Smart Agricultural Technology 3 (2023) 100064

Contents lists available at ScienceDirect

Smart Agricultural Technology

journal homepage: www.elsevier.com/locate/atech

Design and development of smart cover system for vineyards

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ARTICLE INFO

Keywords:
Smart cover system
Vineyards
Weather condition
Mobile application
Control card

ABSTRACT

With the abrupt change of climatic conditions every year, the effect on nature increases visibly. Grape producers experience the effects of climate change negatively. For example, frost, hail, and extreme temperatures are undesirable conditions for grape producers. When any of these natural events occur, they can greatly damage grape crops. In this study, a cover system that can be opened and closed automatically has been developed against undesirable natural events that vineyards are exposed to. The developed system consists of a DC gear motor capable to open and close the vineyard cover, a control card that collects the information from the sensors (rain sensor, temperature sensor, hail sensor, and frost sensor) and interprets the results, a solar battery that will store energy, a PV panel that will charge the battery, and mechanical components. In this work, an easily portable prototype was studied. The dimensions of the design have been realized as 1/3 of the dimensions of the real system. The system is designed to be 1 m high and 2 m wide. The control card of the system is designed to be suitable for outdoor conditions. Moreover, a remote management and condition monitoring of the system have been realized via a mobile application. Thus, it was aimed to increase the productivity of the vineyards and to protect the grapes.

1. Introduction

Each year, various areas and provinces in the world face a variety of calamities, including hailstorms, frost, severe rain, and other abiotic pressures. Shifting weather patterns, as a consequence of a changing climate, have posed a danger to vineyard output (Hannah et al. [1].; Irimia et al. [2].). Climate change and its fluctuation provide significant difficulties to agriculture's performance, including damage to fruits and vineyard plants (Malhotra [3]; Costa et al. [4].).

Despite this breadth of available options, frost continues to be a problem for the majority of producers. Frost damage causes greater economic losses than any other weather-related phenomena (Papagiannaki et al. [5]). In Europe, the fruit and vegetable industry has been especially hard hit by frost, with frost damage to fruits and vineyards reaching a record high in 2017 (Creasy and Creasy [6]). Frost damage occurs when freezing temperatures are lower than the plant tissues' critical damage temperatures (Sakai and Larcher [7]). Minimum temperatures are determined by climate and microclimate, while a plant's frost resistance is determined by its constitution and other variables. As the phenological cycle progresses, plants become less resistant (e.g. blooming and fruit stages, especially small-nut are the most critical) (Bannister and Neuner [8]). Favorable growth circumstances reduce the resistance of plant organs to cold at a particular stage. On the other hand, as plants are exposed to less favorable growth environments, this resistance rises. Natural environmental circumstances may exist or may be the product of human activity (Clayton and Radcliffe [9]).

Hailstorms are one of the most serious difficulties in agriculture (Cagnetti et al. [10]; Raihan et al. [11]), in particular, they wreak havoc on the proper development and ripening of grapes (Van Leeuwen and Destrac-Irvine [12]). Its activity may be particularly harmful to the grapes, shattering the berries and so jeopardizing the vintage and wine quality (Santos et al. [13]). Hail is a kind of solid precipitation that comprises of balls or irregular lumps of ice, each of which is referred to as a hailstone and ranges in diameter from 5 to 15 cm (Martínez-Frías [14]). Unfortunately, hail is a sudden and unpredictable phenomenon that is exacerbated throughout the summer when the grapes are maturing and yet too fragile. As a result, particularly after July, or towards the time of crop sale, grape farmers wrap their goods with a nylon cover to protect them from exposure to the aforementioned natural phenomena (Bal et al. [15]). However, these coverings, which remain on the vineyard continuously for around three months (this time period may vary depending on when the farmer sells his grapes), cause the vine

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https://doi.org/10.1016/j.atech.2022.100064
Received 20 February 2022; Received in revised form 1 May 2022; Accepted 1 May 2022

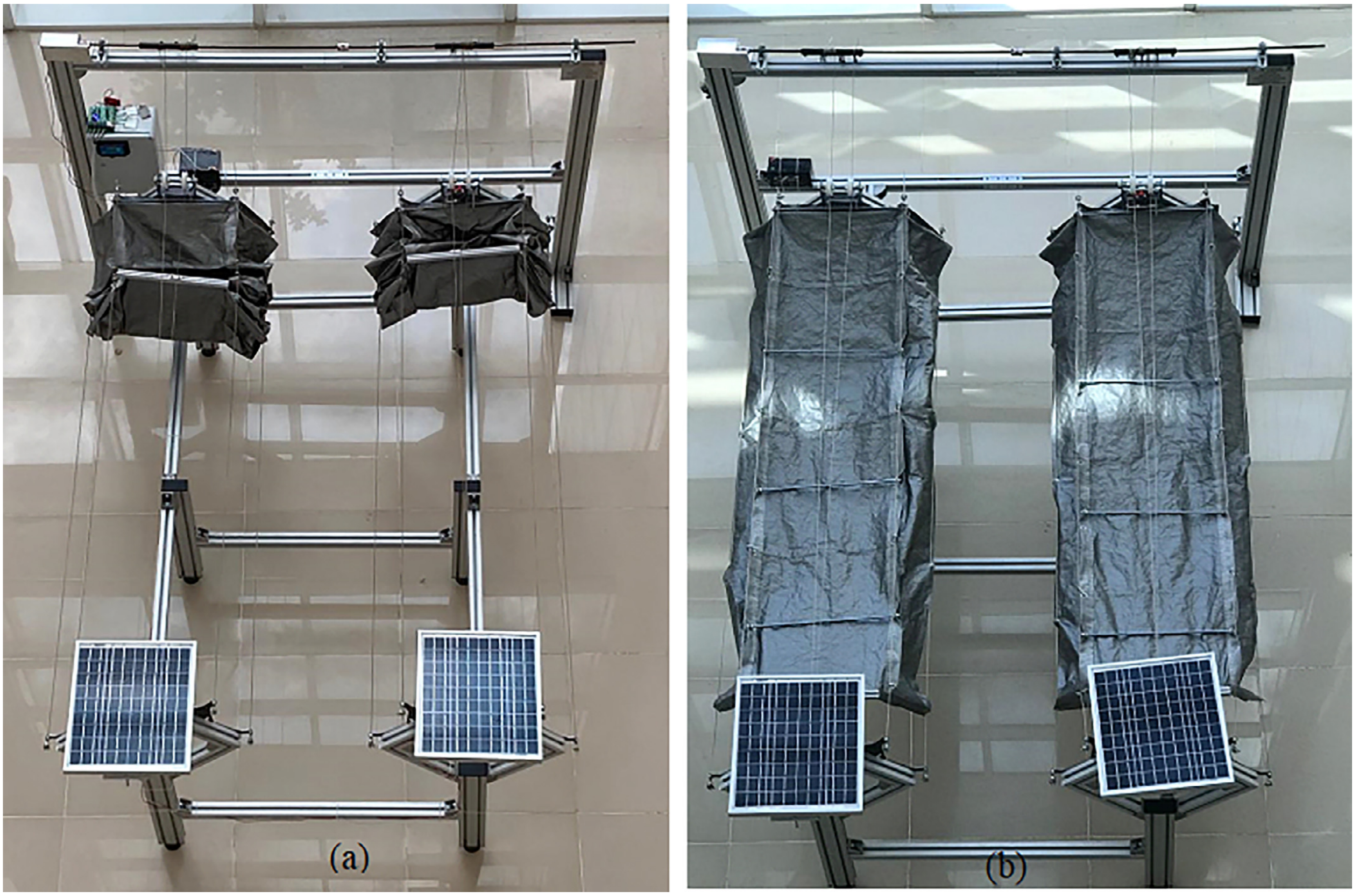

Fig. 1. (a) The system with the cover open, Fig. 1(b) The system with the cover closed.

to sweat in response to the summer heat, reducing the vineyard's output substantially. Another circumstance is that if the events mentioned above occur before to these coverings being applied, the product developed up to that point is harmed. Additionally, it is a time and economic drain, since personnel are required to cover these coverings and remove them after the grapes are sold. Another scenario is that the farmer insures his goods against individual natural disasters (frost, hail, excessive heat, etc.) and pays a charge, and a specific budget is set up each year for these natural events, and the yield drops as a result of the damaged product (Steiner et al. [16]).

