Republic of Yemen
University of Science and Technology
Faculty of Computing and
Information Technology
Department: SE, IT

HYPO

A Hydroponic Monitoring System

Submitted by:

    Ekram Omar
    Iman Basaif
    Nusibah Al-Haddad
    Nashwa Al-aghbari

Supervised by:

    Dr. Nosaiba Almaqtari

This research has been completed to fulfill the graduation requirements of software engineering and information technology departments.

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Abstract

Hydroponics is a method of planting or cultivating plants without using soil but uses water, nutrients, and oxygen. It has advantages such as higher quantity and quality of production, cleaner, more efficient use of fertilizers and water, and also easier in pest and disease control. The goal of this project is to develop a system for maintaining a hydroponic growing environment, which simplifies the process of growing plants hydroponically by abstracting the details from the user. The system monitors the parameters needed by the plant to grow healthily and efficiently and adjusts those parameters accordingly. It also provides the user with a mobile application that helps the user monitor the conditions their plants is growing in.

Chapter One: Introduction

1.1 Introduction

Agricultural lands are already declining in the world due to the conversion of agricultural land into industry and settlement purpose. This happens because of economic and social phenomena, the limitation of land resources, population growth and economic growth [1]. Currently, agricultural technology developed rapidly in urban areas, it is often called Hydroponics or urban agriculture [2]. Hydroponics or urban agriculture is one powerful solution to cope the dwindling agricultural land. Hydroponic is an efficient way of cultivating crops in a soilless manner with increased productivity per area, reduced water and fertilizer usage. Hydroponics can be used to produce variety of crops in compact spaces such as the backyard, terrace, or in offices, by using a nutrient rich water solution. The areas of the world with poor or infertile soils can completely rely on hydroponics system. This gives people in these areas access to healthy and fresh produce. Other advantage of this method is that it enriches the crops with full flavor and delicious taste with higher nutrients values [3]. Hydroponics is derived from Greek, hydro meaning water and ponic means work [2]. In hydroponic farming system, the water is used continuously and just diminishes because of evaporation by the Sun or by the photosynthesis process of plants. If it is compared to conventional agriculture, water is used once at the time of irrigation, the conventional agriculture method be said to be very wasteful in the use of water [3]. There are many factors that are critically important for crops production and quality in hydroponics such as correct pH level, air temperature, relative humidity, nutrient level in the water, and correct irrigation of water. Therefore, the help of a management system that monitors these factors is valuable and will ensure higher success and efficiency rates of the grower. The project proposed in this document, The HYPO project enables users to monitor the pH level, nutrient concentration and water level through a mobile application. HYPO is based on IoT. Figure (1.1), shows the overall architecture of the system.
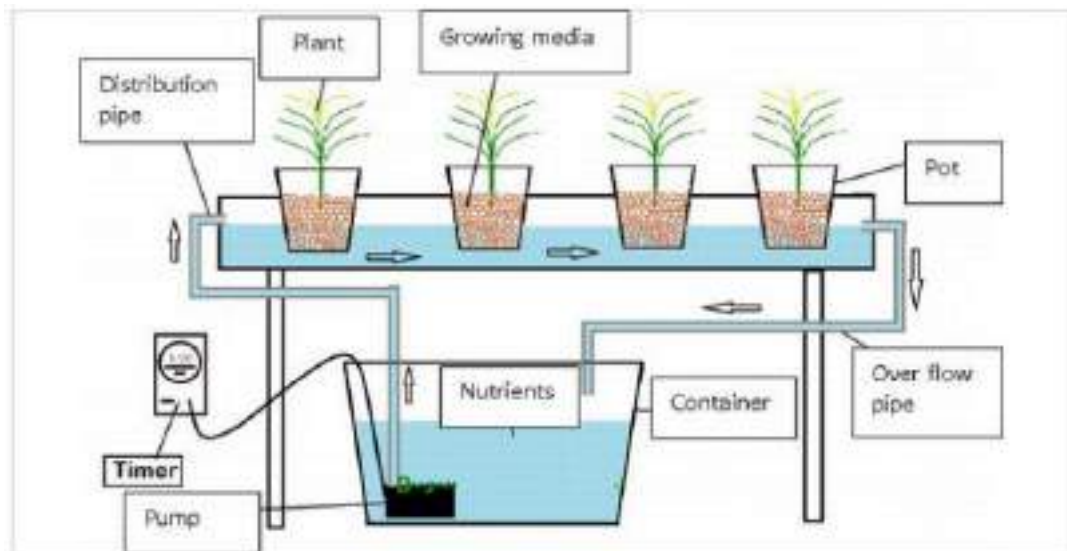
Figure (1.1): Overall Architecture of HYPO

1.2 Problem Statement

Although hydroponics has solved many of the traditional agriculture difficulties, such as the need for suitable environment (fertile soil and particular climate), it is still facing other problems of its own, which are represented in lack of control over the nutrients' levels and its concentration. Thus, an automation of a system that is capable of monitoring nutrients concentration in the water, in addition to pH level and water regulation, will save the user time and effort, provide more accurate data on the growth of plants. Therefore, result in more organic and healthier crops.

1.3 Aims and Objectives

The aim of HYPO is to automate a hydroponic system that is capable of fulfilling the following objectives:

- Monitor nutrients and pH levels and concentration.

- Provide statistics on pH level and plant growth.

- Regulate water.

