Project Title: Innovative Transformation in Agriculture: The Role of UAV Technology in Frost Risk Management

Abstract

This project develops an innovative approach aimed at reducing the impacts of frost events on agricultural lands. Early detection of frost risks and effective intervention methods were examined. Through the use of temperature sensors developed within the scope of the study, frost events can be detected early in the field, and this information can be transmitted to farmers via mobile devices. Special fog capsules developed with UAV technology are distributed over agricultural areas, preventing radiation from escaping into the atmosphere and maintaining temperatures, thus preventing frost formation. These integrated methods aim to increase agricultural productivity while minimizing environmental impacts. Compared to traditional frost prevention methods, this approach offers a more effective and environmentally friendly alternative, detailing technological processes, system operation principles, and potential impacts on agricultural production. The research emphasizes that this approach can play a significant role in enhancing sustainability in the agricultural sector and combating climate change. The system's energy efficiency and cost-effectiveness were also analyzed, enhancing its feasibility and environmental sustainability while offering an economical solution for frost risk management. This study provides practical benefits for agricultural applications and proposes effective solutions to increase agricultural productivity.

Keywords: UAV Technology, Fog, Agriculture, Frost Events, Sustainability

Problem Statement

What is the effectiveness and feasibility of the newly developed approach, which utilizes temperature sensors and UAV technology to reduce the adverse effects of frost events on agricultural lands, compared to traditional methods?

Objective

The objective of this study is to present the details of an innovative approach aimed at reducing the adverse effects of frost events on agricultural lands. This approach is based on the deployment of fog capsules over agricultural fields using UAV technology. The system is integrated with temperature sensors capable of early frost detection and an automated alert mechanism triggered by these sensors. The use of UAV technology ensures the rapid and effective distribution of these fog capsules, aiming to minimize the harmful effects of frost events on plants.

The primary goal of this study is to offer a more effective and environmentally friendly alternative in cases where traditional frost prevention methods fall short. The use of UAV technology allows the system to be implemented more flexibly and quickly, while also optimizing labor and resource usage. Consequently, the productivity and quality of agricultural products are preserved.

The technical details of the system, the integration of UAV technology, the system's operating principles, and its potential impacts on agricultural production have been emphasized. This innovative approach is highlighted as a significant contributor to improving sustainability in the agricultural sector and combating the adverse effects of climate change.

Introduction

The agricultural impacts of weather and climate information were first documented in Roman and Chinese records, with phenological calendar records dating back to 500 BC. During the Renaissance period, significant instruments such as Galileo's hydrometer in 1593 and Torricelli's barometer in 1643 were developed. Additionally, Halley in 1694 described the effects of sunlight and wind on evaporation. Over the past 150 years, Linsser (1867) studied plant-climate-evaporation relationships, and Hommen (1896) conducted soil temperature measurements, leading to significant advances in the field of agricultural meteorology (Asar et al., 2007).

Progress in biology, alongside contributions from physics—especially in the use of instruments and electronic technologies in microclimatology research—has enabled a more detailed understanding and analysis of the physical environment. This has led to remarkable advancements in agricultural meteorology, driven by successes in environmental measurements (Asar et al., 2007).

Today, the continuous increase in the global population and reductions in agricultural production caused by extreme weather events have amplified volatility in global food markets. This volatility has caused significant fluctuations in the prices of basic food commodities, raising serious concerns about food security and sustainability and threatening global economic stability. Furthermore, this situation adversely affects food access and nutrition security, particularly in developing countries, leading to socio-economic imbalances and widespread humanitarian crises. These recent fluctuations have underscored the deep dependence of agricultural production on atmospheric conditions and the critical importance of meteorological data in agricultural activities.

At every stage of agricultural processes—such as sowing, planting, fertilization, harvesting, pesticide application, mechanization, irrigation, and livestock production—detailed integration of meteorological data has become a globally recognized necessity to enhance efficiency and reduce risks. In this context, the dissemination of daily and long-term weather forecasts plays a vital role in the decision-making processes of agricultural producers. This enables farmers to minimize risks associated with weather conditions and implement more efficient and sustainable agricultural practices.

Farmers engaged in agricultural activities must anticipate future meteorological events, necessitating the implementation of various technical and traditional precautions. These include strategies for protecting plants against frost, methods to minimize the adverse effects of excessive rainfall on soil, and measures to reduce the impacts of storm conditions. The applicability of such precautions is directly linked to cost-effectiveness. Additionally, different meteorological data are required during the planning and execution stages of agricultural production. Specifically, analyzing long-term climatic averages is essential during the planning phase, while making decisions during sowing and harvesting periods requires updated weather conditions and short-term weather forecasts (Asar et al., 2007).

