Prototype of a watering autonomous mobile robot for mini greenhouse with manipulator and computer vision

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Abstract. The development of a watering autonomous mobile robot capable of performing intellectual labor functions in place of humans is a pressing task in the fields of robotics and bioinformatics. These robots can be widely utilized in precision agriculture to conserve resources, particularly in the area of optimal plant irrigation. In the context of global urbanization, this study is dedicated to the development of a watering autonomous mobile robot for mini greenhouses. This robot is integrated with microelectronics and micro-automation systems. A prototype robot equipped with a manipulator and computer vision system was created. The developed irrigation schedule and planting methodology enable efficient resource utilization, increased crop yield, and reduced labor costs. Such an approach holds significant practical value for urban agriculture.

1 Introduction

Urban greenhouse farming is becoming increasingly significant as the demand for fresh produce grows in megacities such as New York, London, and Shanghai. Almaty is now joining this trend by cultivating lettuce in urban greenhouses. Unused spaces in residential buildings and offices offer excellent opportunities for the development of greenhouse agriculture, contributing to the resolution of environmental problems. Mini-greenhouses, especially those that operate autonomously and remotely, can not only generate additional income for owners but also provide sustainable solutions for urban cultivation. Special attention is given to the economic efficiency and practicality of new technologies, including intelligent robotic systems. Research on initial investments and long-term economic indicators highlights their importance. The adaptation of technology to different conditions and scalability play a key role in ensuring the sustainability of urban food systems and efficient resource utilization.

Thus, the implementation of intelligent robotic systems can significantly impact the resilience of urban food systems by enhancing access to fresh products and reducing water and energy consumption. Previously, researchers from foreign countries have developed AI-enabled watering robots with manipulators and video surveillance systems to enhance productivity and resource utilization efficiency in agricultural enterprises. The existing

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watering robots have been developed using various technologies. For instance, the design of a prototype mobile intelligent watering robot for a mini-greenhouse with a manipulator and video surveillance system can be based on several key parameters identified in previous studies. Jiahui Li [2] and Lysenko [3] emphasize the importance of a control center: Li utilizes STM32F4, while Lysenko suggests using the ROS software framework. The use of Li's proposed soil moisture sensor is also crucial for the irrigation function. Mosalanejad [4] presents a navigation system that includes ultrasonic sensors and proportional control mechanism. Ye [5] presents the concept of a deformable water mobile robot, which has the potential to be adapted for mini-greenhouses. Su [6] focuses on a home monitoring system using a mobile robot, and Chand [7] develops an intelligent agricultural robot powered by solar energy and batteries for irrigation and pesticide spraying. On the other hand, researchers from the People's Republic of China, Saike Jiang et al. [8], have developed an autonomous navigation system for a greenhouse mobile robot based on 3D Lidar and 2D Lidar SLAM. The hardware mainly consists of 3D Lidar, IMU, odometer, and encoder. The control level software was developed based on ROS, and the information interaction was implemented through a distributed communication node. To enhance the robot's safety during movement and reduce the computer's energy consumption, the three-dimensional environmental information collected by the multi-line Lidar was filtered and transformed into two-dimensional laser information. Similarly, authors from Indonesia, B. Widiawan et al. [9], have developed a wireless control system for a mobile robot for remote monitoring of greenhouse conditions. The mobile robot is equipped with two DOF manipulators for controlling the monitoring camera, as well as temperature and humidity sensors connected to a Raspberry Pi controller. VNC technology is used for remote access. Furthermore, the work of M. Polic and his team [10] should be noted, as they have developed a robotic manipulator equipped with an RGB-D camera and soil moisture sensor, capable of assessing soil moisture conditions for planning optimal greenhouse irrigation strategies. In the recent past, Agus Suwandi and his colleagues developed and tested a mobile robot for automatic plant watering. It is controlled via Bluetooth using a smartphone. The authors used the App Inventor platform to create the user interface and Arduino Uno as the controller. The testing results showed that the robot successfully performs watering tasks with an average delay of 1 second and a maximum operating radius of 5 meters [11].

Our approach, which combines FPV technology and Raspberry Pi, offers clear advantages such as increased operational flexibility, real-time response, and reduced computational requirements, making it particularly suitable for dynamic environments where adaptability and instant feedback play a significant role. This methodological innovation not only demonstrates the potential for more efficient resource utilization but also opens new avenues for practical applications of robotics in various conditions, making a significant contribution to this field.