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- Allow user to access growing environment data anytime through application.

1.4 Scope

The target of this project is to automate and monitor the levels of the most important parameters of a closed hydroponics system. the system shall be able to measure:

- the water level.

- the pH level.

- the nutrient concentration.

After collecting the data from sensors it sends them to the server for storage and analysis. Then view the analyzed data through the mobile application.

This system will not measure the temperature and humidity of the growing environment and web application will not be developed.

1.5 Feasibility Study

Technical feasibility - There are many tools needed to build this project, since it consists of a hardware unit, web server, an android application and an iOS application. The tools needed are outlined in the tools section of this chapter.

Most of the technologies needed to build this project are either freely available or have already been purchased. Some technologies still need to be purchased, but there is no anticipated difficulty in acquiring them.

Since the project has many different aspects to it, a wide range of skill sets is needed to implement it. The team members have most of the skills needed to build this project. The expertise of domain experts is readily available.

The functionality that this project is aiming to achieve is not completely new, and it has been done in one form or another in the past. Therefore, it is obviously technically feasible.

Financial Feasibility - The costs required to build this project are mostly associated with the technologies that are yet to be purchased. Those costs are not expected to exceed budget.

The costs of the system once it's operational will include the cost of the hosting server from the executive side of things. But from the customer side there will be costs associated with the nutrient solutions, the water, acids and bases needed to regulate pH levels, the seedlings, the growing medium, and maintaining a continuous Wi-Fi connection. Those costs are generally minimal and the benefits the customers will get form the system outweigh them. Therefore, the project is obviously financially feasible.

1.6 Methodology

The incremental model has been chosen for the methodology of this project because the project can be neatly divided into two well defined systems: the growing environment system, which is comprised of the hardware component (sensors, microcontroller and actuators), the mobile application and the server (the mobile application is for both android and iOS platforms). Each of those systems is developed in its own increment respectively. It is better to develop each system in its own iteration rather than develop both of them simultaneously. Figure (1.2) shows a flowchart of the methodology.
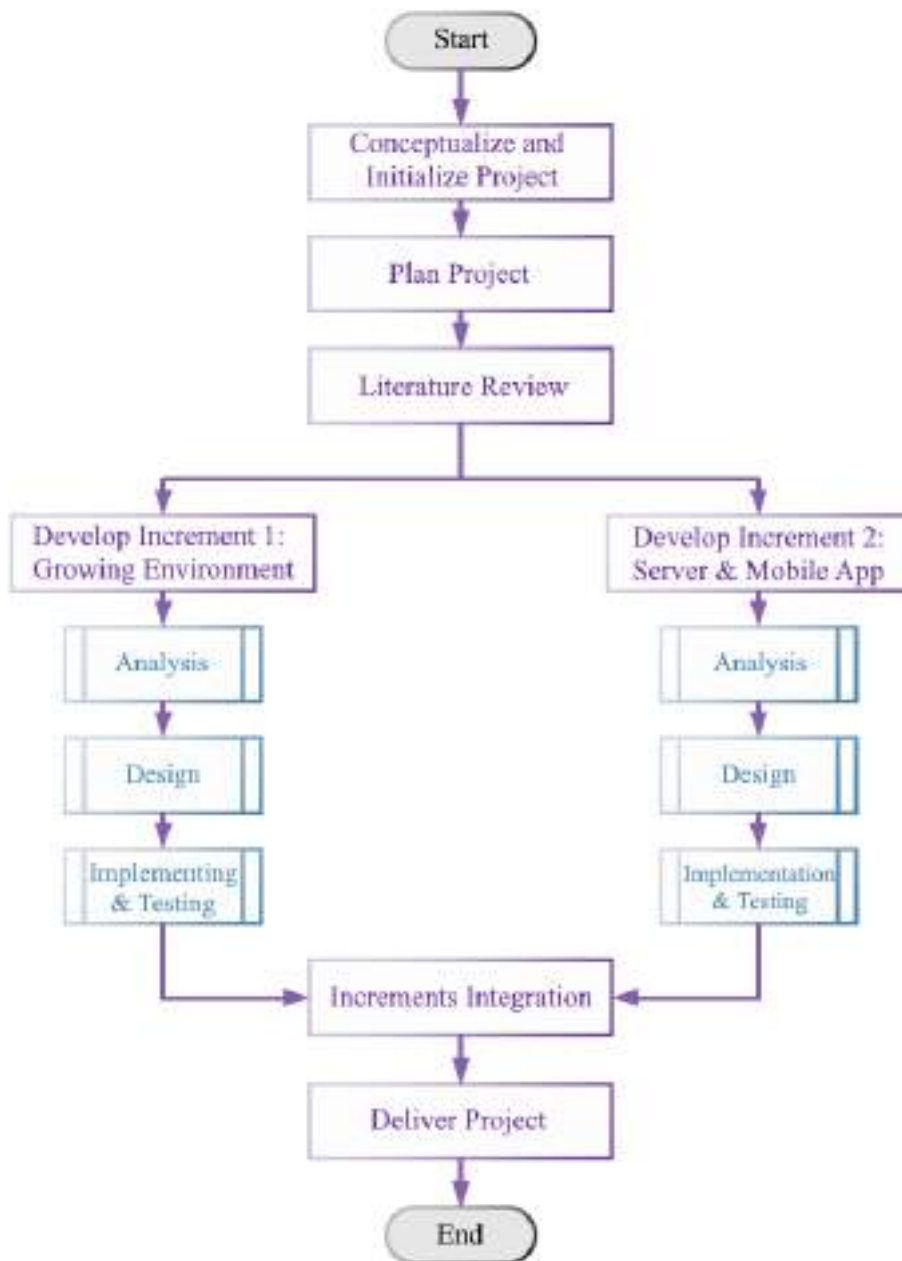
Figure (1.2): Methodology Flow of Events

1.7 Time Schedule

Table (1.1) shows the main tasks of this project.

