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Article

Development of a GIS-Based Autonomous Soil Drilling Robot for Efficient Tree Cultivation and Orchard Planting

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Abstract: A typical orchard's mechanical operation consists of three or four stages: lining, digging for plantation, moving the seedling from nurseries to the farm, moving the seedling to the planting hole, and planting the seedling in the hole. However, the digging the planting hole is the most time-consuming operation. In fruit orchards, robots' usage is increasingly becoming more prevalent to increase operational efficiency. They offer practical and effective services to both industry and people, whether they are assigned to plant trees, reduce the use of chemical fertilizers, or carry heavy loads to relieve staff. Robots can operate for extended periods of time and can highly adept at repetitive tasks like planting many trees. The present study aims to identify the locations for planting trees in orchards using geographic information systems (GIS), to develop an autonomous drilling machine and use the developed robot to open planting holes. The agricultural mobile robot is a four wheeled nonholonomic robot with differential steering and forwarding capability to stable target positions. The drilling system, which is a y-axis shifter driven by a DC motor with reducer includes an auger with a 2.1 HP gasoline engine. SOLIDWORKS software was used for designing and drawing of the mobile robot and drilling system. The Microsoft Visual Basic.NET programming language was used to create the robot navigation system and drilling mechanism software. The cross-track error (XTE), which determines the distances between the actual and desired holes positions, was utilized to analyze the steering accuracy of the mobile robot to the drilling spots. Consequently, the average of the arithmetic means was determined to be 4.35 cm, and the standard deviation was 1.73 cm. This figure indicates that the suggested system is effective for drilling plant holes in orchards.

Keywords: soil drilling machine; GIS; robotics in agriculture; orchard; navigation

1. Introduction

The aim of agricultural mechanization is to reduce dependence on labor, increase farm productivity, speed up field operations, and achieve high income while minimizing costs (Chi et al., 2021). Automation and precise management technologies have significantly improved agriculture during the last few decades. The implementation of automation and precision management, however, has not been focused on specialized crops, such as tree fruit, because orchard tasks are difficult and orchard systems are inconsistent (Jiang and Ahamed, 2023). For this reason, human labor continues to be a major component of most tree fruit producing operations. In the meanwhile, more food must be produced to feed a population that is growing steadily while there are less resources available, such water and agricultural area. Whatever happens in the orcharding sector, in order to reduce the production inputs and environmental impact of agricultural systems, precision agriculture has become crucial in today's dynamic environment. Precision agriculture has been

applied extensively to field crops and is becoming increasingly popular among academics and industry participants working with tree fruit crops (Karunathilake et al., 2023). As a result, intelligent mechanical and automated systems are the answers to the problems facing the tree fruit sector, as they lower the need for labor.

Agricultural production areas, whether plant production areas or orchards, have a complex and heterogeneous structure. The environment in which robots are to be commissioned is crucial to the development of agricultural robotic solutions since the cost of the system increases with its complexity. Orchards appear to be the best location for robots and automated systems to be implemented in agriculture because of their organized environment (Bochtis et al., 2015). Furthermore, a serious danger to orchard industries is the declining availability of skilled labor for seasonal orchard task. For this reason, it's critical to develop robotic orchard solutions (Verbiest et al., 2021). Many studies on the automation of various orchard tasks, like as spraying and harvesting, have been conducted during the previous fifty years. The majority of these research studies focus on a single task (Silwal et al., 2017). There are numerous automated harvesting robot prototypes for orchards (Bac et al., 2014; Onishi et al., 2019; Zhang et al., 2021; Xiong et al., 2022; Chen et al., 2022). Additionally, there are also studies in the literature on robotic tasks like thinning (Gonzalez Nieto et al., 2023), spraying (Liu et al., 2022), pruning (Botterill et al., 2017), and mobile navigation (Jia et al., 2023) in orchard environments. Every orchard management operation listed above requires a mobile platform in order to move the actuators around the orchard. Mobile platforms must be precisely navigated through orchards. In addition to being accurate in guiding robots from point A to point B inside the orchard, the system must consider the simultaneous manipulations directed towards the tree or fruits. Precise orchard maps are essential for accurate mobile robot localization in orchards because they enable the robot to navigate between tree rows by accurately estimating its position and orientation (Shalal et al., 2015). The mapping of the orchard can also be utilized to create an autonomous navigation system that uses an appropriate control strategy to manage the mobility of the mobile robot within the orchard. As a result, a priori environment map is required for all the navigation and localization techniques for mobile robot platforms.

Mobile robots must be able to successfully navigate through feature extraction, mapping, localization, path planning, and obstacle avoidance in orchard environments. Using its on-board sensors, a mobile robot can map the orchard and identify its surroundings, updating the map in real time. Accurate orchard maps are crucial for agricultural robots' navigation, localization, and path planning. The accuracy of the orchard map can be increased by integrating several sensors for developing the feature extraction and mapping orchard. The process of precisely calculating a mobile robot's attitude in relation to an environment map using information gathered from the robot's sensors is known as localization (Cheein and Carelli, 2013). Reliability in gathering sensor data and its automatic association with the environment map constitute the basis of the localization challenge. All the navigation and localization expressions explained above indicate that an environmental map should be created starting from the establishment phase of the orchards. Global Navigation Satellite Systems (GNSS)-based technologies and GIS are becoming increasingly popular among farmers these days for their farming tasks, particularly in the area of landscape design. Software known as GIS (Geographic Information System) is designed specifically to work with spatial data and enable the creation of intricate, scaled maps with quantifiable features (Li et al., 2024). The core of orchard planting plan, which is about comprehending and creatively planning the natural and artificial topography of a particular place, is closely tied to GIS (Yadav et al., 2024). In this respect GIS can be regarded as an instrument to create orchard planting maps and development in orchard planning research and design.

