Precision Farming (Smart Greenhouse)

Smart Greenhouse as an Autonomous System Based on DL

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Contents

Abstract

This paper is particularly about improving the present greenhouse practice by adapting the latest technologies. This paper comes up with a model that helps the greenhouse users (Farmers) to automate the processes. The greenhouse servers as shield that protects the plants from biotic and abiotic pests. The micro-climate environment requires control and surveillance. Therefore to control the greenhouse, several system such as irrigation, ventilation and lighting were designed. In addition plant growth monitoring system, fruits recognition system and plant diseases monitoring system were designed for surveillance purpose. These systems produce a more dependable greenhouses. A deep learning approach was selected for the monitoring systems. A deep learning model was developed (DL). The DL model has promising accuracy. The IoT plays an important role in the smart greenhouse model. Therefore, a communication system based on the ZigBee was designed. This system ensure efficient communication between components of the greenhouse and it establish a remote control connection.

1 Introduction

1.1 Purpose

The traditional greenhouses have a lot of advantages but there are some disadvantages as well. The most significant disadvantage is that traditional greenhouses require constant monitoring. In constant monitoring maintenance and care is included. The main aim of the smart greenhouse is changing this disadvantage. Farmers can monitor the system remotely through a internet connection. This type of system is able to operate autonomously. All conditions inside the greenhouse are done automatically. By implementing the smart system the operational costs will decrease. This leads to more greenhouses construction even in poor countries. The system is more efficient with lower costs. This system is innovative and can be part of precision farming. To control all processes inside the greenhouse is not a easy task. The user should have a solid knowledge background to grow crops successfully. The smart greenhouse can solve this problem as well. Deep learning is a powerful tool that helps in this direction[3]. This means that the system can learn from different inputs and optimise the autonomous behaviour. This ensure the reliability of the greenhouses even if they are in huge dimensions[30].

1.2 Background

Traditional and smart greenhouses have been around for a long time. There are several researches done in this direction. Since the technology is evolving, more autonomous and intelligent greenhouses are developed[29]. The hardware and components that are used to build the smart greenhouses are improving and costing less. Nowadays there are more hybrid smart greenhouses where the user (Farmer) still has a significant role. Several process operate autonomously but there are processes that still run manually. In this paper is discussed the possibility of building a more autonomous system closer to full-autonomous smart greenhouse. Low-energy or battery-operated sensors can help in this direction. The second accelerator of the smart greenhouse is a financial friendly communication between sensors and remote actuators inside a greenhouse. The third tool to fill the gap in greenhouse monitoring system is machine learning and deep learning. Deep learning can be used to transfer the data gathered from sensors to decisions on farming processes. These technologies are linear and they can be easily updated and adapted. They can be implemented even in existing greenhouses[30].

1.3 Tools and Methods

The smart greenhouse is a complex system. To design the system a model based design approach was chosen. This approach was selected because it is beneficial in case of the complex embedded systems.The models that are designed are reusable, this can improve development time and costs.There in not an explicit need for hardware during the design as well. The companies find this approach beneficial because it achieves a faster time to market and it is faster to produce a first demonstration. To implement the smart greenhouse several requirements were to be met. The overall system was split in three main sub-systems to reduce the complexity of the system [3]. The first is the control sub-system. This sub-system has three main components. The first component is irrigation system. The second one is the ventilation system. The last component of the first sub-system is illumination (Lighting). The second sub-system that was designed is monitoring. This sub-system has three main components. The first is plant growth monitoring. The second is fruits of the plats recognition and monitoring. The last component is plant diseases monitoring. The third sub-system and the last one is the communication sub-system[30].

2 General Structure and Analysis of The System

2.1 Smart Green House Overall Information

Basic notation of a greenhouse is a construction composed of metal construction and glass or transparent resistant plastic[14]. Specific field dimensions are covered by this construction. The purpose of a greenhouse is to create a micro climate inside. Therefore, several plants can be grown despite of the outside conditions. The greenhouse is used to grow plants faster and healthier. The plant growing is not related to seasons and location. this is the reason why greenhouses can be built almost in every country and produce crops. The climate inside should be regulated and monitored. The ventilation is one of several processes that regulates the climate inside the greenhouse. In normal greenhouse the regulations and adjustments are done manually by the farmer. In a smart greenhouse the automation takes place. The main components of a greenhouse are soil, plants and climate conditions also lighting is included. The soil can be monitored for water presence, moisture, fertiliser, $CO2$ and other parameters that are connected with the plants.The second component is plants. It is important to monitor the plant conditions such as their growing process, detecting their fruits and checking the wellness (Diseases monitoring). And the last component is micro-climate. In the micro-climate are included irrigation, ventilation (Humidity and Temperature), fertilisation and illumination. These are the main parts that form a micro-climate inside the greenhouse. Usually in a traditional greenhouse all processes are correlated with the help of the farmers. The farmers keep the climate conditions inside under control. In the same way they can check the soil conditions and start irrigation or fertilisation if it is needed. The farmers check the conditions of the plants and their fruit manually. All the monitoring and decisions are taken by the farmers. In a smart greenhouse is the other way around. These processes are connected together and they are performed autonomously[2]. For example, if the temperature is getting higher the ventilation process starts automatically. Also if the soil is not wet enough the irrigation process starts automatically. In the same way the cameras can monitor the plants. They can detect plant growing process, fruits and diseases.

All this information is transmitted to the farmer in the real time. All the required systems run autonomously and the farmer just monitor the systems remotely. In an advanced smart greenhouse the deep learning approach can make the system more reliable and dependable. The deep learning can be implemented in systems that are based on the sensors and optimize their operation[13].

2.2 Vertical Farming

Vertical farming can be used in the greenhouses. It is relevant when the resources such as soil or water are limited. In a vertical greenhouse the production can be increase by adding more rows. At first glance looks like the costs are less than a traditional greenhouse. This is not true became vertical farming requires more construction efforts[19]. The main problem is light. Only the first row from the top can use the natural sun light. The lower rows are in shades. There are plenty plants that require sun light for growing their fruits. Therefore for the lower rows is required artificial lighting, this increases the power consumption and directly the costs. In some cases there are plants that do not require direct sun exposure. These plants can be planted in the lower rows. Still this is not a good idea because it can reduce the usage of the greenhouse. In this way it is a limitation in usage for the lower rows. The vertical farming is beneficial in areas where the climate condition or soil is not suitable for farming. In this situation in a small amount of terrain it is possible to produce more. Also it is easier to turn a small unusable terrain to usable because it requires less efforts[8][7]. It is beneficial also in populated areas where the open fields are few. Another advantage is the irrigation. The water can be gathered by upper rows and reused for lower rows. This is important in dry areas where water is sparing. Another point that can be advantage and disadvantage in the same time is the weather resistance. Due to weather changes extreme weather conditions might occur in specific areas.

Figure 1: Indoor Vertical Farming Greenhouse[24].

For example in case a flood the vertical farming is more resistant. In case of a flooding depending on the water level only the ground row is compromised and upper rows are safe[24]. In case a traditional greenhouse the whole area can be damaged. In this case it is a advantage but it is not the same in case a tornado. If a vertical greenhouse is hit by a tornado the whole plants can be destroyed. Due to bigger amount of area occupied by traditional greenhouses , the damages can be partially. In this case this is a disadvantage. The technology is moving ahead and in the future the efficiency of vertical farming can be increased. A important thrust for vertical farming can be the usage of green energy.