Appropriate heat and water during the growing season, as well as sufficient cold during the dormant phase, are critical for healthy vine growth and the production of high grade grapes (Evans [17]). Grapevines love summers that are long and hot and winters that are moist. During the growing season, warm weather enables grapevines to blossom, set fruit, and ripen (Keller [18]). Grapevines require temperatures of roughly 10 °C to ripen correctly (Ruml et al. [19]. However, severe heat is detrimental to plants.

The main contribution of this study is to present the design and development of an automated vineyard covering system that uses a forecasting approach and collects environmental data. The developed approach is capable of protecting grapevines from the damage caused by hailstones and heavy rains by using a cover system that can open and shut automatically in the presence of unfavorable natural phenomena that vineyards are subjected to. The hardware components include a control box that connects to and obtains environmental data such as temperature, precipitation, and force, as well as a mechanical system that holds the vineyard cover and allows it to open and close automatically depending on sensed data. This project uses the Message Queuing Telemetry Transport (MQTT) protocol to provide data from sensors to subscribers via a mobile application, enabling remote administration and condition monitoring of the system while simultaneously reducing network traffic and device resource requirements.

The remainder of the paper is structured as follows. Section 2 discusses the related studies as well as the motivation for doing the research. In Section 3, we present the materials and methods for designing the hardware structure and system software. Section 4 contains the results and discussion. Section 5 concludes this study by providing future insights into our findings.

2. Related works

Weather satellites and weather radar images may be used to identify hail-producing thunderstorms (Murillo and Homeyer [20]; Stefan and Barbu [21]). They are effective systems, but they are prohibitively costly and difficult to handle for small and medium-sized farmers who often lack the technical skills to operate a sophisticated electronic system. Adaptation methods to reduce the effects of severe weather have therefore been a research focus on recent years (Kaján and Saarinen [22]).

Despite Turkey's vineyards' high sensitivity, few growers have taken efforts to prevent the effects of harsh weather (Olesen et al. [23]; Sabir et al. [24]). Hailstorms, frost, extreme heat, strong winds, and severe precipitation throughout the growing season may impact not only crop output and quality, but also market pricing (Kistner et al. [25]).

In comparison to many other high-value crops, wine grapes are less typically protected against frost owing to high costs and management issues. However, the damage that may ensue from severe frost episodes

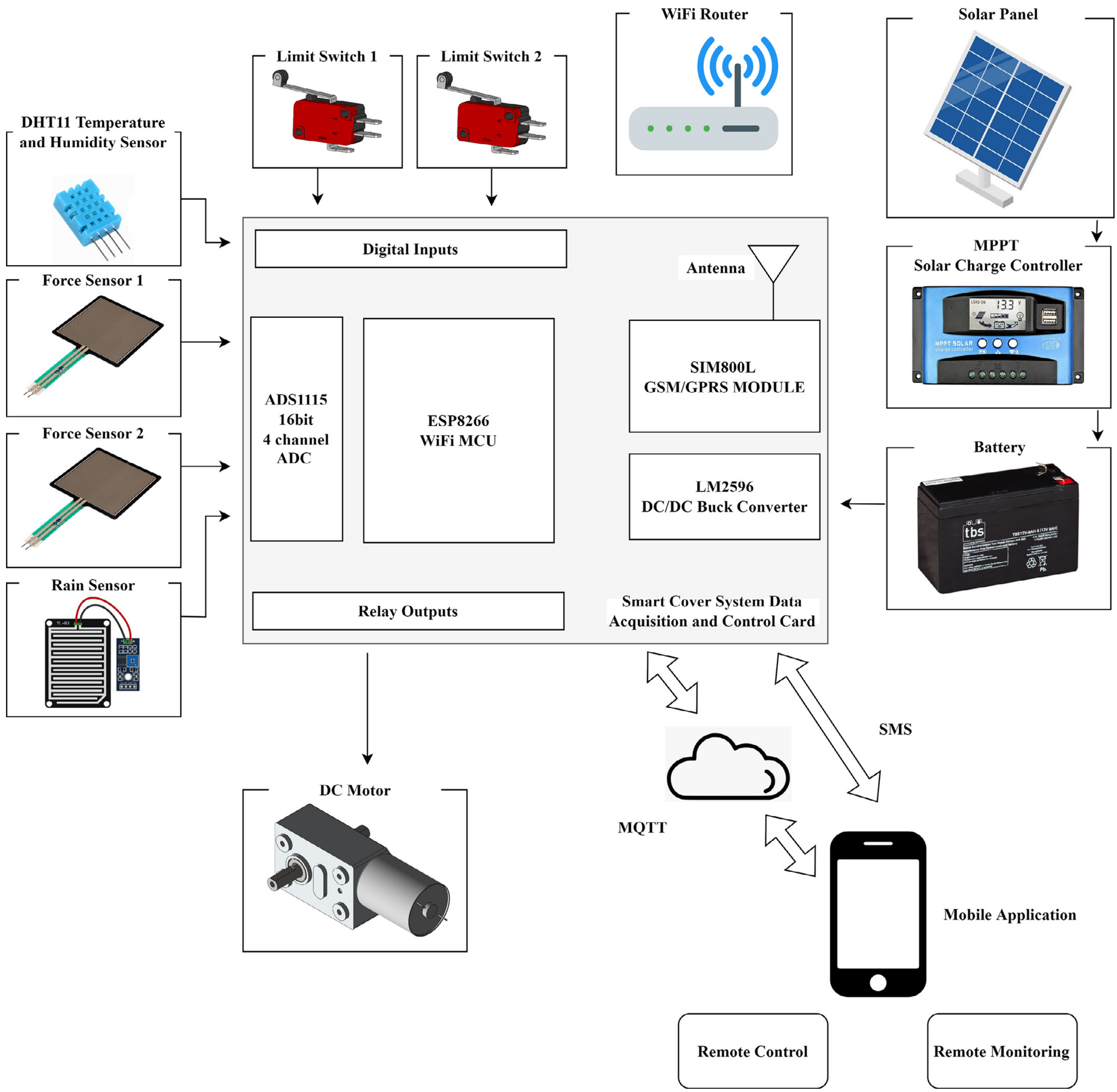

Fig. 2. The block diagram of the developed data collection and control card.

is sometimes catastrophic (Kron et al. [26]). Frost is a severe threat to grape production in Europe and Australia, and recent study indicates that the frost season in many grape growing areas may be lengthening (Meier et al. [27]; Gobbett et al. [28]). Hoarfrost occurs when temperatures fall to or near zero degrees, either as a result of an inflow of cold air or as a result of a temperature inversion (Brutsaert [29]). This is the most prevalent kind and results in frost freezing on the vine's surface, perhaps inflicting harm to the plant. Cold air remains in the lowest layers of the atmosphere, eventually reaching the ground and pushing warm air upward (Ahrens and Henson [30]).

