TESTING THE SYSTEMS OF THE AUTONOMOUS AGRICULTURAL ROBOT

Jasiński M. PhD[1], Mączak J. PhD, DSc[1], Szulim P. PhD[1], Radkowski S. Prof[1], Rokicki K. M.Sc [1],
Szczepaniak J. Prof[2], Rogacki R. MSc[2], Wojciechowski J. PhD[2]
Institute of Vehicles – Warsaw University of Technology, Poland [1]
Industrial Institute of Agricultural Engineering in Poznań, Poland [2]
jachuu@simr.pw.edu.pl

Abstract: *The aim of the paper was to test of the concept of the navigation system for the autonomous robot for sowing and wide row planting. Autonomous work of the robot in the field of traction and agronomic processes is implemented based on data from many sensors (cameras, position sensors, distance sensors, and others). The robot is intended for ecologic cultivation requiring mechanical removal of weeds or in crops with application of selective liquid agrochemicals limited to the minimum. The use of a vision system, based on the map coordinates of the position of the sown seeds, allows for their care on an early stage of plant development. Main sensor system is based on a specialized GPS receiver and inertial navigation providing position information with an accuracy of around 10 mm. To determine the angular acceleration the IMU (Inertial Measurement Unit) is used. Additionally, information from the acceleration sensors and wheel encoders is used for navigation purposes. This system is used to: control the speed of the robot, keep the robot on the designated path, and detect the precise position of the seeds. The exact information of the seeds position is used to build maps of seeds, which will be used as supporting information for precision weeding, and to control the position of and operation of key components. The front camera view is used to increase positioning accuracy of the robot. It will allow corrections of the robot path regarding the rows of plants. The vision system is also used for detection of non-moving objects. A structure of requirements for the SQL database has been developed, which is used to store plant and weed geo-data, as well as store data about plants and weeds, based on images recorded by the vision system.*

Keywords: AGRICULTURE ROBOT, CARE OF PLANTS, AUTONOMOUS WORK, POSITION OF PLANTS DATA BASE

1. Introduction

Syndicate of Industrial Institute of Agricultural Engineering in Poznań, with the Institute of Vehicles of Warsaw University of Technology and PROMAR company from Poznań started a design of autonomous farm robot for sowing and cultivation of wide row planting (Figures 1 and 2).

The aim of the project is to develop the construction and operation procedures for the autonomous robot for sowing and wide row planting. On the current stage of the product development laboratory and exploitation tests on an experimental model are carried out. Autonomous work of the robot in the field of traction and agronomic processes is implemented based on data from different sensors (cameras, positioning sensors, distance sensors, and others). Positive test results will allow for the use of the robot in organic crops requiring mechanical removal of weeds or in crops with application of selective liquid agrochemicals limited to the minimum. The use of a vision system, supported with the map coordinates of the position of the sown seeds, allow for their care on an early stage of plant development. The applicability of the robot to onerous work in organic farming may encourage farmers to discontinue the use of herbicides in crops.

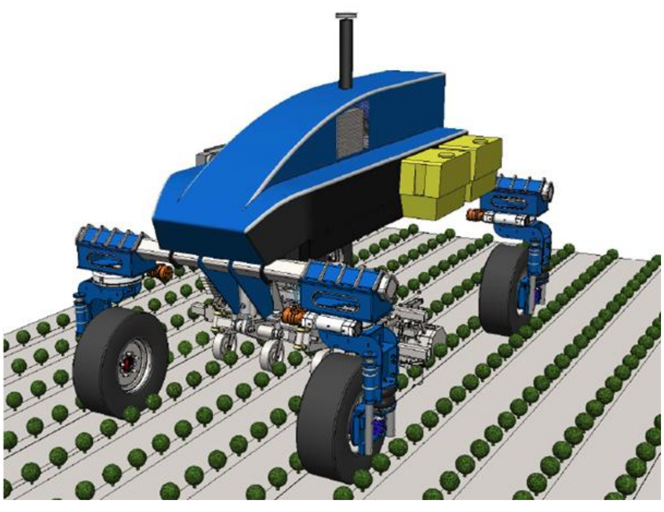

Fig. 1 *CAD Model of the robot[2]*

The autonomous farm robot is intended to work in different working conditions:

- terrain: empowered field, field roads,
- work 24 hours/day (for this special lightning system for cameras was implemented),
- work in areas with varying degrees of lighting and visibility,
- temperature: 5 to 40 ° C,
- weather: average rainfall, moderate wind, fog,
- typical obstacles in the open area.

