DEVELOPMENT OF AN AGRICULTURE ROBOT FOR ROW-TYPE SEED SOWING APPLICATIONS

Cihan YURTSEVER[1,+], Yasin ERTAS[1], Oben SUSTAM[1], Cenk ULU[1]
[1]Department of Mechatronics Engineering, Yildiz Technical University, Besiktas Istanbul Turkey
cihan.yurtsever1@gmail.com, y.ertas97@hotmail.com, obensustam2@gmail.com, cenkulu@yildiz.edu.tr

Abstract

In this study, the design and development of an agriculture robot which has row type seed sowing feature are presented. The robot consists of four subsystems; a four-wheel mobile platform, a digger mechanism, a seed dropping mechanism, and an irrigation mechanism. The electrical and mechanical designs of the robot are performed depending on the specified design criteria. System control software and user interface are developed considering stakeholder expectations. Designed subsystems are manufactured and integrated. Furthermore, robot functionality tests are performed and the desired performance of the agriculture robot is validated by the test results. The robot is remotely operated via an Android application on a mobile phone and all operation data can be monitored via this android application. Additionally, the robot can perform the row-type seed sowing operation in an autonomous mode. The developed agriculture robot has the potential to provide an efficient and inexpensive way for future seed sowing applications.

Keywords: Agriculture Robot, Row-type Seed Sowing, Android Application, Remote Control.

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SIRALI TİP TOHUM EKİM UYGULAMALARI İÇİN TARIM ROBOTU GELİŞTİRİLMESİ

Özet

Bu çalışmada, sıralı ekim yapan bir tarım robotunun tasarımı ve geliştirilmesi gösterilmiştir. Robot dört tekerlekli mobil platform, kazıcı mekanizması, tohum düşürme mekanizması ve sulama mekanizması olmak üzere dört altsistemden oluşmaktadır. Robotun elektrik ve mekanik tasarımı belirlenen tasarım kriterlerine bağlı olarak gerçekleştirilmiştir. Sistem kontrol yazılımı ve kullanıcı arayüzü paydaş beklentileri göz önüne alınarak geliştirilmiştir. Tasarlanmış olan alt sistemler üretilmiş ve entegre edilmiştir. Buna ek olarak, robot fonksiyonel testleri gerçekleştirilmiş ve tarım robotunun istenen performansı test sonuçları ile doğrulanmıştır. Robot, bir cep telefonu Android uygulaması üzerinden uzaktan kontrol edilmekte ve tüm operasyon verileri bu uygulama üzerinden izlenebilmektedir. Ayrıca, robot sıralı ekim işlemini otonom çalışma modunda da gerçekleştirebilmektedir. Geliştirilen tarım robotu, gelecekteki tohum ekim uygulamaları için ucuz ve efektif bir alternatif sağlama potansiyeline sahiptir.

Anahtar Kelimeler: Tarım Robotu, Sıralı Tohum Ekimi, Android Uygulaması, Uzaktan Kontrol.

1. Introduction

Today, robotic developments have spread over many different and wide areas. The development of robotic technologies provides better process implementation and quality improvement for many different purposes. The agricultural fields are also under the effect of this development. In literature, a significant increase in the number of agriculture robots is expected in the near future [5-7].

The main operations of the agriculture robots can be classified as; seed sowing [1], harvesting [2], irrigation [3], and quality detection [4]. In agriculture, seed sowing applications take a fundamental role. Various seed sowing types such as broadcasting, drilling, sibling, and row type seed sowing are used by farmers. The most prevalent types are row and broadcast seedings. Compared with the broadcasting type, the sowing in a row is more complicated and requires higher manpower. Therefore, farmers use expensive, inefficient, and non-eco-friendly machines for the sowing in a row. On the other hand, by using agriculture robots, the seed sowing applications can be performed with lower labor, lower cost, and high quality and efficiency.

There are many different types of seed sowing robots [11-13] which are autonomous [8], remote-controlled [9], and solar-powered [10]. However, there exists no agriculture robot that deals with digging and spraying problems, which are important for seed soil.

