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Article

Hardware Software Co-Design of a Farming Robot

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Abstract. Food means life and no one can think about living without food. This is the most fundamental human necessity and food security is one of the major global concern of this century. With the revolution and recent advancements in the field of electronics and communication, there has been a paradigm shift from conventional farming ways to the modern one. This paper talks about the development of hardware software co-design of agricultural farming robot. Our developed farming robot has two parts namely hardware part which further consists of mechanical, electrical, control and tools segments and the software part which allows user to interact with the farming robot via cloud service. Our proposed hardware architecture is compatible with commercial Farmbot product and the developed web-based software can be extended for more features and applications. Furthermore, the developed robot has been tested and it works well.

Keywords: Robots, agriculture, co-design, automation.

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1. Introduction

Food is the most important living being necessity. "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" is the second sustainable development goal of United Nations (UN) by 2030 [1]. Despite untiring efforts both at regional and global level, more than 790 million people worldwide still suffer from hunger. It is safe to say that food security is one of the biggest global concern and this concern is also increasing with the increase in human population. Agricultural land is being converted into colonies and cities in order to accommodate the growing housing need. Countries like Thailand, Pakistan, India etc. where majority of the work force is associated with agriculture contributes less than 10% of the gross domestic product (GDP) to the country's economy. This is an alarming situation and with the unprecedented growth in human population, modern technologies should be used in agriculture sector in order to increase the growth of this sector in terms of yield and revenue [2].

There has been a paradigm shift in the use of technology in agriculture sector in the last decade, however, farmers from the developing countries are still lacking in modern tools usage primarily because of cost, unavailability of products in local market and lack of education. Human force is generally used for all the steps of crop growth starting from sowing, irrigation, monitoring the growth, pest control till harvesting. In order to cope up with the demand of food ingredients and enhance the economic returns, it is necessary to adopt autonomous/semiautonomous systems which can help and assist humans to have more productivity. There have been many success stories around the globe where robots are used to pick citrus fruits in United States, harvest tomatoes and pick up strawberries in China, picking dates from palm tree in Kingdom of Saudi Arabia, sowing rice by robots in Japan and irrigating crops autonomously in many parts of the world [3]. Apart from it, drones are being used for aerial monitoring of crops growth and looking for pests. Machine learning is being used in-conjunction with the vision sensors to predict the outbreak of pests in the fields, detect the moisture level and many other parameters [4]. Automation of farms systems include agricultural robots, specialized sensors, real-time kinematics and internet of things (IOT) based setups. [5-10]. Talking more about these systems, the task is to control the application specific fertilizers, pest/water sprays, seed planters, fruit/vegetable picker, with the help of machine vision, cameras, range and distance sensors and actuators. Minimizing the hardware cost while maintaining reliability and redundancy in addition to user friendliness of the device is a key design challenge. Main systems of autonomous/semiautonomous robots are shown in Fig. 1 [7].

Farm robots are getting a lot attention these days because of their several advantages over manual system [5-9]. This work is an extension of our previous works [14-15]. In this paper, we have presented a hardware software co-design of a farming robot which has the ability to grow multiple types of crops in the soil bay and this idea was inspired by Farmbot [16-17] - a commercial open-source software and hardware platform for automatic farming robots[]. Additionally, seeding and plant watering are carried out automatically and efficiently throughout the crops life cycle virtually without using human labor. This work aims to build our own hardware prototype from scratch and yet compatible with the software platform of Farmbot. In order to accomplish these tasks, mechanical, electrical and control systems for the farming robot has been developed. The farmer (user) can control the farming robot from a computer via local network and customized the plan for growing the crops can be fed to it.

The rest of the paper is organized in the following manner. Section 2 talks about the overall system architecture followed by the hardware architecture of the farming robot in Section 3. Software architecture is discussed Section 4. Results and additive advantages of our designed farming robot are debated in Section 5 followed by the conclusion in Section 6.

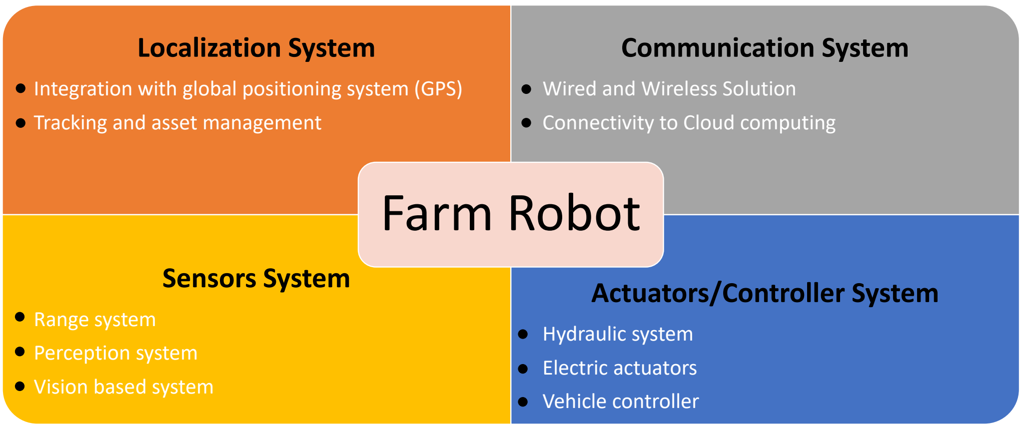

Fig. 1. Typical systems inside an agriculture robot.

