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Electronic Demarcation Technique for Robotic Precision Planter

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Abstract: Precision agriculture has revolutionised the way we used to think about agriculture. Robotics and analytics are two crucial technologies, changing the way we think about agriculture by providing precise treatment as required in different environments. The aim of this study is develop an electronic demarcation technique for robotic precision planter. The objective is to develop an robotic precision planter which can plant seeds in rectangular strips of fixed dimensions. We propose a Vision Aided Inertial Navigation System in this study which relies on artificial landmarks for guiding the planter and helping to demarcate the area. Once the area has been mapped by planter, it initiates the seeding procedure.

Key words: Precision agriculture, robotic precision planter, vision aided inertial navigation system, autonomous navigation, crucial technologies

INTRODUCTION

Agriculture is one of the most important sectors in developing countries. Most of the farming is done using conventional methods which results in poor productivity and economic crisis for farmers. The solution to this problem is precision agriculture which helps in increasing the productivity of farming by providing specific solutions to problems based on varieties of factors. Precision agriculture not only deals with optimising our inputs but also preserving natural resources to promote environmental sustainability. Different navigation and positioning systems used by robotic platforms are mentioned by Bechar and Vigneault (2016).

Most of the autonomous systems used Real Time Kinematic Global Positioning System (RTK-GPS), Differential Global Positioning System (DGPS) or Geographic Information System (GIS) for navigation. A base station monitors the signals coming from the GPS Satellites and sends out the correction data to one or more rovers. DGPS covers a large geographic region whereas RTK corrections are more localised. DGPS's best implementations offer an accuracy of 10 cm whereas typical RTK systems offer 1 cm ±2 ppm. RTK has two basic differences compared to DGPS that is it's evaluation for timing correction and error correction is streamed immediately.

However, such systems still remain costly enough to be used in more low cost precision farming solutions. Also as a matter of fact, RTK-GPS systems usually require cellular connection with high speed internet which is not present in most of the rural areas. LIDAR stands for Light Detection and Ranging. The basic working principle of LIDAR is that it constructs feature map of the environment from its measurement. The feature map generated is used for 3D reconstruction of the environment and can be used for navigation. LIDAR is used in conjunction with Simultaneous Localisation and Mapping Algorithm (SLAM) which is being used in most of the autonomous robots. Although, this approach is most appropriate solution for autonomous navigation but requires expensive LIDAR technology and intensive processing due to the large amount of data being generated from the LIDAR sensor.

Active and Passive Beacon based systems work on the principle of Triangulation which works with angles or Trilateration which works with distances. These systems mostly use Time of Flight (TOF) or Difference of Time of Arrival (DTOA) for distance calculation. It has been used with most of the technologies like Ultrasonic, Infrared, Radio-Frequency Identification (RFID), Ultra Wide Band (UWB) and Zigbee. There are many famous systems such as MIT's cricket system. Such systems require sophisticated circuitry and complicated processing to offer a higher level of accuracy which may result in high maintenance costs. Dead reckoning systems rely on Odometry and Inertial Navigation System (INS). Odometry is measuring the distance covered by the rover using the humber of wheel rotations.

The problem with odometry is that there maybe wheel slip on terrain which results in error. This error in odometry accumulates over time. Inertial navigation system use Inertial Measurement Unit (IMU) which consists of accelerometer, gyroscope and magnetometer. Except high quality Industrial grade IMU units, nearly all of the IMU unit suffers from drift error which means even when the system is in rest there is some form of acceleration. In order to reduce the errors in dead reckoning systems, it is used with some combination of Kalman filter or particle filter.

Table 1: Table of technology used in different robotice planters and platforms

Name	Type	Years	Authors	Technology
Thorvald	Proceedings	2015	Lars Grimstad, Huynh T. Phan, Cong D. Pham, PI J	RTK-GPS
Ladybird	Articles	2014	Underwood, James P and Calleija, Mark and Taylor, Zachary and Hung, Calvin and Nieto, Juan and Fitch, Robert and Sukkarieh, Salah	RTK-GPS, INS and Lidar
Csar	In proceedings	2014	Linz, A and Ruckelshausen, A and Wunder, E and Hertzberg, J	Lidar and GPS
Robotti	In proceedings	2014	Green, Ole and Schmidt, Thomas and Pietrzkowski, Radoslaw Piotr and Jensen, Kjeld and Larsen, Morten and Jrgensen, Rasmus Nyholm	Camera and RTK-GPS
Modified design of a planter for a rbotic assistent farmer	Thesis	2014	Aminzadeh, Reza	Grizzly consisting of DGPS, IMU and laser unit
Armadillo	In proceeding	2012	Nielsen, SH and Jensen, K and Bgild Anders and Jrgensen, Ole, Juul and Jacobsen, NJ and Jger-Hansen, Claes Lund and Jrgensen, Rasmus Nyholm	GPS
BoniRob	Article	2009	Ruckelshausen, A and Biber, P and Dorna, M and Gremmes, H and Klose, R and Linz, A and Rahe, F and Resch, R and Thiel, M and Trautz, D and others	INS, Lidar and RTK-GPS
Hortibot	Article	2007	RN Jorgensen, RN and Sorensen, CG and Maagaard, J and Havn, Ib and Jensen, Kjeld and Sogaard, HT and Sorensen, LB	Camera and RTK-GPS
Autonomous research platform	Article	2004	Bak, Thomas and Jakobsen, Hans	RTK-GPS