2.3 Irrigation,Ventilation and Lighting System

In a smart autonomous greenhouse operate different systems that are interconnected. In this project, the main focus is in three operations. The first operation is irrigation. The second operation is ventilation. The last one is lighting. The smart greenhouse could be implemented in different ways based on the requirements. After further analysis, the system was divided into two components. Further specification regarding the components were taken into account.To visualise this specification a use case diagram was developed. As it is noticeable on the use case

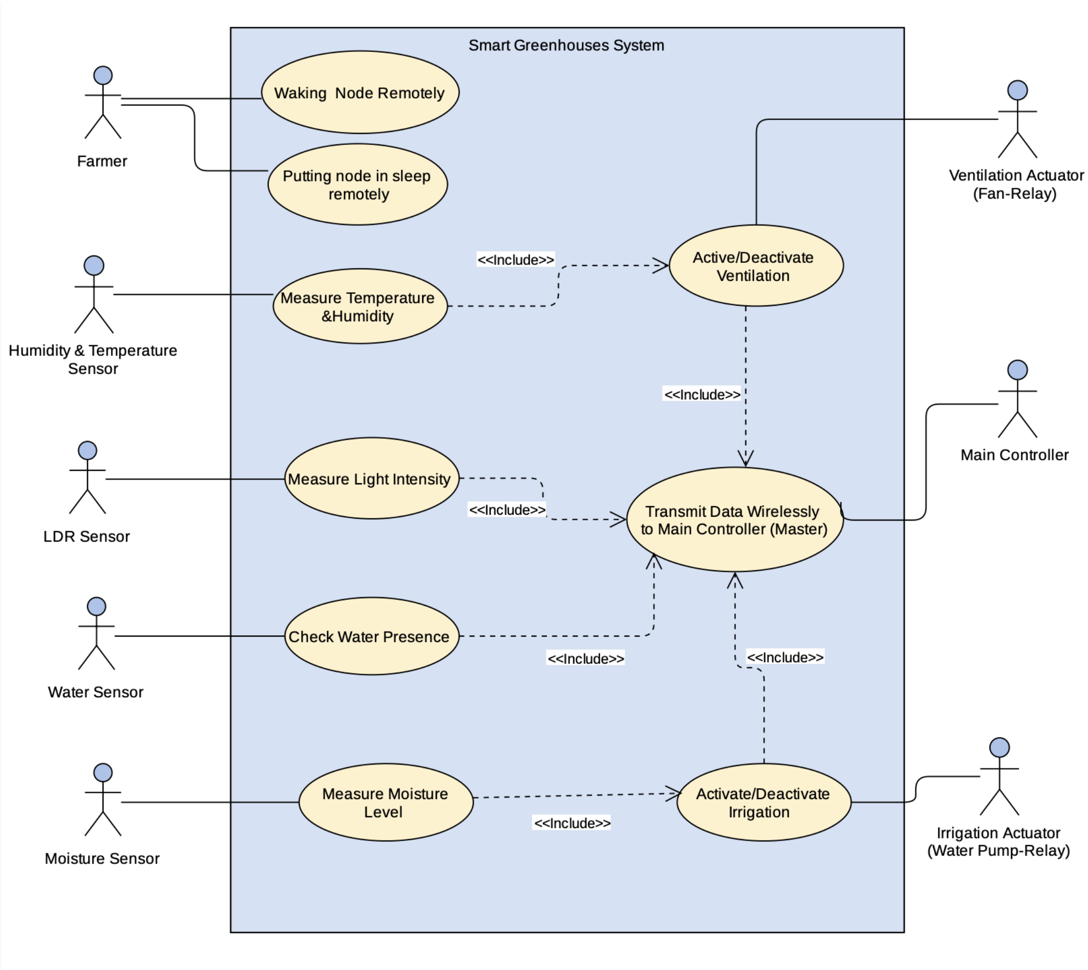

Figure 2: Use-Case Diagram for Irrigation,Ventilation and Lighting

diagram the first actor that has access to the system is the framer. The farmer can wake up a note or the main system remotely. After some specific information or required data that are gathered from farmer, the system is put in sleep. Another actor is the humidity and temperature sensor.

This sensor is responsible to collect Information regarding the temperature and humidity inside the greenhouse.The sensors can be placed in different position for a optimized measure. Also multiple temperature and humidity sensors can be used. It depends in the greenhouse dimensions and position. The following actor is LDR sensor. This sensor is in charge of monitoring the light exposure. Light can be generated from sun or even from artificial lights that helps the plant growing. In both scenarios the LDR sensor is capable to detect the light intensity and transmit the information. The next actor is the water sensor. This sensor can be used for different purposes in a smart greenhouse. The first is to detect the rain drops in case a weather change condition. For example the roof of a green house is opened for ventilation process and it starts raining. It is possible to use the sensor to detect the rain drops and prevent the outside weather condition from damaging the plants inside. Another application is to detect the water during the irrigation process. In this case the water sensor provide information regarding the water presence. It can ensure that irrigation process is successful. It serves as double sensor for irrigation. Together with moisture sensor they can provide a significantly better results for the irrigation. The upcoming actor is the moisture sensor. This sensor is really important because it can provide information for the soil moisture level. The moisture is game changer when it comes to greenhouse plants. The micro climate that is created inside the greenhouse can change the soil moisture really fast. In the same way as other sensors ,the moisture sensor can be placed in different places and they can be multiple as well. The succeeding actor is ventilation actuator. This actor is responsible for enabling or disabling the ventilation. This actuator can be a fan ,a steeper motor to open the window or other DC-Motors which can be activated by a relay. The activation/deactivation of ventilation case has a connection with the temperature and humidity sensor. This connection is visible in the system. To continue with the next actor which is the irrigation actuator. This actuator is responsible for enabling or disabling the irrigation process. This actuator can be a water pump or a relay. Also the irrigation case is related to moisture case. The last actor is the main controller or an external system that has access to the system. This actor is responsible for transmitting all the information generated by sensors an actuators. The data are transmitted wirelessly to the main controller or to a specific external system that has requested for the information[33][13][20].

2.4 Surveillance System Based on Image Processing and Deep Learning

In an autonomous greenhouse is necessary the surveillance. The process of growing and fruits development from the plants, is faster than field plants. Therefore is important for the farmer to have a better overview on the system. It can help the farmers to detect if a plant is growing well and to check if fruits are ready for harvesting. The surveillance system can help to detect plan diseases. To have a better overview regarding the surveillance system a use case diagram was modelled.The first actor in this use case is the camera. Cameras in this scenario are used as a sensor. The first case is to set the cameras. This means cameras can be activated. Also they can be settled up for different usages. They can perform multitasking based on the requirements. The next case is to capture images. Also the cameras can stream live footage of the plants if it was required from the farmer or from an external system (Agronomist). The next case for the cameras as an actor is to transmit the information to the main controller. The transmission is done in a specific period of time and as far as it is required from the farmer. Also if it is required from an external system the recording and live streaming can continue in the background without any time limit. If this scenario is present the node and the whole system that is responsible for this process, has to operate and has to be awake (active). The second actor in this use case is the external system. External system can be an agronomist that is interested to analyse and process the data gathered from cameras. The agronomist can be interested to know plant conditions and wellness. The external system can be a local authority that is interested to access specific information for scientific purposes. The external system can grant the access through cloud based system by using an API. In this case the external system will have access only to a specific group of data. The last actor in the use case is the farmer. The farmer can check the images from the main controller user interface based on the greenhouse by visualising the date. Also the farmer can monitor the condition of the plants remotely. Base on the results that the surveillance system provides, the farmer can perform data analysing. For example if a plant is not growing as it was planned the farmer can check the plants condition. Maybe the irrigation process is not working or a disease is responsible for the malfunction. Base on the footage farmer is able to analyse the data and can provide a faster solution to the problem[6][28].