Table (1.1): Main Tasks

Task Name	Duration	Start	Finish
Conceptualize & Initialize Project	8 days	Sat 10/5/19	Sun 10/13/19
Project Proposal	8 days	Sat 10/5/19	Sun 10/13/19

Milestone: Project initialization completed	0 days	Sun 10/13/19	Sun 10/13/19
Plan Project	**13 days**	**Sun 10/13/19**	**Mon 10/28/19**
Project Report: Chapter 1	**13 days**	**Sun 10/13/19**	**Mon 10/28/19**
Milestone: project planning completed	0 days	Mon 10/28/19	Mon 10/28/19
Literature Review	**15 days**	**Tue 10/29/19**	**Sat 11/16/19**
Project Report: Chapter 2	**15 days**	**Tue 10/29/19**	**Sat 11/16/19**
Milestone: Literature review completed	0 days	Sat 11/16/19	Sat 11/16/19
Increment 1: Growing Environment	**22 days**	**Sat 11/16/19**	**Wed 12/11/19**
Analysis	**5 days**	**Sat 11/16/19**	**Thu 11/21/19**
Project Report: Chapter 3 – Analysis	**5 days**	**Sat 11/16/19**	**Thu 11/21/19**
Milestone: Analysis completed	0 days	Thu 11/21/19	Thu 11/21/19
Design	**5 days**	**Thu 11/21/19**	**Tue 11/26/19**
Project Report: Chapter 3 - Design Details	**5 days**	**Thu 11/21/19**	**Tue 11/26/19**
Milestone: Design completed	0 days	Tue 11/26/19	Tue 11/26/19
Implementation & Testing	**12 days**	**Wed 11/27/19**	**Wed 12/11/19**
Simulated Growing Environment	**3 days**	**Wed 11/27/19**	**Mon 12/2/19**
Physical Growing Environment	**9 days**	**Mon 12/2/19**	**Wed 12/11/19**
Project Report: Chapter 3 - Implementation & Testing Details	**9 days**	**Mon 12/2/19**	**Wed 12/11/19**
Milestone: Implementation & Testing completed	0 days	Wed 12/11/19	Wed 12/11/19
Milestone: Increment 1 - Growing Environment completed	0 days	Wed 12/11/19	Wed 12/11/19
Increment 2: Server & Mobile Application	**71 days**	**Sat 1/18/20**	**Mon 4/6/20**
Analysis	**8 days**	**Sat 1/18/20**	**Sun 1/26/20**
Project Report: Chapter 4 – Analysis	**8 days**	**Sat 1/18/20**	**Sun 1/26/20**
Milestone: Analysis completed	0 days	Sun 1/26/20	Sun 1/26/20
Design	**10 days**	**Mon 1/27/20**	**Thu 2/6/20**
Project Report: Chapter 4 - Design Details	**10 days**	**Mon 1/27/20**	**Thu 2/6/20**
Milestone: Design completed	0 days	Thu 2/6/20	Thu 2/6/20
Implementation & Testing	**53 days**	**Thu 2/6/20**	**Mon 4/6/20**
Server	**28 days**	**Thu 2/6/20**	**Mon 3/9/20**
Mobile Application	**53 days**	**Thu 2/6/20**	**Mon 4/6/20**

Task Name	Duration	Start	Finish
Project Report: Chapter 4 - Implementation & Testing Details	**53 days**	**Thu 2/6/20**	**Mon 4/6/20**
Milestone: Implementation & Testing completed	0 days	Mon 4/6/20	Mon 4/6/20
Milestone: Increment 2 - Server & Mobile Application completed	0 days	Mon 4/6/20	Mon 4/6/20
Close Project	**5 days**	**Mon 4/6/20**	**Sun 4/12/20**
Project Report: Chapter 5	**5 days**	**Mon 4/6/20**	**Sun 4/12/20**
Milestone: Project closed	0 days	Sun 4/12/20	Sun 4/12/20

Table (1.2) shows the detailed activities of this project.