The planning of agricultural facilities requires a long-term perspective and a careful evaluation of influencing factors. These factors include climate, soil, seeds, and the producer. From an agricultural meteorology perspective, climate is the primary determinant of the production process. Depending on the plant species selected in accordance with climate conditions, seed selection and soil improvement can be carried out. Even if other factors are favorable, climate remains the key element directly influencing agricultural activities. Agricultural meteorology not only studies the state of the air layer near the ground and the physical phenomena occurring in this area but also aims to develop preventive and adaptive methods against adverse weather conditions such as frost, drought, and floods.

Climate changes occurring in Turkey significantly affect the development of agricultural plants, particularly under adverse conditions caused by low temperatures. Climate change influences agricultural production not only through rising average temperatures but also by increasing temperature fluctuations and unexpected cold spells. These effects manifest differently across Turkey’s diverse agricultural regions.

Low temperatures directly influence the phenological stages of plants, such as their growth cycles. Sudden cold spells, especially in spring, pose significant risks for plants during flowering and fruit formation periods. Frost events during these times can reduce pollen viability, damage flower and fruit tissues, and result in substantial yield losses. Frost during the flowering stage of fruit trees can negatively impact fruit set, leading to low yields or fruitlessness.

The resilience of agricultural crops to low temperatures varies across Turkey’s different climatic regions. Therefore, the increasing temperature fluctuations and unexpected cold spells associated with climate change necessitate adjustments in agricultural planning and production strategies. Adaptation strategies in the agricultural sector must be revised in areas such as crop selection, planting schedules, frost protection techniques, and water management. Developing strategies to adapt to climate change forms the foundation of research and applications in this field, ensuring the sustainability and productivity of agricultural production. In this context, agricultural meteorology plays a crucial role in agricultural planning and risk management studies.

Although air temperatures above 0°C may not cause frost, if they fall below the minimum growth temperature of plants, the plants enter dormancy. During this period, the nutrients produced through photosynthesis become insufficient, leading to chlorosis (yellowing) in plants. If temperatures drop suddenly and drastically, the protoplasm of plant cells begins to suffer damage, which manifests in three ways:

a) Before reaching the freezing point of cell water, the direct damage to proteins within the cell and coagulation of the protoplasm can cause plants to die.

b) At low temperatures, ice formation in the intercellular spaces draws water from the protoplasm. If this situation persists, the protoplasm experiences continuous water loss, coagulates, and causes cell death.

c) Rapid and severe temperature drops lead to the formation of ice crystals within the protoplasm. These ice crystals disrupt the structure of the protoplasm and tear cell membranes, resulting in plant death.

Frost events can be classified based on their timing:

a) Early Autumn Frosts:

These typically occur in September, October, and November, affecting summer vegetables, fruits, and field crops that are harvested late. Plants whose development period is prolonged due to excessive nitrogen fertilization may suffer damage from early autumn frosts. During the winter, plants are usually dormant, making them less affected by frost events, and winter crops are generally resistant to low temperatures.

b) Spring Late Frosts

Late spring frosts are the most risky and damaging frost events for agriculture, especially occurring in the last months of spring. This period coincides with the germination, budding, and flowering phases of plants. Plants that awaken early due to warming weather conditions can be exposed to sudden frost events in February, March, and April. This situation can lead to the drying of flowers, shoots, and leaves and the spread of fungal diseases. In Turkey, frost events are typically observed in the Eastern Anatolia Region until June, in the Aegean and Marmara Regions until April, and on the Mediterranean coasts until the end of February. People engaged in agriculture must know the late spring frost dates of their regions and take necessary precautions based on this information. This strategic knowledge is critical for protecting agricultural production and increasing efficiency (Asar et al., 2007).

The situations where frost can be expected are as follows:

- If the sky is clear and bright after evening hours,
- If stars and the moon are clearly visible at night,
- If the air humidity is low and dry,
- If there is no wind or the wind is blowing very lightly from the north,
- If air pressure is increasing or remains stable at a high level.

These observations should be made and carefully evaluated during times when frost events are likely. However, the presence of such weather conditions does not always mean that frost will occur (Asar et al., 2007).

