Vertical Farming Control System
(Technical Report)

Analysis of Effects of Sensor-Based Automated Irrigation Systems in Agriculture
(STS Research Paper)

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Bachelor of Science, School of Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Agriculture has always been a vital industry throughout the history of the United States. For centuries, people have relied on farmers to grow food for customer consumption. From the time of the Industrial Revolution, there have been numerous solutions engineered to solve technical problems within the industry. These solutions have had various impacts on different aspects of society.

Through my technical capstone project, I will be exploring the development and methodology of creating an automated maintenance system for household plants. In the project, myself and my other team members will design and create a household appliance that will monitor and distribute water and light intake of the user's plants. The goal of this device is for users to be able to optimize light and water intake for each plant in the device's system. This will prevent users from overwatering and decrease water consumption. Additionally, it will allow the user to monitor each plant's status from their smart phone.

In my STS research paper, I will analyze how the development of sensor-based, automated irrigation systems have affected areas of the agriculture industry such as the consumer, economics, laborers, businesses and the environment. This topic is tightly coupled with my capstone project, and the Social Construction of Technology (SCOT) framework will be employed to adequately approach the research topic. This will allow for the discussion and exploration into how this technology has affected society in America as well as how society created a need for the technology.

Technical Topic

Description

The technical project is the design and fabrication of a vertical plant control system. This system will provide users the ability to monitor and control the light and water intake of individual plants placed along a shelf-like structure through a mobile application. The application and the device will communicate through a WIFI module attached to the system's microcontroller. The structure of the system resembles a shelf with plants placed on each level along with a soil moisture sensor. On the top level of the structure will be a water reservoir which will be user-filled and monitored by a water-level sensor. On the underside of each level will be an LED light strip which allows the user to adjust each plant's light intake. Additionally, the underside will support a sprinkler head connected to a corresponding pump system which dispenses water from the reservoir (Bonfadini, Aggarwal, Nilsson, Tran, & Rogers, 2020). An overview of the project design can be seen in Figure 1.

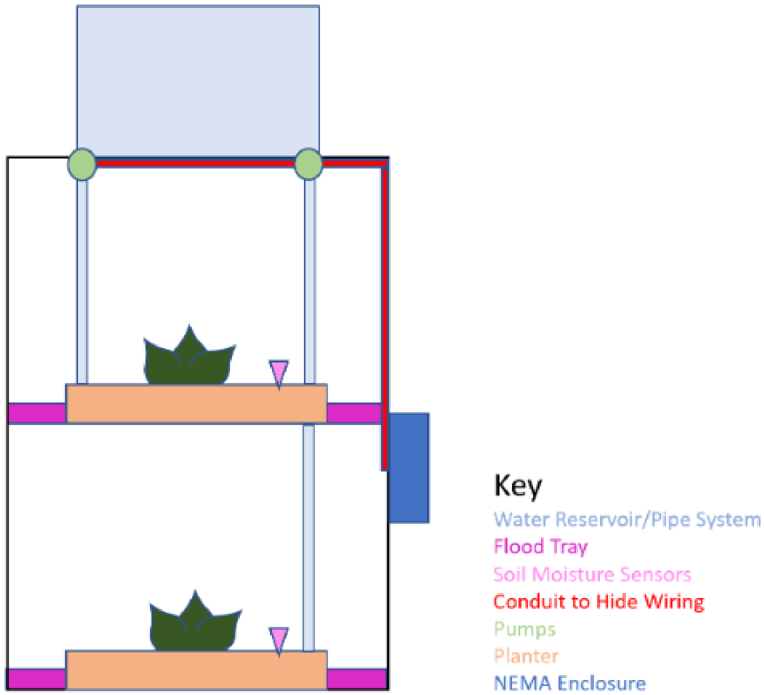

Figure 1: Technical Project Overview

Background

Vertical farming is a way to save space by stacking crops on top of each other as opposed to having crops grown spread out. Hydroponics is the preferred way to deliver nutrients to the crops in vertical farming systems. It uses water to carry nutrients to plant roots directly as opposed to through soil. Oftentimes vertical farming systems further use controlled environment agriculture (CEA) to result in more productive crops (Li, Adhikari, Yao, Miller, Kalbaugh, Nemali, 2019). Environmental control factors can include nutrient concentration, light, temperature, humidity, carbon dioxide, and nutrient pH.