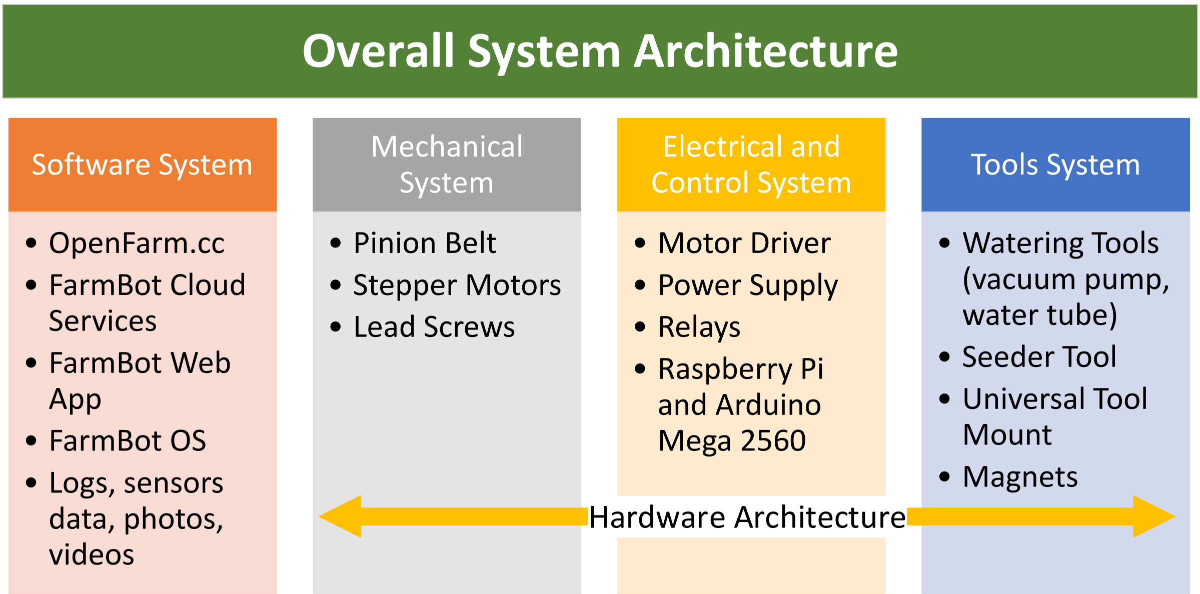

Fig. 2. Overall system architecture of a farming robot.

2. Overall System Architecture of a Farming robot

The overall system architecture consists of the hardware and the software being used. Owing the complexity, it is better to visualize the system as shown in Fig. 2 and the details of each part will be discussed in the subsequent sections.

Various systems (mechanical, electrical, control and tools) can be controlled with the help of software system and the details of the software architecture will be discussed in Section 4. Overall structural dimensions of the farming robot is shown in Fig. 3. The whole system is 1 meter in length, 0.7 meter in width and about 0.8 meter in overall height.

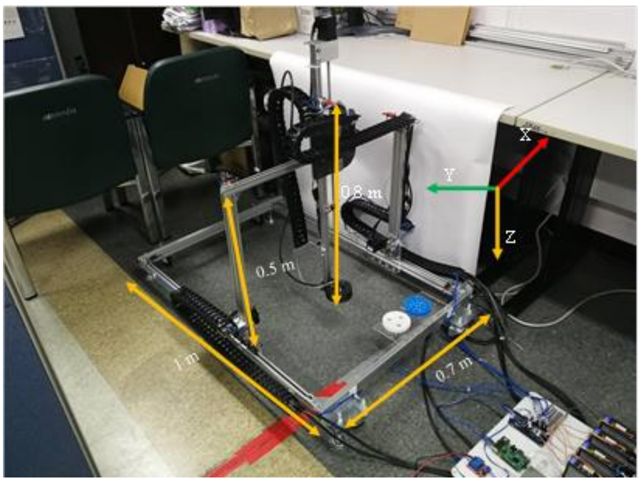

Fig. 3. Structural dimensions of a farming robot.

3. Hardware Architecture of Farming robot

As shown in Fig. 2, the hardware part of the farming robot consists of three main parts namely mechanical, electrical and tools & control part and we will be discussing each part in detail in the subsequent section.