Methods of Protection Against Frost Events

Measures to Be Taken Before Sowing and Planting:

Site Selection: Agricultural activities should be avoided in areas with frost risk. If necessary, frost-resistant species should be preferred. Special attention should be given to frost-prone areas such as valley bottoms, narrow basins, and low-lying areas.

Plant Selection and Production: Late-flowering varieties should be chosen, and weeds in areas where frost-sensitive plants are grown should be cleared before the frost danger begins. No cultural practices, including soil tillage, should be performed.

Measures to protect against frost include:

a) Choosing tall plants in areas exposed to severe climate conditions to protect sensitive flowers and fruits from ground-level cold.
b) Avoiding frost-sensitive crop cultivation in valley bottoms, narrow areas, and lowlands. Mountainous areas and south-facing warm slopes are ideal for vineyards and early-harvest potatoes.
c) Locations near large water bodies such as lakes, dams, and rivers have a lower risk of frost.
d) Forested areas help disperse cold air.
e) In soils where frost-sensitive plants are grown, soil tillage should be avoided.
f) In high frost-risk areas, it is not appropriate to grow frost-sensitive plants near areas such as alfalfa, grasslands, cereals, shrubs, and nurseries.
g) In areas with frost-sensitive plants, weed cleaning should be done before the frost danger begins, but no other cultural practices should be performed (Asar et al., 2007).

Measures to Be Taken After Sowing and Planting:

Stopping Radiation Loss to the Atmosphere: Artificial clouds are created to prevent radiation loss to the atmosphere and to avoid temperature drops.

Thermal Insulation: Products are covered with non-toxic protein foams for protection.

Mixing the Air: The mixing of warmer air from the upper layers with cold air below reduces frost damage.

Direct Heating of Air and Plants: Using appropriate heating equipment or lighting small fires prevents heat loss through radiation.

Water Application: Sprinkler or overhead irrigation can be effective in preventing frost events. However, this method should only be applied to plants that can bear the weight of the ice on them.

Soil Management: Keeping the soil moist, free from weeds, leveled, and compacted can reduce frost damage.

Sand Covering: Spreading a thin layer of sand in frost-risk areas minimizes evaporation.

Delaying Flowering: In areas where late spring frosts are common, snow or ice blocks can be placed around the base of trees to delay the flowering period of fruit trees and prevent frost damage.

Forced Harvesting: If a frost or freezing temperatures are predicted in advance, farmers can immediately harvest ripe fruits, vegetables, and other crops (Asar et al., 2007).

In the literature, the effects of low temperatures on plant development and productivity are described as follows:

Şensoy, S. and Türkoğlu, N. (1994), examine the effects of climate changes in Turkey on the developmental processes of agricultural plants. The study reveals that changes in air temperature observed since 1994 have significantly influenced the phenological periods of plants, especially fruit trees and wheat. It emphasizes that the growing season in Turkey has extended, creating both positive and negative impacts on agricultural production. These changes are noted to cause early flowering in fruit trees and increase the damage caused by late spring frosts.

Yılmaz, H. and Yıldız, K. (2000), investigated the impact of frost damage during the flowering period on strawberry yield under Van's ecological conditions. The study, conducted in 1996, focused on strawberry varieties such as Tufts, Vista, Doritt, Tioga, Aliso, Brio, Cruz, Pajaro, Selva, Douglas, and Chandler. Estimated yield losses due to frost damage in flowers were determined for the years 1997 and 1998. The highest estimated loss was recorded in the Cruz variety in 1997 at 30.2 g/plant and in the Tufts variety in 1998 at 16.6 g/plant. The results indicate that overall yield loss from frost damage in flowers is not significant. However, given that the damaged flowers produce the first fruits, a general quality loss may occur. This study evaluates the impact of frost events during the flowering period on yield in strawberry cultivation in the Van region and underscores the importance of managing these effects.

Çukur, F. and Saner, G. (2008), address frost events as a significant risk factor affecting apricot production in Malatya. Despite being a leading apricot production center in Turkey and globally, Malatya experiences severe production losses due to natural conditions like frost. The research examines the impact of such natural risks on apricot production and the strategies developed by producers to counter these risks. Frost-related losses during harvest time are identified as a major risk source for producers, and methods and strategies to mitigate this risk are evaluated.