Table (1.2): Detailed Activities

Task Name	Duration	Start	Finish
Conceptualize & Initialize Project	**8 Days**	**Sat 10/5/19**	**Sun 10/13/19**
Project Proposal	**8 Days**	**Sat 10/5/19**	**Sun 10/13/19**
Prepare Project Proposal	1 Day	Sat 10/5/19	Sat 10/5/19
Milestone: Project Is Approved	0 Days	Sun 10/13/19	Sun 10/13/19
Milestone: Project Initialization Completed	0 Days	Sun 10/13/19	Sun 10/13/19
Plan Project	**13 Days**	**Sun 10/13/19**	**Mon 10/28/19**
Project Report: Chapter 1	**13 Days**	**Sun 10/13/19**	**Mon 10/28/19**
Perform Initial Study	13 Days	Sun 10/13/19	Mon 10/28/19
Carry Out Feasibility Study	5 Days	Sun 10/13/19	Sun 10/20/19
Choose Project Methodology	7 Days	Sun 10/13/19	Tue 10/22/19
Prepare Chapter 1	13 Days	Sun 10/13/19	Mon 10/28/19
Milestone: Chapter 1 Completed	0 Days	Mon 10/28/19	Mon 10/28/19
Milestone: Project Planning Completed	0 Days	Mon 10/28/19	Mon 10/28/19
Literature Review	**15 Days**	**Tue 10/29/19**	**Sat 11/16/19**
Project Report: Chapter 2	**15 Days**	**Tue 10/29/19**	**Sat 11/16/19**
Perform Detailed Study	15 Days	Tue 10/29/19	Sat 11/16/19
Compare Related Work	9 Days	Tue 10/29/19	Thu 11/7/19
Prepare Chapter 2	15 Days	Tue 10/29/19	Sat 11/16/19
Milestone: Chapter 2 Completed	0 Days	Sat 11/16/19	Sat 11/16/19
Milestone: Literature Review Completed	0 Days	Sat 11/16/19	Sat 11/16/19

Increment 1: Growing Environment	22 Days	Sat 11/16/19	Wed 12/11/19
Analysis	5 Days	Sat 11/16/19	Thu 11/21/19
Project Report: Chapter 3 – Analysis	5 Days	Sat 11/16/19	Thu 11/21/19
Elicit Requirements	2 Days	Sat 11/16/19	Mon 11/18/19
Specify Requirements	3 Days	Mon 11/18/19	Thu 11/21/19
Milestone: Chapter 3 - Analysis Completed	0 Days	Thu 11/21/19	Thu 11/21/19
Milestone: Analysis Completed	0 Days	Thu 11/21/19	Thu 11/21/19
Design	5 Days	Thu 11/21/19	Tue 11/26/19
Project Report: Chapter 3 - Design Details	5 Days	Thu 11/21/19	Tue 11/26/19
Specify Architecture	2 Days	Thu 11/21/19	Sun 11/24/19
Specify Design Details	3 Days	Sun 11/24/19	Tue 11/26/19
Specify Data Design	1 Day	Sun 11/24/19	Mon 11/25/19
Milestone: Chapter 3 - Design Details Completed	0 Days	Mon 11/25/19	Mon 11/25/19
Milestone: Design Completed	0 Days	Tue 11/26/19	Tue 11/26/19
Implementation & Testing	12 Days	Wed 11/27/19	Wed 12/11/19
Simulated Growing Environment	3 Days	Wed 11/27/19	Mon 12/2/19
Simulation Setup	2 Days	Wed 11/27/19	Sun 12/1/19
Simulation Testing	1 Day	Sun 12/1/19	Mon 12/2/19
Milestone: Simulated Growing Environment Completed	0 Days	Mon 12/2/19	Mon 12/2/19
Physical Growing Environment	9 Days	Mon 12/2/19	Wed 12/11/19
Physical Setup	4 Days	Mon 12/2/19	Sat 12/7/19
Physical Testing	5 Days	Sat 12/7/19	Wed 12/11/19
Milestone: Physical Growing Environment Completed	0 Days	Wed 12/11/19	Wed 12/11/19
Project Report: Chapter 3 - Implementation & Testing Details	9 Days	Mon 12/2/19	Wed 12/11/19
Design Simulation	2 Days	Mon 12/2/19	Tue 12/3/19
Note Simulation Testing Results	1 Day	Tue 12/3/19	Wed 12/4/19
Note Physical Testing Results	5 Days	Sat 12/7/19	Wed 12/11/19

Milestone: Chapter 3 - Implementation & Testing Details Completed	0 Days	Wed 12/11/19	Wed 12/11/19
Milestone: Implementation & Testing Completed	0 Days	Wed 12/11/19	Wed 12/11/19
Milestone: Increment 1 - Growing Environment Completed	0 Days	Wed 12/11/19	Wed 12/11/19
Increment 2: Server & Mobile Application	**71 Days**	**Sat 1/18/20**	**Mon 4/6/20**
Analysis	**8 Days**	**Sat 1/18/20**	**Sun 1/26/20**
Project Report: Chapter 4 – Analysis	**8 Days**	**Sat 1/18/20**	**Sun 1/26/20**
Elicit Application Requirements	4 Days	Sat 1/18/20	Tue 1/21/20
Specify Application Requirements	8 Days	Sat 1/18/20	Sun 1/26/20
Specify Database Requirements	7 Days	Sat 1/18/20	Sun 1/26/20
Model Application Requirements	6 Days	Sat 1/18/20	Sat 1/25/20
Milestone: Chapter 4 - Analysis Completed	0 Days	Sat 1/25/20	Sat 1/25/20
Milestone: Analysis Completed	0 Days	Sun 1/26/20	Sun 1/26/20
Design	**10 Days**	**Mon 1/27/20**	**Thu 2/6/20**
Project Report: Chapter 4 - Design Details	**10 Days**	**Mon 1/27/20**	**Thu 2/6/20**
Specify Application Architecture	8 Days	Mon 1/27/20	Tue 2/4/20
Specify Application Design Details	10 Days	Mon 1/27/20	Thu 2/6/20
Specify Application Data Design	5 Days	Mon 1/27/20	Sat 2/1/20
Design Application Ui	8 Days	Mon 1/27/20	Tue 2/4/20
Specify Server Data Design	3 Days	Mon 1/27/20	Wed 1/29/20
Milestone: Chapter 4 - Design Details Completed	0 Days	Wed 1/29/20	Wed 1/29/20
Milestone: Design Completed	0 Days	Thu 2/6/20	Thu 2/6/20
Implementation & Testing	**53 Days**	**Thu 2/6/20**	**Mon 4/6/20**
Server	**28 Days**	**Thu 2/6/20**	**Mon 3/9/20**
Program Server	25 Days	Thu 2/6/20	Thu 3/5/20
Test Server	10 Days	Wed 2/12/20	Sun 2/23/20
Perform Integration Testing With Growing Environment	13 Days	Mon 2/24/20	Mon 3/9/20
Milestone: Server Completed	0 Days	Mon 3/9/20	Mon 3/9/20
Mobile Application	**53 Days**	**Thu 2/6/20**	**Mon 4/6/20**
Program Mobile Application	53 Days	Thu 2/6/20	Mon 4/6/20
Test Mobile Application	14 Days	Sat 2/15/20	Sun 3/1/20
Perform Integration Testing With Server	6 Days	Mon 3/9/20	Mon 3/16/20
Milestone: Mobile Application Completed	0 Days	Mon 3/16/20	Mon 3/16/20
Project Report: Chapter 4 - Implementation & Testing Details	**53 Days**	**Thu 2/6/20**	**Mon 4/6/20**