Projected robot enables complex care of field crops including: red beet, sugar beet, sweet corn, cabbage, lettuce, forest nurseries, orchard, production of vegetables and ornamental plants. Additionally, it should enable the mechanical destruction of weeds and, if necessary, precise application of crop protection formulations and fertilizers. Robot is equipped with interchangeable tool sets: seeders and smart weeders, and spraying tools, which uses digital image analysis for their control[1, 2].

3. Concept of the navigation system

Main navigation system of the robot is based on a dedicated GPS receiver providing position information with an accuracy of around 10 mm. This system, in conjunction with the IMU (Inertial Measurement Unit) for determining the angular accelerations, is used to control the robot on the designated path and to provide precise position required during precision seeding, weeding and spraying. The exact information of the seeds position obtained during the process of sowing is used for creating maps of seeds, which is then used as a supporting information for precision weeding and spraying and control the position and operation of key components.

The front camera view is used to increase positioning accuracy of the robot. It allows corrections of the robot path regarding the rows of plants. The vision system is also used for detection of non-moving objects. Simultaneously, main vision unit is used for acquiring camera images immediately before active hoes and sprayer for detecting the exact position of growing plants. Additional information from the acceleration sensors and encoders built-in wheels is used for navigation purposes.

The navigation system enables:

- trajectory correction of the robot,
- precise work of active hoe,

- position adjustment and precise dosing of liquid fertilizer plant health products.

The exact position of the robot is obtained from the fusion of signals from precision GPS (in the test version standard GPS receiver Ublox NEO7) and integrated system of inertial and magnetic sensors VN-100[3]. VN-100 is a complete AHRS (attitude heading reference system) system integrating measurements from three axial sensors: acceleration, angular velocity and Earth magnetic field. All of the sensors have temperature compensated sensitivity and common values. Moreover, all the skewness of axes was calibrated. VN-100 device provides accurate information from all the sensors and estimates of the spatial orientation angles, DCM (direct cosine matrix) transformation matrix, and estimated values of linear accelerations and angular velocities in the absolute coordinates (NED – north/east/ down) independent from the angular orientation of the sensor. It is planned that two AHRS systems will be placed on one robot: first related to the vehicle and the second with a connection to the tools (e.g. seeder). AHRS integrated with the vehicle will provide the detailed momentary angular orientation and acceleration of the body while the second set allows better estimation of the momentary position of the tool thus allowing precise localisation of the seeds. Detailed information about their positions, stored in the internal database, will be used in further fieldwork related to the care of plants[4, 5].

***Fig. 2** Robot during sugar beet seeding work*

4. Concept of the collision avoidance system

The collision avoidance problem is divided into two different subproblems: detecting the obstacle and bypass the obstacle[6, 7].

The raw measurements from Laser scanner 2D are at first transformed into Cartesian coordinates. The obstacles are detected from the transformed measurements using clustering method. The whole clustering process is illustrated in Fig. 3. The initial positions for the clusters are gained from the set of known obstacles. The cluster initial position is added if known obstacle is in sight of the scanner.

The path tracking method is based on the Nonlinear Model Predictive Control. Vougioukas[8] has used the Nonlinear Model Predictive Control (NMPC) method to control the position of the vehicle. Moreover, the collision avoidance was included into the controller by using additional cost from distance sensor readings. The controller was able to follow a predefined path as well as avoid collisions with static obstacles. The functionality was proven with simulations.

In the NMPC, the control values are calculated, so that the given cost function is minimized. The constraints of the optimization problem are obtained from the system model and the constraints of the states and control values. There are different ways to include the object avoidance into the NMPC. One way is to add additional constraints to the state values. Another way is to add an additional cost from the obstacles or simply to modify the reference trajectory to go past the obstacle.

In this way, the modification of the cost function was chosen. The underlying path tracking cost function is not changed nor the reference trajectory, but the cost from state is modified. This is because of the calculation capacity and the possibility that the obstacles could move.

When the reference trajectory is near an obstacle, it cannot be followed without colliding to the obstacle. Therefore, it is irrelevant to keep the cost from the reference trajectory. Instead a cost that makes the vehicle drive past the obstacle should be added. The obstacle can be closer on the side of the vehicle.

The calculated distance to the edge of the avoided area is used in the cost function, when the obstacle is inside the avoided area or the obstacle is closer to the avoided area than the vehicle is to the original reference trajectory. the cost is calculated only from one obstacle. If there are multiple obstacles inside the avoided area, the one with the largest value of the distance from the obstacle to the edge of the avoided area is chosen. The same methods are also used for the cost from the trailer position.