Hail may be very harmful to grapevines, causing damage to the bark, leaves, and fruit (Bal et al. [31]). Hail may also do serious damage to young, thin-barked vines. The falling hailstones make wounds in the vine's bark. Hail may inflict significant harm to vineyards, not only in terms of amount and quality of grapes harvested, but also in terms of grapevine survival and long-term vineyard growth (Simeonov et al. [32]). Hail is capable of wreaking havoc on leaves, stems, shoots, flower clusters, and fruits. Leaves, flowers, or fruits may be bruised, ripped, or holed; while shoots and trunks might be fractured or have fractures. Therefore, in addition to reducing productivity, hail might result in a crop of inferior quality.

While various mitigation technology may have a variety of benefits, their application may have several unintended consequences and include risks that most farmers find difficult to evaluate. Anti-hail rockets and aircraft have been utilized by certain people (Wieringa and Holleman [33]). This protection is dubious from an ecological and economic standpoint, and due to its poor long-term performance, it is being phased out in various parts of the globe. This strategy is effective only in a lim-

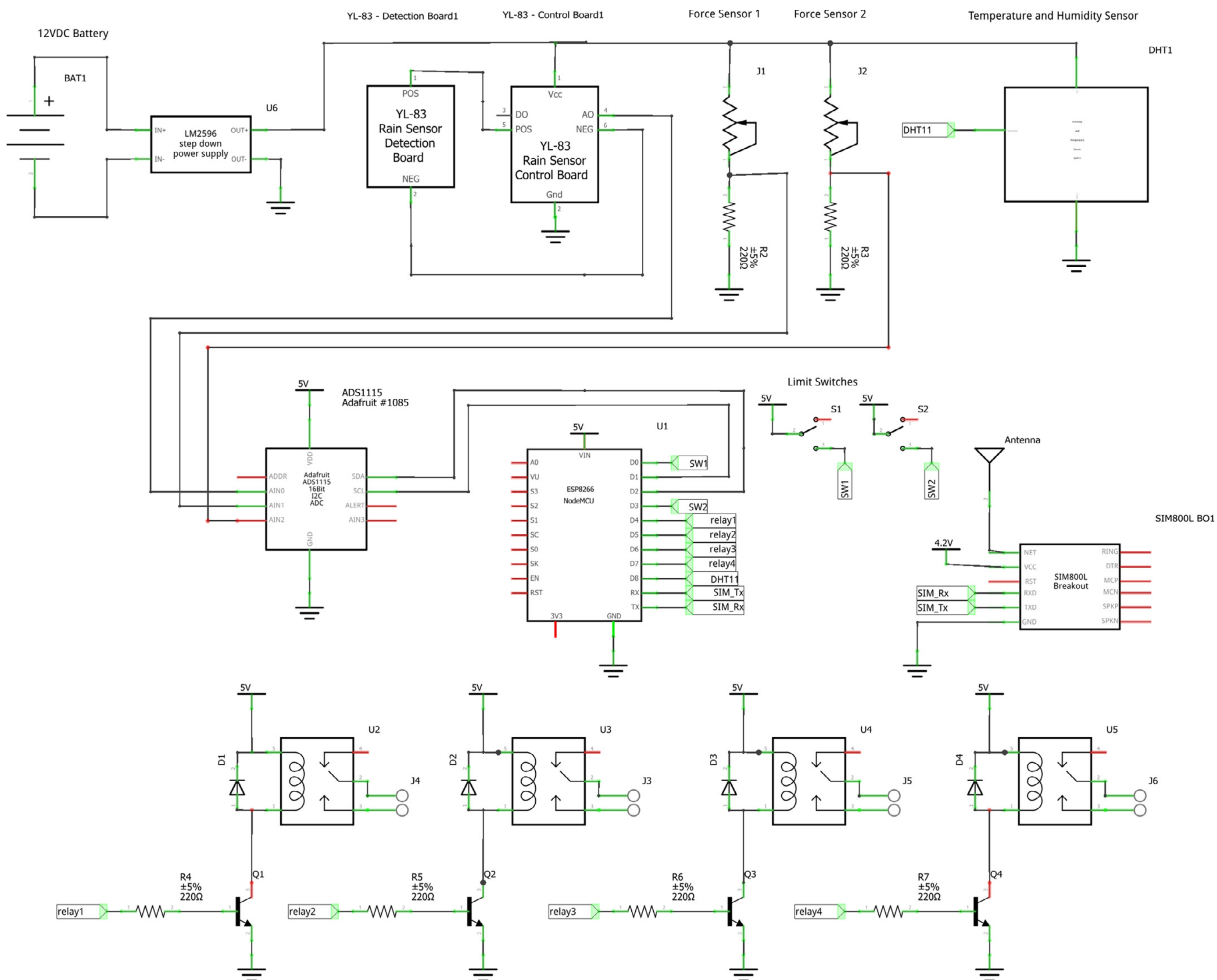

Fig. 3. The circuit architecture for the designed data acquisition and control card.

ited number of areas and needs a high level of technological compatibility and organization. A disadvantage of this protection is that it does not totally exclude the potential of hail; so, hail may still fall but do less harm. Hail nets are the most effective method of protection for commercial vineyards currently available on the market (Basile et al. [34]). However, this is a typical approach that requires human operation. It is a labor-and cost-intensive process.

Commercial vineyards also utilize a method that involves running enormous sprinklers all night, forcing water on the vines to freeze over the sensitive growth (Poling [35]). However, this approach is costly in terms of the energy necessary to pump water as well as the cost of water.

Recent study (Pérez-Expósito et al. [36]), proposed a hardware and software platform for remote monitoring vineyards in the Internet of Things (IoT) era. Since its deployment, the system has been generating alerts that warn vine growers about the measures that have to be taken and it has stored the historical weather data gathered from various locations of the vineyard. However, the system misses control mechanism for covering the vineyard when the adverse parameters are sensed. Cagnetti et al. [10] uses for the vineyard hail protection based on ZigBee sensors, raspberry-Pi electronic card and WiMAX.

Farmers who can maintain their production and crop quality while reacting to such weather occurrences are likely to earn more money (Tucker et al. [37]). By using automated cover systems to protect vineyards from inclement weather, growers may be able to avoid significant losses.

3. Materials and methods

In this work, a cover system that can be opened and closed automatically and remotely was designed to protect vines from unfavorable natural phenomena (hail, rain, frost, and extreme temperatures). It is expected that the suggested approach will safeguard crops while increasing yield. For the sake of demonstrating system performance, a portable prototype was conceived and produced. The prototype was one-third the size of the actual system that would be used in vineyards. The prototype's height and width are 1 m and 2 m, respectively. The following describes the hardware and software system designs.