Note Server Implementation & Testing Results	28 Days	Thu 2/6/20	Mon 3/9/20
Note Application Implementation & Testing Results	53 Days	Thu 2/6/20	Mon 4/6/20
Note Integration Testing Results	19 Days	Mon 3/9/20	Mon 3/30/20
Milestone: Chapter 4 - Implementation & Testing Details Completed	0 Days	Mon 3/30/20	Mon 3/30/20
Milestone: Implementation & Testing Completed	0 Days	Mon 4/6/20	Mon 4/6/20
Milestone: Increment 2 - Server & Mobile Application Completed	0 Days	Mon 4/6/20	Mon 4/6/20
Close Project	**5 Days**	**Mon 4/6/20**	**Sun 4/12/20**
Project Report: Chapter 5	**5 Days**	**Mon 4/6/20**	**Sun 4/12/20**
Report Project Conclusions	5 Days	Mon 4/6/20	Sun 4/12/20
Milestone: Chapter 5 Completed	0 Days	Sun 4/12/20	Sun 4/12/20
Milestone: Project Closed	0 Days	Sun 4/12/20	Sun 4/12/20

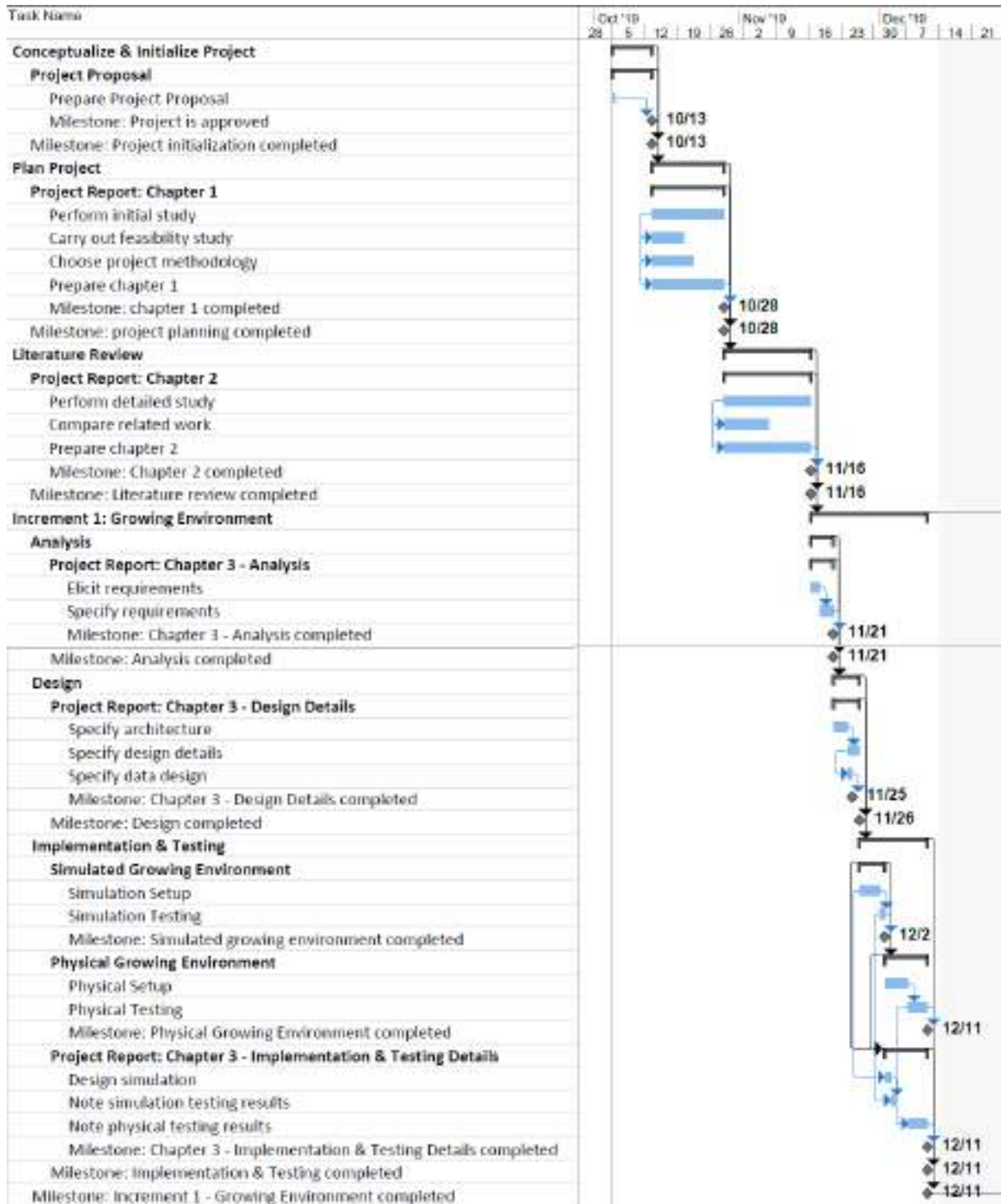Figures (1.3) and (1.4) show the Gantt chart of the project schedule.