The goal of this study is to develop and test a prototype of a robotic system for automated control of urban mini greenhouses, with the aim of maximizing the efficient use of water and energy resources while ensuring high crop yield with minimal labor costs. Within the research framework, we plan to explore the possibilities of integrating artificial intelligence and machine learning to optimize plant care processes, including watering, fertilization, and regulation of climatic conditions inside the greenhouse. Special attention
will be given to the development of algorithms for plant condition recognition using data obtained from video surveillance systems, in order to timely detect and prevent plant diseases and pests.

The use of robotic systems will not only reduce resource consumption but also improve the quality of products by ensuring precise adherence to agronomic requirements.

During the study, we plan to develop software for controlling the robotic system, including a user interface for real-time monitoring and management of processes in the mini greenhouse. Additionally, we will explore the possibility of integrating the system with mobile applications and cloud services to enable remote management of the mini greenhouse from anywhere in the world.

2 Materials and methods

The scientific-practical approach to the development of a robotic complex for mini-greenhouses aims to create an artificially intelligent robot that will utilize single-board computers. The goal is to create a safe and reliable robot for use in domestic settings. The robot will have the ability to exchange data through the internet and will be equipped with mobility, sensory visual perception for object recognition, multi-position manipulators for task execution, and an emergency stop function. The main task of the robot is to move accurately along a given trajectory for efficient operation in the greenhouse, utilizing modern location and control technologies.

The main feature of this intelligent control system is computer vision-based neural network image recognition, which allows for rational control of autonomous agricultural machinery movement across the field. In the limited space conditions of mini-greenhouses containing trays and pots of urban plants, a more rational method of precise control over the robot-sprinkler's trajectory is required. Among them is the method of recognizing changes in infrared (IR) radiation using two IR sensors. The functional scheme of the First Person View (FPV) robot-sprinkler is shown in Figure 1 below.

![Functional diagram of agro-robot with manipulator and video camera, and connection to Raspberry Pi mini-PC, electric actuators of the crawler chassis and video camera for FPV robot trajectory control.](image)

As shown in Figure 1, the distinctive feature of controlling an FPV irrigation robot lies in the utilization of online video imagery to select the correct path for plant watering. This control technology is widely applied in managing modern autonomous quadcopters. The video camera transmits real-time imagery through wireless communication channels or the internet, positioned ahead of the robot. The operator adjusts the robot's trajectory based on the imagery displayed on their smartphone screen. The same FPV control technology is
employed in the case of a ground-based crawler irrigation robot. An application called VNS RaspController exists for the Raspberry Pi 4 mini-computer, which simplifies the implementation of this control technology for the irrigation robot. The application also facilitates the connection of a web camera for transmitting imagery to the Raspberry Pi 4's Python 3 compiler.

In the case of using an android robot as a plant irrigator in a mini-greenhouse, the irrigation functionality needs to be integrated into the robot's computer. A water backpack will serve as the water reservoir, while the robot's manipulator arm will be used for watering, and QR code recognition will be entrusted to machine vision. The android robot will move along the trajectory with the assistance of leg manipulators. This will enable the android robot to function almost like a human, with the exception of fatigue from repetitive work, ensuring accuracy in irrigation and flawless adherence to the operator's program. By altering the program, the android robot can be reoriented to work as a waiter or dishwashing machine. However, the cost of an android robot may present a barrier, whereas hiring workers such as gardeners, waiters, or dishwashers in developed countries would be considerably more expensive. The versatility of utilizing an android robot in various functions demonstrates the foresight of Elon Musk's prediction about the future of the android robot era, while the era of specialized robots continues to develop.

3 Research and Discussion

As noted above, the task of integrating the functionality of autonomous movement of the watering robot into a single code along a specified trajectory can be solved through manual remote control in FPV robot technologies, as well as in autopilot mode. To program the automatic watering mode in the conditions of an urban mini-greenhouse, it is necessary to arrange the plants in pots in the form of a rectangular matrix and equip these plants with placards containing QR codes. This planting method is similar in many ways to planting plants in drip irrigation. In the first case, the soil in the mini-greenhouse is uniformly backfilled horizontally, then a network of drip irrigation pipes is created, and the geometric work points of the drippers are determined by test drip irrigation vertically. In fact, a square matrix with precise square-nest placement of plants is created. In the case of the watering robot, the marking is done with white tape horizontally and vertically, with the pot containing the plant to the right of the intersection with the horizontal line. The diagrams of this planting method and the arrangement of pots with plants are shown in Figure 2.