In this study, we present the design and development of an agriculture robot for row type seed sowing applications. The robot is battery-powered and can be remotely controlled via an android application on a mobile phone. The robot has four main subsystems as a four-wheel mobile platform, a digger mechanism, a seed dropping mechanism, and an irrigation mechanism. Depending on the defined design criteria, all subsystems are designed, and related control algorithms and user interface software are developed. The subsystems are produced, integrated, and tested. After the determination of a sowing area with proper sowing distance on the user interface, the robot starts sowing operation automatically. Firstly, the soil is dug. Then seeds are dropped into the dug area and a small amount of water is given by a nozzle. Finally, the dug area is closed with soil by the broom part of the robot. Thus, the single period of the seed sowing process is concluded. The robot location is always checked by a control algorithm to prevent possible deviations from the predetermined path.

2. System Design

2.1. Design and Functional Requirements

Table 1. Design Specifications

Max. length	500mm	**Min. operation time**	3 Hours
Max. width	400mm	**Field Feature**	Soil
Max. height	300mm	**Max Speed**	1 km/h
Max. weight	15 kg	**Communication**	wireless
Functions	Digging, Seeding, Spraying		

The design specifications, which are determined based on operational requirements, are given in Table 1.

2.2. System Block Diagram

Considering the design requirements, the system general block diagram is designed as shown in Figure 1.

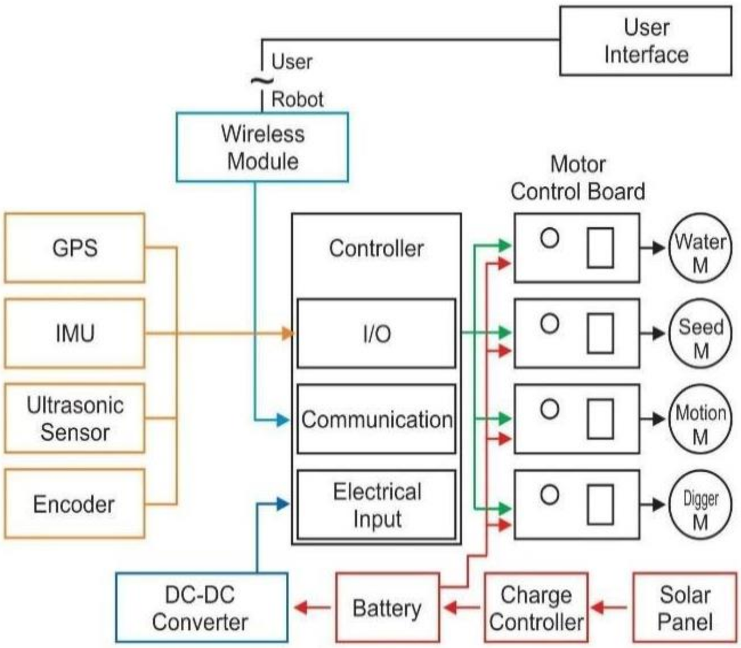

Figure 1. General block diagram

The robot starts its operation by the user command. At first, the robot takes the command from the user interface by communicating with the wireless module. The commands are processed in the controller to start the seed sowing process. The robot starts its operation depending on given commands and sensor information. Then, the robot digs the soil, drops seed to the dug area, sprays water, and closes the dug area. For these processes, electric motors and a pump are used. The battery meets the power requirement of the system. The sensors provide data about the system conditions.

2.3. Mechanical Design

2.3.1. Robot Chassis

The robot's chassis is a flat sheet as shown in Figure 2. On the chassis, there are holders for the motors, battery block control block, digging mechanism, and seeding mechanism. The thickness of the chassis and motor holders is 2 mm. For the outer shell, the plexi material is chosen.

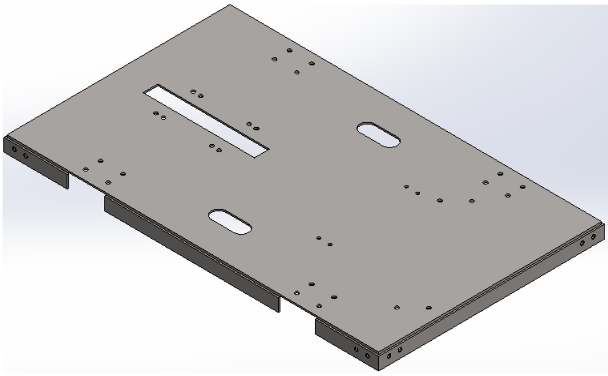

Figure 2. Robot chassis

The mechanical stress analyses are performed by using Solidworks Stress Analysis Toolbox for the chassis and flanges which are the most critical parts in the system. The analyses results for the chassis and flanges are given in Figure 3 and Figure 4, respectively. Considering that the maximum weight value is 15 kg, the obtained test results validate the mechanical design of the robot.