It was recognized that this type of control system, proven effective in agriculture, could be transitioned to indoor spaces to maintain house plant health. Having houseplants is a popular way to bring the outdoors in especially for those living in urban areas. The benefits of having plants indoors include air purification, an increase in creativity and productivity, and mood improvement (Silverhill Institute of Environmental Research and Conservation, 2013). Indoor house plant gardeners will usually have each plant individually potted and placed throughout their space since different house plants vary on the amount of water and light that they need. This dispersed location of plants can consume a lot of space and the differing plant care needs can be complicated for a plant owner to keep track of.

This vertical plant management system is a two-tiered compact structure that aims to automatically control water and light for house plants with minimal user interaction. Water and light are chosen since they are the environment parameters that vary the most indoors. These parameters will be personalized for each of the plants encased in the structure through a plant profile. A plant profile will include the plant's name, preferred soil moisture level and hours of light per day. Additionally, the traditional soil watering method is chosen compared to hydroponic watering since houseplants are not suited towards hydroponics like most edible plants are and the goal with maintaining houseplants is not to optimize yield (Bonfadini, Aggarwal, Nilsson, Tran, & Rogers, 2020).

Methodology

The system will be connected to a household wall socket through a wall-mounted transformer with internal voltage regulation which will step the voltage down to 12 volts. The 12 volts will then be distributed to the LED lights and water pumps through fuses that will provide short circuit protection. Additionally, the 12-volt supply will be connected to a voltage regulator which will step the voltage down to 5 volts in order to power the system's microcontroller and soil moisture sensors. The microcontroller will provide power to the water level sensor. The sensors and water pumps require additional resistors, capacitors, and drivers that result in the need for the creation of a header-board for the microcontroller. The header-board will consist of the fuses, which will allow for the pumps to be turned on and off as desired, as well as resistors and bypass capacitors and test points for voltage supply and ground connections. Additionally, the microcontroller will obtain the information from the sensors and send the data to the mobile application through a WIFI module. The mobile application will allow the user to monitor the plant's status as well as receive reminders to refill the water reservoir through the WIFI module. The microcontroller will send data gathered from the sensors through the WIFI module and back to the mobile application for the user to see historical data and make decisions about refilling the water reservoir (Bonfadini, Aggarwal, Nilsson, Tran, & Rogers, 2020).

STS Thesis Topic

Introduction

Agriculture has been an extremely important development in the course of human history. As the Ice Age gave way to a milder climate that was conducive to farming and overpopulation limited migration, the village lifestyle was created (Why Was Agriculture So Important?, 2014). As these civilizations progressed into the countries and cities of today, developments have been made rapidly in the agriculture industry. These developments shaped numerous aspects of the workforce, environment, and consumer base. Over the course of the Agricultural Revolution and, later, the Industrial Revolution, important technologies and methods were created that increased the ability of farming to produce a surplus of crops with less labor. As of recent, the development of sensor-based, automated irrigation systems is an example of an invention that seeks to continue to maximize crop yield with decrease in human involvement. This technology could have profound impacts on the agriculture industry and its affected social groups.