Motivation: Our aim was to develop an electronic demarcation system for the autonomous precision planter which could plant seeds row-wise in rectangular strips of field when placed in any unmapped area at any location. The system was designed keeping the Indian Agricultural Scenario in mind which put a lot of design constraints on our system. We needed to design a robust GPS-Denied Navigation System which was low maintenance and could be made available commercially at low cost. The system needed to be simple and easy to use such that it didn't require any fine tuning of parameters or calibration by farmers.

Contribution: This study presents a simple vision aided inertial navigation system in which we use artificial landmarks to demarcate the vertices of the field. The proposed models is divided into two phases. The first phase consists of mapping the field using the help of the artificial landmarks, i.e., beacons to guide the rover in the field. The second phase which is the seeding phase consists of transforming the mapped area into rectangular strips and plan the trajectory of the system.

Literature review: A great deal of effort has gone into the development of Autonomous Agricultural Robots for different precision agriculture purposes like seeding, weeding, etc. The research of Madsen and Jakobsen (2004), among others have served as a base for many researchers in developing agricultural platforms. The Autonomous research Platform (API) focuses predominantly on weeding. By combining the reliability of encoders, magnetometers and gyroscope along with GPS is used for the robust navigation system. Jorgensen *et al.* (2007) a semi autonomous robot is an honourable mention. It uses a stereo vision system and GPS.

Ruckelshausen *et al.* (2009), a multifunctional agricultural robot, uses 3D MEMS Lidar, IMU and optionally a RTK-GPS. The main advantage of using the lidar sensor is 24/7 operation. Hans W. Griepentrog presented a robotic tool carrier called as Armadillo which could be deployed for various precision agriculture task. It uses RTK-GNSS, encoders for odometry and a Kalman filter for the fusion. Researchers at Norwegian University of Life Science (NMBU), Grimstad *et al.* (2015) developed Thorvald platform which is a lightweight autonomous robot with interchangeable tools. Thorvald can perform precision seeding, monitoring and weeding. Thorvald's frame is equipped with all necessary sensors for navigation and communication with the base system for RTK GPS. Underwood *et al.* (2015) developed by Professor Sukkarieh at Sydney University is a solar powered autonomous robot which is capable of monitoring different variety of crops. Forward and rear facing lidar and a spherical camera helps in obstacle avoidance and crop row detection. RTK GPS/INS allows for map-based navigation.

A modified precision farming robot was developed by Aminzadeh (2014). The equipment installed for navigation are DGPS, IMU and a tiliting laser scanner unit which detects any obstacles. Bawden *et al.* (2014) from Queensland University of Technology developed small robotic farm vehicle which allows a wide range on operations such as planting, seeding, harvesting and weeding with the help of interchangeable units. Linz *et al.* (2014), the fruit robot is an autonomous machine system for pest management, soil management, fertilisation, harvesting and transport. It can be controlled remotely or can travel using stored routes. 3D time of Flight Camera and 3D Lidar support in navigation and obstacle detection along with IMU and GPS. Vibro Crop Robotti (Green *et al.*, 2014) from Kongskilde is an autonomous agricultural platform which can be used for both precision seeding and mechanical weed control.

Haibo *et al.* (2015) designed a wheat precision seeding robot with detailed overview on the mechanics of the system. Table 1 compares the technology used in different robotic planters and platforms.

MATERIALS AND METHODS

System architecture: Logically the planter is divided into three subsystems which are navigation system, image processing system and trajectory system, respectively. The navigation system is responsible for the motion control of the planter. It controls the movements, i.e., direction and speed and is also responsible for providing data collected from sensors. Image processing system is responsible for searching the artificial landmarks, identifying them and sending the right feedback to the trajectory system. The trajectory system is the most important part involved in decision making and serves as a link between image processing system and navigation system. It calculates it's position and state of the system by processing the values from sensors and feedback provided by image processing system and takes the next appropriate action. Figure 1 shows the logical overview of the system and Fig. 2 and 3 show side view and top view, respectively. The Navigation System was controlled by Arduino Mega micro controller. The prototype used an 9-axis DOF IMU (Inertial Measurement Unit) and rotary encoders to count the number of rotations made by the wheel. 4 Stepper Motors were controlled by Arduino and the sensor data was sent to Raspberry Pi3 using Serial Communication. Raspberry Pi3 was installed with Ubuntu Mate and OpenCV for Image Processing. Raspberry PI Camera was mounted on a 2-axis stand which could be rotated horizontally and vertically. Motor board, battery, power bank and DC-DC converters were also used in the Prototype. The prototype was 4 wheel differential drive with skid steering. However, we would like to propose to use a 4 wheel differential drive with castor wheels.