3.1. Mechanical System

Our proposed farming robot, is in terms of mechanical structure, is primarily based on three-dimensional Cartesian coordinate system namely X axis, Y axis and Z axis. This means that our mechanical structure can move in these coordinates. The movement of X and Y axis is governed by "Pinion Belt" mechanism which fixes the belt with the track and allow motors to move along with the construction along the track. Pinion belt mechanism is very useful for linear motion application as of ours. The Pinion Belt mechanism, as shown in Fig. 4, was chosen because of its flexibility to adjust the belt length, lower cost of the belt and the lower cost of maintenance. The drawback of this mechanism is that it is not very precise, however, the precision is enough to operate the system when used with the stepper motor with encoder [18].

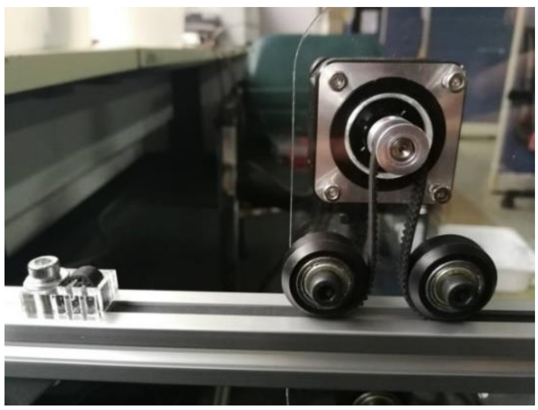

Fig. 4. Pinon belt mechanism for our farming robot structure.

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For Z axis the "Lead Screw" mechanism is used for up and down movements which needs to be a lot more precise than Pinon belt. A lead screw has a thread optimized for reducing friction and is used frequently in many applications. Precise positioning and non-overhauling can be obtained with a shorter lead, however, the main downside of lead screws is that they are mechanical inefficiency converting 20% to 80% of the applied torque into linear thrust and rest of the energy is wasted in the form of heat [19]. Furthermore, in our proposed scheme, the lead screw mechanism is made self-locking as well which will prevent any accident or damage to the crops. The lead screw mechanism is shown in Fig. 5. Figure 5(a) shows the motor of the linear stage which is connected to lead screw with a coupling. Motor is used to drive the lead screw. Figure 5(b) is the nut of the lead screw which is used to mount the tool and is also responsible for its vertical movement.

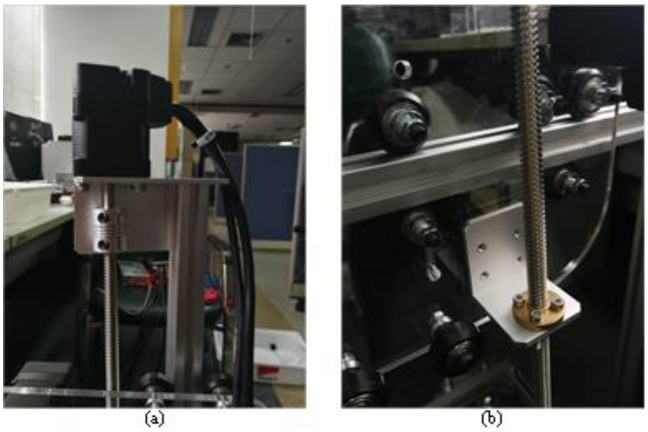


Fig. 5. Lead screw mechanism: (a) Top and (b) Bottom view.

3.2. Electrical and Control System

For the system to operate in three independent axis, four step motors are employed, two of which are used for the motion in X axis, one is on the top of the gantry for movement in the Y axis and another is installed at the top to drive the lead screw, perpendicular to the gantry. Each motor is driven by a separate Sanyo Denki motor driver SANMOTION PBM0007846D using PWM technique with 12 volts power supply. Each stepper motor (as shown in Fig. 6) has 500 steps per revolution which is set at the motor driver. 32000 steps per second speed is used in all axis with 1000 steps per second acceleration and deceleration for smooth movement.

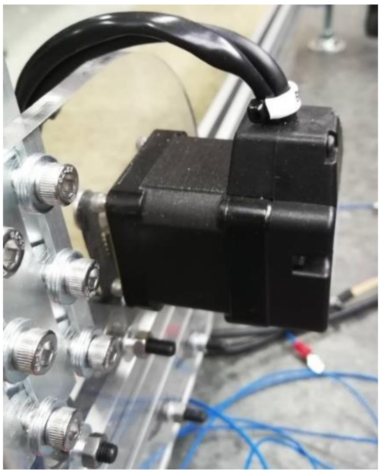


Fig. 6. External view of stepper motor.

An Arduino Mega 2560 board as (shown in Fig. 7) is responsible for the simultaneous control of all four motor drivers. This facilitates the universal tool mount to move in any desired location with any tools including the watering tool and the seeder. In addition, the Arduino board is used to control two solenoid valves for the watering tool and a vacuum pump for the seeder, and these tools are controlled through relays. The overall electrical and control segment is shown in Fig. 7.

