Evaluation of navigation system of a robot designed for greenhouse spraying

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Abstract

This research aims on the development of one efficient and feasible robotic vehicle for spraying inside a greenhouse and evaluation of its navigation system. The proposed system makes its movements by the left and right side motors, and the guidance was provided by ultrasonic sensors. A proportional control mechanism was implemented for continuous and real-time operations of the robotic unit. Such a system uses the 'range information' collected by sensors, so the unit can complete its movement between aisles. A u-shaped path with width and length of 0.98 m and 13.93 m, respectively, was selected for validation experiments. The greenhouse has a concrete floor; the unit was moved in three different speeds ($7, 14, 21 \text{ m min}^{-1}$).

In general, the feasibility of the proposed robotic unit was approved, since it moved successfully in every required path. The RMSE of robotic unit movements' accuracy was placed between 5.22 and 6.38 at different speeds.

Keywords
Ultrasonic sensor, Robotic vehicle, Spraying, Robotic system.

Research attempts to develop agricultural robots that can conduct repetitive field tasks efficiently have developed dramatically over the last decade. Growing the pace and precision of robots for farming applications are the key issues to be solved for the generalization of robotics systems, but the shortage of sufficient development funds and budgets in agriculture has decelerated this cycle compared with the industrial and military cases (Redmond et al., 2018). In the modern era where benefits and efficiency of each activity describe it, greenhouses produce better corps with higher quality. The function of a greenhouse is the measurement and control of any factor to achieve its predetermined goals (Roldan et al., 2015; Pahuja et al., 2013; Rodriguez et al., 2015; Zeng et al., 2012). There is no doubt that robots can perform tasks with a better level of accuracy and speed in comparison to human operators. Hence, encourages many people to take up agriculture as an occupation. The user friendly agriculture robot used for spraying pesticides is an association of all basic feasible technologies, to bring out a new and needed robot to assist farmers in risk involving tasks (Kazi et al., 2018). Advancement in agricultural robotic technology may also bring in some important societal and economic impacts to rural, agricultural areas. For example, a demographic change in rural populations as new farming styles creates a new industry to support robotic farming (Zhang et al., 2019). Nonetheless, an agricultural robot must also be economically feasible, implying that it must feel quickly, measure quickly, and act quickly to react to environmental variability (Redmond et al., 2018). Agricultural technology is one of those areas which faced a vast amount of research works about efficient robotic units and suggests the effective use of technology to meet the agricultural growth (Chaitanya et al., 2020). Boaz et al. (2020) developed and tested validation of SWEEPER, a robot for harvesting bell peppers in greenhouses. The SWEEPER robot...
is the first sweet pepper harvesting robot to demonstrate high performance in a commercial greenhouse. Luciano et al. (2019) proposed and validated the smart spraying mechanism (a robotic platform installed with an external navigation device) that controlled the quantities of sprayed products as regards the quantity and specific activation of the nozzles based on the scheduled spraying procedures. The device should schedule the volume of liquid to be sprayed, depending on the nature of the plant, foliage density, crop type, and forward speed of the device, in terms of the quantity and specific activation of the nozzles. Lars et al. (2018) have presented a fully working robot for greenhouse applications that is able to automatically estimate locations of rails in a map, and it can also identify rails by using its onboard sensors. The mechanical design includes a novel system for attaching tools to the platform, which greatly increase the usability of the robot. They have also showed that robots for greenhouses can be constructed using the Thorvald II modular system without making platform-specific alterations to code or the electric system. Guoqin et al. (2017) concentrated on how a four-wheel autonomous driving greenhouse spraying mobile robot turning in the greenhouse could boost turning control stability. A complex exponential-reaching sliding mode control technique is introduced by taking the sideslip angle of the mass center and the robot’s yaw speed as the control system’s state controlled variables.

Yuanjie, Fuzeng, Yu, Guanting, Jinyi and Yubin (2013) proposed a new idea which combining the visual navigation and remote monitoring to improve navigation reliability that overcame many shortcomings which exist on traditional control methods with only one system.