3.1. Hardware design

Metallic poles are employed in the design to support the entire system, while hanging steel ropes are used to hold the cover in place. The

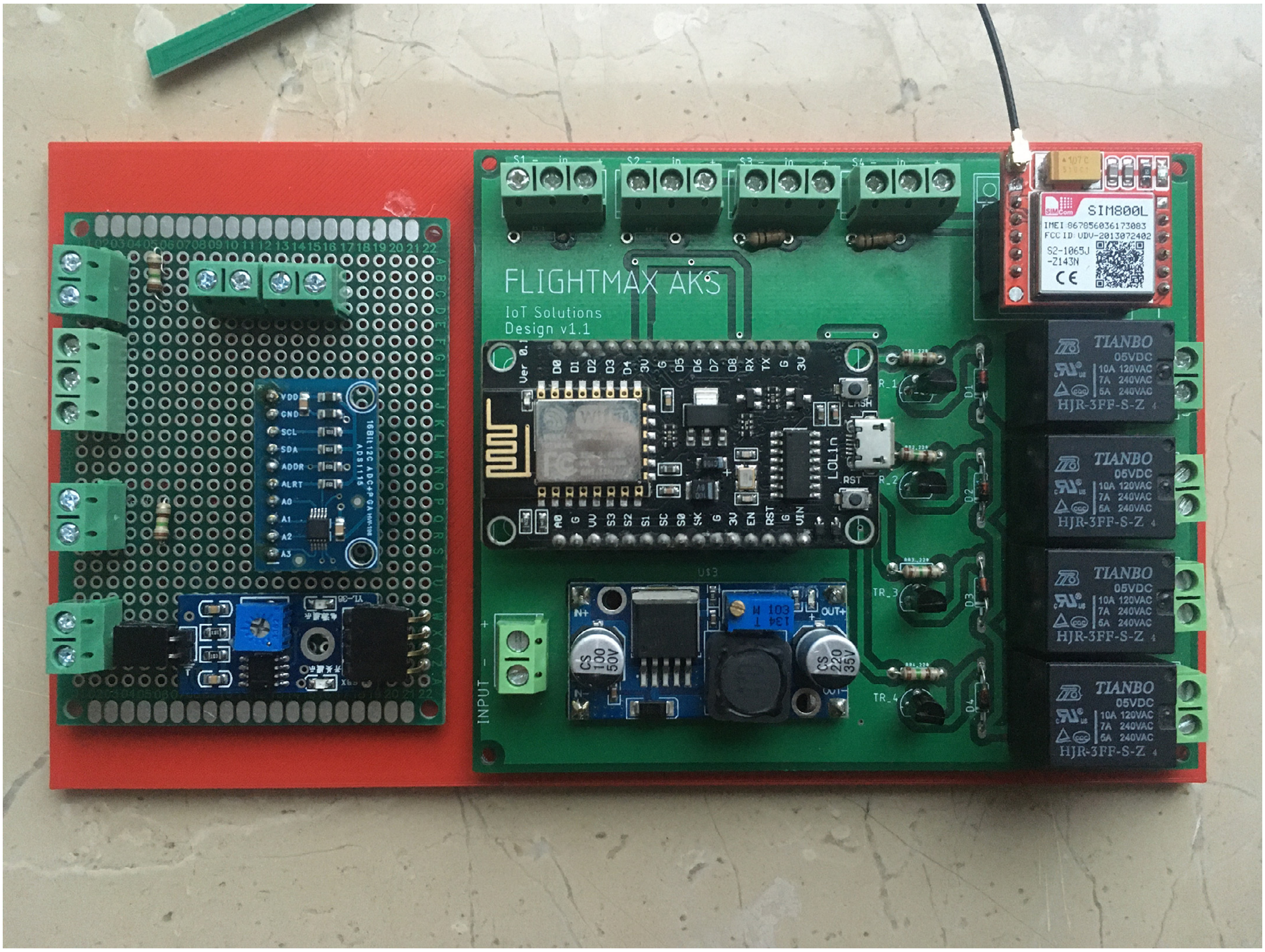

Fig. 4. The developed data acquisition card.

motor-driven cylindrical pipe positioned at the beginning of the hanging array is used to open and close the cover. Fig. 1(a) represents the system with the cover open, while Fig. 1(b) depicts the system with the cover closed.

Vineyard cover system design is a type of intelligent aided technology that can be installed on a vineyard to examine, monitor, evaluate, control, and transfer data regarding unfavorable weather conditions. There are various forms of data obtained from sensors in relation to the weather conditions at the time. Because the system is intended to be utilized on farms where there is a limited possibility of obtaining energy, solar panels and batteries are used. Temperature, hail, and rain are the most fundamental weather indicators. To safeguard the crops, the system can automatically close or open depending on the standard amount required after sensing and assessing the weather state. As a result, all of these conditions must be considered during the design of the cover system, which can play an important role in detecting weather conditions, automatically opening or closing the cover, and sending the information to the farm management team. Let us examine each sensor used to identify and detect the weather, power supply system, control system, and communication system.

3.1.1. *Weather conditions detection sensors*

This paper considers three major weather conditions: rain, temperature, and hail. Too much rain can be detrimental to crops, which is why a manageable amount of rain is essential. Additionally, extremely hot or low temperatures, as well as hail, can have a devastating effect on crop production. Controlling these conditions will improve crop protection and production.

The DHT11 Temperature and Humidity Sensor is used to detect the temperature and humidity. It is equipped with a temperature and humidity sensor complex as well as a calibrated digital signal output. The sensor achieves great reliability and long-term stability through the use of an innovative digital data acquisition technique in conjunction with temperature and humidity sensing technologies. This sensor is composed of a resistive-type humidity sensor and an NTC temperature sensor. It is connected to a high-performance 8-bit microcontroller and offers great quality, rapid response, anti-interference capability, and cost-effectiveness. Additionally, the sensor is factory calibrated, which simplifies interfacing with other microcontrollers. The sensor has a temperature range of 0 °C to 50 °C and a humidity range of 20% to 90%, with an accuracy of 1 °C and 1%, respectively.

To ensure that the vines receive a proper supply of water, the raindrop sensor is utilized to determine the quantity of rain. The sensor is comprised of copper rails that serve as a variable resistor. Its resistance changes according to the state of the rainboard. Two modules comprise the raindrop sensors: a rain board that detects rain and a control module that compares and transforms the analog value to a digital value. The control module for the raindrop sensor has four outputs: VCC, GND, D0, and A0. VCC is supplied with electricity through a 5 V DC source.