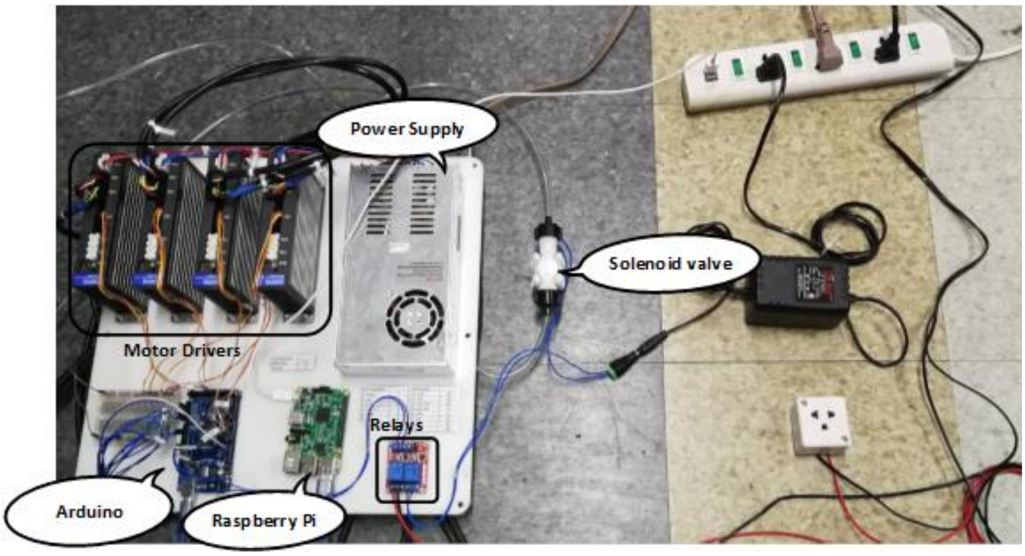


Fig. 7. Overall electric and control system.

For control calibrations, limiting switches are installed at both ends of each axis as shown in Fig. 8, allowing the system to calculate the farm space. All switches are connected to the Arduino board. The system consists of many wires such as the step signal, direction signal, limiting switch signal and power supply wiring. All wiring can be concluded in a wiring diagram as shown in Fig. 9. Plastic cable holders are used to hold all the wiring needed. The holders move with the mechanism, but they are rigid enough to hold their own weight with some additional support.

Fig. 8. Installation of limiting switch.

3.3. Tools System

Our tool set consists of a universal tool mount, a seeder tool and a watering tool. The universal tool mount is fixed at the lower end of the Z axis and can be moved around the farming area according to the control command received. The seeder and watering tools are placed on a tool holder plate fixed on the aluminum profile frame. All tool parts are made by 3D printing method, using ABS plastic with 20 percent density.

The watering tool and the seeder tool design is shown in Fig. 10. It can be firmly attached to the universal tool mount according to the three magnets as presented in Fig. 10 (b). The watering tool and the seeder tool designs are basically the same; consists of three holes for mounting magnets, another three holes made to be compatible with the universal tool mount which has the project tubes, and nine holes reserved for the purpose of sensor in the future.

The water source for the watering tool and the vacuum pump for the seeder tool are connected to the tool function using water tube and vacuum tube respectively and is controlled using Arduino Mega 2560 Microcontroller through active high relays. The control system for the tool function is shown as Fig. 11. From designs, the watering tool is recommended using with 3/16" tube with connector, which could release satisfying amount of water and could prevent leakage. The smallest size of seed that the seeder can deliver without slipping into the tube is about 2 mm diameter.