Yiğit, F. (2005), investigates the biological control of Botrytis cinerea (gray mold) in young leaf tissues damaged by frost in tomatoes grown in greenhouses in Mersin and its surroundings. The study explores the colonization of frost-damaged leaves with the saprophytic fungus *Cladosporium sphaerospermum* and the potential of this method to prevent the spread of B. cinerea. Experiments revealed that C. sphaerospermum inhibited the colonization of necrotic leaf tissues by the pathogen by approximately 50%. These findings suggest this method as a potential approach for biological control of B. cinerea in greenhouses.

Some studies in the literature addressing the fight against agricultural frost include:

Dutta O. and Rivas F. (2022), focus on climate services and early frost prediction systems for organic fruit production in the Valencia region. To reduce losses in agricultural areas caused by extreme weather events induced by climate change, these systems utilize machine learning models trained with hourly historical data from local weather stations. These models have the potential to provide early frost predictions 24 and 48 hours in advance, especially for frost-sensitive organic fruit crops.

Choi, Y., Zimmt, W., and Giacomelli, G. (1999), Researchers developed a watery foam for frost and ice protection. This foam creates a barrier against heat transfer, protecting plants from frost. The gelatin-based foam is more stable, adhesive, biodegradable, and long-lasting. Its resistance to freezing-thawing, heating-evaporation, and wind was evaluated. Moreover, the foam's environmental impact and removal were also examined. This foam is considered an ideal solution for frost and ice protection in agricultural areas.

Method

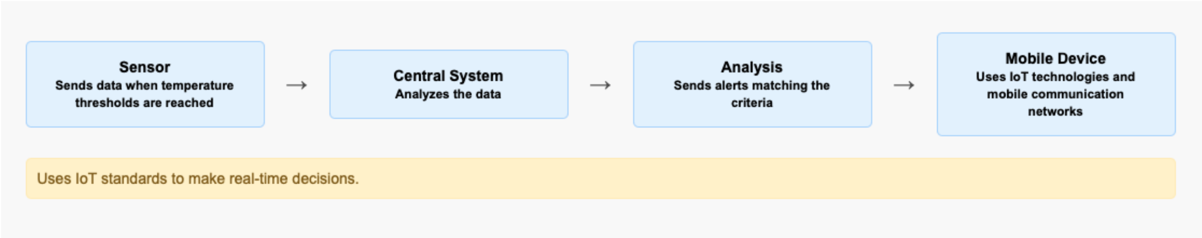
This study employs two main processes:

1.Early Warning System:

The primary objective of this stage is to prevent product loss in frost-prone agricultural areas by providing early warnings and enabling rapid intervention for farmers. This aims to enhance the productivity of agricultural products and minimize economic losses.

The early warning system design includes the installation of temperature sensors in agricultural fields, data collection, and data processing. Temperature measurement sensors are placed at equal intervals across the agricultural area. When critical thresholds are reached, these sensors send data to a connected central system. Based on analyzed data, the system sends warning messages to farmers via their mobile devices. This process is achieved using IoT (Internet of Things) technologies and mobile communication networks.

Table 1: Schematic Representation of Frost Management Method Using Temperature Sensors and Drone Technology



2.Artificial Fog Application Using UAVs:

In this stage, agricultural areas are covered with artificial fog through a semi-autonomous process. A new method has been developed to prevent frost events in agricultural areas. This method involves UAVs specifically designed for agricultural use, distributing specialized fog capsules over the fields.

The primary goal of this approach is to create a controlled artificial fog layer over the agricultural fields, preventing cold air flows from directly reaching the plants. This artificial fog layer blocks cold airwaves from penetrating the agricultural areas, thus preventing frost formation. Consequently, plants are shielded from frost, and agricultural yield is increased.

The use of UAV technology in this way provides an innovative approach to protecting agricultural fields and serves as an effective defense mechanism against the adverse effects of cold weather conditions. This method represents a significant innovation in modern agricultural techniques.

Use of the UAV System

The UAV and its carrier module are manually activated. Once started, the status indicator on the system flashes yellow. The system operates semi-autonomously. A computer interface is launched and switched to connection mode. After a while, the connection is established, the status indicator displays a steady yellow light, and a message confirming the successful connection appears on the computer interface.

The dimensions of the field are manually entered in terms of latitude and longitude or relatively based on the UAV's initial position. Since the system stores this information, it does not need to be re-entered for subsequent uses.

In this system, a continuous connection between the interface and the UAV ensures dynamic data flow. The UAV transmits live telemetry data unidirectionally. This data is monitored in real-time by the computer, and if any anomaly is detected, the information is processed, and necessary adjustments to the flight plan are made by the mission manager.