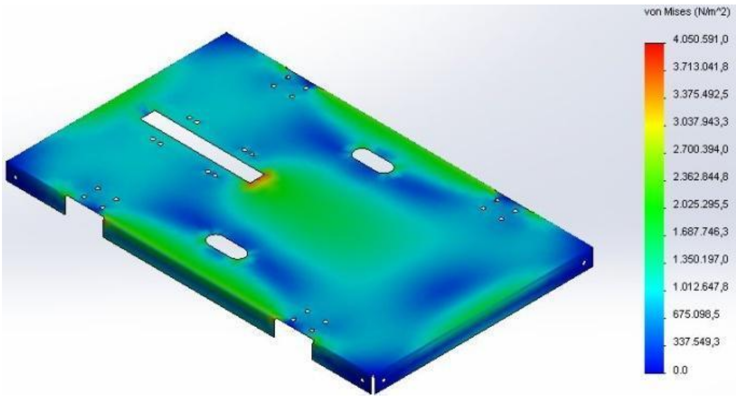

Figure 3. Analysis result for the chassis

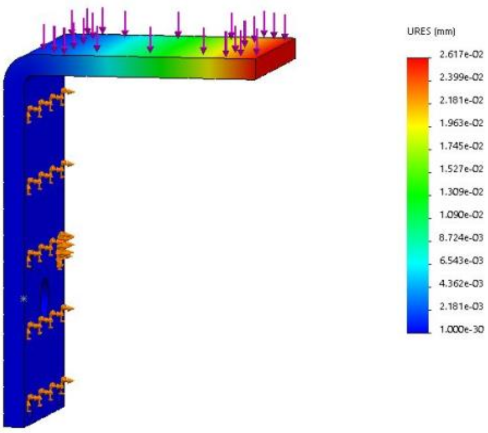

Figure 4. Analysis result for the flange

2.3.2. Digger mechanism

The main purpose of the robot is to perform effective sow seeding in the soil. When the robot reaches the target sowing point which is determined by the sowing algorithm, the mechanism shown in Figure 5 is driven by a DC motor, and the mechanism digs in the ground for the seed. The shape of the digger apparatus is designed to avoid extra soil force resistance. The width of the digger part (shown as blue) is 10 mm and its diameter is 120 mm.

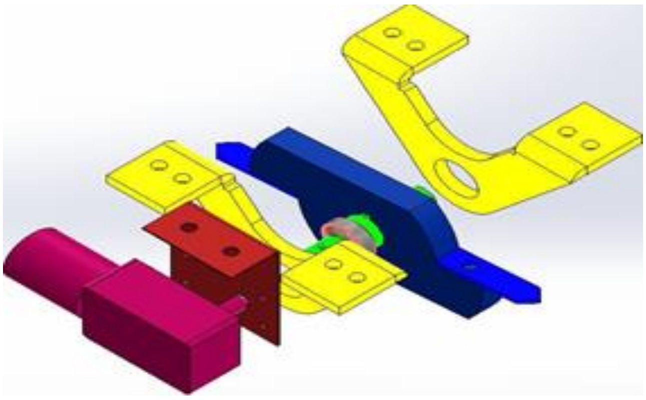

Figure 5. Digger mechanism

2.3.3. Seed Dropping Mechanism

After the digging process, the next step is to drop the seeds to the soil ground. For this purpose, the seed dropping mechanism given in Figure 6 is designed. Seeds are put in the tank. Thanks to gravity, each seed enters the places on the disk which are designed based on a single corn seed dimension. The disk is rotated to drop a seed by a shaft that is driven by a SG-5010 servo motor. All mechanical parts such as the seed tank and motor holder are produced from 1 mm sheet. For the seed disk, 5 mm plexi material is used.

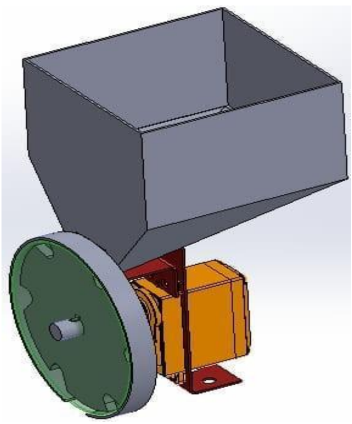

Figure 6. Seed dropping mechanism

2.3.4. Irrigation Mechanism

After the seed dropping process, 5 ml of water is sprayed onto the seed for irrigation purpose. The robot has a tank with a volume of 1 L. In each process cycle, it sprays 5 ml of water which is needed for seed. A water pump is used to draw water from the tank. The level of water in the tank can be monitored via the user interface.