An orchard layout is a plan that illustrates how the plants are arranged in an orchard. Any orchard design strategy should provide to accommodate the greatest number of plants and provide enough space for the orchard's easy cultural operations (Javaid et al., 2017). Planting systems can be broadly classified into two categories: vertical system of planting and alternate row planting system. The first tree in the vertical system of planting is precisely perpendicular to the trees in the orchard's subsequent rows. The vertical systems of planting include square and rectangular systems. The

alternate row planting system is used when the trees in the neighboring row are not quite vertical. This planting method includes the quincunx, triangular, and hexagonal systems. The most effective and economical management of the orchard requires a meticulous plan. The optimum spacing to accommodate the maximum number of trees per unit area can be the result of good planning (Haque and Sakimin, 2022). The simplest and most widely used planting method for fruit trees is the square system. Trees are planted in this technique on every corner of a square, regardless of the planting distance (the space between plants and rows remains the same). The similarity in distances between trees and rows (5 X 5 m, 6 X 6 m, etc.) allows for the execution of intercultural operations in both directions. Establishing an orchard begins with selecting the suitable planting method and correctly marking the planting spots (Murcia et al., 2021). Geospatial analysis, which includes methods and techniques for analyzing data in its spatial context, is regarded as the fundamental component of GIS (Longley, 2010). GIS can assist farmers in effectively managing their orchard design strategy, in providing the planting coordinates of trees for autonomous tree planting, and in creating coordinate maps for autonomous subsequent orchard operations.

It is challenging to complete the afforestation sector's massive work volume solely through manual labor due to the requirement to afforest ever-larger areas in orchards (Pica et al., 2021). Especially, digging holes for tree planting is a laborious and time-consuming task. In the future, planting more trees will be required over even larger areas. As a result, we believe that employing GIS-based autonomous soil drilling robot to automate the process of drilling holes in order to plant saplings is the best course of action in this situation. There are several different types of ground augers on the market that can mechanically dig holes for saplings. Nevertheless, there isn't a mobile robot system on the market or in the literature that can drill plant holes on its own using maps. Based on the planting map generated by the GIS software, the developed mobile robot navigates to the drilling spots on its own and drills holes. The study's conceptual structure is presented in Figure 1.

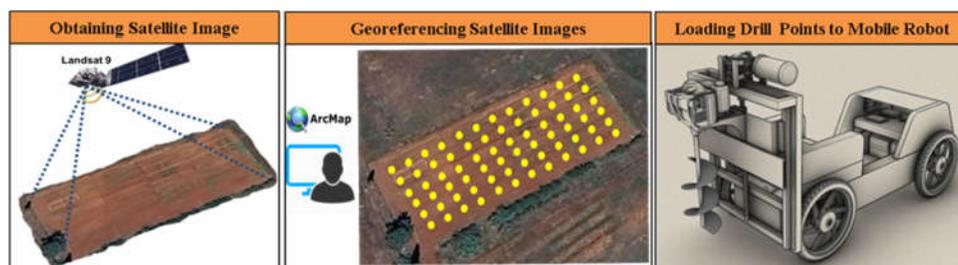


Figure 1. The study's conceptual structure.

2. Materials and Methods

The photograph of the GIS-based Autonomous Soil Drilling Robot is shown in Figure 2. The principal objective of the paper is to employ ArcGIS software to ascertain the geographic locations of the sapling holes in the orchard and to ensure the development and adaptation of the autonomous mobile robot and soil auger machine. There are four primary structures in the system:

1. Development of autonomous mobile robot and navigation algorithm: The four-wheeled autonomous robot is steered by four DC motors. There has a differential steering mechanism. It can be maneuvered manually or autonomously from point to point.
2. Adaptation of the autonomous mobile robot and soil auger machine: The soil auger machine is a specially designed solution for the task of drilling soil; it is a modification of the autonomous mobile robot that we previously developed.
3. Determination of drilling spots of planting holes on the digital map: Drilling spots of planting holes were determined using ArcGIS software to handle and merge data, carry out detailed analysis, and model and automate procedural operations.
4. The designed system's software solutions: The software is designed to enable autonomous navigation of the mobile robot and operation of the auger system.



Figure 2. The photograph of the GIS-based Autonomous Soil Drilling Robot.

2.1. Autonomous Mobile Robot and Navigation Algorithm

The agricultural mobile robot which has four wheels can be maneuvered both manually and automatically. To steer the robot under field circumstances, four rubber wheels measuring 2.50×17 were selected. The steering mechanism of mobile robot is differential. The robot's left and right wheels can move at different speeds from one another. All of the wheels' speeds need to match for the mobile robot to steer in a straight line. The robot turns to the side of the slowest wheel if the left and right wheels are moving at different speeds. The mobile robot can turn 360 degrees in its current location by rotating its left and right wheels in opposition to one another. Four 24V, 0.25 kW, 1440 rpm DC motors are used to power the mobile robot. They are connected to a 1:10 reduction gearbox. The mobile robot was equipped with motor-gearbox assemblies installed on its chassis, to which each wheel was connected independently. This allows the wheels to receive all of the torque produced by the motors. The robot has a maximum speed of 20 km/h and weighs about 150 kg when batteries and the measurement system are included. To guide the mobile robot, two Roboteq FDC3260 3-channel DC motor control units (Roboteq Inc., Scottsdale, AZ, USA) were utilized to adjust the motors' speed and direction. The mobile robot and other equipment were powered by two 12 V-72 Ah sealed, rechargeable, maintenance-free batteries. In addition, two batteries were linked in series to give the DC motors 24 V. A technical drawing of the mobile robot is presented in Figure 3.