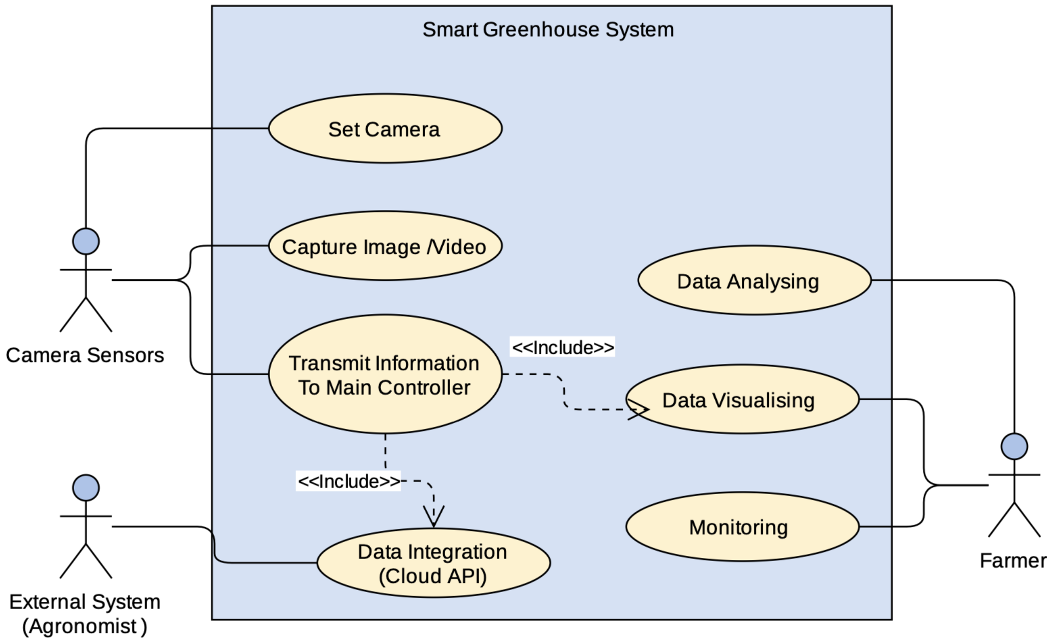

Figure 3: Use-Case Diagram for Surveillance System

2.5 System Architecture

Building an autonomous system for a greenhouse requires several components. Therefore a block diagram was used to describe the holistic system. The system is composed of several nodes and each of them has its own micro-controller. As it is shown in the picture , the nodes are classified in three groups based on the functionality. In the first group are sensors. There are different ways to configure the sensors. It can be one or more connected to a slave micro-controller. For example water sensor and moisture can be connected to the same micro-controller and they form a node that has wireless connectivity with the main controller. In the same approach LDR sensor and temperature sensor can be a node. Depending on the greenhouse dimensions, it might be necessary to have more than one specific sensor. For example ,if it is required to measure the moisture in four different locations that are far from each other, it is required four sensors nodes. If the same logic is followed, the configuration of the sensors can be arranged in another way. In one node we can place all the sensors that are required and we do the same for the three other location. This approach can be economically advantageous because the system can be implemented by using less resources. In the second group are placed the actuators. In this case each actuator is turned on or off by a relay. These relays are controlled by a micro-controller. Depending on the scenario one ore more relays can be composed as a node. For example irrigation pump and pesticide spray pump can be implemented in one node. Also combination of sensors and actors in one node is possible. The actuators can be different but mainly are for irrigation and ventilation. The last group is the cameras as sensors. The cameras usually require more resources to be functional. They can perform different operations such as plant growth surveillance, fruit detection and diseases detection. Even though cameras require more resources than other sensors, they can be combined with sensors and actors in one node. Also several cameras can be placed inside the greenhouse and they can record or stream footage. Part of the system is the main controller too. Main controller is located inside of the greenhouse. The main controller communicate with all the nodes wirelessly. It is responsible for work distribution and coordination. The main controller provides a user interface. The farmer can monitor and control the whole system through the interface. Also the main controller can be accessed remotely by the farmer or by a third part system (External system)[33][20][32].

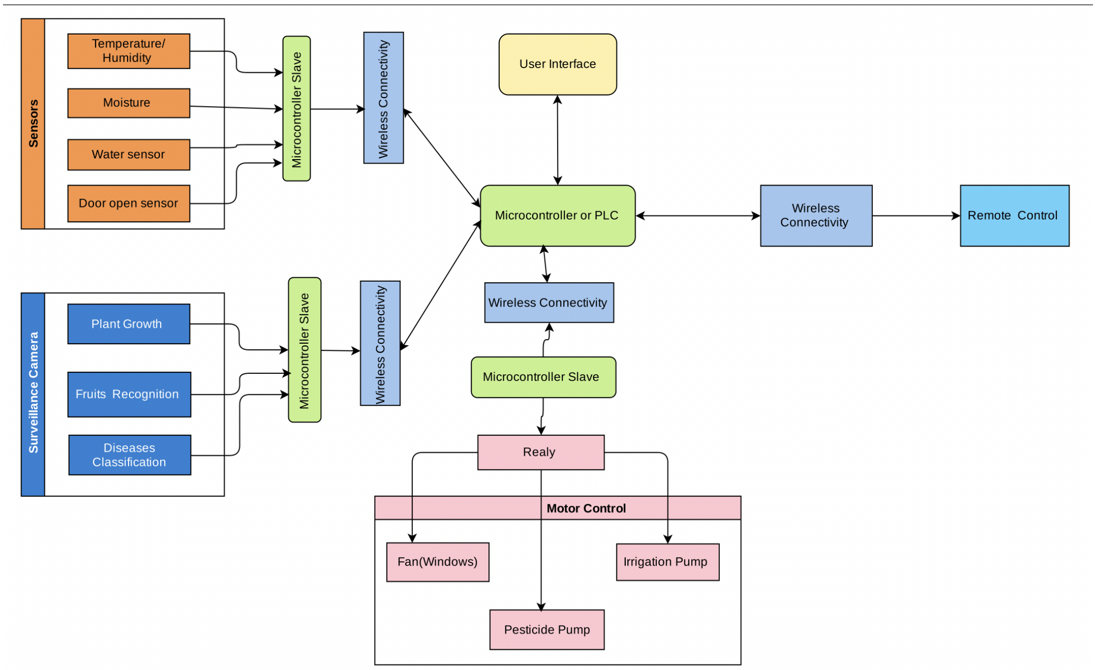

Figure 4: Block Diagram for System Architecture

3 Hardware Configuration

3.1 Hardware Architectural Structure

The design requirements of this system for manual adjustment, integrated with surveillance were developed based on the use cases. For simplicity of implementation the irrigation, ventilation and lighting are considered as a node and all the actions are controlled by single micro-controller. A block diagram for the hardware architecture was developed. As it is mentioned in the diagram there are sensors which provide information to the micro-controller. Data generated by the sensors are two types digital and analog. In the implemented scenario LDR, water sensor and moisture sensor are connected to analog terminals of the micro-controller. The temperature and humidity sensor is connected to digital pins. All outputs are digital values. Outputs are relays, fan and lights. The relays receive digital signals, high for active and low for inactive. In the same way operate the lights and the fan. The micro-controller can be an Arduino, a raspberry pi, Zigbee or any other type of micro-controller that accept as input/output analog and digital values. The node transmit and receive information from the main controller through a wireless communication[1].