Task Name	Oct '19	Nov '19	Dec '19

Conceptualize & Initialize Project
  Project Proposal
    Prepare Project Proposal
    Milestone: Project is approved — 10/13
  Milestone: Project initialization completed — 10/13
Plan Project
  Project Report: Chapter 1
    Perform initial study
    Carry out feasibility study
    Choose project methodology
    Prepare chapter 1
    Milestone: chapter 1 completed — 10/28
  Milestone: project planning completed — 10/28
Literature Review
  Project Report: Chapter 2
    Perform detailed study
    Compare related work
    Prepare chapter 2
    Milestone: Chapter 2 completed — 11/16
  Milestone: Literature review completed — 11/16
Increment 1: Growing Environment
  Analysis
    Project Report: Chapter 3 - Analysis
      Elicit requirements
      Specify requirements
      Milestone: Chapter 3 - Analysis completed — 11/21
    Milestone: Analysis completed — 11/21
  Design
    Project Report: Chapter 3 - Design Details
      Specify architecture
      Specify design details
      Specify data design
      Milestone: Chapter 3 - Design Details completed — 11/25
    Milestone: Design completed — 11/26
  Implementation & Testing
    Simulated Growing Environment
      Simulation Setup
      Simulation Testing
      Milestone: Simulated growing environment completed — 12/2
    Physical Growing Environment
      Physical Setup
      Physical Testing
      Milestone: Physical Growing Environment completed — 12/11
    Project Report: Chapter 3 - Implementation & Testing Details
      Design simulation
      Note simulation testing results
      Note physical testing results
      Milestone: Chapter 3 - Implementation & Testing Details completed — 12/11
    Milestone: Implementation & Testing completed — 12/11
  Milestone: Increment 1 - Growing Environment completed — 12/11
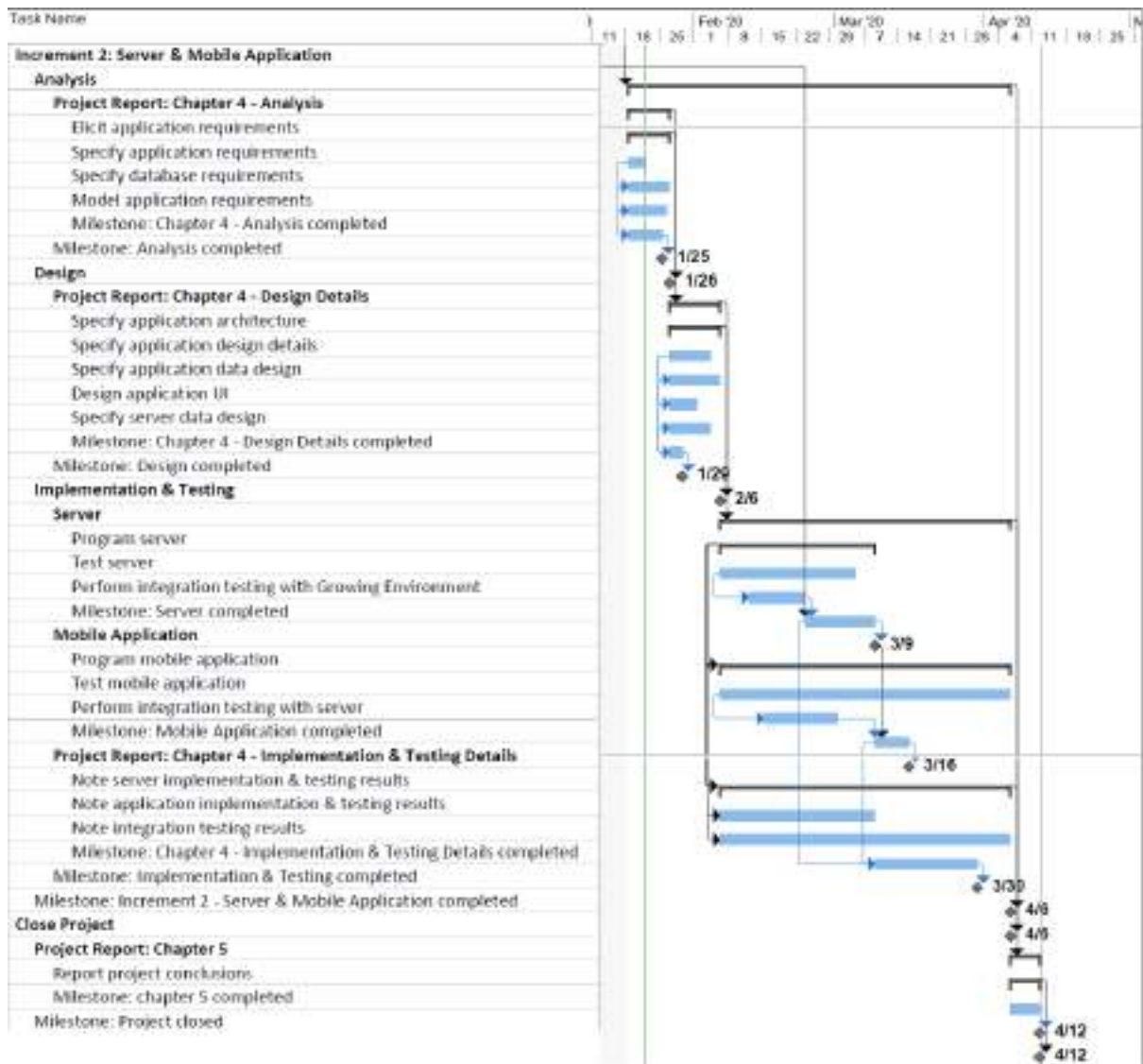
Figure (1.3): Gantt Chart A