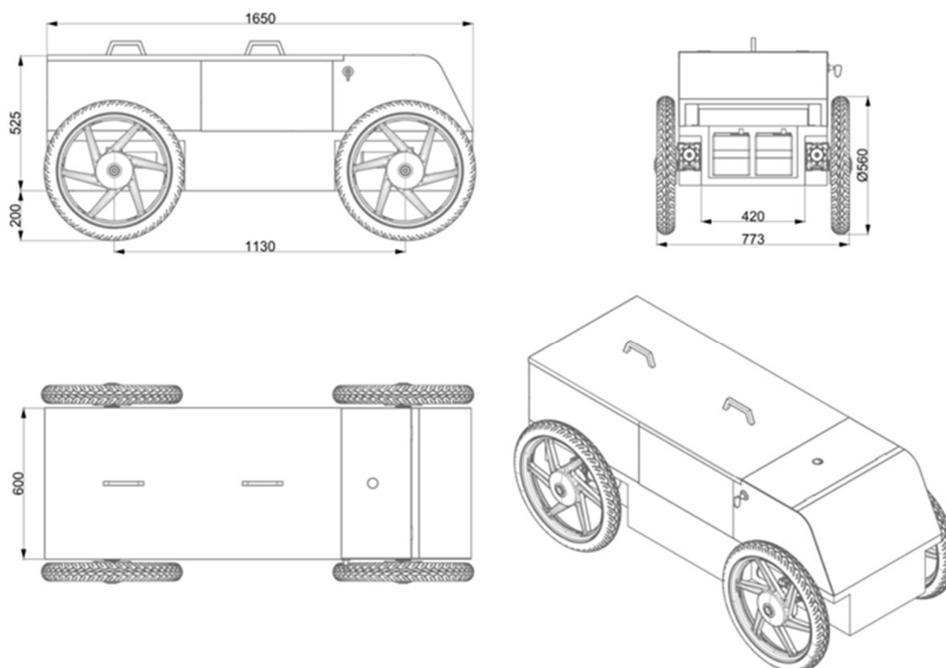


Figure 3. A technical drawing of the mobile robot.

Geographical data for the autonomous steer system was gathered using a Promark 500 RTK-GPS receiver (Magellan Co., Santa Clara, CA, USA). Up to 20 Hz data output rate and 75 channels were available on the receiver. The mobile robot is steered to drilling locations using geographic data (latitude, longitude, speed, time, etc.) obtained from the GPS receiver. The digital compass Honeywell HMR3200 (Honeywell International Inc., Charlotte, NC, USA) was utilized to obtain the robot's precise heading angle for navigation software. The heading angle is the angle in the horizontal plane formed between the present direction of a mobile robot's longitudinal axis and North, whether it is magnetic or true North. The angle between North and the destination point is known as the azimuth. The heading and azimuth angles are used to determine the angle difference. The azimuth and heading angle difference is computed instantaneously by the navigation algorithm. The mobile robot can be guided in the desired direction in this manner. The distance between the target point and the mobile robot location is the computed. Finally, the mobile robot reaches its destination when the heading angle equals the azimuth angle and the distance equals zero. The flowchart for the mobile robot navigation method is shown in Figure 4.

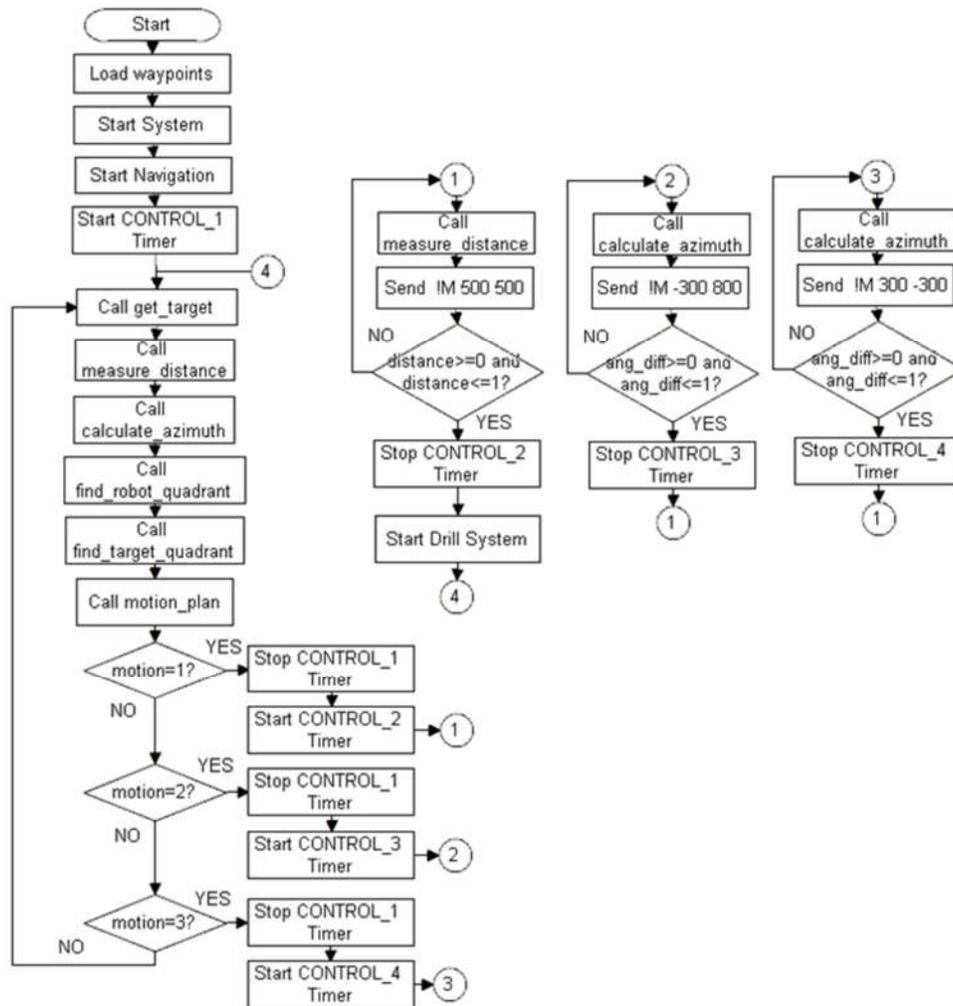


Figure 4. The flowchart for the mobile robot navigation method.

2.2. Adaptation of the Autonomous Mobile Robot and Soil Auger Machine

An instrument for drilling holes in the earth is called a soil auger. Usually, it is made out of a vertical metal rod or pipe that rotates and has one or more blades attached to the lower end of it to scrape or cut the soil. A GIS-based autonomous mobile robot that may be used to drill holes for planting trees, installing telephone or electricity poles, and other suitable sites is the idea behind this work. We have decided that it is more acceptable to combine our built autonomous mobile robot with the gasoline-powered hole drilling equipment that is currently on the market for this reason. The technical drawings for the mobile robot attached to the soil auger machine are presented in Figure 5.

