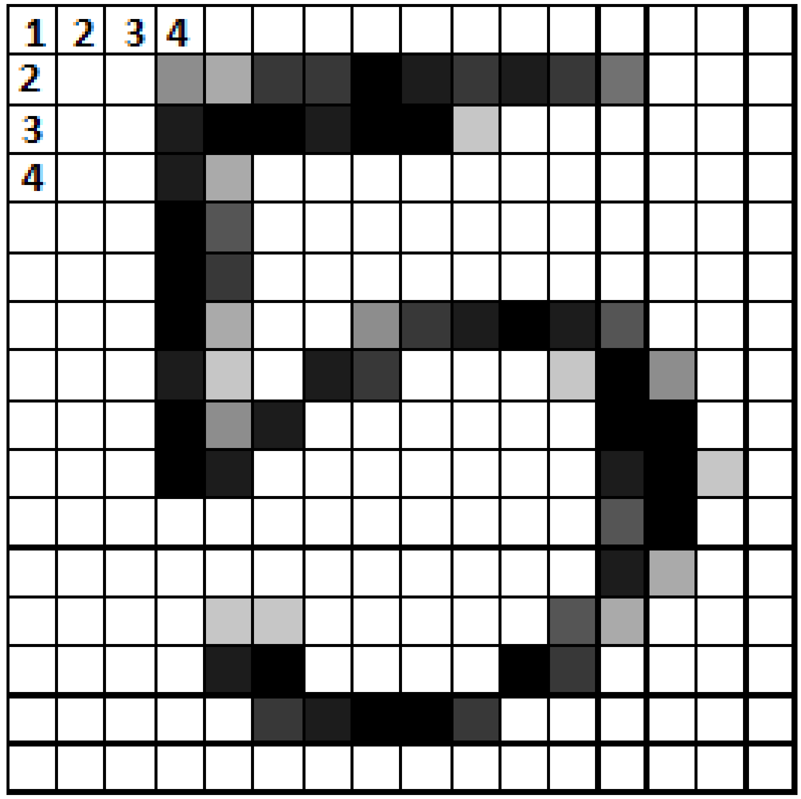

Figure 26 Image representation in digital format (Young, Gerbrands and Vliet, 2007)

From the figure 26 we can determine the coordinate of each pixel. For example first pixel with intermediate gray scale value has a coordinate (x=2, y=4). We can also see that the image is not vivid; in order to enhance this image we can use different image processing methods such as sharpening, de-blurring, adjusting contrast, brightness and highlighting edges.

4.3 Image Features Extraction

A digital image consists of large amount of data. Extracting all information from such source needs large computation power and time. In this project robot had to navigate through maize plant rows and find weeds which were represented by yellow colour golf ball. To minimize computational power and time only certain information was extracted such as colour, texture and shape. This information was sufficient to navigate robot through maize row and determine relative positions of yellow coloured golf balls.

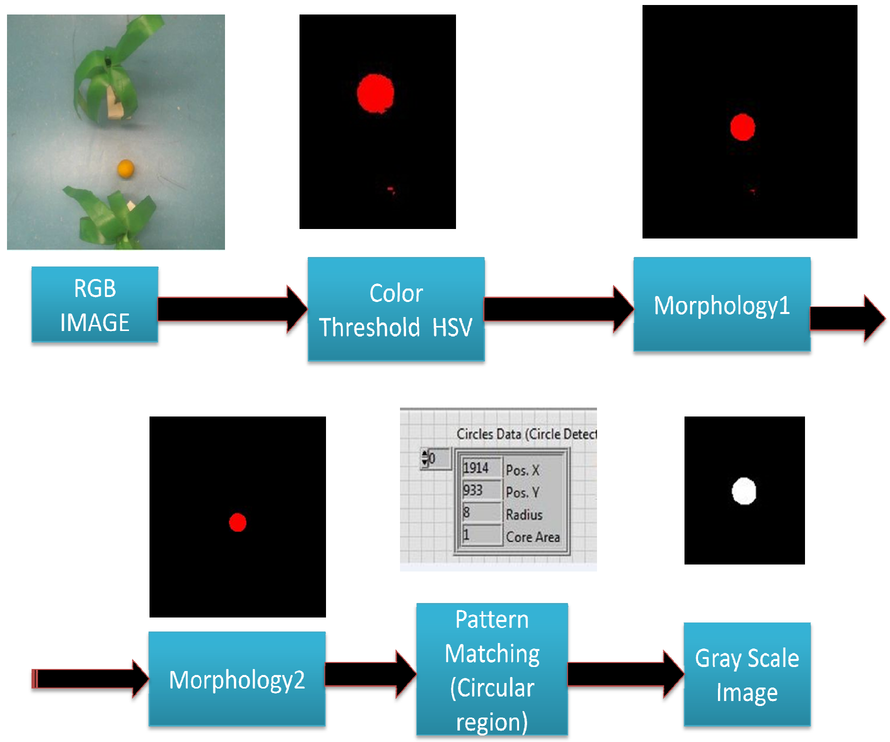

Figure 27 Image feature extraction process (Gautam, 2014)

Figure: 27 shows image feature extracting process using NI LabView vision tool. In this example, yellow colour golf balls were used as a sample objects. The main task was to identify these balls using a camera in an agricultural field. Firstly, RGB image was captured with camera attached on the robot. HSV reference was used to threshold the image (Smith and Chang 1995). Resulting images contain a lot of holes and irregular surfaces. In order to improve texture of image, morphology tool was used to fill those small pores on the images. Again Morphology tool was used to remove small regions which are below rated threshold so that unwanted reason can be removed. To identify the shape, a circular region was searched throughout the image with predefine range of diameter and also the coordinate of circle was determined. Finally, this image was converted into gray scale image to display on GUI. Program block of ball detection is attached in appendix 4.

5 CONTROLLER MODULES

In this section the author had explained about different types of controller modules like: follow row, change direction, avoid obstacle and locate goals. This was designed to simplify the programme and its operation. Before entering programming section first, let's look at hardware architecture figure 28.

Sensors such as: sonar, magnetic sensor, IMU, and wheel encoder were connected to Arduino Mega 1 and actuators including wheel encoder were connected to Arduino Mega 2. Logitech 601 USB camera was connected to computer via a USB port.