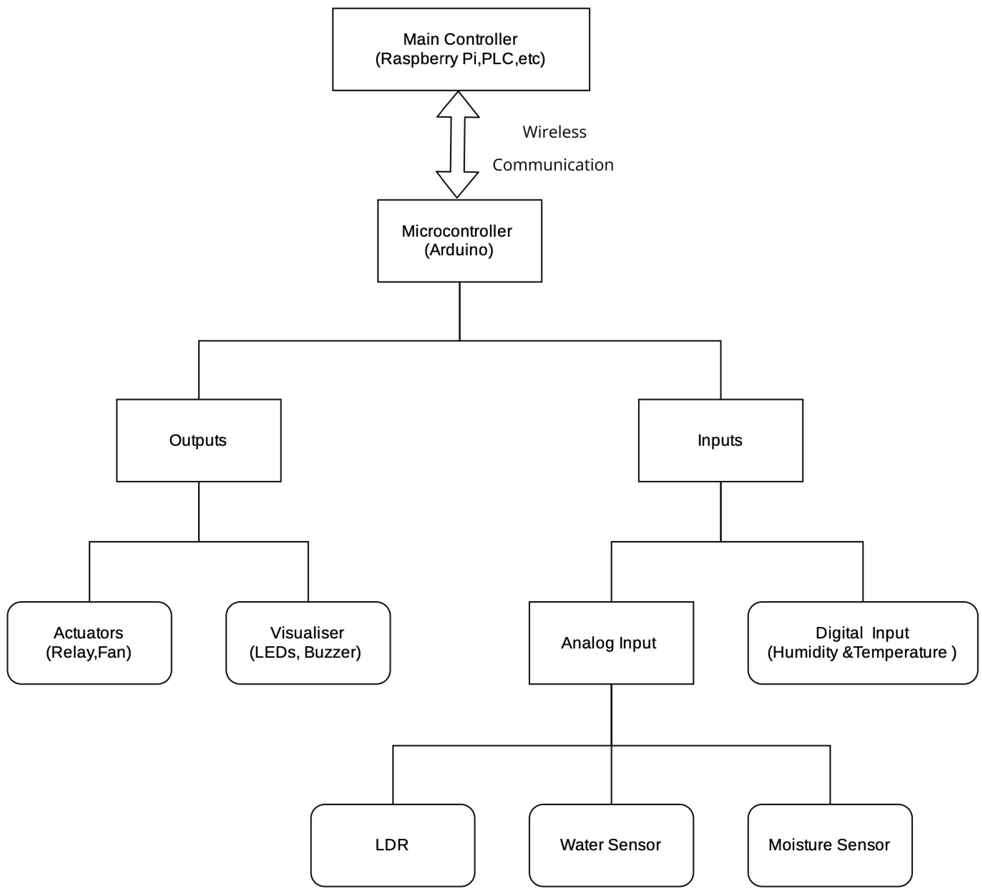

Figure 5: Block Diagram for Hardware Architecture

3.2 Hardware Components

To implement this kind of system a huge amount of components from different brands exist. The component selection depends on how accurate the system should be. For experimental and and academic purposes cheap components are sufficient. Therefore for this project basic components are used. The components have a small error rate and are suitable. In this project are present motors and other components that require more current that actually Arduino can deliver. If these components are connected directly to the micro-controller they can damage the micro-controller port. Therefore another five volt power supply was used as a power source. In the project were DC-Motors and to control the motor ,is necessary a IC. In this case L293D IC was selected . This IC can control two DC-Motors in the same time independently. The IC can communicate directly to the micro-controller through input/output pins.

3.2.1 Micro-controllers

As micro-controller for the node an Arduino Uno was selected. The Arduino satisfies the property of having input/output digital and analog signals. The number of the pins is enough and sufficient. The resolution that Arduino offers is suitable for reading analog values. The analog values are represented in realistic values with a negligible error rate. Also the Arduino accepts a master-slave behaviour[33].UART, I2C, and SPI communication protocols empower the Arduino to interact with a huge amount of devices. Also the communication is done synchronously and asynchronously. To perform the same functionalities some other micro-controllers an be used such as Lora, Raspberry Pi, Beagleboard, Nvidia Jetson and etc[15].

3.2.2 Sensors

- DHT11 Temperature and Humidity Sensor is a common used sensor in different situations. This sensor can measure a wide temperature range from negative to positive[1]. The range depends on the DHT type but usually they vary from -40 to +125 degrees. Also it measures humidity from 0 to 100 percent. The sensor is suitable for the greenhouse implementation.The sensor transmit digital data[11][17][4].

- SE045 Water Sensor is a well known sensor for measuring the water level or even for detection the water presence. The sensor is sensitive and can detect the small rain drops. Usually the sensor provides analog values regarding the amount of water but it can be connected with other modules and ICs and can return a digital value. The sensor is economically friendly and works with low voltage range form 3.3 volts to 5 volts. Since the sensor can transmit digital and analog values it is compatible with almost every micro-controller[17][4].

- LDR Sensor or as it call differently photo-resistor, is a suitable sensor for detecting the illumination. This sensor can measure the natural illumination that comes during the day from the sun, also it can measure the illumination that is generated from artificial lights. This sensor is low cost and can be used in different application in a smart greenhouse. The sensor can transmit just analog values. This might be a drawback for choosing the micro-controllers.

- YL-69 and HC-38 Moisture Sensor is used to detect and measure the water presence in soil. The sensor uses two probes designed on PCB that can be sicked to the soil to measure the moisture levels.The sensor uses an IC to convert the data. It can provide both analog and digital values. This feature is important because the sensor can be connected with most of controllers and with two different in the same time for different purposes. It is a low cost sensor with great accuracy[17][4].

3.2.3 Actors

- A 5 volt DC-Motor is used as an actuator. The DC motor can be controlled by L293D IC. The IC is capable to control two motors in the same time independently. The DC-Motor draws a huge amount of current and it is not compatible with all micro-controllers. It is recommended for safety reasons to be used only with ICs or transistor that can handle high current. The motor can spin clockwise and counterclockwise[27].

- Relays are important and highly used in the scenarios where high voltage is required[1]. The relay has two terminals one that is use in high voltage as a switch and the second terminal is for low voltage that turn the relay on or off. The relays can be turned on or off by using a micro-controller because the require a low voltage. The relay has to states normal opened and normal closed this mean that the circuit is closed or opened when the relay is off and the situation changes when the relay turns on[11][15].

- The buzzer is a important tool in case of an emergency or failure. It can produce sounds in case a malfunction. There are two types of buzzers active and passive. An active buzzer generates the sound by itself. This type of buzzers are suitable for visualising a failure of the system. The buzzers can be activated with a low voltage and they are power efficient. The buzzer loudness depends on the voltage that is applied but they are loud even with low voltage. They are compatible with all type of controllers.

- LEDs are used as indicators for the greenhouse monitoring. The LEDs are used to indicate different processes that are currently happening. They require low power to operate. The cost is low as well. Usually they operate with a specific different voltage depending on the colour. To protect them from burning it is recommended to put in series a resistance, usually grater than 250 ohm. This depends on the voltage that a micro-controller produces as output[33].

4 The Overall System Implementation

4.1 Irrigation, Ventilation and Lighting Implementation

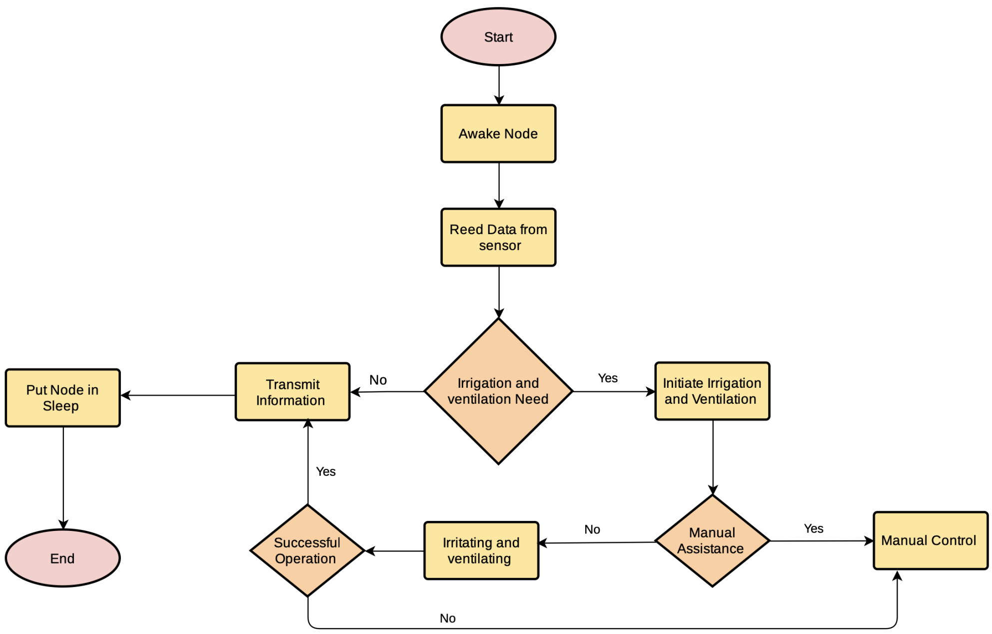

Figure 6: Work Flow Diagram for Irrigation and Ventilation

After the requirements specification ,the next step is to perform a system level design. To model this behaviours, workflow diagram and activity diagram were selected. In the first diagram are irrigation and ventilation. In case a sleeping node, first step is to wake it up. After the node is activated, it is possible to read information for specific operation. In this scenario the focus is on temperature, humidity and moisture[3]. Therefore, we read information for these sensors. The next step is to check if irrigation and ventilation is needed. In case of a need, initialisation of irrigation and ventilation takes place. This means the specific node that is responsible for irrigating and ventilating have to be active. After the initiation of these processes, the next step is to check if there is any need for a manual assistance. In case there is a need for such a task the system switch to manual mode and the farmer can start the irrigation and ventilation manually. This type of failure can occur when there is no connection between two nodes or the communication has failed. This means the system can not operate autonomously. If there are not any issues the irrigation and ventilation can take place. The next operation is to check if the irrigation is performed successfully or not. This is done in two ways, the first is to compare the data from moisture sensors and if there is an increase in moisture this proof that irrigation is in process. The second opinion is to read the data from the water sensor. The water sensor in this case is used as a double sensor to check if irrigation if done successfully. The same applies to ventilation. If the water sensor does not detect water presence and moisture sensor has the same data as before irrigation, the irrigation is not happening and the system is returned to manual again. If the ventilation and irrigation are successfully done, the following action is to transmit the information and put the node in sleep again. In addition, if there is no need for irrigation and ventilation the information is transmitted and node is put in sleep mode[33]. The second process is lighting. This time the implementation of system level design is done