The onboard flight computer of the UAV executes one command at a time, which includes direction, speed, and flight distance. Upon reaching a designated mission point, the integrated module activates the fog capsule and releases it, indicating the successful completion of the task. If the fog capsules are insufficient for the mission, the user is notified during the setup phase. Additionally, when the UAV's fog capsule inventory is depleted, the device returns to its launch point to await replenishment. This protocol also applies in cases of battery insufficiency.

Fog Capsule

Fog capsules are containers or capsules filled with liquids such as glycerin and water.

The capsule is activated using a wick or a heat source.

The wick or heat source heats the liquid, causing it to evaporate and form fog or smoke in the surrounding area.

Capsule Release Module Design

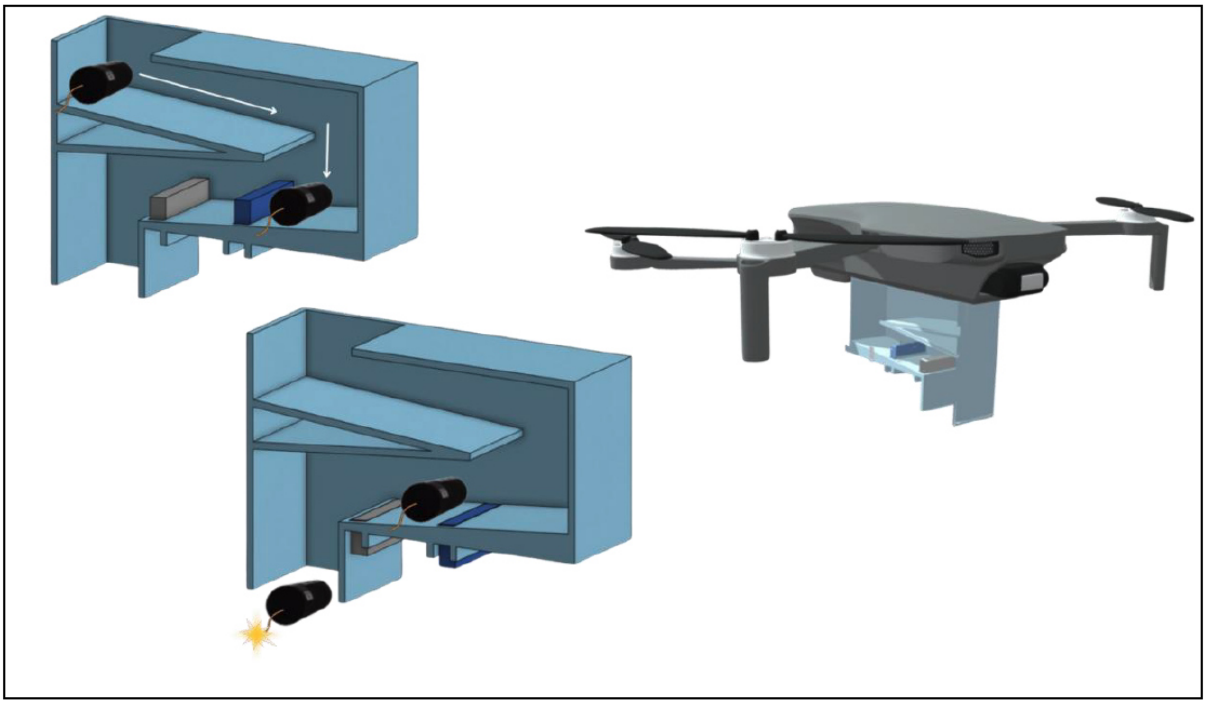
The carrier module depicted in the design is structured as a mechanism with two main functional zones:

Zone 1: This area serves as a compartment without moving parts, designed to transport fogging equipment securely from one point to another. The transported equipment is held stable in this zone and prepared for transfer to the second zone.

Zone 2: Equipped with two dynamic barriers and a firing unit, this section is crucial for guiding and securing the equipment in the correct position. The firing unit controls and initiates the process's activation phase. This section is central to the carrier module's operation, managing all subsequent processes after the equipment is transported.

This design ensures a seamless and orderly execution of all stages, from transporting the equipment to its effective use.

Table 2: Capsule Release Module Design



Ignition Unit

This system demonstrates the fundamental components of an automatic ignition mechanism and their interactions.

Electric Igniter: This is the core of the ignition mechanism. It receives control signals from the control unit and transmits them to the heating element to ignite the wick.