2.3.5. Robot Drive Mechanism

Considering the general structure of agricultural fields, a skid-steer type drive mechanism is chosen for the robot as shown in Figure 7. By differentially driven with four wheels, high maneuverability can be obtained. The related torque and power requirements are calculated and a 12V 60 rpm geared DC motor is chosen for each wheel of the robot.

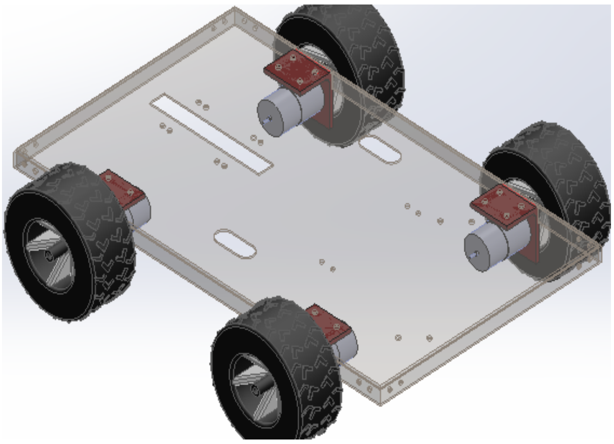

Figure 7. Four-wheel drive system

2.4. Electrical Design

Raspberry Pi 3 Model B + is used as a main controller in the robot. In addition to the wifi module and 4 USB ports of the device, the number of input-output ports is played a key role in the selection of this controller. Arduino Uno and L293D motor shields are used since they provide ease of use for driving DC and servo motors. Since a motor shield can drive up to 4 DC motors, 2 motor shields are needed. As a result, 2 Arduino Uno boards are used.

Four 12V 60 rpm DC motors provide the drive mechanism of the robot. SG-5010 servo motor is selected for the seeding mechanism. Also, a 12V 100 rpm DC motor is selected for the digger mechanism. Finally, a 6V mini water pump is selected for the irrigation mechanism.

The robot provides its electrical power from a 12V 7Ah battery. For the voltage requirement of 5V for the Raspberry Pi, a 12V-5V voltage regulator is used.

There are two HC-SR04 ultrasonic sensors on the robot. These sensors are used for the measurement of the water and the seed levels in the tanks. These level values can be monitored via the user interface.

IMU and GPS sensor are used for the localization of the robot. The location of the robot in the operation field can be monitored via the user interface.

2.5. Communication System

The communication system block diagram is shown in Figure 8. In this system, Raspberry Pi interacts with the mobile application on the cell phone and the IoT platform. Movement and actuator commands are transferred from the Android device to Raspberry Pi via TCP/IP protocol. Sensor data such as seed and water levels in the tanks are uploaded to the IoT platform and then forwarded to the user interface. Depending on the application commands, Raspberry Pi communicates with 2 Arduino boards via serial ports.

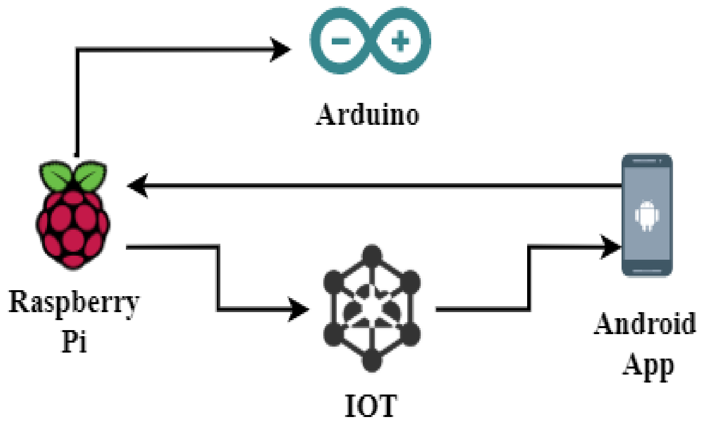

Figure 8. Communication diagram

2.6. Software Development

2.6.1. IoT Software

Thingspeak IoT platform is used for a free cloud service. 2 channels of this platform are used to inform farmers about seed and water levels. As it is shown in Figure 9, instant changes at the seed and water levels are visualized on the platform graphically and numerically.