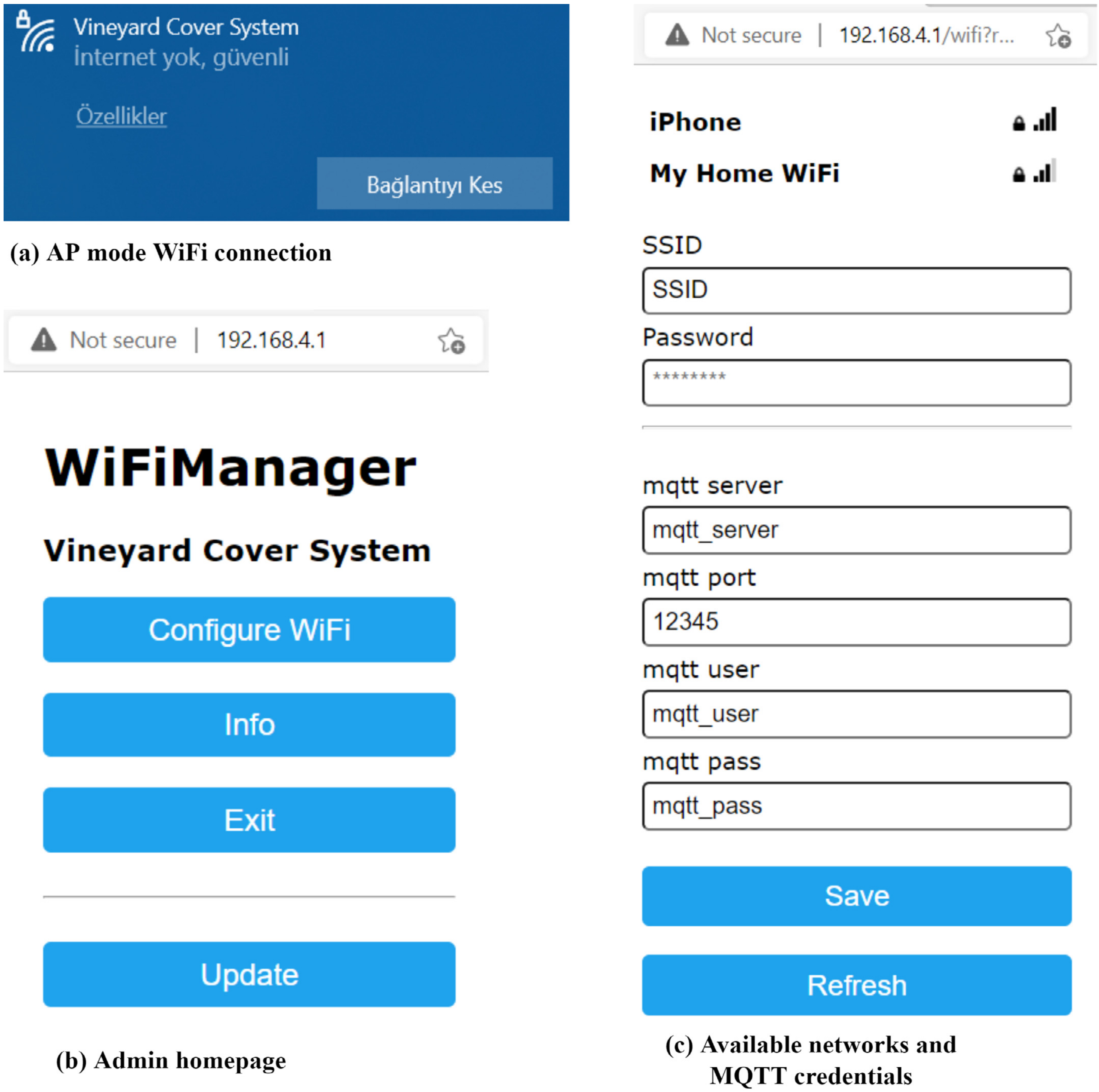

Fig. 5. The access point mode WiFi setup.

The GND pin of the module is linked to ground. The D0 pin is linked to the microcontroller's digital pin or the analog pin can be utilized for digital output. To use the analog output of a microcontroller, the A0 pin can be linked to the analog to digital converter (ADC) pin. When the raindrop sensor detects heavy rain, the cover system may be utilized to protect the vines from the negative impacts of rain and excess water.

Hail may be destructive to vines. Two RP-S40-ST thin film force sensors are used to detect hail. When a force is applied to these force sensors, they exhibit a change in resistance. Thus, when hailstones strike the force sensors, they may quickly be identified. The sensor is extremely durable and is designed to rapidly detect static and dynamic pressure. Due to the benefits of recording force density and frequency, they are extensively employed in a range of applications. Additionally, these sensors are straightforward to utilize. The sensors are activated by a weight of 20 g and are capable of measuring pressures ranging from 20 g to 10 kg. The force sensors are capable of measuring static and dynamic pressure at a frequency of 10 Hz and operating in temperatures ranging from −40 °C to +85 °C.

3.1.2. System power supply

The 12 V DC geared motor that drives the cover mechanism and the electrical system are entirely battery operated, requiring no external energy supply. The 12 V battery is charged by photovoltaic (PV) panels.

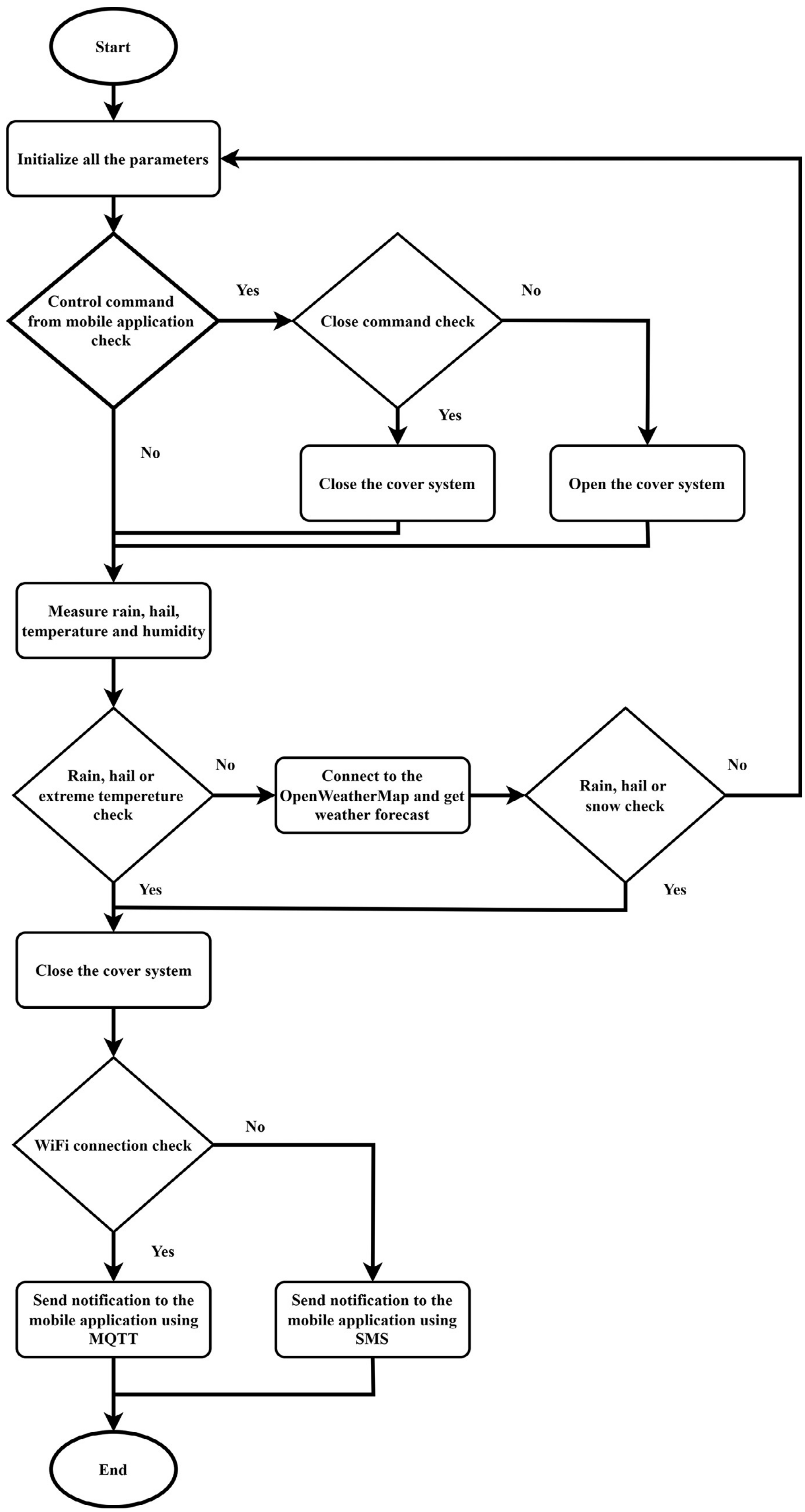

Fig. 6. The program flow.