Heating Element: Converts electrical signals from the electric igniter into heat, which ignites the wick.

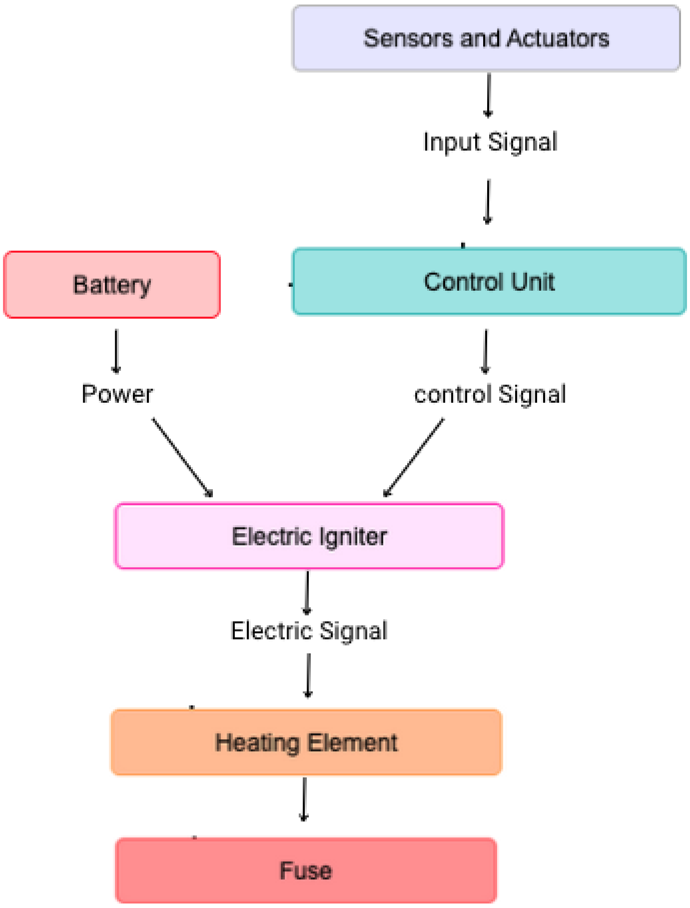
Wick: Ignited by the heating element, it acts as the critical component in starting a pyrotechnic device or ignition system.

Battery: Powers the system, supplying energy to the electric igniter for its response to control signals and activation of the heating element.

Control Unit: The brain of the system, managing when and how the ignition mechanism operates. It sends control signals to the electric igniter based on input from sensors and triggers.

Sensors and Triggers: Monitor environmental conditions, timing, or other triggering factors, transmitting this information to the control unit. The control unit activates the ignition mechanism appropriately based on this input.

Tabe 3: Ignition Diagram of the UAV Capsule Module



Software

The communication between the main device and the UAV (Unmanned Aerial Vehicle) is ensured using the LoRa (Long Range) protocol. The reasons for choosing the LoRa protocol and the advantages it provides are as follows:

•Long Range: Compared to Wi-Fi connections, which are short-range and require high energy, LoRa offers a theoretical range of up to 15 km, depending on conditions, making it ideal for remote operations.

•Low Power Consumption: This feature extends the battery life of UAVs by reducing energy consumption.

•Reliability: LoRa is resistant to environmental conditions and enables reliable and lossless communication even at low signal strengths.

•Bandwidth: The frequency band used by LoRa is rarely utilized by other devices, reducing the likelihood of interference or background noise from other devices.

Active communication occurs between the two devices. The UAV not only responds to the computer but also actively broadcasts signals. The computer monitors the situation and requests information about the report and mission status. These commands can be categorized into two main groups:

1. Report Commands:

- Status
- Position

2. Action Commands:

- Go
- Drop

The task computation process functions as follows: The computer retrieves the GPS coordinates of the field and displays them on a graph. Each grid cell on the graph is scaled proportionally to the actual distance. The map is divided into regions according to the influence area of frost particles, and the most suitable route is determined using the A* pathfinding algorithm. While the UAV waits in the air, the computer performs calibrations and issues a command for the UAV to move to the nearest point. Upon arrival, the “drop” command is sent. This process repeats until all points are reached.

The primary goal of this system is to provide a reliable UAV communication network with long range that can operate efficiently and effectively over large areas. This enables the maximization of the potential of UAV technology in agricultural areas, research and exploration missions, or other large-scale operations.