STS Framework

In order to adequately analyze the effects of sensor-based irrigation systems on the agriculture industry, the Social Construction of Technology framework will be applied. SCOT addresses the interactions between technology and society and views the relationship as one mutually affecting the other. This framework argues that "technological development is shaped by a wide variety of social, cultural, economic, and political factors" but also that "technology and society cocreate each other" (Mitcham, 2005). Within this framework there are four main tenants; relevant social groups, interpretive flexibility, closure, and stabilization. *Relevant social groups* refers to the groups that provide engineers with a problem to solve as well as who is affected by the engineer's developments. *Interpretive flexibility* refers to the idea that "artifacts are open to radically different interpretations by various social groups" (Mitcham, 2005). *Stabilization* refers to the adoption of a technology by all relevant social groups due to the fact that the design solves problems for each social group. *Closure* refers to how when the most stable design is chosen, engineers often work within the framework of that original design (Mitcham, 2005). This framework applies to the thesis topic in that in order to comprehensively understand the potential effects of the new technology employed in this irrigation system, all relevant social groups must be addressed. Additionally, it is important to explore how the development could be interpreted by these groups. In Figure 2, a diagram of the relevant social groups is shown and areas of societal impact. The blue bubbles show areas of society and the yellow bubbles show affected social groups. The arrows on the diagram flow both ways to show how the technology affects the groups but also how the groups influence technology.

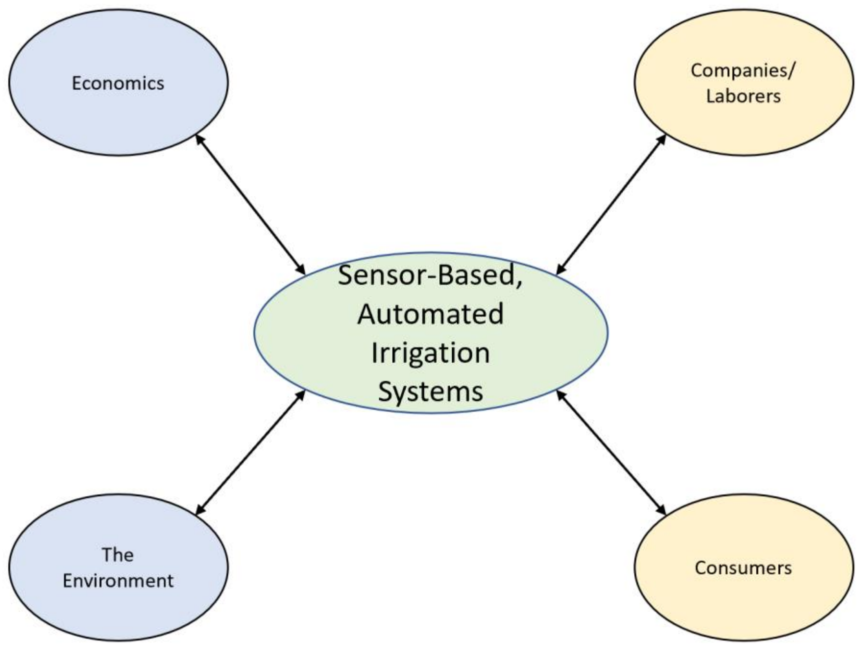

Figure 2: Relevant Social Groups and Their Interactions

Analysis

In 1790, nearly 90% of employed Americans were working in the agriculture industry (The Story of U.S Agricultural Estimates, 1973). Since the beginning of the Industrial Revolution, there has been a steady downturn in the number of American's working in agriculture, and as of 2000, only 1.9% of employed American's worked in agriculture (Dimitri, Effland, & Conklin, 2005). This shift in employment can be attributed to the rapid increase in efficiency and automation that began with the Industrial Revolution. The invention of automated irrigation systems seeks to further decrease the number of laborers necessary to run a farm and could further affect the distribution of the workforce in America. The development of these irrigation systems affects the workforce, which is a relevant social group in the SCOT analysis of this technology.