![Fig. 2. Square-nested drip irrigation method and pot arrangement in a mini greenhouse.](image)

The irrigation robot is equipped with two infrared (IR) sensors located at the edges of the front bumper. These sensors are used to monitor the intensity of the reflected IR radiation. If the robot deviates from a straight line, the intensity of the IR radiation
decreases, prompting the robot to adjust its movement accordingly. The control algorithm for the robot is implemented using Python 3 programming language on the Raspberry Pi4 mini-PC operating system. The geometric interpretation and control command lines are illustrated in Figure 3.

```python
1. # Initializing the library
2. from gpiozero import LightSensor, Buzzer
3. lsLeft, lsRight = LightSensor(29), LightSensor(31)
4. if lsLeft.when_dark and lsRight.when_light:
5.     # Right turn
6.     pass
7. elif lsLeft.when_light and lsRight.when_dark:
8.     # Left turn
9.     pass
10. elif lsLeft.when_light and lsRight.when_light:
11.     # Both sensors detect white light, which means stop
12.     pass
```

**Fig. 3.** Algorithm and a fragment of the programme for holding the line of motion by IR sensors of the autopilot of the agro-robot watering robot and plant search by the manipulator arm.

It should be noted that the robot is equipped with standard encoders on the electric drives, which can count the number of motor revolutions, and the computer can calculate the distance traveled online. This allows creating a matrix of routes in the robot's computer memory and then automatically reproducing them. This is a brief summary of the autopilot algorithm. In case of emergencies, the robot can switch to online video streaming mode, and the operator-dispatcher can remotely correct the error.

The main attention was also paid to creating an efficient system for determining the water needs of plants using QR codes, as well as optimizing the robot's movement trajectory for maximum efficiency in irrigation.

Figure 4 shows the graph of adjusted daily water consumption by lettuce (per planting).

The data shows that water consumption increases until the 30th day, reaches its peak, and then gradually decreases. This trend served as the basis for developing an irrigation cyclegram that allows the robot to accurately dose the amount of water through QR codes according to the needs of each individual plant.
Fig. 4. Cyclogram of watering of leaf lettuce varieties.

The technology being developed enhances plant management in small-scale greenhouses by improving water usage precision and reducing the need for manual labor. It achieves this by distributing water with greater accuracy and efficiency, especially in conditions where resources are limited. By utilizing Raspberry Pi and FPV technologies, a flexible and scalable system can be designed to suit various greenhouse environments and requirements. Additionally, to ensure automatic watering and to take into account the individual needs of each plant, moisture sensors can be used in the system. Of course, such factors as the accuracy of QR code recognition and manoeuvrability of the robot in a limited space should be taken into account. Establishing a watering regimen customized for each plant's requirements is crucial for maximizing resource utilization and improving crop production through optimal water supply. These elements are essential for promoting a more efficient and environmentally-friendly approach to automating plant care in small greenhouses, which is vital for advancing agriculture and sustainable resource utilization. It should be noted that the robot is equipped with encoders on the electric drives as standard, which can count the number of motor revolutions, and the computer can calculate the distance covered in real-time. This allows creating a matrix of routes in the robot's computer memory and then automatically reproducing them. This is a brief summary of the autopilot algorithm. Overall, the development of autopilots for electric vehicles is a highly complex branch of applied computer science and robotics. In our case, the location of the plants plays an important role in this complex task. If an urgent response is required, the robot can activate live video feed mode, allowing the operator to remotely troubleshoot problems.

**4 Conclusion**

Summarizing earlier studies and available urban crop production methodologies, developed and implemented agro-robots, the following conclusions can be drawn that the integration of modern agricultural technologies into the urban infrastructure opens up new opportunities for medium and small businesses. Despite some of the challenges faced by agricultural businesses in Almaty, innovations in smart technology and robotics can significantly change existing approaches to growing fresh produce. Agricultural robots specialising in irrigation represent a promising area of development that can help improve efficiency and crop quality in urban areas. The emergence of robots equipped with automatic irrigation controllers will open up opportunities to automate plant care processes, making this technology available not only to large-scale growers, but also to individuals...
and offices. This, in turn, contributes to the creation of a more sustainable and environmentally friendly urban environment, reducing the need for manual labor and increasing overall levels of ecological responsibility.

The developed system meets the criterion of price/quality ratio, implying its affordability for the population with an acceptable level of service. The cost of the system will not exceed the minimum wage of a Kazakhstan citizen, and the payback period for the greenhouse is four seasons.

References


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