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Figure (1.4): Gantt Chart B

1.8 Implementation Tools

The tools used to implement and develop this project fall into two categories:

1.8.1 Hardware Requirement Tools

- pH sensor

- EC sensor

- Water Level Sensor

- Arduino Uno Microcontroller

- Peristaltic Liquid Pump

- Wi-Fi Module for Arduino

- Power Source

- LCD

1.8.2   Software Requirement Tools

- Arduino C IDE

- Flutter IDE

- MySQL Database Management System.

1.9 Project Document Organization

Below is a description of the project document's contents.

- Chapter One: This chapter is an introduction to the project. It contains a description of the domain and the problem statement. It contains the project goals and its scope, the methodology that is used, the schedule of the project and the tools that are needed for its successful completion.

- Chapter Two: This chapter contains the literature review for the project. It outlines previous studies and projects that have tackled the same area of problems this project intends to solve. It compares those studies with each other and it explains the difference between them and this project.

- Chapter Three: This chapter contains the design details of the growing environment and the requirements specification for the mobile application.

- Chapter Four: This chapter contains the software design.

- Chapter Five: This chapter contains any implementation notes, and any tests that are performed on the mobile application and server.

- Chapter Six: This chapter is the closing section of this document, and it contains such things as the conclusions of this project and evaluation notes to compare to what extent has the project's goals been realized.

Chapter Two: Background and Related Work

2.1 Introduction

In this chapter, the background of hydroponics and its field related concepts, in addition to similar systems that automate hydroponics are discussed.

2.2 Background

The background of the hydroponics process is discussed and it is followed with the technical aspects of automating it.

2.2.1 Hydroponics

Hydroponics is a method of growing plants without soil by using mineral nutrient solutions in a water solvent. Plants can be grown with their roots in the mineral solution alone or they can be supported by an inert medium such as rockwool or gravel. In hydroponics, the most important factor that impacts the crop yield and quality is the nutrient solution. Currently 17 elements are considered essential for most plants, these are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel. The most basic nutrient solutions contain only nitrogen, phosphorus, potassium, calcium, magnesium and sulphur; and they are augmented by micronutrients [4].

Two aspects of hydroponics (nutrient solution parameters and hydroponic systems) are discussed as shown in Figure (2.1).
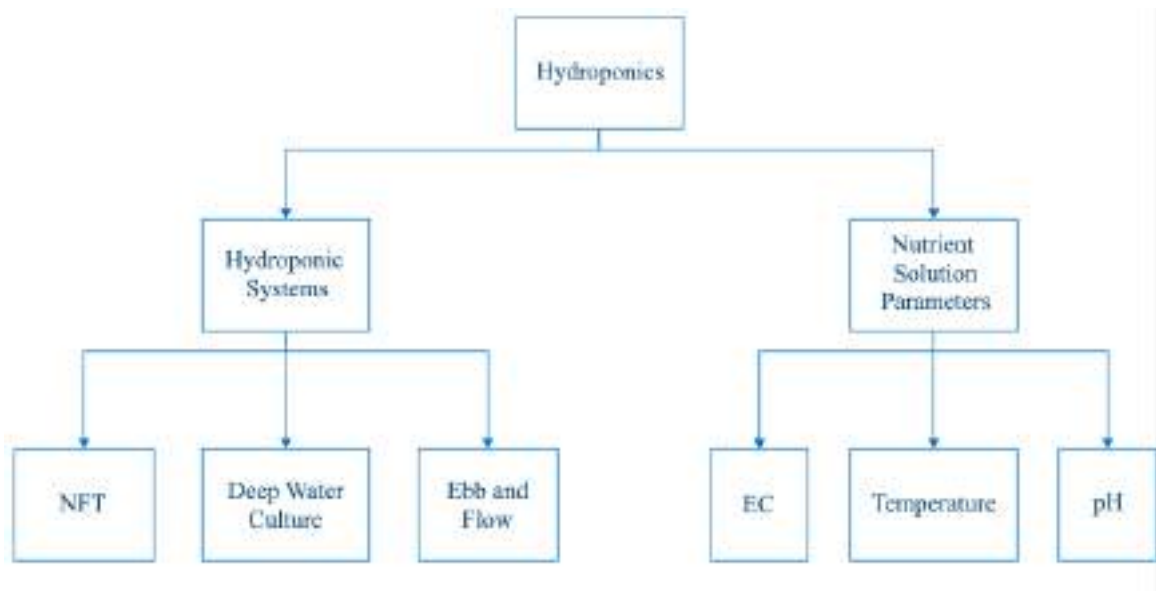
Figure (2.1): Hydroponic Aspects