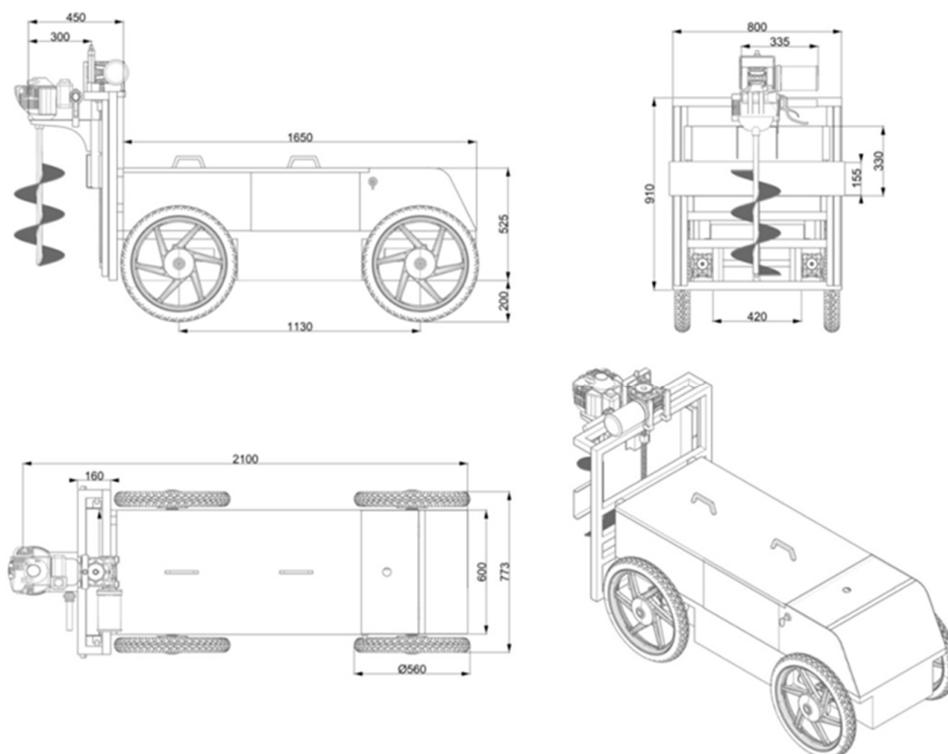


Figure 5. The technical drawings for the mobile robot attached to the soil auger machine.

In the study, the Palmera ZLAG520B soil auger machine (Remaş Inc., Istanbul, TR) was coupled to the vertical movement mechanism designed for the rear of the developed mobile robot. Stainless steel was used to construct the vertical movement mechanism. Square steel tube measuring $30 \times 30 \times 3$ mm was used to make some of the mechanisms components. The H-shaped carrier grid and the soil auger machine are the two components that make up the system's mechanical structure. Two $30 \times 30, 910$ mm and three $30 \times 30, 800$ mm square steel tubes were used to build an H-shaped carrier grid for the system's vertical movement. Then this H-shaped carrier grid was attached to the rear of the autonomous mobile robot. The soil auger machine was mounted on an H-shaped grid (Figure 6). The two steel linear guides on the H-shaped grid are adjusted by pillow blocks and 30 mm linear rail shaft guide supports. The linear guides have a length of 910 mm. For vertical movement, a 1:40 reduction gearbox was connected to a 24 V, 500 W, 1440 rpm DC motor that drove a 30×850 mm ball screw, forming a linear actuator.

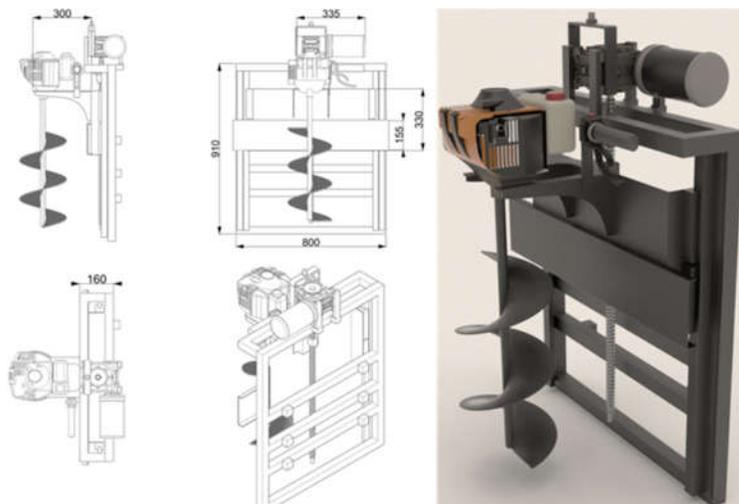


Figure 6. Full-scale technical drawing of the soil auger machine and H-shaped grid.

The developed four-wheel differential driving mobile robot on a two-dimensional plane is displayed in Figure 7. It shows the local coordinate system (x_1, O, y_1) , where y_1 is the robot's lateral direction, O is the robot's center point, and x_1 is the driving direction.

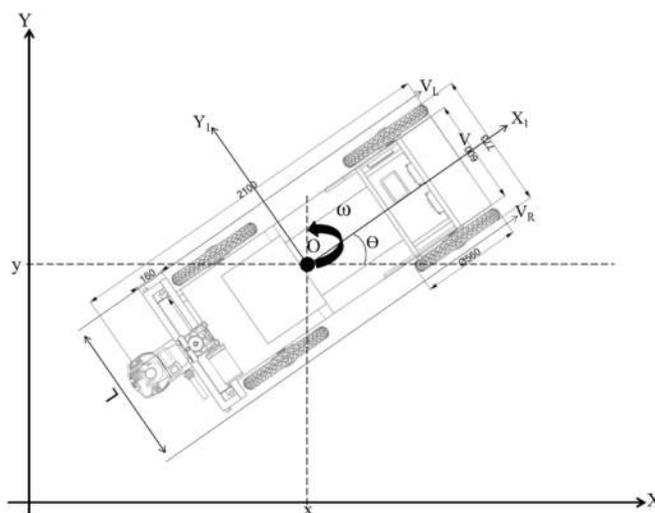


Figure 7. Full-scale technical drawing of the soil auger machine and H-shaped grid.