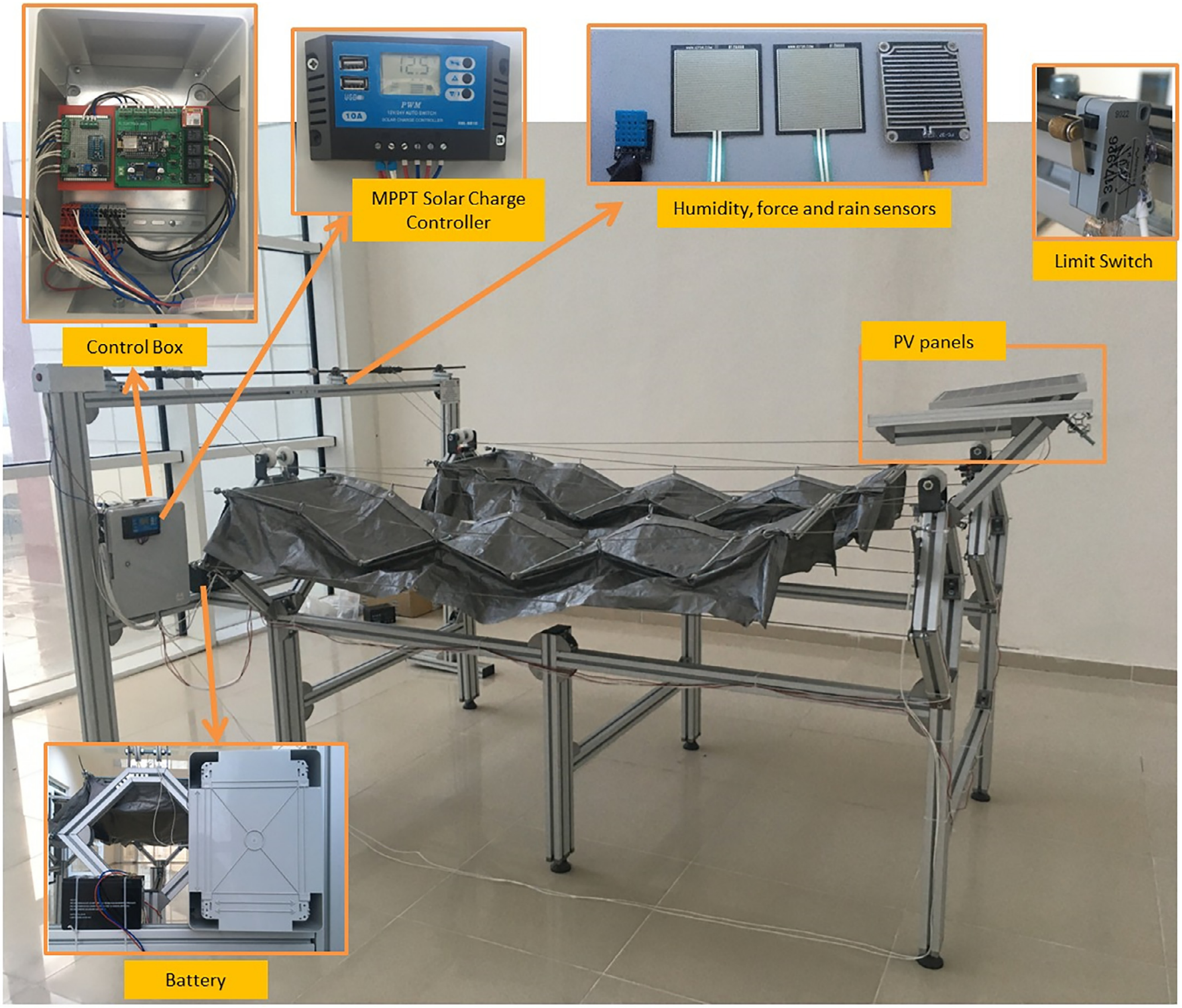

Fig. 7. The complete system prototype.

The 12 V system is comprised of two 10 W 12 V solar panels linked parallel to a 12 V maximum power point tracking (MPPT) solar charge controller. A solar charge controller protects the battery from overcharging by limiting the voltage and current going from the solar panel to the battery. It is configured as a 15-A/200-W device and utilizes MPPT to accelerate solar charging by up to 30% per day.

The 12 V battery powers the control card. The LM2598 voltage regulator is used to regulate the amount of voltage applied to the card. The LM2596 is a switching regulator for DC-DC conversion. The regulator is capable of carrying up to 3A of current. The input voltage range is 4–35 V, and the trimpot on the board allows for adjustment of the output voltage between 1.25 and 30 V. When utilizing this board, the input voltage must always be larger than the output voltage. IN+ indicates a positive voltage input, IN- indicates a negative voltage input, and OUT+ indicates a positive voltage output, and OUT- indicates a negative voltage output. The regulator converts the 12 V battery supply voltage to the lower values required by the WiFi module, GSM/GPRS module, and Analog to Digital Converter (ADC), which are commonly 5 V and 3.3 V.

3.1.3. Motion control

The cover is opened and closed with the assistance of the motorized cylindrical pipe installed at the beginning of the suspended metallic array. A 12 V DC geared motor powers the pipe. When the pipe spins, it pulls the cover's pair of steel ropes. The spinning of the roller pipe causes the ropes to travel horizontally across the rollers. Four relays fitted in the developed control card offer direction control for the motor. The H-bridge driver circuit is constructed by these relays, allowing the motor to run in both forward and backward directions. Limit switches are fitted at the beginning and end of the designed system to identify the cover's end of travel. They are able to determine when the opening and shutting operations are complete.

3.1.4. Data aquisation and control card

The developed data acquitision and control card is equipped with a system that can be handled remotely via a mobile application and is capable of sending notifications directly from the vineyard. When a WiFi router is installed in the vineyard, two-way communication is enabled using MQTT, one of the most widely used machine-to-machine