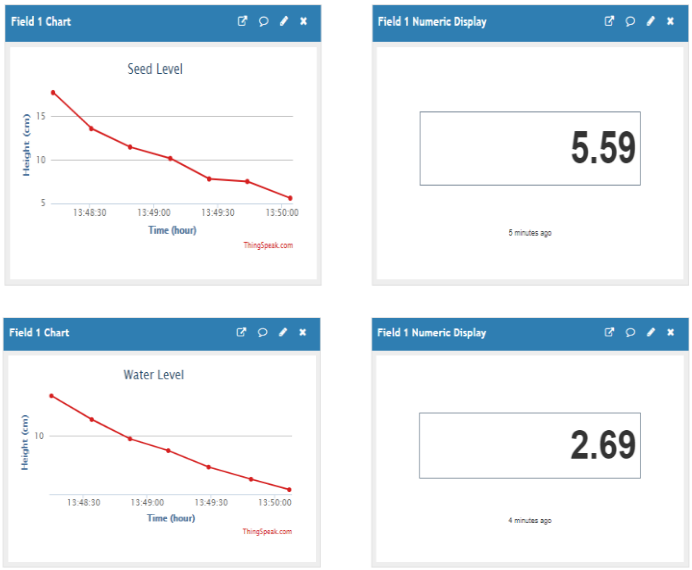

Figure 9. Representations of seed and water levels on the IoT platform

2.6.2. Mobile Application Development

Android app which is developed at MIT App Inventor enables users to control the robot and view the robot's data. There are two separate screens on the user interface. These are the manual control screen and the autonomous control screen as shown in Figure 10. Farmers can manually control the robot movements, the digger, seed dropping, and irrigation mechanisms via the manual control screen. Additionally, all sensor data can be monitored on this screen.

Figure 10. User interface

On the autonomous screen, farmers are able to choose the waypoints on the farm area for the determination of autonomous operation trajectory. Additionally, the number of successful seed sowing is visualized on the screen. The user can define the seed distances on the line and the distance between two lines. The corresponding waypoints are automatically generated for the autonomous seed sowing process and the related trajectory is sent to the robot.

2.7. Control System Design

The overall system control flow chart is shown in Figure 11. The control algorithm is run on Raspberry Pi Model 3+. This control algorithm includes two sub-algorithms which are the seed sowing control algorithm and the trajectory tracking algorithm. These algorithms are implemented by using Python language.

The seed sowing control algorithm is given in Figure 12. The aim of the seed sowing control is to provide sequential row type seed sowing operations.