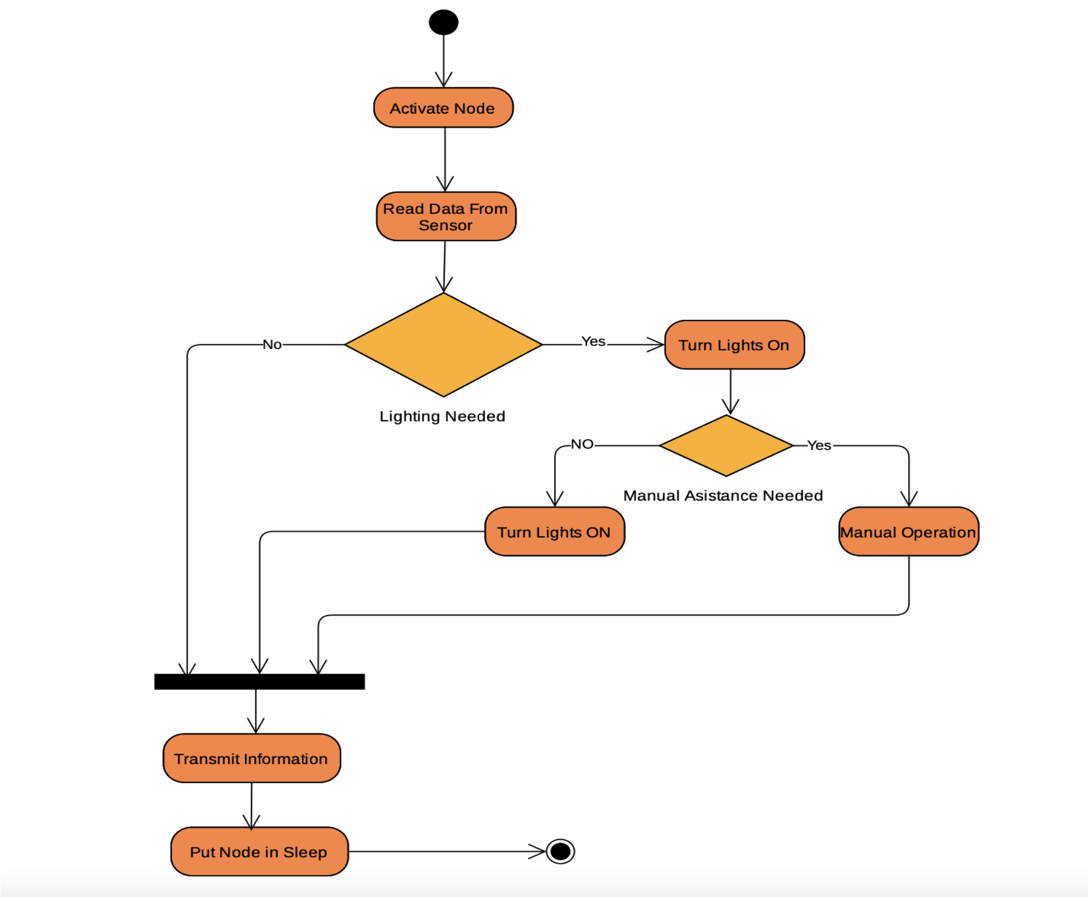

Figure 7: Activity Diagram for Lighting

by using the activity diagram. The same approach as the irrigation and ventilation is followed for the illumination. First of all, the nodes that contain LDR sensors are activated. They can be more than one node. Next step is to read the data from the sensor and to check if there is a need for extra illumination. In case there is a need, the artificial lighting is activated. In case there is a need for sun light the roof of the greenhouse can be opened by activating the actuator (Motor)[3]. These nodes can be several and activating them is necessary to perform illumination process. The next step is to check if there is a need for manual assistance. If there is a need, manual mode is activated and the farmer can start the process manually. If there is no need for manual assistance, the illumination process continues and in the same time the LDR sensors provide feedback for the increase in illumination[18]. The next activity is to transmit the information and put the nodes in sleep. The illumination process is activated in case the values of the light exposure are lower that defined values. In case the values are more the information is transmitted and node is put in sleep again. this process can happen locally. This means that inside a greenhouse there are spots that require more light, therefore the light can be activated in this specific spot. This is an important feature when inside the greenhouse are planted different plants that require different light exposure[33][20].

4.1.1 Irrigation, Ventilation and Lighting Simulation (Arduino)

After system level design for Irrigation, Ventilation and Lighting the following step is system implementation. The next step is realised by switching from high level design to low level. For such kind of implementation Arduino was selected. The Arduino programming through its IDE is easy to be implemented and code generation is close to c language which is a low level language . For simplicity and disposal resources , sensors and actors are controlled by a single micro-controller(Arduino). In this case the nodes are supposed to be active, sensors and actuators as well. The humidity and temperature sensor (DHT11) continuously measure and print the temperature and humidity. The update frequency is one second. The values are selected randomly for simulation purposes and there is no connection with real life scenarios. For the moisture sensor a limit was set. If the values are below 300 the soil is considered wet enough and this means that we are in irrigation mode. In the same time a green LED with turn on to visualise the presence of the moisture. If the value is greater than 300 this means the soil is dry and the water pump should be activated therefore the relay is activated every one second. The information is shown in Arduino serial monitor also the LEDs are used to visualise the processes the red LED means relay is off and green means relay is on. The relay stop switching on if the moisture is greater than the limit. The same methodology was followed for the water sensor. The values of water sensor were updated every four seconds and if the values are greater than 100 this is symbolism of a water presence. To visualise the process a blue light with blink. The same approach was followed for the temperature and humidity sensor. If the temperature is higher than 28 degrees, this temperature will be considered as a staring point for the ventilation. Therefore, the fan will star spinning also a white LED will start blinking. All information are displayed on the serial monitor. The critical humidity is defined as 90 percent. If this value is reached a yellow LED will start blinking. The last sensor is the LDR. This sensor measures the light intensity. The values above 900 are consider as high sun exposure and critical for the plants and to simulate this alarm scenario a buzzer will turn on for as log as the value is above 900. In the same time a red LED with start blinking. All the simulation is done to visualise a greenhouse environmental behaviour. The information is displayed in serial monitor depending on the scenario. The code level is generated from the high level implementation of the system which is the activity diagram and workflow diagram. The diagrams were translated into code. The activity and workflow diagrams were generated from the abstract level implementation of the system which are the use cases diagram. These steps are followed to fulfil the model based design[33].