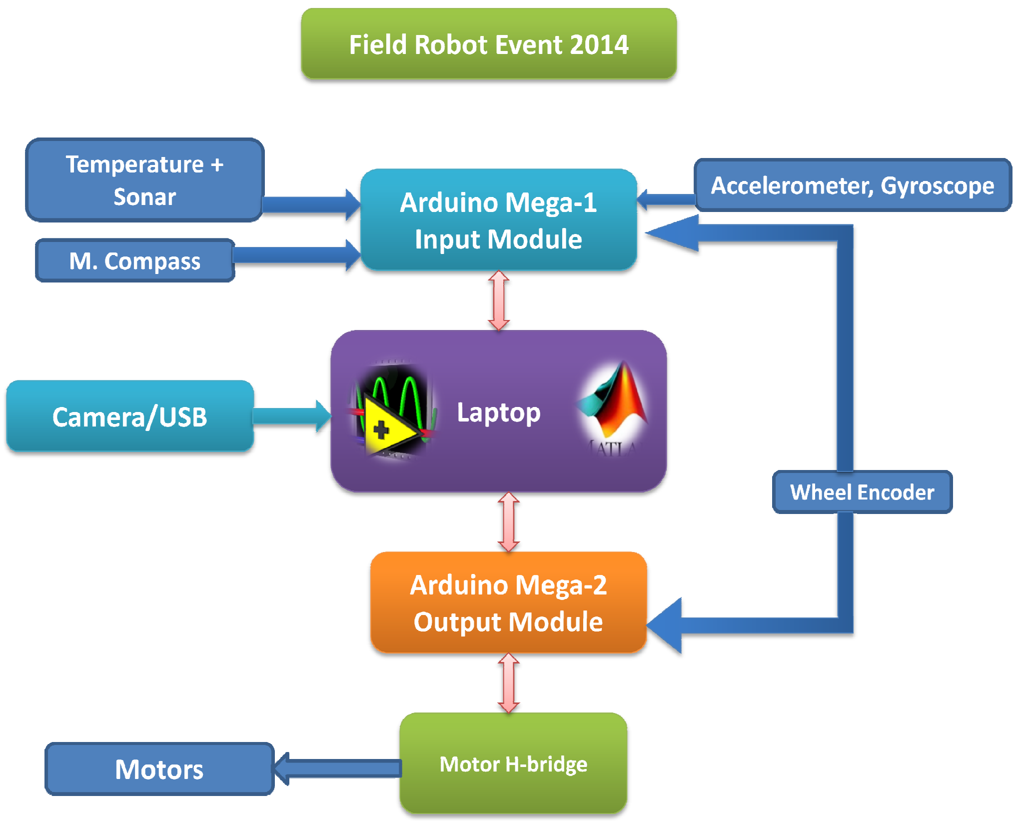

Figure 28 Peripheral Architecture (Gautam, 2014)

Raw datas from sensors were processed by Arduino Mega 1 and a string of data containing distance value, heading angle, linear and angular acceleration in X and Y axis were updated in every 200 millisecond. However, that string of data was transmitted only on the request of master device that was the computer.

PID control algorithm was implemented on Arduino Mega 2 to auto-tune wheel velocities. A feedback from each wheel encoder was used. The goal of controller is to closely maintain velocity of wheels. Though there are four motors; left hand side motors were controlled by one control output and right hand side motors were controlled by another control output. Figure below shows the block diagram of controller.

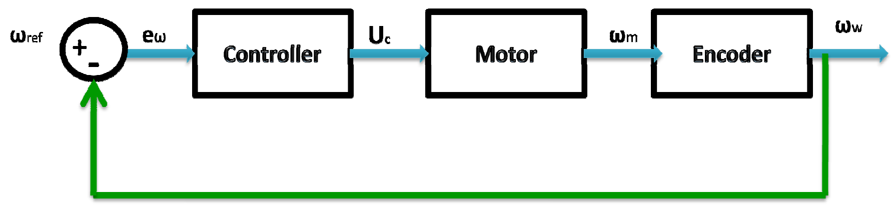

Figure 29 Controller Block Diagram (Phillips and Harbor, 2000.)

From the figure 29:

ω_{ref} is the desired angular velocity computed by controller.

e_ω is the error value sensed by wheel encoder.

Uc is the control output from the controller as a voltage signal to the motor H-bridge and finally to the actuator.

ω_m is the angular velocity of actuator.

ω_w is the angular velocity of wheel.

Above block diagram is a second order system. It consists of two first order systems (describing motor and wheel) in cascade. From this observation it can be concluded, that this is a second order system with two real distinct poles. This system will have no overshoot because second order system has damping coefficient greater than one (Phillips and Harbor, 2000.).

5.1 Follow Rows

First and foremost control module developed was follow row. This module was used to navigate robot in between two maize plant rows. For this task data from camera and sonar sensor was used.

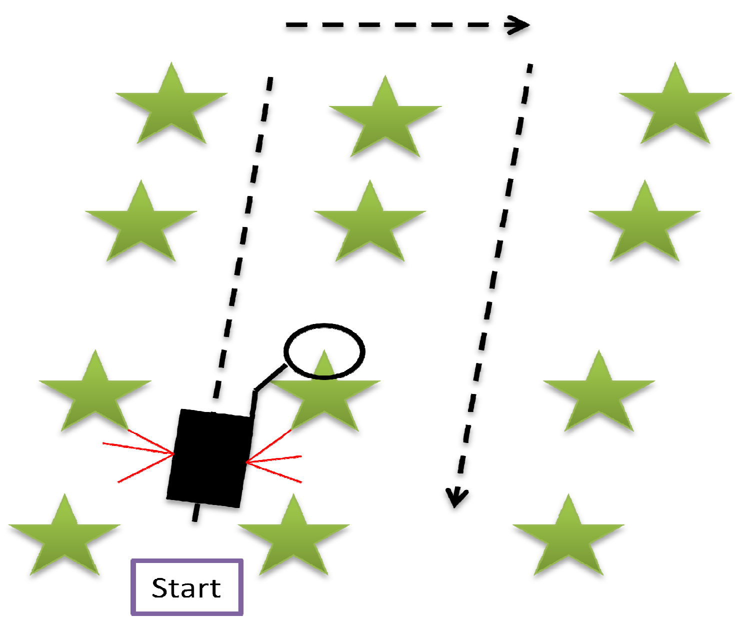

Figure 30 Follow Row (Gautam, 2014)

As shown in figure 30 camera was placed just above the crops field so that robot can follow crops row to reach the goal. Sonar sensor attached on the side was used to keep robot equidistance from the rows and the heading angle was obtained from compass attached to it. This module was used in all the task of FRE with other modules. Wheel encoder signal was used to store the total distance travelled before the change of controller.