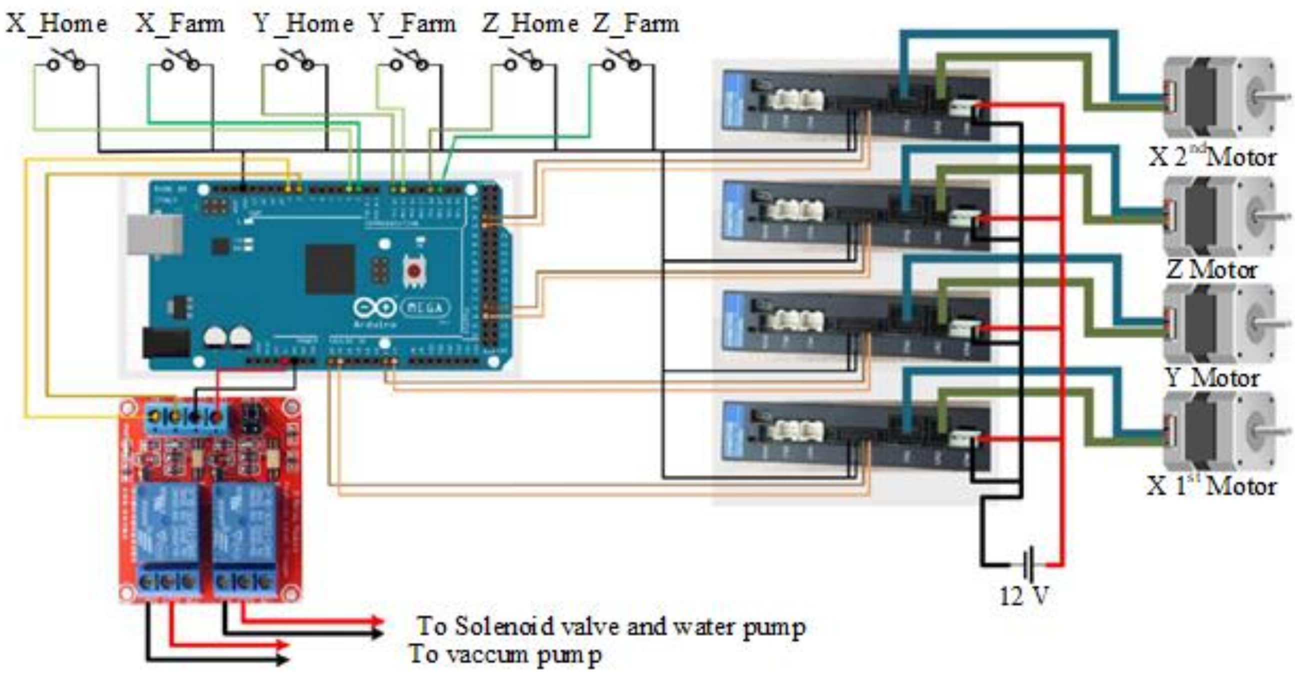


Fig. 9. Connection among various peripherals.

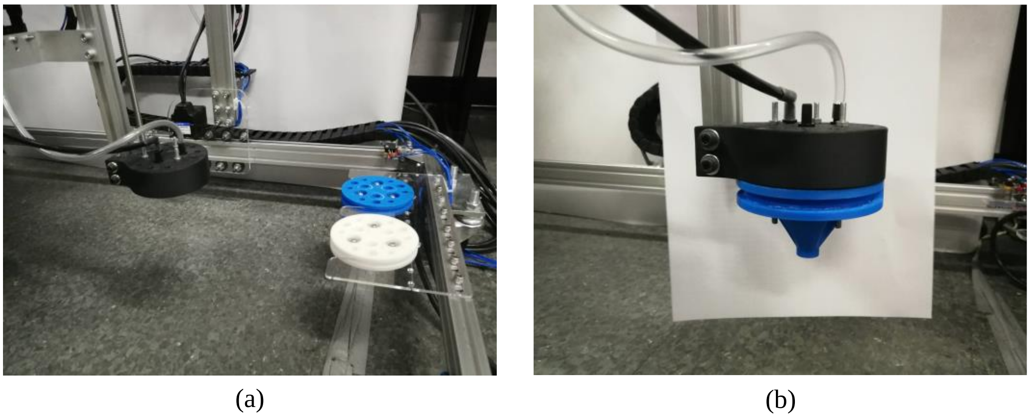


Fig. 10. (a) Watering and seeder tool; (b) Watering tool mount with universal tool mount.

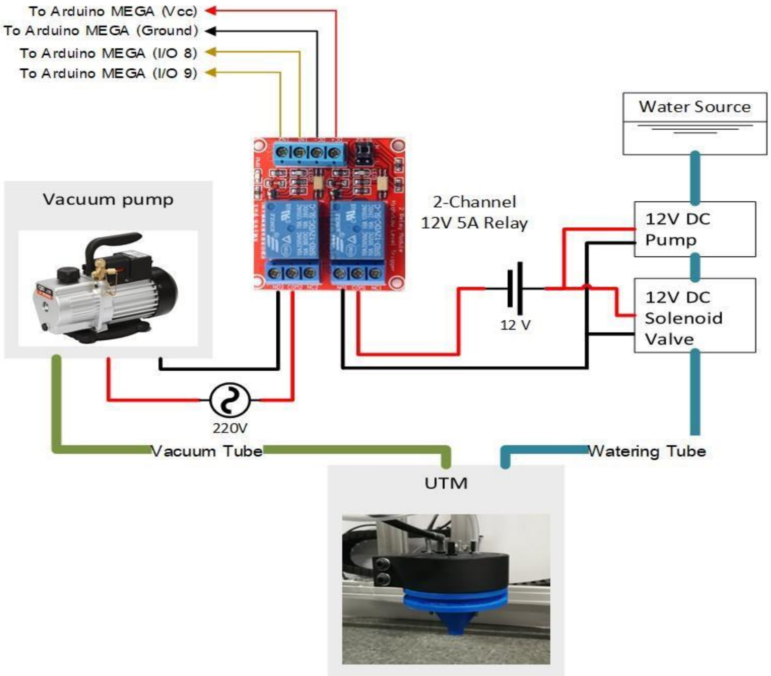


Fig. 11. Overall structure of tool control.