The idea of using a colored area for the navigation of a robotic unit was proposed by Misao (2001). Such a system used machine vision technology for automatic navigation. The colored objects were monitored by a high-quality video camera. The difference between current and targeted locations is estimated by image processing algorithms. The automatic navigation system acts according to these principles. Since the area under control can be managed by a differential GPS (DGPS), Stombaugh and Shearer (2001) used this technology in the design of a variable-speed sprayer. The feedback was collected by DGPS receiver and the movement was controlled by a solenoid control valve. The tractor proposed by Iida and Burks (2002) is equipped with ultrasonic sensors and make it possible to estimate the instantaneous distance between the vehicle and three rows of the canopy. They also proved the capabilities of the system consisted of the fuzzy PD controller and the ultrasonic sensor. In other study, analyzed and researched motion control strategies and methods of design for an agricultural robot that acquires navigational information from a visual system and uses a fuzzy control method to process and analyze information (Yuanjie, Fuzeng, Yu, Guanting, Jinyi and Yubin, 2013; Yuanjie, Fuzeng, Tao, Qiang and Xiudong, 2013). Among Iranian researchers, there are many examples of efforts for the design of automatic robotic units. Surface laid cables is another mediating mechanism used in automatically guided tractors (Aghkhani and Abbaspour-Fard, 2009). In the surface laid cable system, tractor moves along a path. The cables are buried inside the ground and have weak voltages. The difference between the voltage of paths (for cables and tractor) is transferred into a smart analytical system and path correction would be applied later. In this research, authors focus on the design of an automatic robotic unit for greenhouse operations. After introducing the software and hardware parts of this system, the results of the experiments are represented.

Material and methods

The proposed robotic unit was inspired by the differential steering method. The robot has four wheels, two driving wheels at the back, and two driven wheels in the front, the required energy for the movement of the unit is provided by two electrical motors (24 volts, 500 watts, 1,500rpm). Miniature mechanical gearboxes were used for transferring the forces to the wheels. The speed and direction of the movement of the robot were controlled through electrical motors. Their speed would be equal, higher, or lower for different operations (movement in a straight line or turning). Figure 1 is dedicated to the simulated system. Autodesk inventor professional 2018 was used for the designing purposes. Any greenhouse unit should be able to do tasks such as data collection, spraying, irrigation, etc. The additional abilities are provided by the supplementary equipment.

The robot units

Any artificial system consists of two parts: (i) – software, (ii) – hardware, and our robotic design is no exception. Central station, sensor unit, actuator unit, safety unit, spraying unit, and chassis make the hardware part of the design, while the software part consists of two independent software and one source code for synchronization with hardware unit. Figures 2 and 3 show the control system.
basic software was used as operational software. Microcontroller programming and circuit simulation were done in BASCOM-AVR 11 and PROTEUS 7, respectively.

The spraying system requires correct information as inputs, so the proper function of a robot (its controlling and spraying units) mostly depends on the efficiency of external sensors (Fig. 3). Therefore, a combination of infrared, ultrasonic, and level sensors was installed. Another important subject was the effect of mechanical structural and other environmental factors, so analysis of advanced position was performed to find the best possible locations and encoder sensor was used. The LCD/Keypad module shows the user relevant information on the status of the robot and allows the user to control the robot directly with ease. Further, controlling operations were done through this module.

C and VC++ are appropriate languages for software development. One of the software was installed on the robot’s central station, while the other installed on the controller’s laptop. The customized GUI made it simple to give and take operational orders. ATmega128 programmer was used for coding of the robotic unit. The microcontroller is actually some type of mediating context between the robot’s software and hardware. The data transmission process is completed via the WLAN network, which connects the controller to the robotic unit. Any communication passes through the central station. This configuration is shown in Figure 4. The initial parameters such as the number of aisles, width and length, distance, turning direction at each end are determined by controller and then reach the robotic unit. The initial performance is configured according to these parameters; in addition the online operational data are gathered and send back to the central station for further adjustments.