5.2 Change Direction

In this module, turning mode was defined. This mode was used to take clock or counter clockwise turn as soon as the robot reaches end of row in conjunction with distance value from wheel encoder. This mode was used in all tasks when the maize plant was not detected within the field of view of camera. Data from magnetic compass was used to align the orientation of robot with respect to earth's magnetic north. Angular acceleration was closely monitored for smooth turning. Turning radius was calculated from the formula shown in equation (5) and described on "differential speed steering control for four wheel independent drive electric vehicle" (Wu, et al. 2013).

$$Ro = \sqrt{ICRx^2 + ICRy^2} \tag{5}$$

Where,
Ro is radius of turn
ICR is an instantaneous centre of rotation.

5.3 Avoid Obstacle

This module was designed to prevent robot from direct collision to surroundings. If any foreign body comes within the threshold of sensor effective area, then the robot will try to steer clear of it and then plans a new path to reach the goal. This module was designed especially for task 2. In this task obstacles made up of traffic cones were placed on the maize rows to block the robot path. For this module, sonar sensor placed at the front section was used.

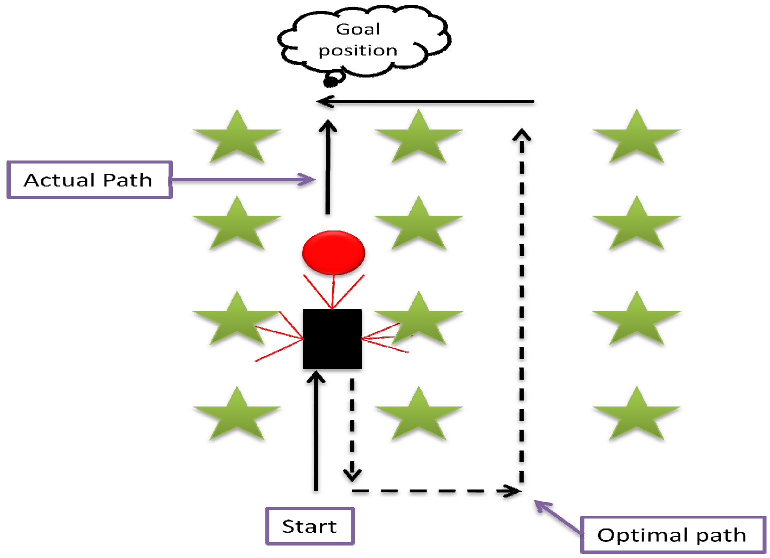

Figure 31 Avoid Obstacles (Gautam, 2014)

As shown in figure31 robot path was completely blocked by obstacles. There was only one way to steer away from it and which was achieved by reverse tracking and moving to a new row. Avoiding obstacles was also implemented on follow row control module as the robot had to navigate avoiding direct collision with maize plant while navigating through it.

5.4 Locate Goal

The main aim of this control module was to locate the absolute position of weed plants randomly placed in maize field. This was achieved by using RTK GNSS system to know the absolute position of the robot on the crops field and relative positions of weed plant were determined by processing images captured from camera.

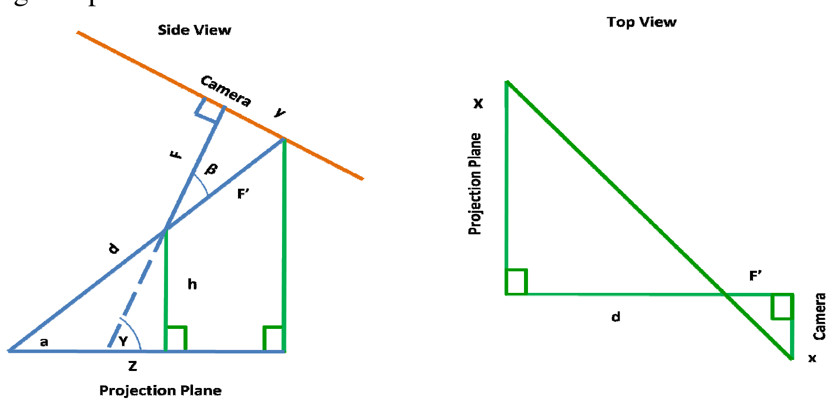

Figure 32 Resultant vector to determine weed plants from known height

Whenever a weed plants were detected within the effective field of view then its centre was calculated using NI vision tool and a buzzer was activated as a successful identification. The coordinate transformation algorithm was used in LabView. It was assumed that the height of the camera and the weed plant were known and were kept constant throughout the test. Thus it was possible to project the pixel describing the centre of mass of the object down to a plane that was parallel to the ground. It was also possible to obtain desire height by using pinhole optics as an approximation.

Figure 32 shows the resultant vector that was calculated between robot's camera lens centres to weed's centre point which was based on following equations:

$$x = \left(\frac{x_{px}}{w_{px}} - \frac{1}{2}\right) w_{mm} \quad (6)$$

$$y = \left(\frac{1}{2} - \frac{y_{px}}{h_{px}}\right) h_{mm} \quad (7)$$

$$Z = \frac{h}{\tan\alpha} \quad (8)$$

$$\beta = -\tan^{-1}\frac{y}{F} \quad (9)$$

$$d = \frac{h}{\sin\alpha} \quad (10)$$

$$F' = \sqrt{y^2 + F^2} \quad (11)$$

$$X = \frac{xd}{F\prime} \quad (12)$$

Where Wwmm and hmm are the dimensions of the camera sensors,
Wpx and hpx are the dimensions of the image pixel,
γ is the tilt angle of the camera
'h' is the difference in height between the weed plant and camera
And F is the focus length. (Hafren, J., Alaiso, S., Karppanen, E., Kostiainen, J., Rannisto, J., Sosa, R., Valli, A. And Virta, A. 2012, 35-37.)