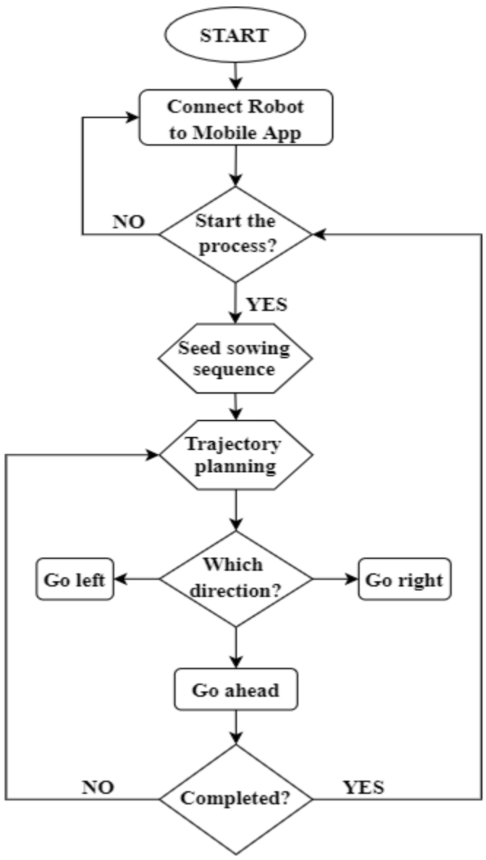

Figure 11. System control algorithm

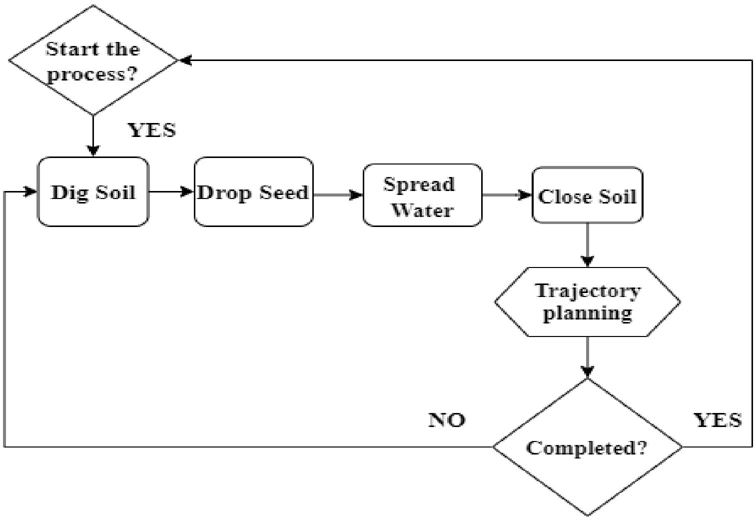

Figure 12. Seed sowing control algorithm

The aim of the trajectory tracking control is to keep the robot on the desired trajectory [14]. The robot's location is estimated by using the Kalman filter method [15]. GPS and IMU sensor measurements are used in the Kalman filter algorithm. To validate the trajectory tracking control algorithm, the simulation studies are done on MATLAB/Simulink environment. The example of obtained trajectory tracking performance is shown in Figure 13.

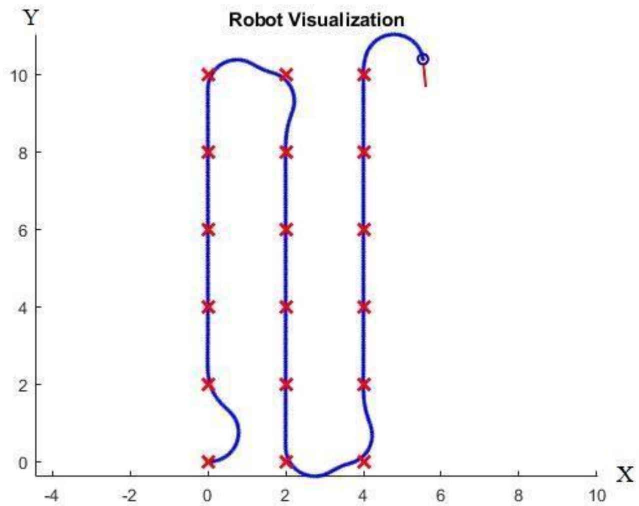

Figure 13. Robot trajectory tracking simulation

3. System Integration and Functional Tests

The final design of the system is shown in Figure 14. Considering this final design, the system mechanical parts are produced.

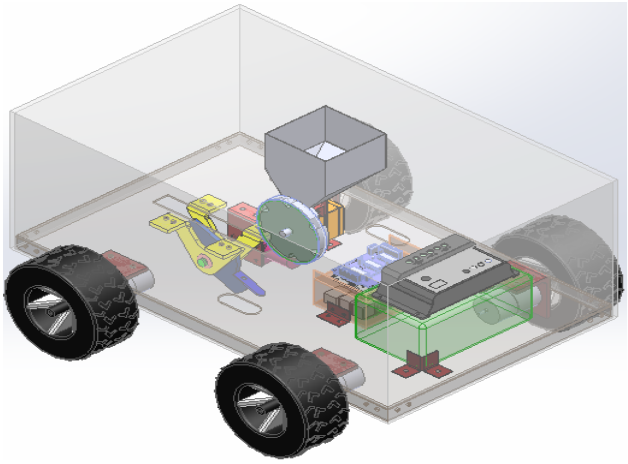

Figure 14. Final design

The produced and integrated subsystems are shown in Figure 15.

Figure 15. a) Digger mechanism b) Seed dropping mechanism

The overall system integration is performed as shown in Figure 16.