Automatic guidance system

The task of the guidance system is moving the robot inside the greenhouse in a correct and appropriate manner. It is expected that the robot moves correctly in the path defined between rows of plants. Plants usually kept in decorated conserving spaces, which are arranged hierarchically inside the greenhouse. Their edges act as a guidance line and their center line is selected as the optimum path. When the robotic unit starts its movement inside the aisles, the information related to positions inside the aisles are gathered by six ultrasonic sensors (product of Best Technology Co., Japan), which cover the left and right side of the robot. Meanwhile, the information related to outside
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Figure 2: Control system of the sprayer robot.

Figure 3: Schematic of various connections and units.
of aisles is needed for turning and they are analyzed based on the dead reckoning method. A simple viewpoint is shown in Figure 5. The safety unit consists of two ultrasonic at the top of the robot and two micro switches installed at the bottom. They are used for the detection of any obstacles in the path of the robot.

**Guiding through aisles**

The proper movement of the robot among the aisles is controlled by two parameters: (i) – distance from the desired line ($e$), (ii) – the angle of the robot with respect to the optimum line ($\alpha$) (Fig. 6).

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Figure 4: Schematic showing the communication of central station and robot unit.

Figure 5: Target and conductor lines in a greenhouse.
A combination of \((e, \alpha)\) is defined as a steering angle \((\theta)\). The adjustment of output parameters (voltages of left-right motors, \(V_L - V_R\)) is done by this moderating angle \((\theta)\). The following equation is proposed for linking \(e, \alpha, \) and \(\theta\) (Barawid et al., 2007):

\[
\theta = -\left(\alpha + \arctan\left(\frac{e}{L}\right)\right)\Psi
\]  

(1)

where ‘look ahead distance’ is shown by \(L\) and is equal to 1 m. Again, it is repeated that the output of the operation cycle is ‘voltages’, which are calculated based on steering angle.

**Turning mechanism**

There are various options for turning the robot at the end of aisles. One special characteristic of the greenhouse is its size limitation. Kise et al. (2002) proposed an innovative algorithm for controlling the turning operations of smart vehicles, which is repeated in this study. A schematic of the acquired turning path is shown in Figure 5.

The turning procedure is completed in three steps: (i) finishing the end of the current aisle with a 90 degree turning (point A) and entering the AB path, (ii) take a zero steering angle and move in forward/backward direction, according to the distance between two parallel aisles \((l)\), and (iii) returning to a new aisles with a 90 degrees movement, the robot takes the CD path and gets to point D. Forward/backward movement \((b)\) is calculated based on turning radius \((r)\) and the distance of two parallel aisles \((l)\):

\[
b = l + 2 (r - l) = 2r - 1
\]  

(2)

Three situations exist for \(b\) values. For \(b>0\), a movement in the forward direction is needed. The amount of this movement is equal to \(b\). For \(b=0\), no extra movement is needed and the robot goes to the next aisle, by a 90 degree turning. For \(b<0\), the backward movement is experienced. These situations are shown in Figure 7.

**Experiments**

The robotic unit was assembled from hardware components and then the proposed guidance system was installed on it. For validation of the proposed system, two sets of experiments had been conducted. The rows of plants are cemented fixed, and the floor has a very simple layout. The tray of plants is kept at the height of 0.92 m, the distance between aisles is 3.82 m, test path is u-shaped with...
Table 1. Robot error values at different speeds.