For a nonholonomic 4WD mobile robot, the differential equations of motion can be written as:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} * \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (1)$$

$$P = \begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ r & -L \end{bmatrix} * \begin{bmatrix} v_R \\ v_L \end{bmatrix} \quad (2)$$

Here, the position, velocity, and angular velocity of the mobile robot are represented by $((x, y, \theta))$, (v, ω) , and their derivatives are denoted by $(\dot{x}, \dot{y}, \dot{\theta})$, respectively. L denotes the breadth of the left and right wheels, while v_L and v_R respectively represent the left and right driving wheels' velocities.

Based on the given formula, when $v_R = v_L$ and $\omega = 0$, the robot travels straight at a consistent speed. If $v_R = -v_L$, it will spin around its center of mass. When $v_R \neq v_L$, the robot follows a curved path with a specific radius (ρ). The formula for calculating the radius of this curve is detailed in Equation (3):

$$\rho = \frac{v}{\omega} = \frac{L * (v_L + v_R)}{2 * (v_L - v_R)} \quad (3)$$

Upon reviewing the above equations, the kinematic equation for the nonholonomic mobile robot can be formulated as shown in Equation (4):

$$P = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{r}{2} * \cos\theta & \frac{r}{2} * \cos\theta \\ \frac{r}{2} * \sin\theta & \frac{r}{2} * \sin\theta \\ \frac{r}{L} & \frac{-r}{L} \end{bmatrix} * \begin{bmatrix} v_R \\ v_L \end{bmatrix} \quad (4)$$

2.3. Determination of Drilling Spots of Planting Holes on the Digital Map

With the aid of a GIS, users can produce interactive maps with multiple layers that are useful for both geographical analysis and the visualization of complicated data. GIS is essentially the fusion of database technology and mapping. GIS are utilized in urban planning, emergency management, photogrammetry, cartography, remote sensing, land surveying, and geography. The most important advantages of GIS for fruit cultivation are the provision of a planned land use strategy obtained by predetermining the most suitable areas according based on products and the preparation of the seedling planting plan. Assessing the aforementioned benefits, it is clear that the first step in implementing autonomous systems for orchards will be planning the planting of trees on a digital map and mapping out the location of seedling holes. In this context, a digital image of the orchard was first imported into the ArcMap program in order to locate the seedling holes. Next, holes locations were marked on the image, separated by 6 meters in both the horizontal and vertical orientations (Figure 8). Finally, a database table was created after the coordinate information of the seedling holes was extracted from the image. In order to autonomously guide the mobile robot to the drilling holes, the database table was used as a task file.

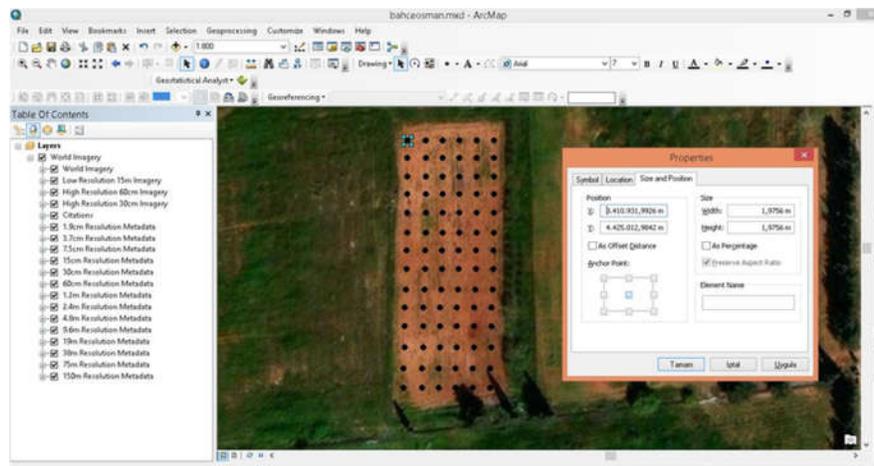


Figure 8. ArcMap program in order to locate the seedling holes.

2.4. Determination of Drilling Spots of Planting Holes on the Digital Map

The navigation program was built in Visual Studio.NET 2015 using the Visual Basic.NET language to control the mobile robot both manually and automatically (Figure 9). Furthermore, the developed software instantly activates the soil drilling mechanism when the mobile robot arrives at

the target spot. All of these activities to occur depend on the task file being uploaded to the mobile robot's industrial computer. Task file is a list of points defined by a geographical position, latitude and longitude coordinates used by the mobile robot navigation. Furthermore, the locations of the drill spots for the soil are indicated by these coordinates as well.

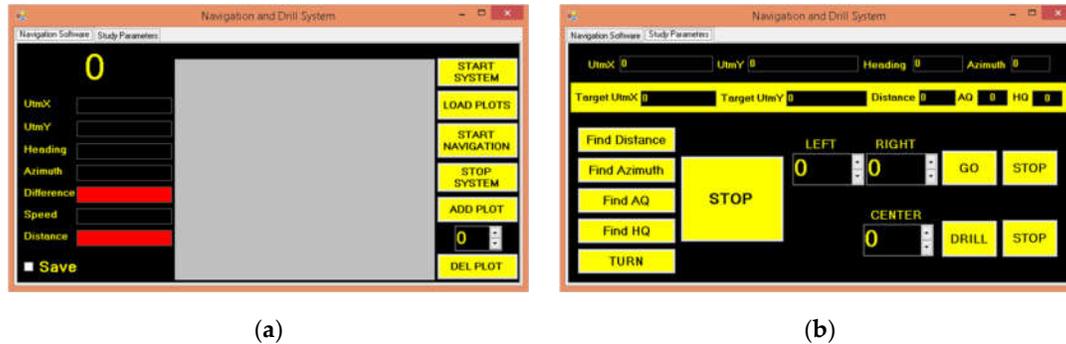


Figure 9. Developed navigation and drilling software: (a) The software that was designed for mobile robot navigation; (b) soil drilling procedures.