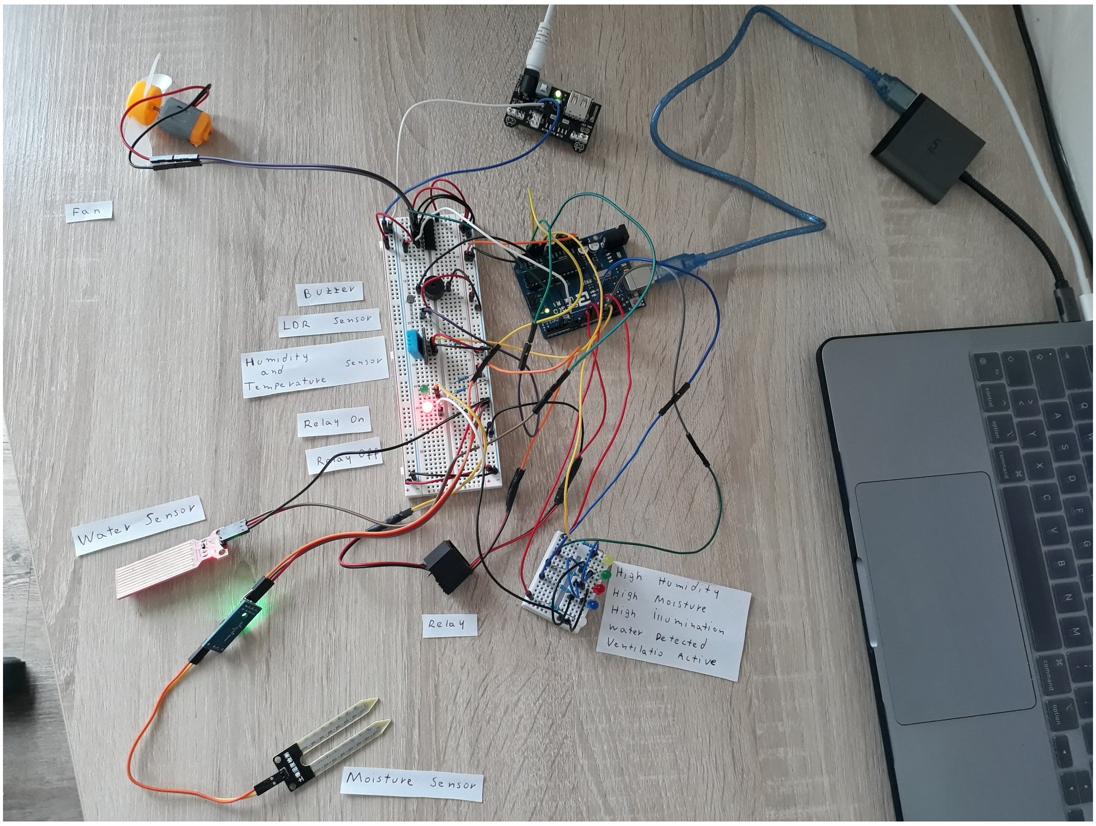

Figure 8: Greenhouse Arduino Implementation

4.2 Plants Growth Monitoring

The plant growth is faster than normal plant growth in the field. Therefore it is important in a smart greenhouse to monitor the process. The monitoring is important and plays a significant role. The monitoring system is a useful tool to check the plant wellness and state[3]. In the same time it is possible to determine the amount of the water, fertilizers or pesticides that a specific plant might need. Most of the times when the plants are young is difficult to recognise them. This implies a difficulty in classification of the plants. These difficulties can lead to wrong irrigation or pesticide amount. With other words it is possible to harm the plants. The plants pass through several phases in their life span. The first phase is sprouting. This phase is important and monitoring is useful. The next step is growing . During this phase there are several parts in plant that can be monitored. The last stage is harvesting. In this stage is crucial to monitor fruit growth and wellness[12][16].

4.2.1 Image Segmentation

There are diverse ways to process the image. It depends on what Information we are interested. Processing the image as whole can take time and resources especially in embedded systems. Therefore filtering and processing specific segments on a image can improve the process and save the resources. In the same way by putting different types of masks, it is possible to gain different results in a faster way. Image segmentation can be implemented in a smart greenhouse. The first implementation is to detect plants in their early growth stages[9]. In this case the mask can help to distinguish between plants and the background. In the first two months the plants are young and in images, the percentage that plants covered is less than background. It makes sense to perform segmentation and than process the images. Another implementation can be for plant diseases recognition inside the greenhouse. In case of a disease in the leaves, masks are used to separate the leaves from other plants parts and background. The segmented area can be further processed. In the same way the plant stalks is realised if the disease is located in the stalks. Also two masks can be implemented in the same image one can be for a disease in leaf and the other for disease in the stalk. The last implementation can be for fruits detection. After the plants are grown and the fruits has began. The segmentation can be used to separate fruits from the plants. This procedure can optimise the fruit recognition[17][12][10].

4.2.2 Image Segmentation Data Set

The data set that was used in this paper is generated from Kaggle. Plant semantic segmentation data set is open source and can be used by everyone. The masks are open source as well. The data set was created from a group of electronic and computer engineering students. The images has gone through pre-processing phase. This kind of operations can increase the data set quality[26]. The data set contains 288 total images. Half of them are images of plant seedlings. The images are taken in a two month interval. Approximately 40 plants are inside a container. The other half of images are the masks. With other words the data set is split in two folders with the same number of pictures. One folder in named images and the other masks. The masks are precise and are generated based on the leaves. Segmentation is done by taking in consideration two components which are the background (soil, container) and plants. The images are in RGB colour space. The masks are developed by covering with black the background and with green the plants. The Information in the images is very important and crucial for processing. Therefore the pictures have a high resolution and quality. A single image can contain more than 10Mb information. In the other hand the masks have less information it is in Kb level because image contains less information.

4.2.3 Deep Learning Implementation for Plants Growth

Google Colab was used as a tool to implement plant image segmentation. As a language was used Python bases on Tensorflow library. In case of a segmentation a specific convolutional network is necessary. For this implementation the U-Net convolutional network was chosen. This network is fast and precise for image segmentation. This supervised CNN model was developed by Freiburg University and it was mainly used for diseases classification because it is very precise[9]. Also this CNN model can localise the area of the disease. This model is beneficial for recognising the plants in early stages by using image segmentation. This can help in a precise irrigation process. Based on one input it is able to generate a label. The images were flipped vertically and horizontally to ensure an higher accuracy. Train model generator was used to distinguish between two classes of images. Also a test generator function was used to check if there is any images classified in another class. The u-net model was generated and compiled. To train the whole data set ResNetV2 was used . This version of ResNet is a updated version of previous ResNet architecture. Therefore, it has a better filtering also a better classification. The model was accurate. Five Epochs with a batch side 32 were performed and the model was able to train 474 parameters out of 535. This results are promising because only sporadic miss classification were occurred. Also the result can be optimised by increasing the epochs number[26].

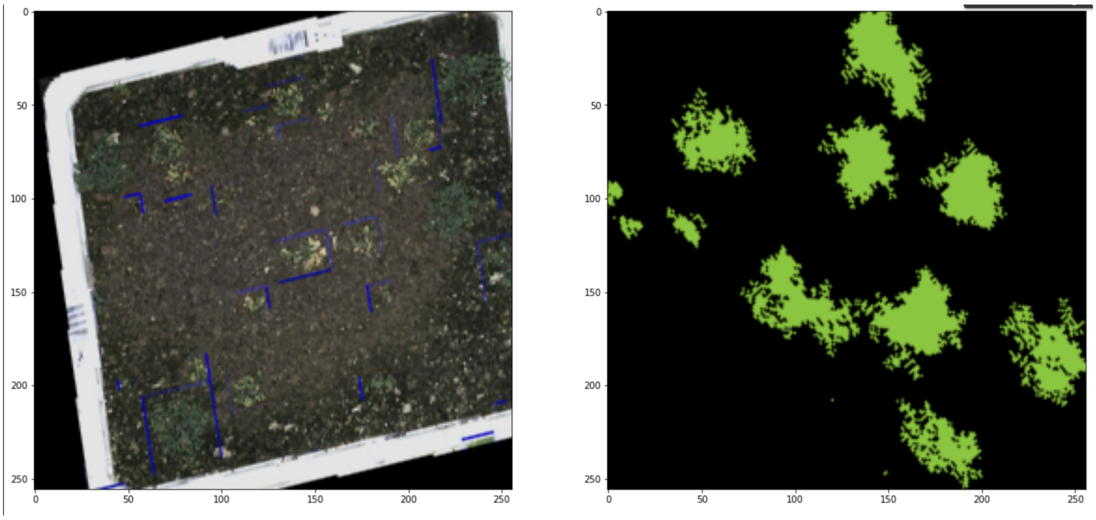

Figure 9: Image Segmentation Python Implementation

4.3 Fruits of the Plants Monitoring

4.3.1 Fruits Recognition

Fruits recognition in a smart greenhouse increase the dependence of the system. The fruit recognition can empower automatic harvesting as well. The fruit of a plant pass through different phases of growth. It is important to distinguish between a done fruit and not done. The detection of fruits is dynamic and is depended in size and colour. In case a tomatoes the red or yellow colour demonstrates that fruit is done and ready for harvesting and the green represents the not done fruits. It is not the same case when the focus is on size. Because there are small tomatoes called cherry tomatoes and the fruits is small and read and based on dimensions is hard to define. It is other way around for cucumbers because the colour is green same as the plants but the dimensions can produce a lot of information. In this phase the plant has different needs for irrigation, fertilization and pesticide spraying. Depending on the fruits growth a plant might need different pesticides therefore is crucial to determine the fruits growth and if it is done or not. By detecting the fruits, the farmer can take decisions for several processes. Recognition can be done by performing image pre-processing. By changing the colour space or illumination of a image, the classification and recognition is faster and more accurate[12][10][25][5][16].