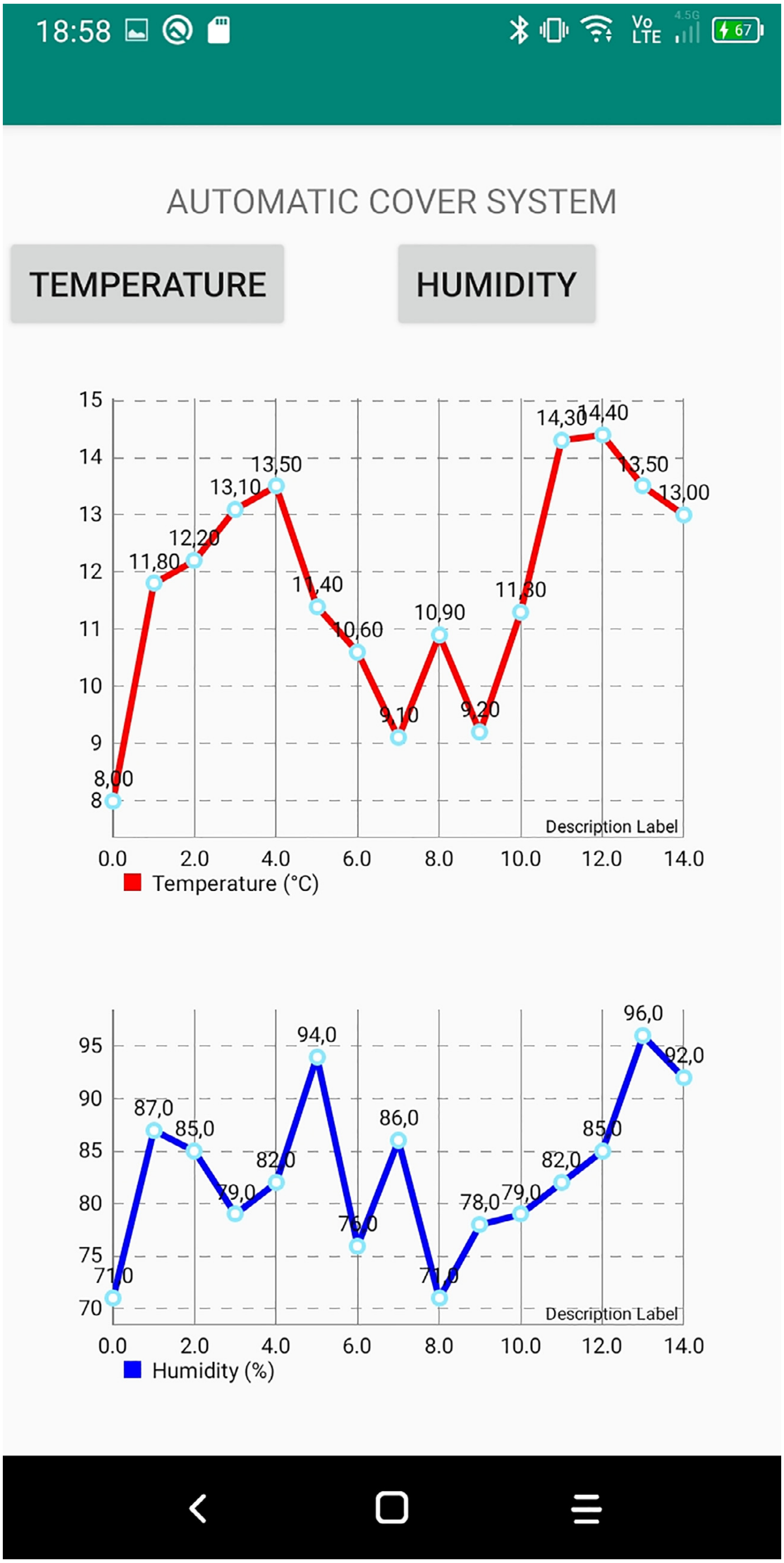

Fig. 8. Humidity and temperature data received during the two-weeks operation.

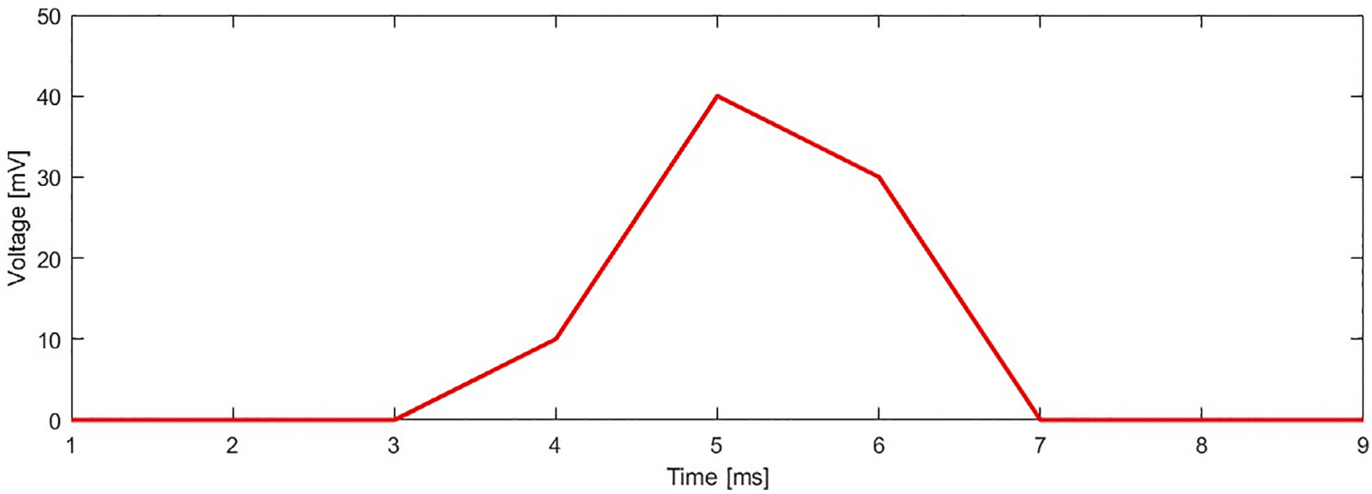

Fig. 9. The frost and hail data received from force sensor the two-weeks operation.

communication protocols today. If the vineyard lacks a WiFi network, two-way communication can be accomplished through Short Message Service (SMS). The card is equipped with a DC/DC converter, a WiFi module, and a GSM/GPRS communication module in order to gather data and establish connection.

NodeMCU, an open source platform based on the ESP8266, is utilized to establish wireless connection with the WiFi router. NodeMCU enables the connection of items and the transport of data via the Wi-Fi protocol. Additionally, it may provide some of the most critical microcontroller functionalities, including as GPIO, PWM, and ADC. The primary qualities of NodeMCU are their simplicity of use, their ability to be programmed using the Arduino IDE or IUA languages, their ability to be used as a station or an access point, and their applicability in event-triggered API applications. On the board, the Node MCU features an inbuilt antenna, 13 GPIO pins, 10 PWM channels, I2C, SPI, ADC, UART, and 1-Wire connectors. NodeMCU includes an integrated 8.11a 802.11 b/g/n WiFi module, a 3.3 V operating voltage, and can operate at temperatures ranging from −40 to 125 °C.

The SIM 800 L GSM/GPRS module is used to communicate between a mobile device or a computer and a GSM or GPRS system. The module can be used to perform practically every task that a standard cell phone can. It is used to send and receive SMS text messages and to connect to the internet via GPRS in the cover system. The SIM800L GSM/GPRS module is compact and consumes minimal power. Due to its power-saving method, the current consumption in sleep mode is as low as 1 mA. It communicates with the microcontroller through the UART port and takes commands. It operates between 3.7 and 4.2 Vs and delivers a peak current of 1 amp. Remote access to the control card for the smart cover system is possible via the MQTT protocol or SMS communication. Notifications may be sent automatically via a mobile phone application designed in response to observations of rain, hail, and severe temperatures in the vineyard.

For data processing, ADCs convert analog electrical signals to digital signals. The cover system is equipped with a 16-bit, four-channel ADS1115 ADC. The ADC digitizes analog electrical inputs from the force sensors and rain drop sensors. The ADS1115 is a precision-engineered device that is simple to implement. It operates on a single power source with a voltage range of 2 V to 5.5 V and a temperature range of −40 °C to 125 °C. The ADC is capable of sampling at a rate of up to 860 samples per second. Additionally, the ADS1115 includes a multiplexer (MUX) that supports two differential or four single-ended inputs. Fig. 2 illustrates the block diagram of the developed data collection and control card. Fig. 3 illustrates the circuit architecture for the designed data acquisition and control card. The system's data acquisition and control card is built to withstand outdoor environments. Fig. 4 illustrates the developed data acquisition card.

3.2. System software

The control card for the smart cover system supports both WiFi and SMS connection. If the vineyard has a WiFi router, the card may easily be connected to the WiFi network. To configure WiFi, the Access Point (AP) configuration technique was used. The control board begins functioning as a WiFi access point using this way. When a mobile device is connected to this network, the admin webpage is shown. The administrator's home page displays a list of available WiFi networks in the environment. The user selects one of the various WiFi networks in the surroundings and enters the password information. Additionally, this page requires the entry of MQTT credentials. This page is used to input and store the address, user, and personal password information for the MQTT service that will be utilized. The data acquisition and control card may then simply connect to the designated WiFi network and have access to the internet. Fig. 5 illustrates the AP mode WiFi setup.