Project Work-Schedule

The identification of the problem situation and a literature review based on this problem started as of September. A roadmap for the project was created through the examination of domestic and international references. Within the scope of the project, task distributions were carried out, with a focus on R&D processes. Starting from December, data collection and analysis processes were initiated in accordance with the calendar. In this context, a SWOT analysis was conducted for the traditional methods and the improved methods we developed. The process was completed by dedicating December and January to report writing.

Table 4. Project Work-Schedule Table:

Task	April	May	June	July	August	September	October	November	December	January
Literature Review						x	x			
R&D							x	x		
Data Collection and Analysis								x	x	
Project Report Writing										x

Findings

Traditional methods for combating frost events, although frequently applied in agricultural fields, can lead to various environmental and operational issues. For instance, while the use of non-toxic protein foams for frost insulation protects plants, the production and application of these foams result in energy consumption and carbon emissions, which have environmental consequences. The air mixing method, which mixes warm air at the upper levels with cold air at the bottom, can reduce frost damage but may lead to issues such as high energy consumption and noise pollution. The placement of wind machines can negatively affect local habitats and wildlife.

Furthermore, direct heating methods for air and plants can release harmful gases into the atmosphere, creating problems such as fuel consumption and fire risks, while also negatively affecting local air quality. Water applications, especially overhead irrigation or sprinkling, can be effective in preventing frost events, but excessive water usage may deplete water resources and increase the spread of plant diseases. Soil management, while reducing frost damage, requires intensive labor and excessive soil tilling, which can lead to erosion and disrupt the organic structure of the soil. The mulching method can alter soil structure and drainage, disturbing ecological balances.

The method of delaying flowering can create physical stress on plants and disrupt their natural development processes. It also demands intensive use of water resources. Forced harvesting, when frost or freezing temperatures are anticipated, involves emergency collection of fruits or vegetables, which can disrupt their natural ripening process and adversely affect quality. Therefore, environmental impacts must be carefully evaluated when developing frost protection strategies. More sustainable alternatives need to be researched to mitigate frost damages.

In the development of don conservation strategies, researches are a must to have more careful consideration of environmental impacts and more sustainable alternatives. While these traditional methods may be effective in reducing frost damage, they also pose several challenges and restrictions in regard to sustainable agriculture and the preservation of environmental balance. Attention needs to be given to important matters such as sustainable use of water resources, protection of soil structure, reduction of energy consumption and control of carbon emissions.

As a new approach for dealing with frost in agricultural areas, fog capsules using temperature sensors and UAV technology offers many advantages. Compared to the traditional system and methods, this system stands out as more technological and a more innovative solution. Temperature sensors detect frost incidents early, which provides farmers with sufficient response time. These sensors are placed at several locations in agricultural areas to track local temperature variations accurately. This early warning system ensures that precautions can be taken before the occurrence of frosts, which reduces crop losses remarkably.

Fog capsules, distributed using drone technology(UAV), are an example of an alternative way to prevent frost. These capsules create a thick layer of fog when they come into contact with the air, which protects crops from cold weather and frost. UAVs offer the ability to rapidly and effectively engage large areas of agricultural land. This provides a solution to the time and labor restrictions faced by traditional methods, especially in large agricultural areas.

In addition, this system has the potential to reduce the impact on the environment. While traditional methods can often lead to environmental problems such as a high energy consumption, water wastage or chemical use, fog capsules and UAV technology provide an alternative with less environmental impact. By providing a more efficient use of resources, this method can contribute to sustainable agricultural practices.

As a result, this new approach offers a more effective, faster and environmentally friendly solution than traditional methods of frost control in agricultural areas.

Conclusion and Discussion

The findings obtained in this research project have shown the effectiveness of the system based on temperature sensors and drone technology in the management against frost events in agricultural areas. In accordance with the research question, the advantages and potential impacts of this alternative approach over traditional methods are examined in detail.

In the project, the method of early detection of frost conditions through the use of temperature sensors and effective distribution of fog capsules by drones were evaluated as an important step in managing frost risk in agricultural areas.By predicting the risk of frost, the sensors allow farmers to take action in time, reducing potential losses of crops.The use of drone technology has attracted attention for it's ability to respond quickly and evenly over large areas. This has provided an effective solution to the limitations of manual tasks in terms of time and labor, especially in large agricultural areas.

The debate on the applicability and sustainability of this system, however, has been characterized by high start-up costs, technical know-how requirements and potential environmental impacts, but also points to some challenges. Overcoming these challenges may help the system to have a wider acceptance in the agriculture field.