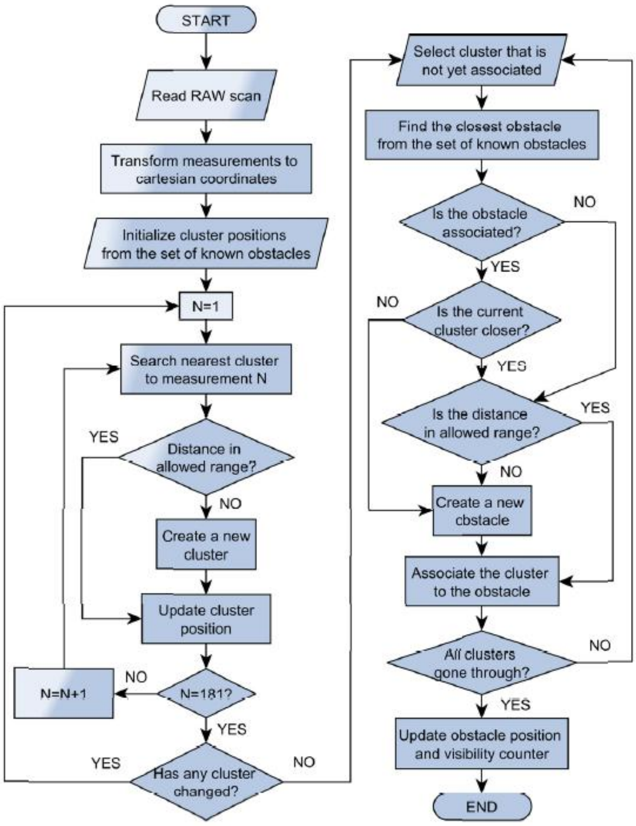

***Fig. 3** The clustering algorithm[8]*

5. Database system for storing information about the location and characteristics of crop plants and weeds

The plant and weed geo-data is stored in the specially developed SQL database. The database stores also data about plants and weeds, based on images recorded by the vision system.

The developed structure allows storing information about:

- geographical location of the plant (longitude and latitude parameters),
- date of measurement
- plant identifier in the database

The developed structure also allows storage of:

- graphic files representing photos of the analysed plants,
- plant features acquired through image processing and analysis.

During the preparation to the mission data from the SQL database are being transformed to the robot system using the JSON format[9].

6 Testing of the vision system

The position of each plant must be determined for intra-row weeding. This means that plants must be classified into two classes, i.e., sugar beet (sweet corn) or weed. The pictures were taken with a normal colour photo camera and later digitised. For analysis of the object in the image it is essential to distinguish between the object of interest, here plants, and the background, here soil. In our case this means that we use the grey level distribution on the normalized green component. A total of seven shape features were selected: (area, perimeter, compactness, elongation, solidity, form factor and convexity) (Fig. 4).

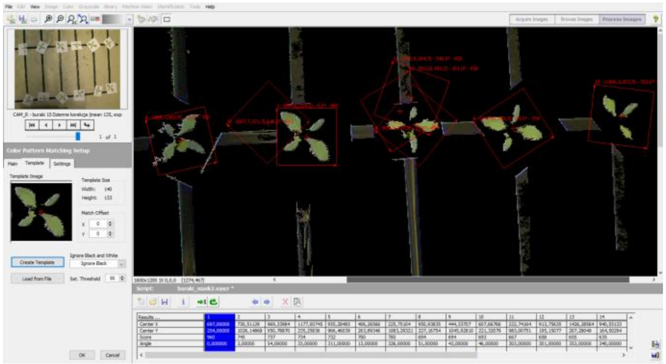

Fig. 4 *Positions of plants identification*

The first operation was to check the depth of field of the cameras mounted on the vehicle. The 8.5 mm lens provided theoretical sharpness in the range of 200 mm to infinity. During the tests, it turned out that the only reasonable choice was aperture 8.0, which reduced the depth of field. After properly calibrating the focus, using suitable markers, we managed to obtain a fairly sharp image for several plant height tests.

Another test task was to investigate the effect of lighting changes on the camera image. The tests were performed in full sun (Fig. 5) and in shadow (Fig. 6)[10]. This was the biggest problem for the vision system as this affects the quality of plant detection. This problem was solved by automatically changing the camera exposure time based on the analysis of grey level histograms.

Best results of plant detection were obtained by normalizing green component and the area. These features were used to classify sugar beets (green) and weeds (red)[11, 12] (Fig. 7).