The azimuth angle of the destination point and the robot's heading angle are the two key angles for mobile robot navigation. The navigation program uses the HMR3200 digital compass to determine the heading angle of the robot. It additionally computes the azimuth angle continually. It also computes the distance between the robot position (X_1, Y_1) and the target position (X_2, Y_2). For the purpose of statistically analyzing the discrepancy between the desired drilling spots and the real drilling spots where the robot stops, all location data is stored in the SQL Server 2005 database.

2.5. Field Study Experiment

All experimental evaluations with the developed robot system were performed in land of University of Akdeniz ($36^{\circ} 53' 54''$ N and $30^{\circ} 38' 27''$ E). The experimental field is 32 m above sea level and areas 3.1 da. The mobile robot was autonomously navigated to 84 distinct spots throughout the investigation in the experimental field. The soil auger was used to dig a planting hole that was 40 cm deep at each spot. The autonomous stop-and-go navigation approach was employed to drill planting holes in this study. The main idea behind the stop-and-go technique is to halt the robot while it is drilling the planting holes. With this approach, the agricultural robot travels to the first drilling spot, stops, digs a hole, and then moves on to the next.

2.5. Data Analysis, Interpretation and Visualization

The main purpose of the navigation software in mobile robot navigation is to minimize XTE, which allows the robot to precisely approach the destination spot. XTE is utilized to estimate the overall 2D positional error statistics or to make comparisons (Sharp and Yu, 2012). XTE is the Euclidean distance between desired target position and the real position of the robot:

$$XTE = \sqrt{(X_R - X_{TP})^2 + (Y_R - Y_{TP})^2} \quad (5)$$

The mobile robot's latitude and longitude are represented by the values X_R and Y_R in the equation. The desired target's latitude and longitude are represented by the values X_{TP} and Y_{TP} . The XTE values' standard deviations and standard errors were calculated for each drilling process. The XTE data acquired for 84 places was interpreted in order to assess the system's overall success. ArcGIS 10.5 software was used for the purpose of visualization.

3. Results

There are two stages to the experimental study of the GIS-based autonomous soil drilling robot. The first stage involves setting up the task file for the mobile robot by utilizing the ArcMap

application in an office setting to find the holes locations that need to be dug in order to plant seedlings. In the second phase, the prepared task file is uploaded to the mobile robot computer, after which it autonomously goes the drilling locations one after the other and drills the holes. In the study area, a total of 84 seedling drilling locations with ranges of 6x6 m were identified for the task file. The target locations and the locations where the mobile robot drills a hole are displayed in Figure 10. No data was lost because of a weak GPS signal.

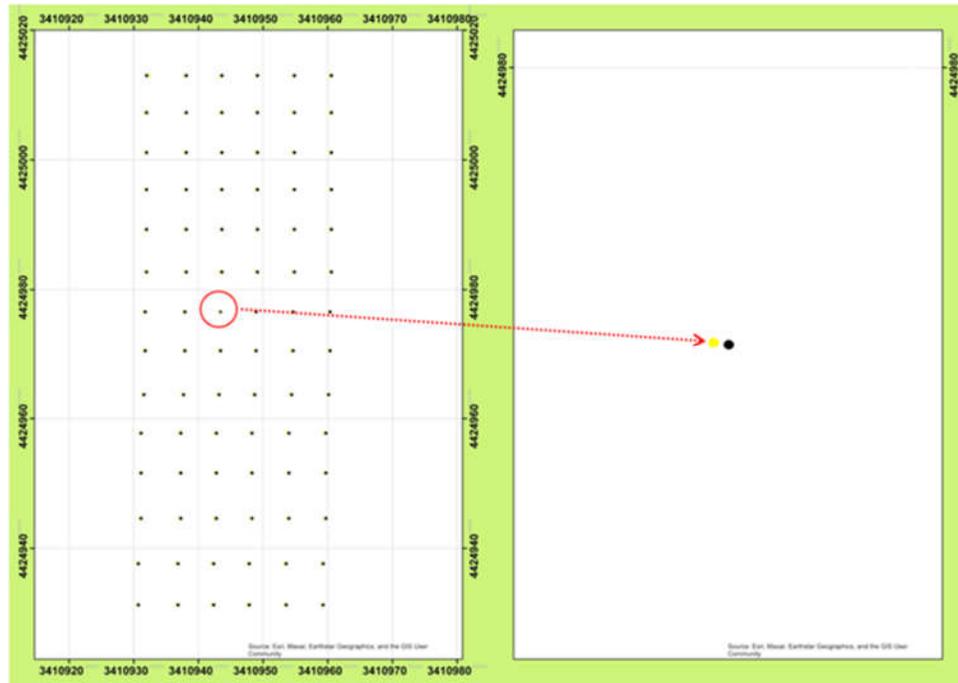


Figure 10. The target locations and the locations where the mobile robot drills a hole.

Data visualization is often achieved through the use of histograms. Histograms are graphical depictions of a data collection that indicate the frequency at which each value appears. The histogram of XTE values between the location where the mobile robot digs a hole and the intended digging point is displayed in Figure 10. For a total of 84 spots, the minimum and maximum XTE values were calculated to be 2.41 and 9.41 cm, respectively. The data's standard deviation was computed to be 1.73 cm. Also, the data's mean was computed to be 4.35 cm. It is seen that the majority of XTE values are found to be stuck between 2.51 cm and 5.96 cm. It is important to know the shape of our data sets on the histogram. Positive or right-skewed graphs have a tail that seems to be pulled to the right. Positively skewed data are characterized by a large number of values that are near to the lower end of the range and a rare occurrence of higher values. When Figure 11 is examined, it is observed that the histogram is positive or right-skewed. For this data set, the skewness is 1.38 and the kurtosis is 4.07, which indicates moderate skewness and kurtosis.