Additionally, if the data acquisition and control card has internet connectivity, it may connect to the OpenWeatherMap program and obtain a three-hour weather prediction. This ensures that the cover system is immediately closed in the event of precipitation or hail. Fig. 6 illustrates the developed program flow. Fig. 7 shows the complete system prototype.

4. Results and discussion

When weather phenomena such as rain, hail, or excessive temperatures are noticed, the created smart cover system has the capacity to automatically turn off the cover system. Data collecting and sensor equipment on the control card can be used to measure such harsh weather conditions. A notification is sent to the user's mobile application if the cover system is closed. As a result, after the bad weather passes, the user may utilize the mobile app to open the cover system.

Fig. 8 shows the temperature and humidity data received during the two-week operation of the smart cover system control card in the field. Fig. 9 illustrates the frost and hail data collected from the force sensor throughout the course of a two-week field trial of the smart cover system control card.

Remote access to the smart cover system control card through MQTT protocol or SMS communication is also possible owing to the created mobile application. When weather conditions such as rain, hail, or se-

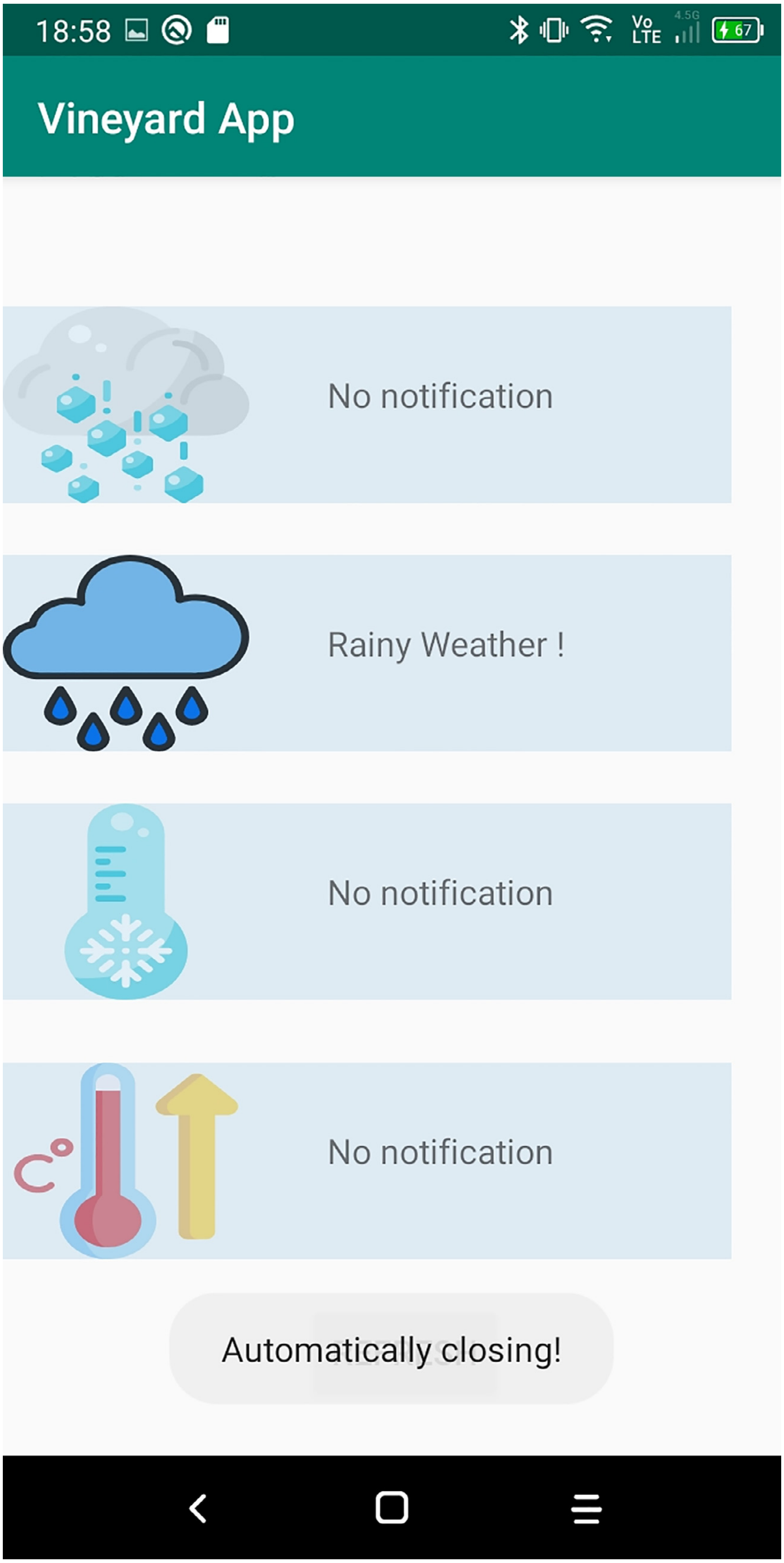

Fig. 10. The user interface for the developed mobile application.

vere temperatures are noticed in the vineyard, automated notifications can be sent. A user-friendly dashboard has been included in the mobile app, which aids in decision-making, data visualization, analysis, and storage. Notifications and alarms are also part of the system. The system shows real-time temperature, precipitation, and force data, as well as the presence of frost and hail. It may generate tracking reports and be viewed and queried remotely, depending on the needs of its users. Furthermore, the platform would have the capacity to assess the environmental effect. The user interface for the developed mobile application is seen in Fig. 10.

The OpenWeatherMap program forecasts the weather for the next three hours. When a WiFi device is linked to this site and a city is chosen, future temperature, precipitation, and force statistics are shown.

The system testing took place on the campus of Manisa Celal Bayar University. The goal of our research is to validate the sensors and parameters used, as well as to assess their usefulness for vineyard protection and to give a decision mechanism for controlling actuators. On the one hand, when the detected data exceeds a certain threshold, the system opens and closes the vineyard cover to preserve the vines and fruits. The mechanism, on the other hand, maintains the grapevine cover open. Furthermore, the dashboard's user-friendly and easily adaptable design gives it an edge over competing systems.

5. Conclusions

Currently, significant rains, often accompanied by hail, have resulted in the severe loss of vineyards and table grapes in a number of places. As a result, developing an autonomous covering system employing contemporary technology is critical. The purpose of this work is to design an automated covering system employing a forecasting technique and environmental data collection. Protecting vineyards with the proposed self-contained covering system is a suitable solution for table grape farmers in particular. The devised method is capable of defending grapevines from the devastation caused by hailstones and strong rainfall. The suggested prototype has been tested, and the findings indicate that it is capable of rapidly covering vineyards without causing destruction due to severe rain or hail. Additionally, one of the design's distinguishing features is the simplicity with which environmental data may be sent to consumers. As a result, they may always be informed on the status of their vineyard. This is accomplished through the use of GSM/GPRS technologies. Thanks to the suggested solution, burden of the farmer is being minimized.

Author contributions

Bilal Karaman performed conceptualization, software, investigation, and validation. Sezai Taskin performed supervision, visualization, reviewing and editing. Daudi S. Simbeye performed original draft preparation, data curation, writing- reviewing and editing. Mbazingwa E. Mkiramweni performed methodology, reviewing and editing. Aykut Kurtoglu performed software and investigation.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The Scientific and Technological Research Council of Turkey (TUBITAK) financed this study under the 2209-B University Students Research Projects Supporting Program for Industry (Grant No. 1139B411801958). Additionally, the authors wish to express their gratitude to Ultimate Automation for their assistance in designing mechanical systems.

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