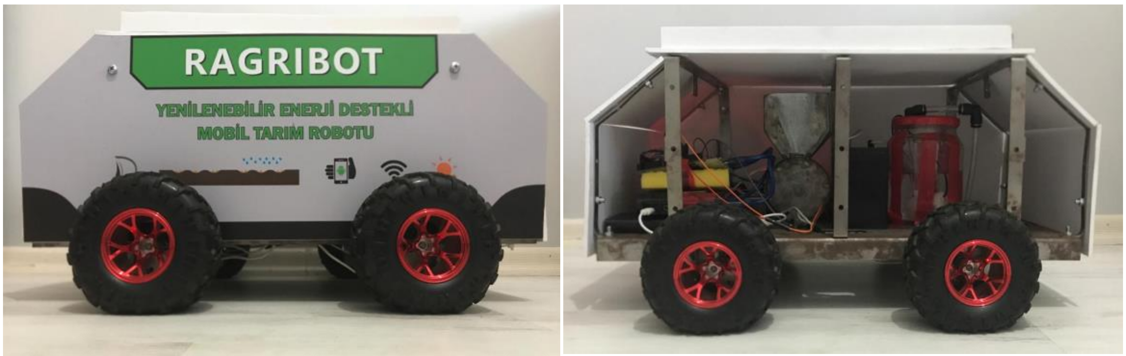

Figure 16. Overall system integration

The functional tests of the drive system are performed on the ground with 15° incline. The functional tests of the digger mechanism and the seed dropping mechanism are performed in XXX University XXX Laboratory by using a specially designed soil platform. In these functional tests, it is observed that all subsystems meet the desired design criteria. Sample images from the functional tests are given in Figure 17.

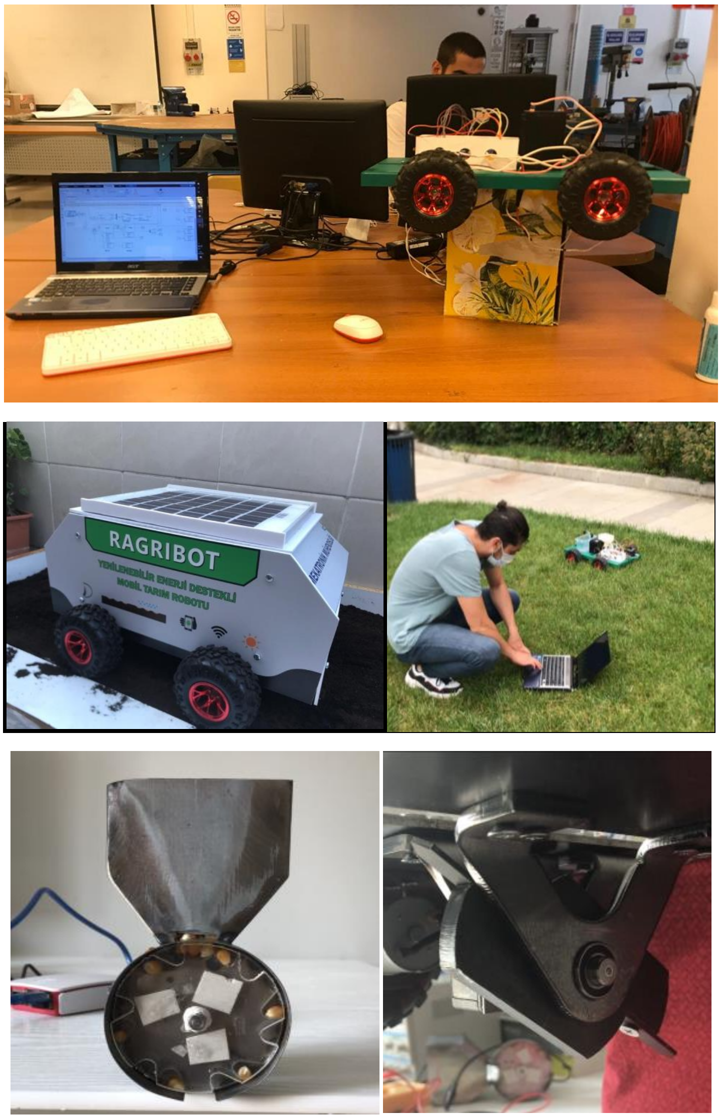

Figure 17. Sample images from functional tests

4. Conclusion

In this study, the development of an agricultural robot which has row type seed sowing feature is presented. The robot can be controlled remotely via the developed android application. Alternatively, the robot can operate in an autonomous mode by following the trajectory determined on the user interface. By using this agriculture robot, seed sowing applications can be done simply, effectively, and eco-friendly. System design and system integration processes are concluded. The outer shell of the robot is produced and integrated. The functional tests of the subsystems are performed successfully. The field tests for the autonomous drive mode are ongoing.

In future studies, weeding and crop detection features based on the image processing method will be added to the robot.

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