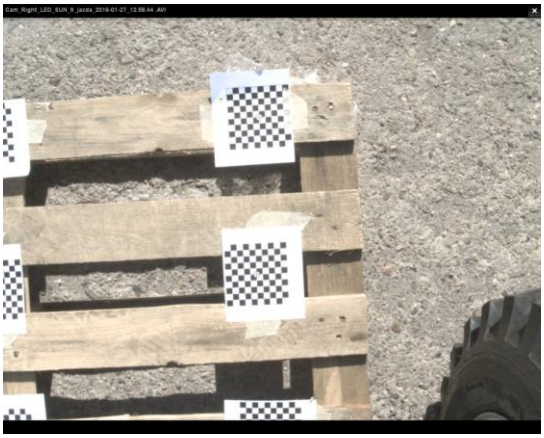

Fig. 5 *Picture from the camera - lighting: the sun*

Fig. 6 *Picture from the camera - lighting: the shadow*

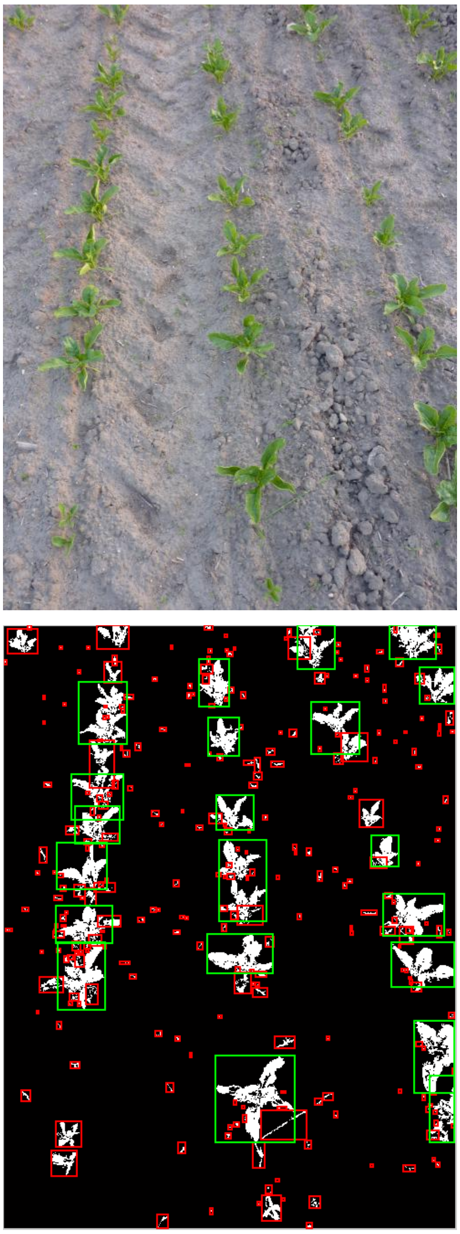

Fig. 7 *Top - colour camera picture; Down - example of sugar beets (green), and weeds (red) classifications[12]*

7. Mission tests

The control system of the robot is distributed (divided) into two controllers that communicate with each other through Ethernet network. The task of the navigation and path planning controller is to control robot Diesel engine and hydraulic systems and to drive the robot along the selected path. It also feeds the mission planning controller with the current position data necessary for the tools control.

The main tasks of the mission planning controller are: processing stage mission data sending them to the navigation controller, performing image analysis from cameras for sowing and weeding and controlling appropriate tools (eq. hoe or sprayer). Vision analysis performed on this controller is also used for obstacles avoidance.

The robot mission (e.g. sowing or weeding the whole field) is divided into the several primitive operations – stages: drive straight, drive to point, turn around, etc. Each of these operations begins in the current robot position and is described by the robot ending position (waypoint), velocity during drive and robot direction to be obtained in the end of the stage. Dividing the whole task into primitive operations significantly simplifies the algorithms of machine control as the robot control algorithm should be able to perform just a finite set of single, simple tasks. This also simplifies the process of testing the robot moving algorithms. For the task of testing the robot drive control algorithms the special robot simulator was developed allowing testing robot commands.

8. Conclusions

Field tests of the autonomous robot for sowing and wide row planting are currently under way. The tests of the navigation systems shown that the accuracy of the GPS position is as planned (~10 mm) however obtaining the proper fix and accuracy takes significant time: around 10 minutes. This also requires setting a base station in the field within the reach of the GPS radio communication.

The vision system for sugar beet/weed and sweet corn/weed classification was build and positively tested in laboratory conditions. Currently the field test on the growing plants are under way. The problem of camera's focus on the soil and the effect of the different lighting on the generated image was located and solved. Optional power of additional LED lighting and a method of sugar beets and weeds classification were also developed.

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