6 VISION BASED PLANNING AND NAVIGATION

This section is aim to explain about vision based servoing. The term means that the control of robot is based on the data acquired from camera. Sensors data discuss so far was easy to process but provided very less amount of data. It was difficult to estimate the region or the environment being sensed on. Limited information about environment results in poor navigation through obstacles. Therefore, a sensor which can provide large amount of data about the sensed environment was necessary. Complementary metal oxides semiconductor (later CMOS) and charged coupled device (later CCD) technology based vision sensors were so far best at sensing the environment. For this project, the author had used Logitech HD webcam C615 was a CCD based fluid crystal camera (logitech,2014). Pair of vision sensors was used to acquire image from crops row. Figure 33 shows the acquired images and images after processing when using single camera at the centre of the chassis.

Figure 33 Row Detection (Gautam, 2014)

For effective navigation robot must be able to extract meaningful information from environment at any situation, it must be able to keep track of its position relative to world coordinate, it must be able to determine optimal path to reach the goal and finally it must have control over its actuators. To accelerate navigation and minimize errors vision sensor was placed in such a way that the field of view was limited to one row for one sensor. The data acquired from this sensor was used for path planning and navigating robot within crops field to reach the set point.

6.1 Reactive Planning and Navigation

This section deals with robot's optimal path planning and collision free navigation to the goal. Robot develops the map of surrounding autonomously from the information gathered through sensors. This map is used for effective planning of path to reach the goal. Different methods are used for path planning and navigation in robotics. Such as Road map, Cell decomposition and potential field (Corke 2011, 89-91). Among which road map baseds, map building was used in the project.
Road map was used because it was simple and easy for computing. Robot had a freedom to move on free space which leads to the shortest displace-

ment to the goal. Sonar sensors on left hand sides and right hand sides of robot provide the distance information to the row follow controller. These information were used to keep the robot always in middle of crops rows. Any deviation on robot position was corrected with its reference. In addition to this, a camera was used to assist the navigation. Position of the camera was just above the maize row (as shown in figure 34). This position was selected because the crops rows were curved in nature. Change in the orientation of robot was synchronised with instantaneous change in crops row. A closed loop PI controller was used to keep track of change and to produce a control output to meet the changes.

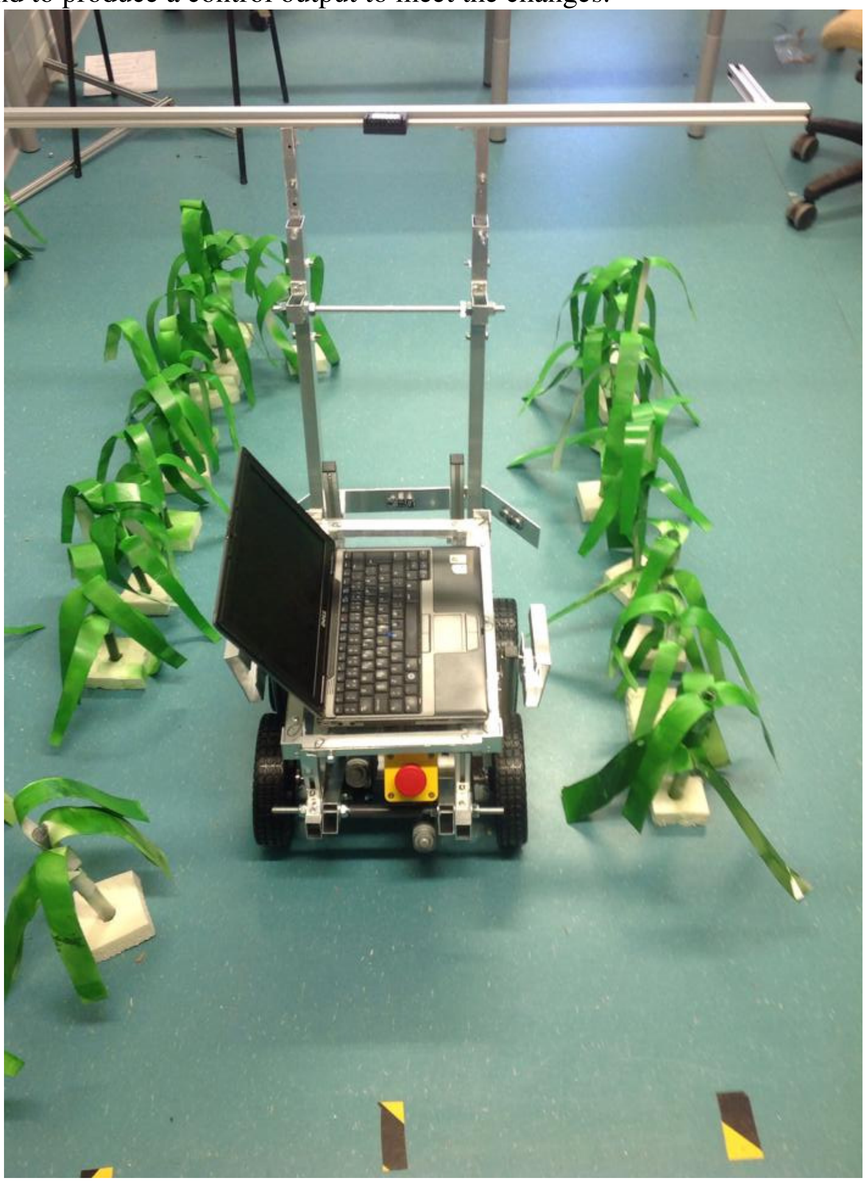

Figure 34 Navigation based on crops row (Gautam, 2014)

Reactive planning was used in task 1 and task 2 in FRE 2014. In task 1 input from camera was only used for navigation because in this task all rows had equally distributed maize plants and there was no missing plant. However, in case of task 3: several maize plants were missing in maize row and the maximum gap between two plant can be up to one meter in either of the side. Hence sonar sensor reading was also used to determine the presence of maize plant in opposite row. Program block of basic navigation is attached in appendix 5.