The automation of irrigation systems in agriculture will also impact the consumer. Given that the technology could decrease produce prices, consumers may become more likely to purchase produce items instead of processed and packaged food. As of 2017, 57% of the average American's diet is processed foods which is linked to higher risk for diseases such as cancer, diabetes, and heart disease (RD, 2017). The potential to decrease the price of fresh produce may result in an increased number of consumers moving towards a healthier diet. Additionally, with agriculture currently consuming 80 to 90% of U.S. water, the system's water-conserving qualities would mean less water consumed by the agriculture industry and greater volumes would be available for the consumer (Irrigation & Water Use, 2019). This technology has the potential to alter the purchasing habits of consumers.

Sensor-based, automated irrigation systems also have the potential to largely impact the environment, if adopted more widely throughout the U.S. Assuming an adoption rate of 50% across the U.S., Table 1 shows the estimated reduction in water as well as harmful elements used in traditional farming. Since the system would require less water being pumped, the pumps would be run less, meaning a decrease in the burning of fossil fuels which leads to less carbon dioxide emission. Nitrogen and phosphorous are chemicals found in fertilizers which frequently runoff into streams, harming wildlife. If plants are stronger due to more specialized care, they may not need as much fertilizer.

Table 1: Projected Savings of Certain Chemicals with 50% Adoption of Sensor-Based, Automated Irrigation Systems (Majsztrik, Price, King, 2013)

Chemical	**Estimated Savings**
Water	223 billion liters
Carbon Dioxide Emissions	36,232 Mg

Nitrogen	282,000 Kg
Phosphorous	182,000 Kg

All of the social groups, the workforce, companies, and the consumer, can interpret this technology differently, as defined by *interpretive flexibility.* For example, farmers could find the technology extremely beneficial since it reduces labor and saves water costs. However, laborers might reject the technology since it could decrease job availability. Each social group interprets technologies differently. It is also important to note, the sensor-based, automated irrigation system design was developed by the needs of these social groups. The need for an increase in available food without substantially harming the environment, which affects all of these social groups, drove the development of this technology. This addresses the aspect of the SCOT framework that shows society affects technology just as much as technology affects society. This technology was developed as a result of societal needs, and now, that technology has the potential to also affect that society.

The economy is another relevant area that may be affected by this technology. Automated irrigation systems have been estimated to reduce water consumption by approximately 16% by increasing efficiency by nearly 90%. This decrease in consumption could result in significant economic savings for farms in the U.S., which could potentially drive produce prices down. Additionally, it has been observed that farmers undertake large financial losses due to incorrect weather predictions or incorrect irrigation methods (Munoth, Goyal, & Tiwari, 2016). The technology's removal of human error, decrease in water consumption, and decreased need for additional laborers could lead to the decrease in price of products produced by farms, thereby affecting the country's economy.

Research Method

To conduct the analysis of the effects of the automated irrigation system, sources will be found that describe the technologies impacts in the areas of the workforce, consumer, environment, and economics. Using the University of Virginia library system, Virgo, as well as Google Scholar, the information necessary for this assessment will be gathered through internet articles, technical reviews, as well as books. Important resources that will be reviewed include data from the United States Department of Agriculture, the Encyclopedia of Science, Technology, and Ethics, IEEE articles, the American Society for Horticulture Science, and important studies done on the technology from various universities.

Conclusion

Agriculture plays an influential role in how American society operates, and as technologies in the industry advance, there are sure to be changes in different areas of society. In order to appropriately explore how this specific technology has and could have social impacts, the SCOT framework will be applied to this research paper. This allows for the thorough investigation of the social factors that led to this technology as well its potential and current impacts. This will be an important tool to show how the irrigation system's ability to reduce water consumption and labor will affect several areas of American society. Through the exploration of the effects on several different social groups, the question is analyzed from multiple perspectives.

References

Aktar, W., Sengupta, D., & Chowdhury, A. (2009, March). Impact of pesticides use in agriculture: Their benefits and hazards. Retrieved October 12, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2984095/

Bonfadini, B., Aggarwal, S., Nilsson, V., Rogers, C., & Tran, C. (2020). *Capstone Midterm Design Review* [Scholarly project].