4.3.2 Fruits Recognition Data Set

Fruits and vegetables data set used in the smart greenhouse project is a open source data set and all data set operations and usages are granted by the owners. Therefore it is possible to access and use the whole data set and accompanying files like research paper and PhD. The name of the data set is Fruits 360 and it is available in Kaggle. The final version of the data set was created in 2020. The data set contains a total number of 90483 images. The data set is split 80 percent for training and 20 percent for validation. This data set contains all types of fruits and vegetables. Some of them might not be suitable for the smart greenhouse implementation. Images are clear and in high quality. The background of the images is white and is easy to recognise the fruits and vegetables. The images were shot with high quality cameras used in laboratory. The light conditions were not the same and to eliminate this problem the fruits and vegetables were separated from the background. There are 131 classes of fruits and vegetables. Every class have almost the same number of images. The images dimensions are 100x100. Using this dimensions can help to reduce the data set size since there is a huge amount of images. With all the pre-processing modification the size of the data set is around 2 GB. Reducing the data set side requires less processing power and training can be done faster. Images are in JPG format and RGB colour space. The name of a image holds information for dimensions (100px), image index and image rotation according to axis(r, r2, r3). This data set is designed by taking into consideration the real-world. Therefore deep learning model trained using this data set is capable of detecting every type of fruits despite the angel of the images. Since the data set was used in PhD the data set is optimised and is suitable for every deep learning implementation[25].

4.3.3 Deep Learning Implementation for Fruits Recognition

For fruit recognition and detection two software were used. The first is Google Colab. The programming language for Colab implementation is Python and the library is fastai. The first step is to install fastai in the colab notebook.After this step the Kaggle data set was included in Colab. In this way is possible to manipulate the data remotely without uploading them directly to the Colab. The Kaggle offer a API connection which makes the implementation easier. All necessary libraries are installed and now is possible to build the model. The data bock is created by using batch size (bs) 16 and dimensions 100 px. In this point everything is ready and we can began to train our model by using a CNN learner based on ResNet34. After the training is done we achieve an accuracy around 99 percent.

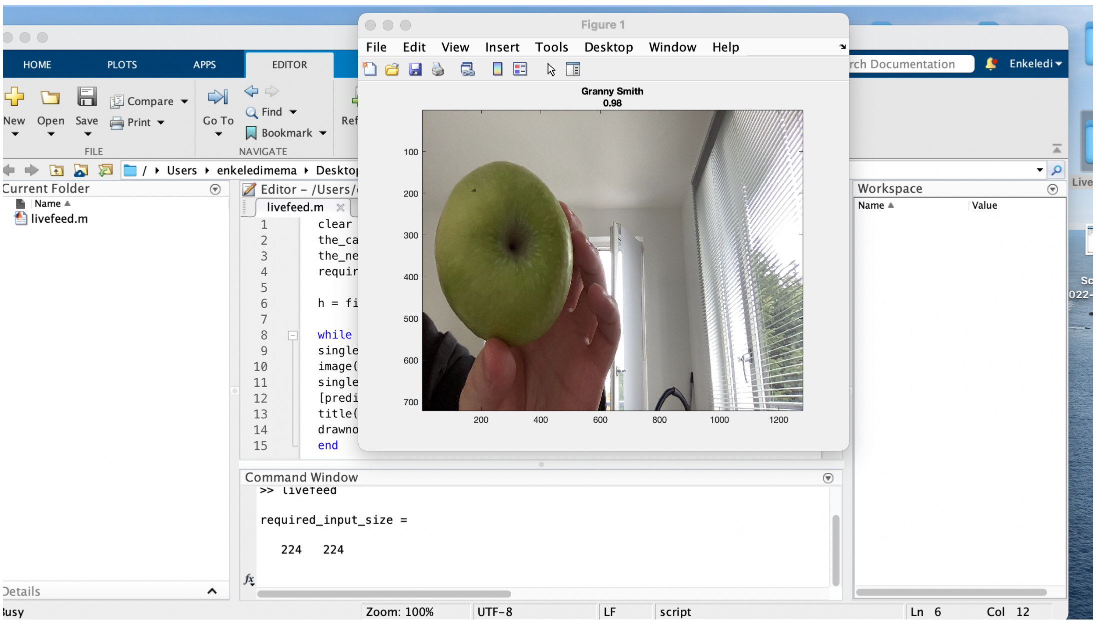

Figure 10: Fruit Recognition Matlab Implementation

This accuracy is consider a good one and now the model is able to detect and classify the fruits with a 99 percent accuracy. Such level accuracy derives from the pre-processing work and optimisation that was done beforehand on the data set[25]. The second software is Matlab. Matlab was used to detect the fruits and recognise what type of fruit they are. The camera is used to detect the fruits an in real time it makes a prediction and classification in a random background. The recognition and predictions is continuously running. This means that images are processed continuously. Also below the name of fruit that is recognised, it is displayed the probability of being that fruit. Probability challenge depending on the angle of the camera and illumination as well. Usually the accuracy varies from 50 percent to 99 percent. Since the processing is continuously running for the same fruit are different probabilities generated based on the camera angel and lighting conditions. Matlab offers several tool for image processing therefore different CNN can be used. They can be easy switch depending upon the scenarios. In the Matlab simulation ResNet and GoogleNet were used. Several fruits and vegetable such as apple, lemon, tomatoes, cabbage cucumbers and bananas were tested. The probability was different for different fruits but the accuracy was mos of the times more than 80 percent[12].

4.4 Plants Diseases Monitoring

Plants diseases monitoring can be added as a feature to increase the autonomy of smart greenhouse. In a smart greenhouse exist different type of sensors to monitor the conditions inside. These sensors are not sufficient to prevent the plants from diseases. The growth of plant inside a greenhouse is faster than in a open field. Therefore detecting or preventing a plant from a disease is important. Sometimes the diseases can be caused by the artificial environment that it created inside a greenhouse. For example in case an evaporation the water drops can be gathered at the top cover of a greenhouse. These water drops can be warmed by the sun. At the moment they drop back to a plant leaf they can cause burns or other damages. Usually sensors inside a greenhouse regulate this type of scenarios but they still might occur. In the other hand inside the greenhouse there are cameras. The main purposes of the cameras are for plant growth monitoring or fruits detection. But the same cameras can be used to monitor the health of the plants. The farmer or agronomist can analyse the data from the monitoring system and in case they notice the presence of diseases, they can use the cameras and a pre-trained model to detect and classify the type of the disease[17]. The information that is gathered for the diseases can be used in two ways. The first usage is to figure out the elements that have caused the disease. This factors can be biotic and abiotic. This information can help to make the necessary adjustments for irrigation, ventilation, illumination or for other processes optimisations inside a greenhouse. The second usage of the gathered information is to spray the pesticide. Immediately after the farmer or agronomist has the whole information for what type of pests they are dealing with, they can spray the specific pesticides to the plants. In this way they can prevent the plants from diseases damage faster and safer. Plants diseases monitoring system is a complex and requires different operations. This system can be implemented and it can operate autonomously. this means that now the system is able to detect and classify the diseases by itself and based on this information it can perform pesticide spraying. In the same way the system can make adjustments for the other systems such es irrigation, fertilisation, ventilation and illumination. This type of system requires more interaction between different components of the greenhouse but it is operational and can be implemented. This implementation will lead to a less human surveillance require. The farmer or the agronomist are not obligated to take decisions and activate other components of a greenhouse manually. The farmer can monitor the system and he can check at anytime for the status and what is happening in the background. In case of a malfunctioning the farmer can interrupt the process. If some adjustments are required the farmer can interact with system and can perform necessary adjustments manually[11].