4. Software Architecture of Farming robot

4.1. Overall Software Architecture

The overall software architecture and its hardware co-design is shown in Fig. 12. There are three main components in it. The first one is the development of graphical user interface (GUI) which is used to control and govern the farming robot. Details about the GUI will be discussed in Section 4.2. User is not directly connected with the farming robot but with the help of cloud service. These services are provided by Network Platform for Internet of Everything (NETPIE). So the instructions are routed from the user to the farming robot via NETPIE. The farming robot has two main components. The first one is the Raspberry Pi which is working as a server. Clients can connect to IP of this Raspberry-pi in order to communicate. The raspberry-pi sends commands to the Arduino (the second part of farming robot) which is responsible for motions of the farming robot's motors. Arduino board is facilitating the function of simultaneous control of all four linear bipolar motor drivers. The universal tool mount has the ability to move to any desired location carrying the watering and seeding tools. Furthermore, the Arduino is also responsible to control the solenoid valves for the watering tool and a vacuum pump for the seeder.

Initially, the program builds a connection between Raspberry-pi and Arduino. These two board communicated with each other via serial communication. Python serial library is added first and then Arduino's port is defined which establishes a connection. Then, the Raspberry-pi (which is acting as a server) has an IPv4 address. The program assigns an IP address to the server and the port 8000. The server has a provision to establish connection with the number of clients simultaneously.

Once connection is established, client is ready to send the signals to the Raspberry-pi over the local network. Finally, using a loop, we make our server to receive commands from clients iteratively otherwise the server can take only one command and get close. Unicode character encodings “UTF-8” is used for encoding the inputs.

4.2. Development of Graphical User Interface

In order to control the farming robot remotely, we developed a self-explanatory GUI which is shown in Fig. 14. Python language is used to develop this GUI. Our developed GUI has a base window (as shown in Fig. 14(a)) which refers to our virtual farm. This window can be adjusted in a ratio of actual farm’s width and length. The user can plan the farm crops using the GUI and various type of crops can be sown in the farm. The grid line refers to the location of actual farm. The GUI also gives liberty to the user to delete or move some vegetable/fruit to some other location. When the user has selected the crops, then user has to place them on the grid and click on “plant” and “watering” button to plant and giving water to the crops. These actions made on GUI will instruct the farming robot to perform these operation in actual. The overall process of farming robot program is shown in the class diagram as per Fig. 15.

5. Results

By automating the farms, countless advantages can be achieved in terms of avoiding human labour in harsh weathers, precision, remote monitoring and so on. Our developed farming robot can work by using local network in contrast with open source web application which requires internet connection and the our developed web application as long as the system connected with the Internet. Furthermore, it is convenient and easy to develop additional features, optimize the already existing features of the developed Farming robot as compared to the conventionally used open source farming robot.

The complete developed system has been tested and is reported to work precisely. All the mechanical, electrical, control and tool systems have been developed from the scratch which gives liberty to the developers to further enhance the performance of the developed farming robot in future.

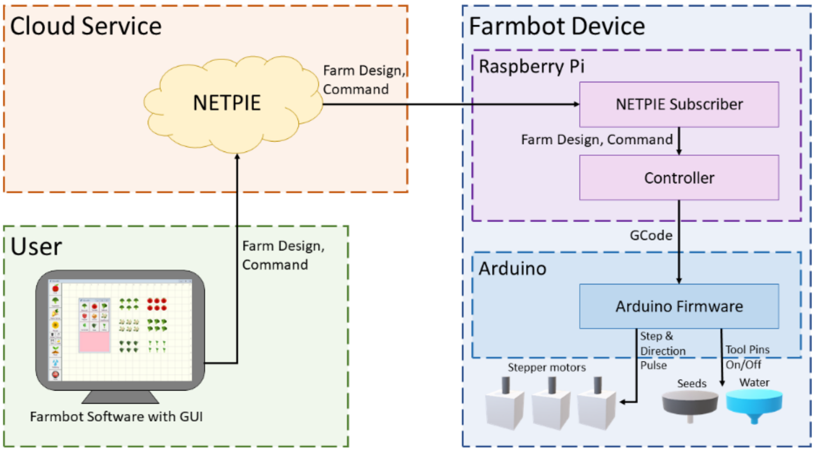
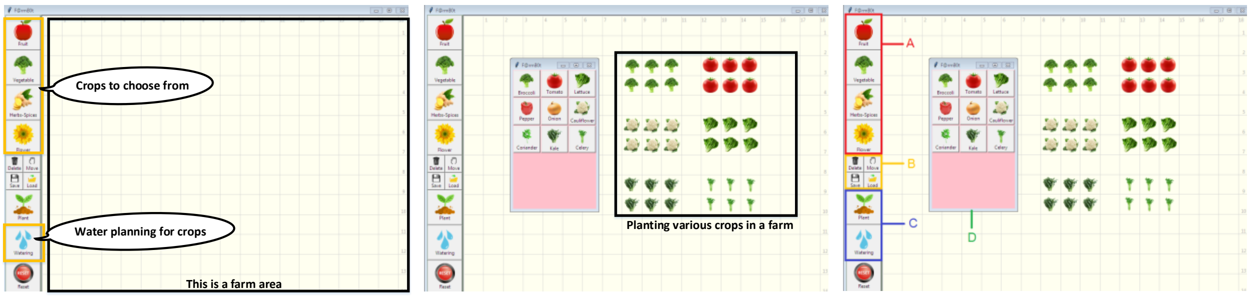