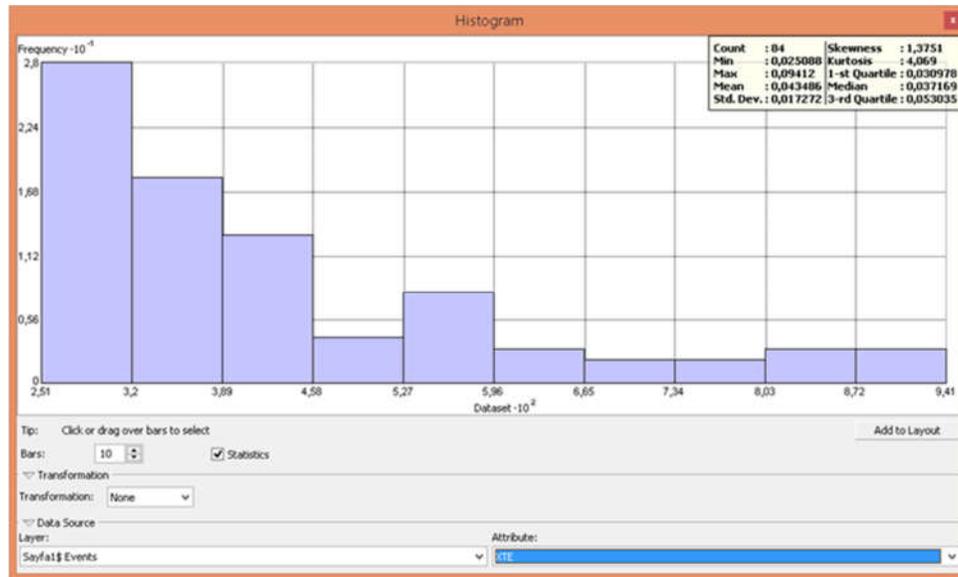


Figure 11. The histogram of XTE values.

One kind of graphic that we can use to determine whether or not a set of data may have originated from a theoretical distribution is the Quantile-Quantile (Q-Q) plot. A dataset's univariate normality can be determined by looking at the points on the Normal QQ plot. A 45-degree reference line will be where the points fall if the data is normally distributed. In the event that the data is not normally distributed, the points will deviate from the line of reference. The corresponding quantile values of the dataset are represented on the y-axis of the Normal QQ plot in Figure 12 below, while the quantile values of the standard normal distribution are plotted on the x-axis. It can be seen that the points almost fall close to the 45-degree reference line. The main departure from this line occurs at high values of XTE. Right-skewed data shows up as a concave curve on a normal Q-Q plot.

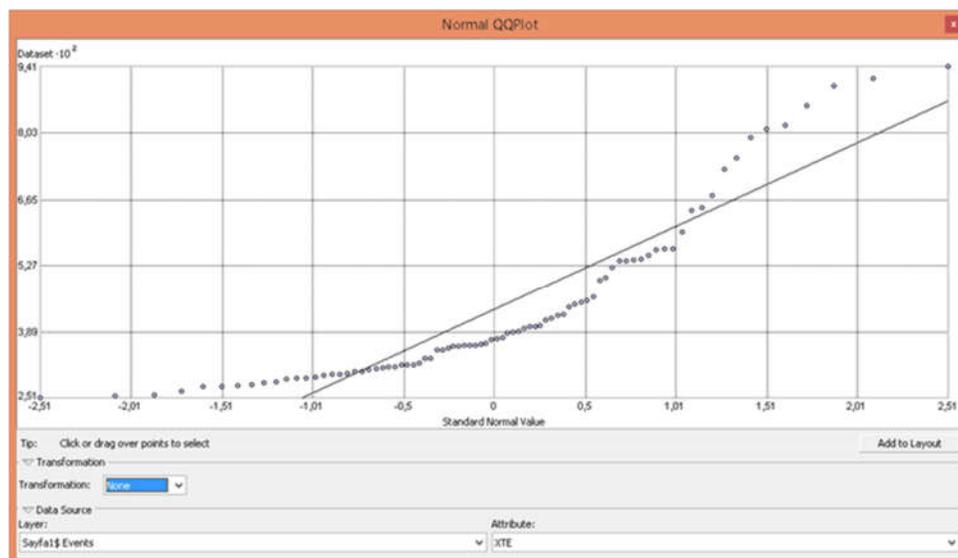


Figure 12. Normal QQ plot of XTE values.

The simple kriging method was used to understand the differences to the research area. Simple kriging is less complex than ordinary kriging, yet it produces a smoother result by averaging of the entire dataset. No general trends were subtracted, nor the data values transformed or declustering to

produce regularity. The spatial distribution of the XTE is shown in Figure 13. It shows that the XTE is less than 4.7 cm in a significant part of the studied area. This indicates that the GIS-based autonomous soil drilling robot may function in the work area with reasonable XTE errors.