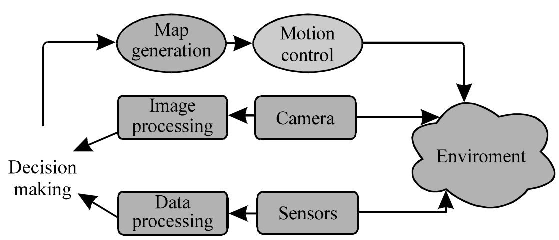

Fig. 1: Top level view of the system

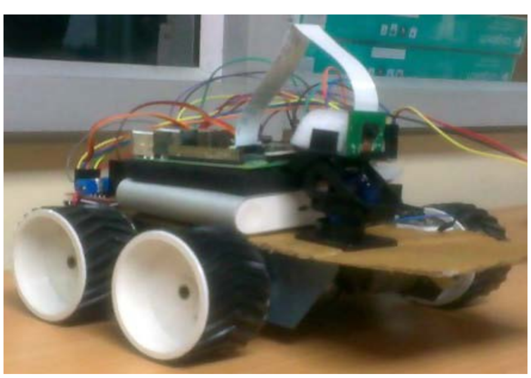

Fig. 2: Side view of the prototype

Motion model: In order to accurately determine the position of the planter we used odometry along with Inertial Navigation System. The number of rotations made by wheel using rotary decoder, acceleration values and gyroscope values from the Micro Electro Mechanical Systems (MEMS) IMU unit. However, the values from IMU units contains error due to random noise and drift. In Drift, the robot shows positive acceleration even in stationary position. This results in error in accelerometer values. In gyroscopes, the gravitational force causes errors. Hence, the value from IMU unit are corrected using Complimentary filter and then fed back into the system. Magnetometer data can however be fused with gyroscope data to improve the accuracy of the calculated orientation. The estimates of position obtained from number of rotation and velocity from acceleration are taken as the states for Kalman (1960).

Kalman filter is an optimal recursive data processing algorithm. It starts by taking an initial estimate and as the iterative process starts it narrows down quickly to actual position. The initial position X_0 and initial velocity P_0 are taken as 0 in our case form the initial state. The process error and process covariance matrix need to be predetermined. The readings were sampled at 500 msec. The new predicted states are predicted by the following equations given as:

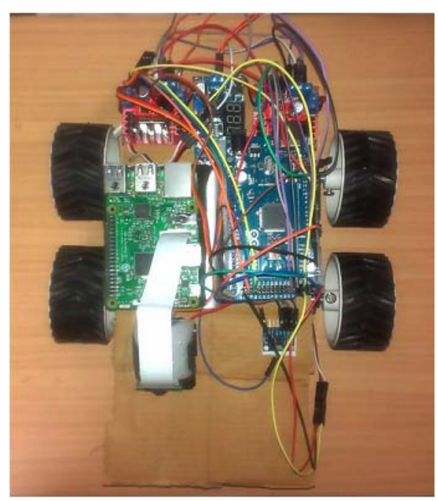

Fig. 3: Top view of the prototype

$$X_k = AX_{k-1} + B\mu_k + W_k$$

$$P_k = AP_{k-1}A^T + Q_k$$

Where:

P_k = The process covariance matrix

W_k and Q_k = The respective error in calculating the position and velocity

H matrices are transformation matrices which is used for conversion into Kalman filter gain. R the error and accounts for uncertainties in observation. Y_k is the observation matrix. In order to calculate the new predicted state by the help of Kalman gain K taking into account the weight to be provided to initial position and to the observation:

$$K = \frac{P_{kp}H^T}{HP_{kp}H^T + R}$$

$$Y_k = CY_{km} + Z_m$$

$$X_k = X_{kp} + K[Y - HX_k]$$

We update the process covariance matrix P_k to be ready for next iteration and the X_k is fed back so that the most current state become the previous state for the next step of Kalman filter:

$$P_k = (1\text{-}KH)P_{kp}$$

The process is continued from initial position till we reach our final position.

Vision aided inertial navigation system: To implement this system, the artificial landmarks which are beacons with signs are planted on the vertices of the field and the planter is left in the field. The camera on the planter scans 180° for any sign of beacon. If it identifies the beacon, it moves in that direction by estimating the distance using the tilt angle and the dimension of sign on beacon. In case the planter fails to find the artificial landmark, it is directed to move towards a patch of same colour as that of the sign. The planter's initial position is where the home sign beacon is placed. The planter moves along the boundary keeping a note of it's position and mapping the whole field. It stops when it encounter's the home sign again.