Fig. 13. Overall software architecture of developed Farming robot.



(a) (b) (c)

Fig. 14. Development of graphical user interface.

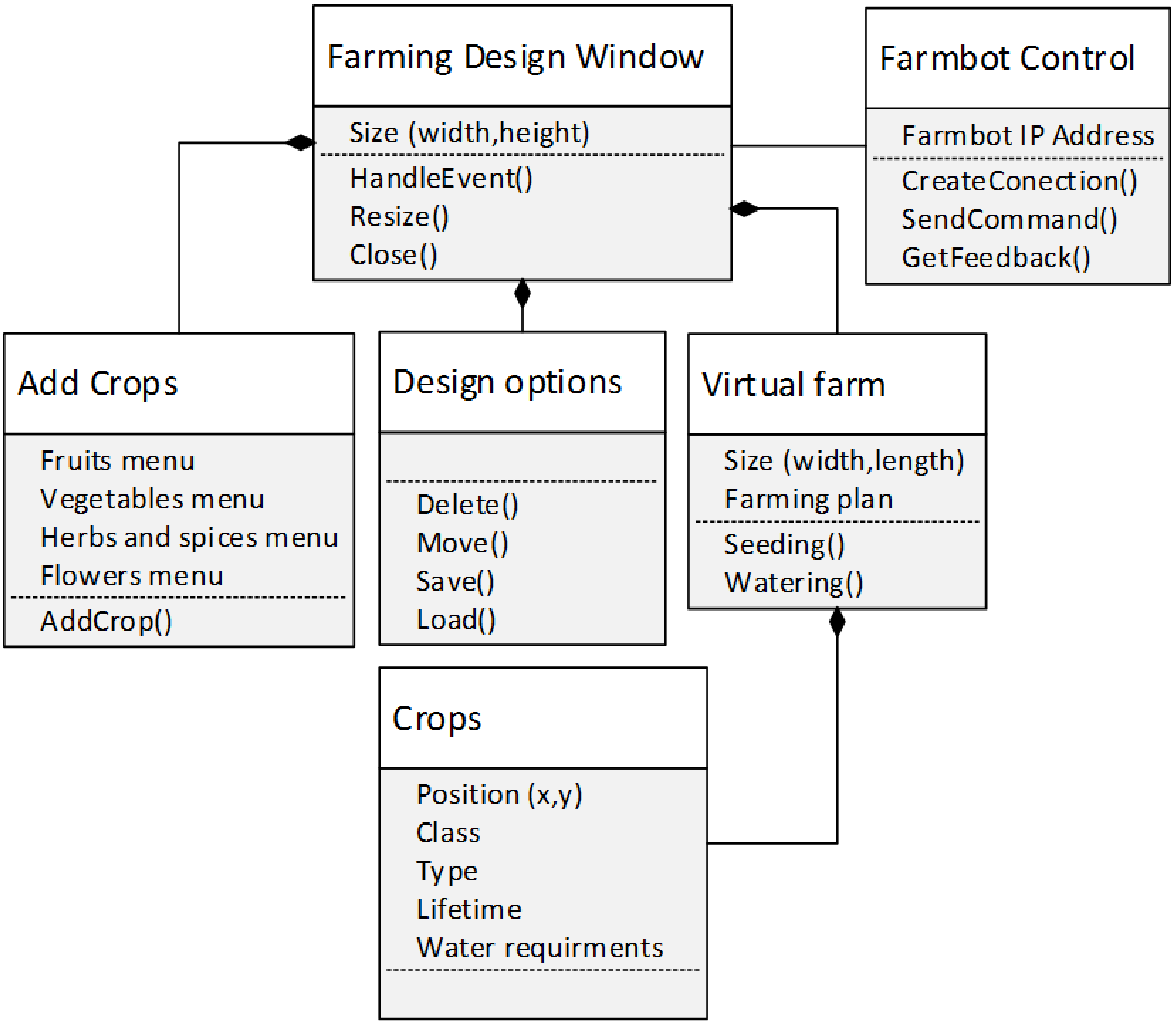


Fig. 15. The class diagram of farming robot program.