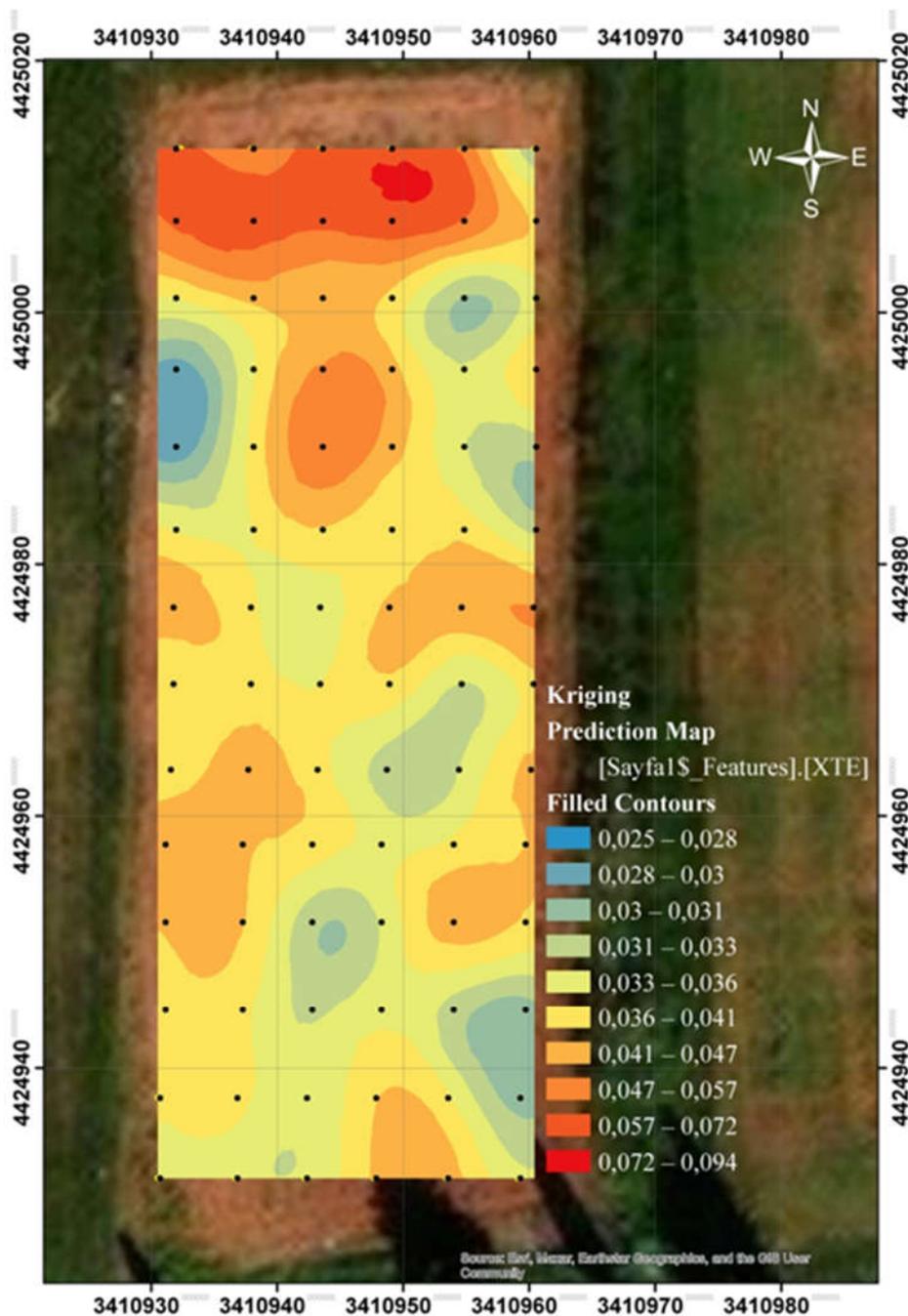


Figure 13. The spatial distribution of the XTE.

4. Discussion

The need to modify orchard mechanization technologies to meet contemporary demands has resulted in the development of new, efficient machinery. Intensive orchards ensure favorable circumstances for large fruit production and autonomous mechanized processes. Table 1 showed that the spacing between rows varies from 2.5 to 6 meters, while the spacing between trees within a row

varies from 0.5 to 5.5 meters depending on the planting density and culture type. In this study, the horizontal and vertical spacing between the trees for the seedling pits was determined to be six meters. Depending on the type of tree that needs to be established for the orchard, the user can adjust this predetermined distance on ArcMap software. The following stages must be completed in order to set an orchard: selecting planting material, determining spacing, field marking, ditching holes, and planting trees. In this process, mechanization is needed in two stages: ditching holes and planting trees. The presented study focuses on GIS-based autonomous soil drilling robot.

Table 1. Density of planting depends on the type of culture.

Tree Name	Spacing between rows (m)	Spacing in rows (m)
Apple	2.5 – 6	0.8 – 5
Pear	3.5 – 5	1.5 – 4.5
Plum	5 – 6	3.5 – 4.5
Apricot	5 – 6	3.5 – 5.5
Peach	4.5 – 5.5	3 – 4
Cherry	5 – 7	4 – 5.5
Sour Cherry	4 – 6	2 – 4.5
Currant	2.8 – 3	1 – 1.2
Raspberry	2.5	0.5
Blackberry	2.5	1.5 – 1.8
Nut	4 – 5	3 – 3.5

The majority of research on automated methods for producing tree fruits focuses on operations related to pruning and harvesting. In the literature, no GIS-based autonomous robot has been found to dig holes in orchard setup. The issue of mechanized operations must be carefully considered while building a new orchard and it must be equipped with autonomous systems and related supporting infrastructure (Lei et al., 2023). Thus, the study is crucial for figuring out where the trees should be planted when establishing a new orchard. Because the actual location of the trees is predetermined by this technology, autonomous machines can operate for the following planting and following maintenance procedures.

Mechanization is crucial to agriculture since it ensures timely completion of tasks and lower costs per unit area. Nowadays, due to the rapid development of fruit tree cultivation, horticultural practices now largely require the use of various mechanical equipment. One of the most significant tools for horticulture is the soil drilling machine. The process of preparing the planting hole takes about 30% of the total time required for mechanical seedling transplanting in horticulture (El-Gendy et al., 2009). This rate covers a very large amount of time in the total process. In addition to being time-consuming and physically demanding, the traditional method of digging soil can quickly cause operator fatigue. The two main categories of soil drilling machine are hand augers and power augers. Power augers run on an engine or a drill, whereas hand augers need human labor and are best for smaller projects. There are several types of power augers, including tractor augers, gas-powered augers, and electric augers. The primary purpose of all these soil drilling machines used in horticulture is to reduce manpower and increase horticultural productivity (Kaur et al., 2023). One of the biggest concerns with soil augers driven by gasoline engines is its transportation; because to their weight, they are very difficult to handle and generate a lot of dust, which can be harmful to the workers' health. When all these explanations are evaluated, it is clear that the development of an autonomous soil drilling mobile robot will result in significant benefits including lower labor costs and higher productivity per unit of time.

5. Conclusions

In intensive horticulture, intelligent technology and equipment can save labor costs while simultaneously enhancing management accuracy and efficiency and yielding higher yields. Horticulture automation with mobile robots is yet a field that is constantly evolving. Mechanized and intelligent operations are becoming more and more prevalent in the process of planting orchards, especially during the establishing phase. In this context, a new design for a GIS-based autonomous soil drilling robot for efficient tree cultivation and orchard planting has been presented in this paper. There is no published study on the use of mobile robots for soil drilling in orchard environments. In this sense, the conducted study will provide new gains to the horticultural sector. Opening a seedling planting hole in large orchards is a time-consuming and tiring process for growers. The results of the study indicate that producers should utilize this robot to automate a labor-intensive and time-consuming procedure.

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