Bonfadini, B., Aggarwal, S., Nilsson, V., Tran, C., & Rogers, C. (2020). *Capstone Project Proposal* [Scholarly project].

Colorado Green NOW. (2015). Smart irrigation technologies use water efficiently. Retrieved October 12, 2020, from https://www.alcc.com/smart-irrigation-technologies-use-water-efficiently

Dimitri, C., Effland, A., & Conklin, N. (2005, June). The 20th Century Transformation of U.S. Agriculture and Farm Policy. Retrieved October 11, 2020, from https://www.ers.usda.gov/webdocs/publications/44197/13566_eib3_1_.pdf?v=7007

Hellerstein, D., Vilorio, D., & Ribaudo, M. (2019). Agricultural Resources and Environmental Indicators, 2019. Retrieved October 15, 2020, from https://www.ers.usda.gov/webdocs/publications/93026/eib-208.pdf?v=5081.1

Kansara, K., Zaveri, V., Shah, S., Delwadkar, S., & Jani, K. (2015). Sensor based Automated Irrigation System with IOT: A Technical Review [Review]. Retrieved October 15, 2020, from http://ijcsit.com/docs/Volume%206/vol6issue06/ijcsit20150606104.pdf

Kim, Y., Evans, R., & Iversen, W. (2008). Remote Sensing and Control of an Irrigation System Using a Distributed Wireless Sensor Network. Retrieved October 16, 2020, from https://ieeexplore.ieee.org/abstract/document/4457920

Li, C., Adhikari, R., Yao, Y., Miller, A., Kalbaugh, K., Li, D., & Nemali, K. (2019, December 12). Measuring plant growth characteristics using smartphone based image analysis technique in controlled environment agriculture. Retrieved October 16, 2020, from https://www.sciencedirect.com/science/article/pii/S0168169919318769

Majsztrik, J., Price, E., & King, D. (2013, December 01). Environmental Benefits of Wireless Sensor-based Irrigation Networks: Case-study Projections and Potential Adoption Rates. Retrieved October 16, 2020, from https://journals.ashs.org/horttech/view/journals/horttech/23/6/article-p783.xml

Mitcham, C. (2005). Social Construction of Technology. In 981840628 760400644 C. Mitcham (Ed.), *Encyclopedia of Science, Technology, and Ethics* (pp. 1791-1795). Macmillan Reference USA.

Munoth, P., Goyal, R., & Tiwari, K. (2016). Sensor based Irrigation System : A Review [Review]. Retrieved October 15, 2020, from https://www.ijert.org/research/sensor-based-irrigation-system-a-review-IJERTCONV4IS23026.pdf

RD, A. (2020, April 30). Processed Foods, Calories and Nutrients: Americans' Alarming Diet. Retrieved October 12, 2020, from https://www.aicr.org/resources/blog/processed-foods-calories-and-nutrients-americans-alarming-diet/

Silverhill Institute of Environmental Research and Conservation. (2013). The Health Benefits of Indoor Plants. Retrieved October 16, 2020, from https://silverhillinstitute.com/pdf/Health_Benefits_of_Indoor_Plant_2013.pdf

United States Department of Agriculture Environmental Research Service. (2019). Irrigation & Water Use. Retrieved October 15, 2020, from https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/

United States Department of Agriculture. (2012). Census of Agriculture 2012. Retrieved October 12, 2020, from https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,_Chapter_1_US/

United States, U.S. Department of Agriculture, Statistical Reporting Service. (1973). *The Story of U.S. Agricultural Estimates* (pp. 1-137). U.S Government Printing Office.

Why Was Agriculture So Important? (video). (2014). Retrieved October 12, 2020, from https://www.khanacademy.org/humanities/big-history-project/agriculture-civilization/rise-of-agriculture/v/bhp-why-agriculture-was-important