6. Conclusion

This paper presents the design and implementation of farming robot which can be controlled from the smart device. The software design of the farming robot primarily consists of two main parts i.e. GUI development and communication among the user and various hardware entities which includes mechanical, electrical, control and tools components. As far as communication part is concerned, we use cloud services to build a connection between the user and the farming robot via NETPIE. The GUI is developed using Python. The GUI gives freedom to the user to plan the vegetation of various fruits and vegetables in a farm. Once the plan is done, it can be loaded and with the command "plant" it will send the instructions to the farming robot to plant the planned crops in actual. Watering of the crops can also be done via passing the commands from the GUI to the farming robot. The proposed system has several advantages over open source web applications such as reduced latency, connection establishment via local network and further optimizing the prototype in future.

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References

[1] A.D. Jones and G. Ejeta, "A new global agenda for nutrition and health: the importance of agriculture and food systems," *Bulletin of the World Health Organization*, 94(3),2016, pp.228.

[2] R. Kuijpers and J. Swinnen, "Value chains and technology transfer to agriculture in developing and emerging economie," *American Journal of Agricultural Economics*, 2016, pp.1403-1418.

[3] S.S.H. Hajjaj and K.S.M. Sahari, "Review of research in the area of agriculture mobile robots," *In The 8th International Conference on Robotic, Vision, Signal Processing & Power Applications*, Springer, Singapore, 2014, pp.107-117.

[4] A. Milioto, P. Lottes, and C. Stachniss, "Real-time semantic segmentation of crop and weed for precision agriculture robots leveraging background knowledge in CNNs," *In 2018 IEEE International*

DOI:10.4186/ej.2020.24.1.199

Conference on Robotics and Automation (ICRA), IEEE, 2018, pp. 2229-2235.

[5] B. Åstrand and A.J. Baerveldt, "An agricultural mobile robot with vision-based perception for mechanical weed control," *Autonomous robots*, 13(1), 2002, pp.21-35.

[6] M. Li, K. Imou, K. Wakabayashi, and S. Yokoyama, Review of research on agricultural vehicle autonomous guidance. *International Journal of Agricultural and Biological Engineering*, 2(3), 2009, pp.1-16.

[7] L. Emmi, M. Gonzalez-de-Soto, G. Pajares and P. Gonzalez-de-Santos, "New trends in robotics for agriculture: integration and assessment of a real fleet of robots," *The Scientific World Journal*, 2014.

[8] [8] Sundmaeker, H., Verdouw, C., Wolfert, S. and Pérez Freire, L., 2016. Internet of food and farm 2020. Digitising the Industry-Internet of Things connecting physical, digital and virtual worlds. Ed: Vermesan, O., & Friess, P, pp.129-151.

[9] S.R. Rupanagudi, B.S. Ranjani, P. Nagaraj, V.G. Bhat, V.G., and G. Thippeswamy, "A novel cloud computing based smart farming system for early detection of borer insects in tomatoes," *In Communication, Information & Computing Technology (ICCICT), 2015 International Conference on IEEE*, 2015, pp. 1-6.

[10] S. Wolfert, L. Ge, C. Verdouw, and M.J. Bogaardt, "Big data in smart farming–a review," *Agricultural Systems*, 153, 2017, pp.69-80.

[11] O. Vermesan, A. Bröring, E. Tragos, M. Serrano, D. Bacciu, S. Chessa, C. Gallicchio, A. Micheli, M. Dragone, A. Saffiotti, and P. Simoens, "Internet of robotic things: converging sensing/actuating, hypoconnectivity," *Artificial Intelligence and IoT Platforms*, 2017.

[12] H. Burema, and A. Filin, Bee Robotics Corporation, 2016. "Aerial farm robot system for crop dusting, planting, fertilizing and other field jobs," *U.S. Patent* 9,382,003, 2016.

[13] T. Geller, "Farm automation gets smarter," *Communications of the ACM*, 59(11), 2016, pp.18-19.

[14] J. Tangmongkhonsuk, A. Meena, P. Sasithong et al., "Development of a Software Program for Automatic Cartesian Farming Robot," *2nd International Conference on Advanced Information Technologies (ICAIT)*, Yangon, Myanmar, 2018.

[15] Y. Monplub, N. Intaratanoo, C. Wichitphan et al., "A Prototype of Automatic Cartesian Farming Robot," *International Technical Conference on Circuits/Systems, Computers and Communications* (ITC-CSCC), 2018.

[16] Farmbot Official Website [Online], 2014 [Accessed: August 2018], Available: https://farm.bot/

[17] Intro to FarmBot Genesis [Accessed: October 2018] Available https://genesis.farm.bot/docs.

[18] N. Sclater and N.P. Chironis, *Mechanisms and mechanical devices sourcebook* (Vol. 3). New York: McGraw-Hill, 2001.

[19] K.K. Varanasi, and S.A. Nayfeh. "The dynamics of lead-screw drives: low-order modeling and experiments," *Journal of dynamic systems, measurement, and control*, 126(2), 2004, pp.388-396.

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