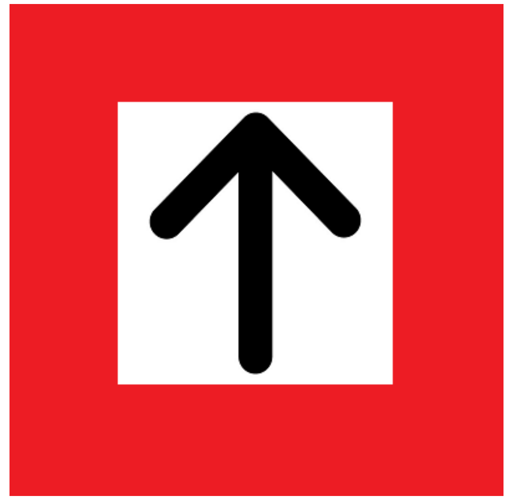

Fig. 4: Forward sign

Identifying the beacon: In order to identify the beacons from the whole scene we first apply HSV filter to identify our sign uniquely. The process of calibrating the HSV filter has to be done manually. On applying the HSV filter we are able to isolate the rectangular sign from the whole scene. After this the contours for the sign is calculated which helps us identify whether it is a sign or some noise. The contours of image is then applied with perspective transformed using OpenCV functions. The SURF Algorithm (Bay *et al.*, 2006) is used to calculate the key points and descriptors of this image. After which the image is matched to find which symbol it is and accordingly the action is taken. Figure 4 shows the forward sign used for image recognition.

Finding approximate distance: The approximate distance of the sign from the planter is calculated using the following equation:

$$d = (f \times b)/s$$

Where:

d = Distance

f = Focal length

b = Actual border width

s = Size of the border in pixels

In the original trials, the sign was printed out and put on the top of PVC pipes to create beacons. The size of the border in pixels can be calculated using contours obtained from image. Also, to steer the robot in right direction, we find the difference between left edge and right edge of image.

Mapping the area: In the proposed system, the artificial landmarks, i.e., beacons are planted on the vertices of the field. There can be two cases in which the field is a regular polygon or in which the field is an irregular polygon. The plantation of seeds is done in the form of rectangular strips, so any shape is transformed into a rectangular strip by finding the minimum rectangle enclosing that area using Open CV. Then, the rectangle is divided into strips of fixed dimensions and only the complete rectangular strips are planted with seeds.

RESULTS AND DISCUSSION

To test the performance, our System we used UMBmark (Borenstein and Feng, 1995) which is a benchmark test for odometry errors in mobile robots. In UMBmark, the mobile robot is programmed to follow a pre-programmed square path of 4-4 m side-length and four on the spot 90° turns. This run is performed 5 times in clockwise direction and 5 times in counterclockwise direction. The systematic errors are calculated by the following equation:

$$r_{c.g.,cw} = \sqrt{x^2_{c.g.,cw} + y^2_{c.g.,cw}}$$

$$r_{c.g.,ccw} = \sqrt{x^2_{c.g.,ccw} + y^2_{c.g.,ccw}}$$

$$E_{max,sys} = \max(r_{c.g.,cw}, r_{c.g.,ccw})$$

On calculation, the prototype without calibration averaged at 395 mm which is consistent with values obtained by Borenstein and Feng (1995). For non-systematic errors, extended UMBmark has been proposed which we didn't run on our prototype. However, due to technical issues, reducing the error after calibration was difficult considering the chassis or prototype which operated using skid-steering and due to the huge number of trial runs. Table 2 shows the results of UMB mark.

Table 2: Results of UMBmark on prototype

	Clockwise		Counter clockwise	
Trials (run)	X	Y	X	Y
1	5	25	11	37
2	11	9	19	43
3	12	12	14	39
4	23	16	12	41
5	26	20	9	27

CONCLUSION

Hence, we proposed a simple yet robust electronic demarcation system for a robotic precision planter. Although, the prototype is slow but it makes up for by working throughout the day. Precision farming is based on the concept of Swarm robotics and such type of technology needs to be incorporated in our system which may add further improvements to the accuracy and efficiency of the planter. Our model is still in prototyping phase and seeding tools are still in development phase. Several improvements to the chassis needs to be made.

Also, the system needs to programmed to work at night with the help of IR camera and radiant landmarks. Our system is very economical compared to all the other systems described in the table. We do not offer the same kind of accuracy as other systems but still our system is better than conventional farming techniques and allow farmers more productive time than before. It is well suited for developing countries where there is no cellular network and can be deployed with array of tools to perform different tasks.

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