6.2 Map base Planning and Navigation

Map based planning and navigation is the best way to reach from point A to point B in any environment (Corke 2011, 91-105). However a predefined map cannot provide every bit of information about the dynamic environment. To overcome this issue artificial intelligence was developed. Whenever a predefine map and a real environment contradict than in this situation robot was able to make an appropriate decision to overcome reactive navigation problem.
This module was especially designed for task 2. In this task, pre define code of turns was given to each team. For example: Start-3Left-0-2Left-2Right- 1Right-5Left-Finish (FRE, 2014). Robot had to navigate through maize row following that pattern. Traffic cones were placed as obstacles in the middle of the robot path. Presences of such obstacles were not defined on the map. Hence, the robot can encounter to such obstacles at any point within the field. To overcome this challenge, following approach was carried out.

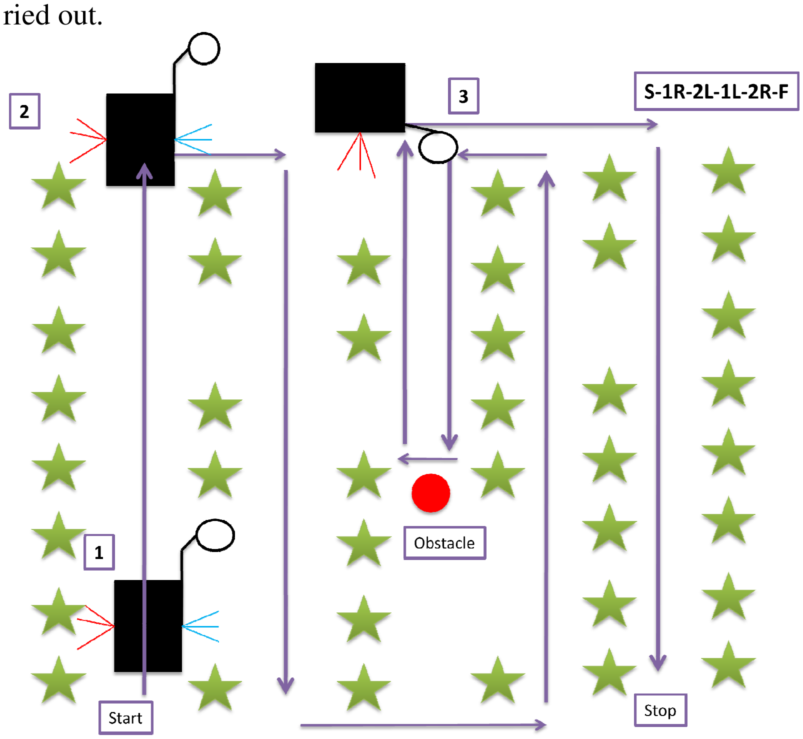

Figure 35 Map based navigation for task 2 (Gautam, 2014)

A code of turn (map) was designed and stored in robot's memory. It consists of a start position; row length value, clock wise and counter clockwise turn after 'x' number of rows (where x represent natural number). Robot was designed to navigate using data from camera. But the maize plant was missing in some part of the row because of that sonar sensor reading and a distance measurement from wheel encoder were used for

navigation in task 2. If maize plant was not detected within effective field of view of camera (as shown in state 1 in figure 35) then data from opposite sensor was checked. If the data from the opposite sonar senor was true then follow row control module was continued otherwise “Change Direction” control module was enabled. Before turning robot was programmed to move 30 cm forward and reverse turn 30 cm if maize was not detected on that move. This action was carried out to detect the end of row. For better approximation wheel encoder value was checked before switching to change direction mode. Each row was counted using inner sonar sensor and if the row was not detected within 0.75m then one row was counted after every 0.75m of distance value from wheel encoder.
Finally, map was updated if any obstacle was detected within crops field. New path was determined after reverse driving until the wheel encoder value reaches back to zero or until the robot reaches to the end of the row. Updated path was followed to navigate through maize plants and to reach the goal.

7 CONCLUSION

The author has closely observed traditional method of agriculture in his home town. And the closeness towards traditional method of farming has dragged his interest for improving it. Thus, working for FRE 2014 provided a great opportunity to design and control an autonomous robot. Different research paper on implementation of autonomous robot for precision farming was examined to improve the stability, maneuverability and robustness of robot.

Test results obtained from wheel encoders, sonar sensors, IMU, magnetic compass were carefully studied. Changes were made based on these data. Initially, the author had implemented IR based distance measurement, but the test results were found to be highly affected by sunlight. Thus, sonar sensors based distance measurement was used. However, the information acquired from sonar sensors was not enough to perform the entire task. Because, the amplitude of reflected echo from maize plant was not strong enough if the plant had small steam and few leaves. So, to collect sufficient data from the dynamic environment, a camera was used. Camera was chosen as a best option because; the programming task could be simplified to one colour extraction. As the green coloured maize plants row could be easily identified from brown coloured soil by using colour separation technique. The robot was programmed to follow the green colour row for safe navigation. The performance of the robot after using camera was found to be very good.

Digital image obtained from camera was used for navigation. It consists of large amount of data. Microcontroller available in market was not capable of computing such a large amount of data to produce desired output. Hence, laptop was used for image processing. And Arduino Mega was used as the interface board to connect sensors and actuators. Serial communication was established between laptop and microcontroller. Use of laptop had added flexibility to connect and control this project remotely. Beside the weight of laptop, the combination of it and microcontroller was found to be perfect.

Before implementing any module, it was well studied and tested in the controlled environment. A test field was constructed to mimic a real maize field. Maize plant was erected with a plastic tube as a steam and strip of green paper as a leaves. Different control modules designed for different tasks were tested in it. After a series to test it was found that none of the navigation algorithms was effective enough to complete all the levels of FRE 2014. Because of which, those navigation algorithms were switched based on the scenario to achieve effective navigation. This method had helped considerably to reduce the number of errors. As a result, chassis of the robot was able to absorb vibration created by uneven terrain; oscillation of the robot was negligible, it was able to make clock wise as well as counter clock wise turn to enter a new row in a single move, it was able to avoid obstacles, and finally; it was able to catch the set points with a very small delay to navigate through crops row.