5 IoT in Precision Farming (Greenhouse)

In a smart greenhouse are several components such as sensors and actuators. Most of the times they are far from each other. Also in high scale smart greenhouse, establishing a communication network is necessary. Just for the irrigation process are required several sensors and actuators. To wire them up is not possible and requires a lot of financial and technical effort. Now days are several wireless technologies available such as WiFi, Bluetooth and ZigBee. Using these technologies it is possible to develop a stable, reliable and save communication. Depending on the dimensions of the greenhouse different communication protocols and topologies can be used. A combination of different technologies can be used as well. A useful communication protocol is Zigbee. Zigbee has several qualities that makes it useful for the smart greenhouse communication system. It can interact easy with all type of micro-controllers. The greenhouse contains multiple nodes and to establish a communication is not a easy task. Most of the times

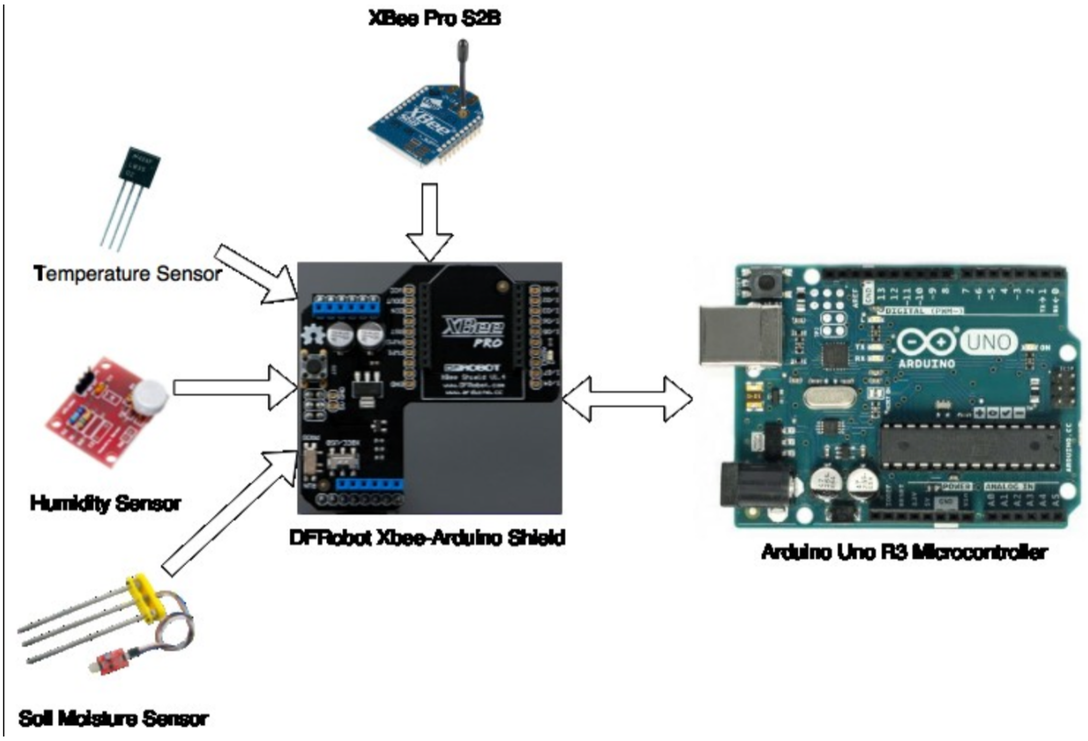

Figure 11: Sensor Node Block Diagram[27].

a sensor node requires low data speed to transmit information and for such nodes is relevant to use ZigBee. For example a sensor node can be several moisture sensors located in a specific part of the greenhouse and they need to send the data to the main controller. The main controller i relatively far from sensors node. In this case as it is noticeable the Bluetooth or WiFi is not efficient. The transmission range of ZigBee is from 10m up to 100m. This can solve the distance problem. This is not the only advantage of the ZigBee. The most important properly is the topologies supported by this protocol. Depending on your application, ZigBee can be configured in a mesh, a star or a peer-to-peer topology. If the same example used above is taken in consideration, it is possible to establish a communication that goes in kilometres. This huge distance is achieved by using routers and coordinators. The Routers in a ZigBee network act as middle guy between the coordinator and the end devices (Node). In Zigbee topology the coordinators are necessary and is not possible to develop a network without the coordinator. It carries out a significant role in security by storing, distributing the network keys and enables end-to-end security between devices. By using this two components is possible to transmit data in long distances. Zigbee can support up to 65 000 nodes on a single network. This amount of nodes is sufficient for the smart greenhouse implementation. Low power consumption is one of the top features of the ZigBee technology. Batteries on ZigBee devices can last for years. This is archived by putting in sleep the nodes. For example the node is activated only in case of a need and is deactivated again. The power consumption is very low. This implementation of the system is beneficial because the sensors are activated only when they are needed. Also this type of communication enable to access specific nodes depending upon the necessaries. ZigBee is a low-bit-rate technology, and it is designed for low-data-rate transmissions. This is a drawback for the communication protocol. The supported data rate is up to 250 kbps. In case of a huge amount of data that we want to transmit this protocol is not relevant. If we try to send or receive big data through ZigBee devices, the performance will be poor. Therefore, other technologies such as Bluetooth or WiFi can be combined to establish a better communication system. The Internet of Things (IoT) implementation can help in developing smart systems such as greenhouses with low cost. In the picture is shown a block diagram of a node. In this scenario the node has three sensors such as temperature sensor, humidity sensor and moisture sensor. The ZigBee is used to transmit the data gathered by sensors in the node . All the process is controlled by a Arduino Uno. By using the same approach other nodes for sensors and actuators can be created[23][21][27][22][31].

6 Conclusion

In this paper, a smart greenhouse system was designed by using a model based design approach. A general overview for a traditional greenhouse was provided. After that a brief introduction to vertical farming was mentioned. Also some specifications how the vertical farming can be useful for greenhouse implementation were discussed. First of all use cases were developed for the holistic system. The use cases were divided in two parts. The first is for controlling the conditions of the greenhouse such as the micro-climate, environment and farming process. The second use case was designed for the surveillance system. Based on use cases and requirements specifications, a overall system architecture was designed. In the greenhouse system the hardware configuration has a significant impact. Therefore, a common hardware structure was suggested. Later this structure was used for the implementation. Some details for hardware components such as micro-controllers, sensors and actors were mentioned. In the surveillance system were included plants growth monitoring, fruit recognition and plant health monitoring. The system can realize the automatic processes. In order to ensure the automatic irrigation, ventilation and illumination, the work of processes was monitored in real time. Activities diagrams and workflow diagrams were used to display the sequence of activities that occur during irrigation, ventilation and illumination process. The succeeding task was implementation and going to a lower level design. The irrigation, ventilation and illumination were controlled by a single board. As a micro-controller an Arduino Uno was selected. Several sensors were used for measuring the water level, moisture, temperature, humidity and light exposure. Several actuators such as relays, fan, buzzer and LEDs were used as well. The surveillance system is based on deep learning approach. This system contains three main processes. The first process is the growth monitoring system. This is implemented by using image segmentation. Image segmentation is important to monitor the plants in the early stages. Most of the times the background is soil and image segmentation can filter faster the plant by using masks. The second process is fruits detection. Fruits recognition is based on the deep learning as well. The model is trained with full data set that contains all fruits and vegetables. Also the model is able to recognise fruits directly from camera feed. The last but not least process was plant diseases monitoring. In the same approach, the plant health can be monitored using cameras. In this paper is not implemented a model that can detect plant diseases. It is mentioned just in theoretical terms. To establish a connection between different components of the greenhouse a communication protocol was described. This protocol is the Zigbee.

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