<table>
<thead>
<tr>
<th>Repeat</th>
<th>Lateral errors (cm)</th>
<th>Robot speeds (m min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE</td>
<td>7</td>
</tr>
<tr>
<td>1st</td>
<td>RMSE</td>
<td>5.48</td>
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<tr>
<td></td>
<td>Average</td>
<td>0.46</td>
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<tr>
<td></td>
<td>SD</td>
<td>4.09</td>
</tr>
<tr>
<td>2nd</td>
<td>RMSE</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>4.17</td>
</tr>
<tr>
<td>3rd</td>
<td>RMSE</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>6.93</td>
</tr>
<tr>
<td>4th</td>
<td>RMSE</td>
<td>4.37</td>
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<tr>
<td></td>
<td>Average</td>
<td>0.30</td>
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<tr>
<td></td>
<td>SD</td>
<td>3.96</td>
</tr>
<tr>
<td>5th</td>
<td>RMSE</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>-0.17</td>
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<tr>
<td></td>
<td>SD</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>RMSE average</td>
<td>5.22</td>
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Note: aDeviation to the right is indicated by the (+) sign and deviation to left with the (−) sign.

Results and discussion

Table 1 is devoted to lateral errors related to 7, 14, and 21 m min⁻¹ speeds. It is proved that increasing the speed of the robotic unit lead to an increase in the average RMSE of lateral error. The lowest speed (7 m min⁻¹) has the lowest RMSE (5.22), while the maximum speed (21 m min⁻¹) has the highest RMSE (6.38), these results also fully match the research results of other researchers. In the research of Iida and Burks (2002), with increasing vehicle speed from 1.08 to 1.84 m s⁻¹, the average value of RMSE distance of ultrasonic sensors from tree mass increased from 10.67 to 19.33 cm. In Kise et al.’s (2002) study, with increasing speed, the RMSE value of the tractor’s lateral deflection increased from the original track. In Barawid et al. (2007) research, with increasing tractor operation; RMSE is the main parameter, calculated for all speeds and repetitions.

The value of e shows the lateral error (cm); n would be equal to the number of collected data in a robotic operation; RMSE is the main parameter, calculated for all speeds and repetitions.

Figure 8: Lateral errors of the robot at 14 m min⁻¹ speed (five repetitions).
speed, from 0.36 to 1.43 m s\(^{-1}\), the RMSE value, the tractor’s lateral deviation from the main path, from 21 to 112 cm, increased.

The mean and standard deviation of all speeds also included in Table 1. Maximum lateral error happened at 21 m min\(^{-1}\), which was equal to 16 cm. The feasibility of the robotic unit, for movement between the aisles of the greenhouse was approved, since RMSE values are all fewer than 7 cm in all situations with different speeds, thus the speed has been determined less than 21 m min\(^{-1}\) to achieve successful aim. Figure 8 demonstrates that the lateral error of the robot in 14 m min\(^{-1}\) forward speed at five repetitions.

By turning at the end of the first aisle, some gaps are generated in order to show robot position. There are some actual paths in greenhouse which is suitable for robots to move on with 14 m min\(^{-1}\) speed and also consists of some straight and round paths at five repetitions, which is illustrated in Figure 9.

There is a direct relationship between the forward speed, lateral errors, and turning radiuses. So an increase in forward speed inevitably leads to higher values for lateral errors and radiuses. Turning at higher speeds definitely needs larger space inside the greenhouse.

Conclusions

The design of a robotic unit with different capabilities for using inside a greenhouse is investigated in this study. Hereby a robotic unit with the capability of movement inside an actual greenhouse was designed and tested in this research. It is equipped with an automatic path-finding system. Investigation of ultrasonic sensor showed that the sprayer robot was capable for spraying plants on both sides of the greenhouse simultaneously. The robot’s guidance was done well by the infrared sensor. Evaluation of the robot’s movement in the straight path showed that the 4 m displacement had a rightward deviation of 2.5 cm. wheels were the main elements of movement, so front wheels were adjusted again. The new system had a deviation of 1.5 cm in 4 m and the sensors repeatedly corrected this deviation and did not increase cumulatively as the displacement continued. The experiment results approved the accuracy of path control-adjustment mechanism in finding ways in the stated area. Also, it was founded that running the robot at higher speeds leads to greater requirements in terms of lateral error, turning radius, and turning space.

Literature Cited