This project was only tested in an artificial environment. There might occur a change in the performance while testing it in outdoor environment. There is always a void between prototype model and a real system. The author had boosted his best to fill this void. Despite of satisfactory working of robot there are several possibilities to improve it. The author had faced difficulties in calibration of low resolution sensors. For example sonar sensor reading was highly affected by noise. Thus, the author suggests using high resolution sensor and to replace sonar sensor by laser range scanner. Laser range scanner has very good resolution and it is robust. Furthermore, the author suggests implementing stereo vision and simultaneous localization and mapping (later SLAM). Stereo vision and SLAM helps to build a 3D map of the environment and which can be updated real-time. This helps to develop artificial intelligence in robot.

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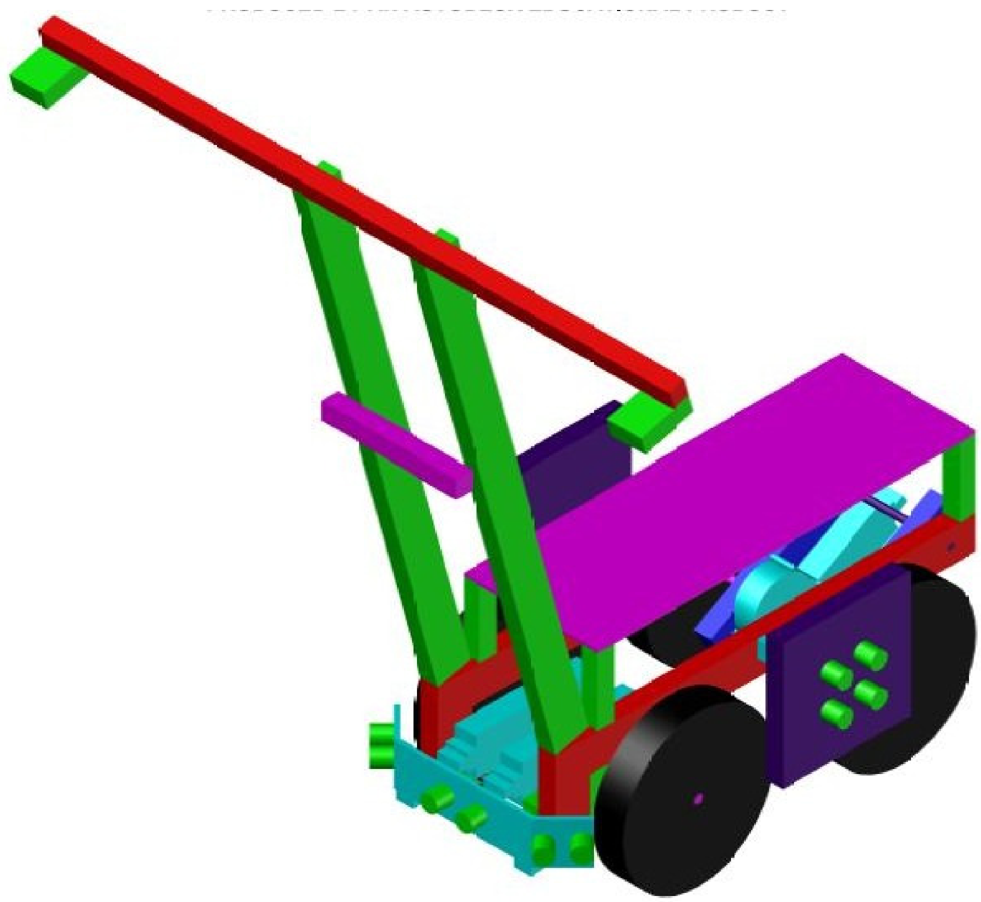
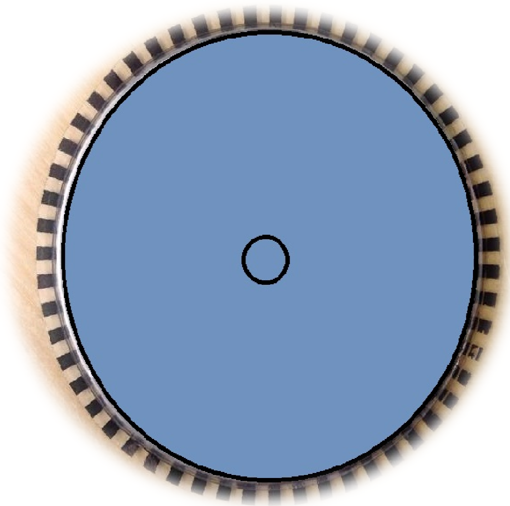
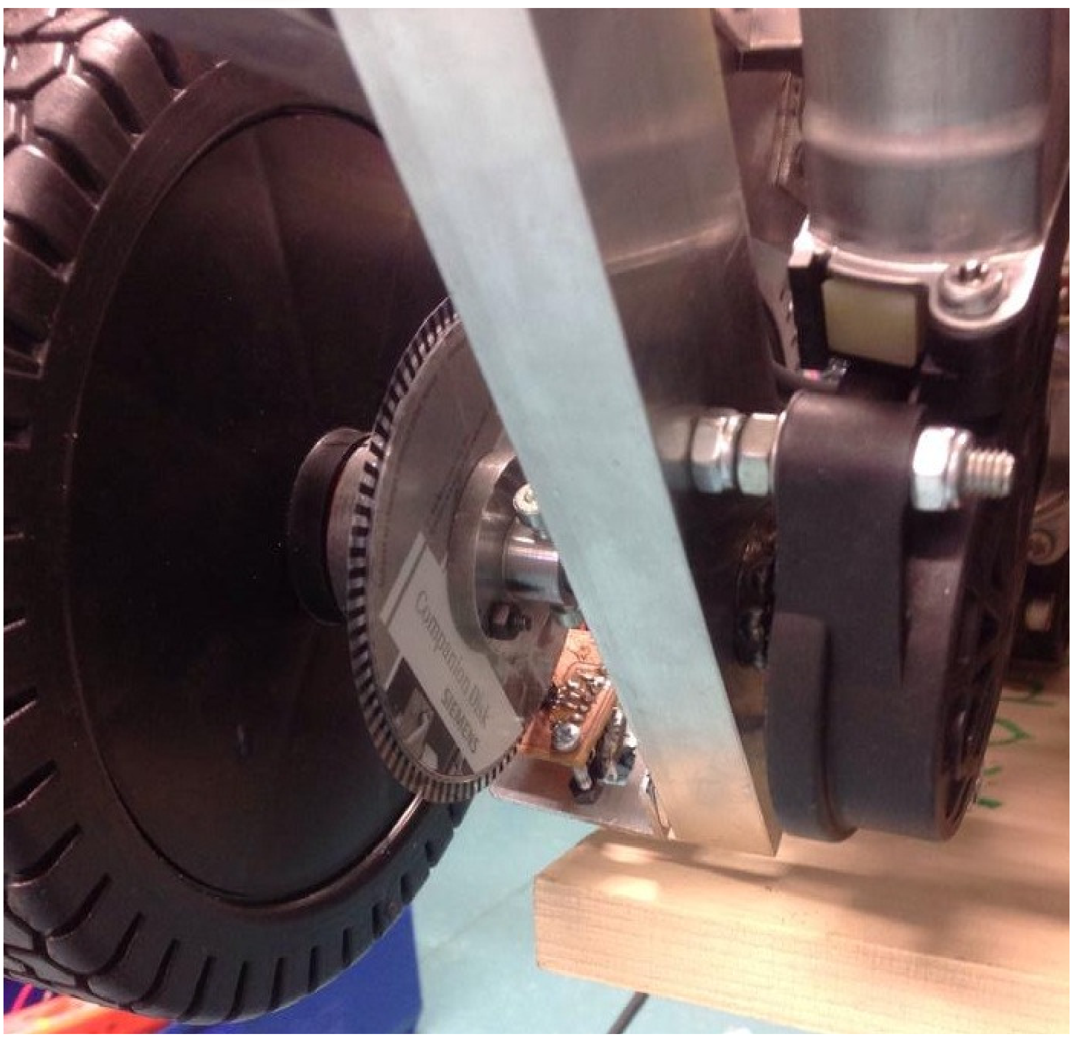
Appendix 1: Modelling of Agro-Bot