In conclusion, this study highlights the potential and importance of technological innovations in the agricultural sector. The integration of temperature sensors and UAV technology has emerged as an effective strategy to address frost events. Temperature sensors and the use of drone technology integration has emerged as an effective strategy to combat frost events. This study represents an alternative approach that overcomes the limitations of traditional methods in the control of frost risk and encourages technological innovation in the agricultural sector. While this research highlights the potential and importance of technological innovations in the agricultural sector, it also demonstrates the need for a comprehensive assessment of these innovations.

Recommendations

A number of suggestions can be made for the development and generalization of the method used in the study. First, pilot projects and field trials should be established in various climatic conditions and on different crops to test the applicability of this technology over a wider area. This will be critical to verify the effectiveness and applicability of the technology and identify its potential limitations.

In order for UAV technology to reach a wider user base, training and awareness programs should be organized for farmers and agricultural sector employees. These programs can provide information on how to use the technology, it's benefits and potential challenges. To overcome barriers to adoption, user-friendly interfaces and clear instruction guidelines should be developed.

In terms of technology development, research and development activities need to continue. This could focus on making temperature sensors and drone technology more efficient, as well as cost-effective and environmentally friendly. Furthermore, the integration of these technologies with other agricultural applications can improve general efficiency and effectiveness.

While this study highlights the potential and importance of technological innovations in the agricultural sector, it also demonstrates the need for their comprehensive assessment and widespread use.These recommendations can lead to sustainable and innovative solutions in the agricultural sector by making the system based on temperature sensors and drone technology effectively used in a wider area.

References

Asar, M., Yalçın, S., Yücel, G., Nadaroğlu, Y., & Erciyas, H. (2007). Zirai meteoroloji.

Çevre ve Orman Bakanlığı Devlet Meteoroloji İşleri Genel Müdürlüğü Yayınları, Ankara.

Choi, C. Y., Zimmt, W., & Giacomelli, G. (1999). Freeze and Frost Protection with Aqueous Foam—Foam Development. HortTechnology, 9(4), 661. https://dx.doi.org/10.21273/HORTTECH.9.4.661

Çukur, F., & Saner, G. (2008). Malatya ili kayısı üretiminde riskin ölçülmesi ve riske karşı oluşturulabilecek stratejiler. Ege Üniversitesi Ziraat Fakültesi Dergisi, 46(1), 33-42.

Doğan, H.M., Mermer, A. Ve Ünal, E., 2000, Bitki Örtüsü İndeks Değerleri, Tarım ve Köy Dergisi Sayı: 135, Sayfa: 38-41, Ankara

Dutta, O., & Rivas, F. (2022). Climate Services for Organic Fruit Production in Valencia Region: Early Frost Forecasting. MDPI. https://dx.doi.org/10.3390/iocag2022-12218

Erol, O. (1999). Genel Klimatoloji, 5. Baskı, Çantay Kitabevi, İstanbul

Eser, D. (1997). Tarımsal Ekoloji, 2. Baskı, Ankara Ü. Ziraat Fakültesi Yayınları, No: 1473, Ankara

Genel Bahçe Bitkileri. (1997). Ankara Ü. Ziraat Fakültesi Eğitim Araştırma ve Geliştirme Vakfı Yayınları, No: 4, Ankara

Günay, A. (1982). Sebzecilik Cilt 1, Çağ Matbaası, Ankara

Güngör, Y. ve Yıldırım, O. (1987). Tarla Sulama Sistemleri, Ankara Ü. Ziraat Fakültesi Yayınları, No: 1022, Ankara

Karaoğlu, M. (2002). Don Hadisesi ve Türkiye'nin Don Takvimi, DMİ Yayınları No:1, Ankara

Özbek, H. (1987). Toprak Bilgisi, Çukurova Ü. Ziraat Fakültesi Yayınları, No: 34, Adana

Rozante, J. R., Gutierrez, E. R., da Silva Dias, P. L., de Almeida Fernandes, A., Alvim, D. S., Silva, V. M. (2020). Development of an index for frost prediction: Technique and validation.Meteorological Applications, 27(1), e1807.

Şimşek, O., Nadaroğlu, Y., & Ayvacı, H. Zirai Don Uyarı Sistemi

Yiğit, F. (2005). Domateslerde don zararı sonucu oluşmuş nekrotik yaprak dokularının Botrytis cinerea'ya karşı Cladosporium sphaerospermum Penz. ile korunma