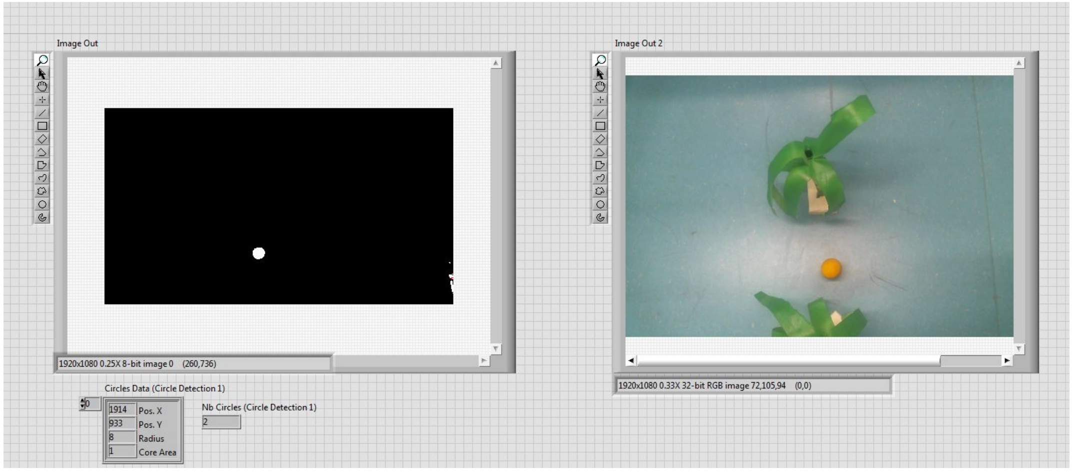
Appendix 2: Indoor Game Field

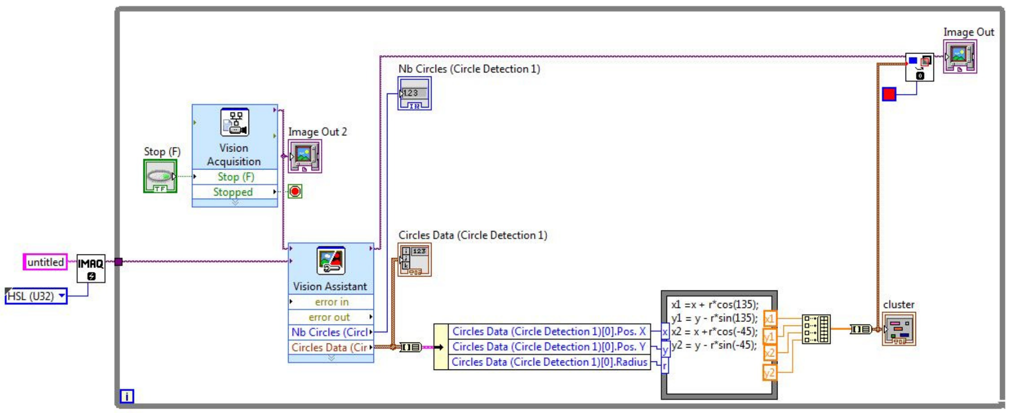
Appendix 3: Wheel Encoder

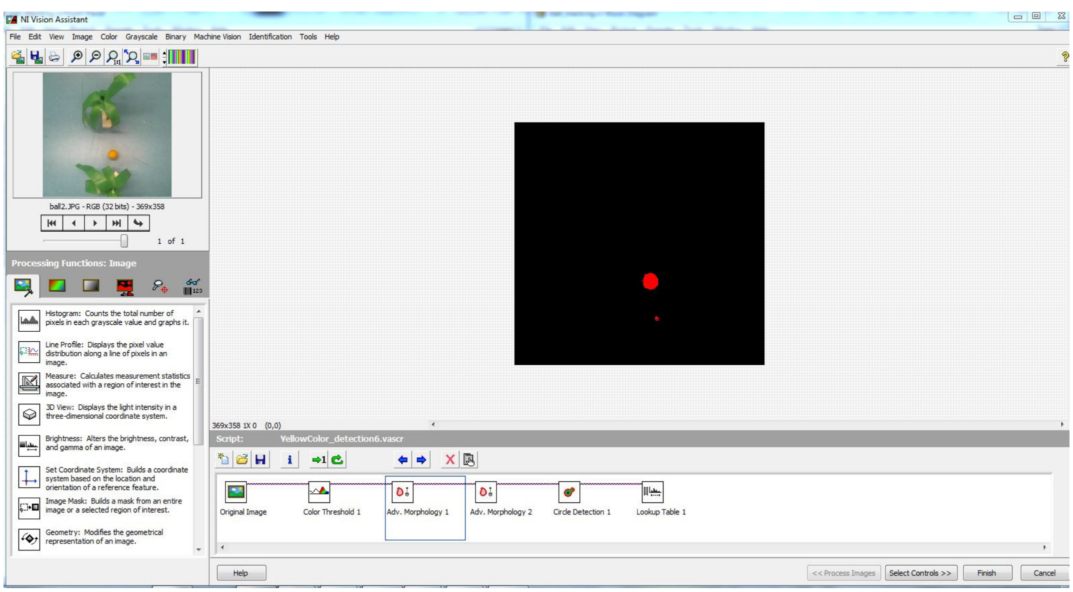




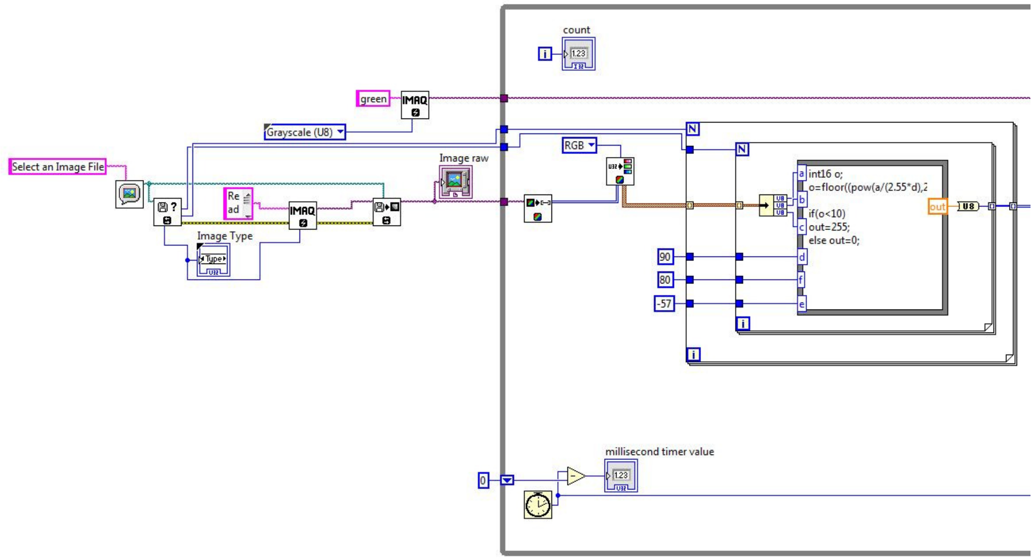
Appendix 4: Ball Detection Program

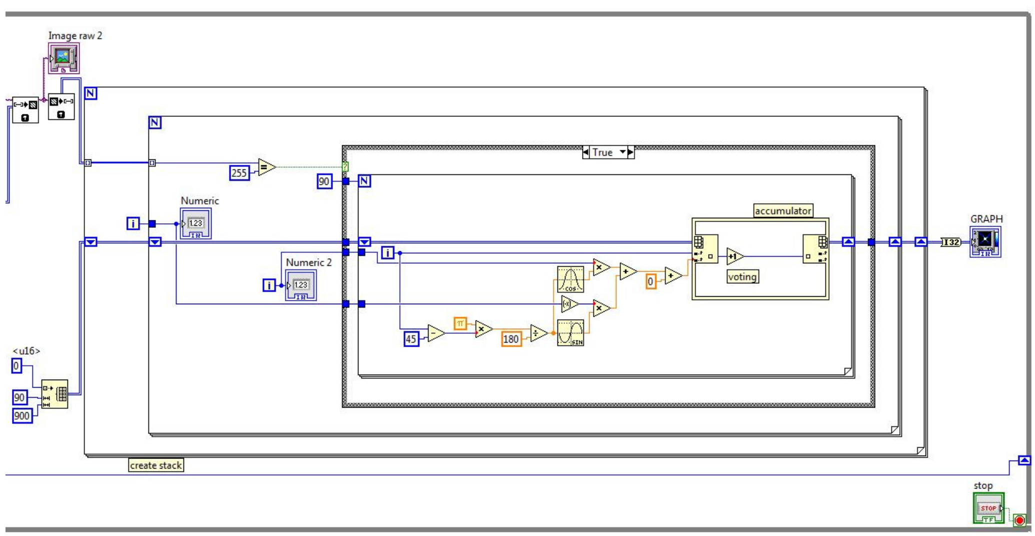


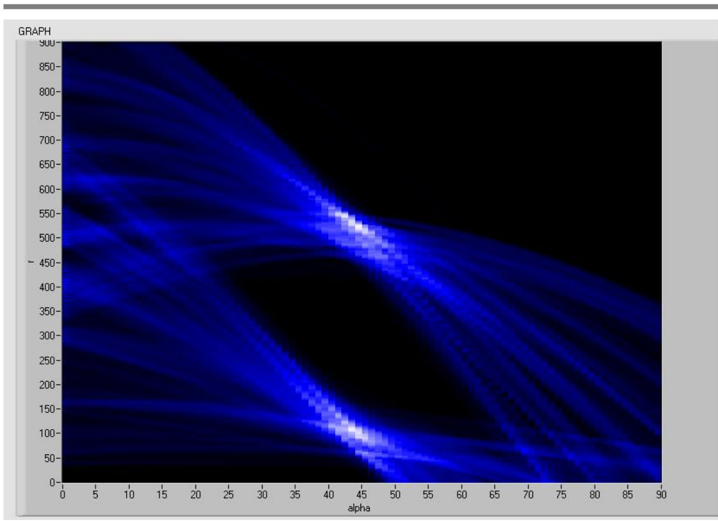




Appendix 5: Basic Navigation Program







notes:
i shifted the angle range from <-45 45> to <0 90> (ex: -35 degree ~ 10 degree)

the brightest area indicate the coordinates of the detected line in hough coordinate. (r is line distance from the upper left corner of the raw image, alpha is the angle the line makes with the vertical central line of the image (alpha>0 if the line tilts to left and vice versa..)

in the picture, the detected lines lies at 45 degree(actually 0 degree) and at two positions: one at 100 pixels from the upper left corner and the other at 525 pixels from the upper left corner.