2.2.1.1 Nutrient Solution Parameters

Electrical conductivity and osmotic potential of the solution are determined by its chemical composition. Other important parameters of the nutrient solution include pH and temperature. Each parameter is described next [4].

pH of the nutrient solution – The pH measures acidity and alkalinity of a solution. It ranges from 0 to 14. Changes in the levels of pH of the nutrient solution affects its composition, elemental speciation and bioavailability. Which means it changes the distribution of elements among their various chemical and physical forms. It's important that the minerals in the nutrient solution are in the form that plants can absorb. That's why it's important to regulate the pH of the nutrient solution [4].

Electrical conductivity of the nutrient solution – The growth and development of plants is determined by the total ionic concentration of the nutrient solution; because it exerts a force called osmotic pressure (OP), which is clearly dependent on the total amount of ions of dissolved salts in a nutrient solution. Osmotic pressure or osmotic potential is what helps the plant absorb nutrients.

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Measurement of the electrical conductivity (EC) of the nutrient solution is needed, because it is required to estimate the OP indirectly. EC is a measure of salt concentration that defines the total amount of salts in a solution. The ideal EC is specific for each crop and dependent on environmental conditions [4].

Temperature of the nutrient solution – The temperature of the nutrient solution affects the plants ability to absorb water and nutrients. Temperature has a direct relationship with the amount of oxygen consumed by the plant and a reverse relationship with the amount of oxygen dissolved in the nutrient solution [4].

2.2.1.2 Hydroponic Systems

There are many different hydroponic systems or techniques they're all based on the same initial idea of replacing soil as a source of nutrients. Some of them are discussed [5].

Ebb and flow – these systems require a growing medium such as perlite or rockwool which serves no purpose other than supporting the plant. They consist of a tray which is used to house the plant in a medium. Below the tray is a reservoir filled with water and nutrient solutions. Periodically the water is pumped form the reservoir to the tray so that the tray is flooded, which allows the plants to absorb nutrients from the water. The water in the tray gradually drains back to the reservoir due to gravity. These systems work best with small plants such as herbs, and are typically small to fit in small areas such as the home [5].

Deep water culture – these systems also use a growing medium. The plants are housed in a plastic mesh that contains the growing medium. Under it is a reservoir filled with nutrient rich water. The plants' roots are able to reach the water through the plastic mesh. The water needs to be constantly oxygenated to avoid bacteria and algae growth. This is achieved using an air pump that supplies the reservoir with air through an air hose. This system is also suitable for small plants and it fits in small places [6].

Nutrient film technique (NFT) – these systems don't use growing mediums. They're built using wooden channels that support polyethylene film liners. The plants are positioned above those channels. Nutrient rich water is pumped through the channels to allow the plants to absorb nutrients. The channels are sloped slightly to allow the water collect at the end of the channel to be pumped up again. This system works with plants with large established roots, and it needs a relatively big space, such as those in farms or warehouses [5].

2.2.2 Automation

Hydroponic systems benefit greatly from gathering more information, which can be achieved through automating these systems for which this process helps in collecting precise measurements of certain parameters that are necessary for the growth of healthy, organic plants which gives the grower the ability to better diagnose problems and better understand the evolution of their hydroponic crops. The automation of such systems is done through using various sensors and connecting them to a microcontroller which uses extension modules for the communication and analysis of the collected measures then viewing and storing the results. The tools used in this project as listed below with a brief explanation on the use of each.

2.2.2.1 Sensors

pH Sensor – measures the acidity or alkalinity of a given solution. Acidic solutions have more Hydrogen ion concentration than alkaline solution. pH probes measure pH by measuring the voltage or potential difference of the solution in which it is dipped [7].The optimum PH range for most hydroponics seems to be within the range of 5.8 - 6.2.

EC Sensor – conductivity is the ability of substance to carry the current. An EC sensor helps determining how much nutrients does a solution have by measuring the electrical conductivity in a solution and then evaluate its quality. In liquid, the reciprocal of resistance, that is conductance, is often used to measure the conductive capacity. The conductivity of water is an important indicator in the measurement of water quality. It can reflect the level of electrolytes

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present in the water. Depending on the concentration of the electrolyte, the conductivity of the aqueous solution is different. Hydroponic nutrient solutions are made of mineral salts dissolved in water. The strength of the nutrient solution can be detected by monitoring the electrical conductivity (EC). Higher EC values indicate higher ionic (salt) concentrations. [8]

Water Level Sensor – measures and identifies the point at which a liquid fall below or rises above given ranges.

2.2.2.2 Actuators

Peristaltic Pump – is a type of positive displacement pump which is used for pumping variety of fluids. The fluid is contained within a flexible tube placed inside a circular pump casing and connected to a motor which runs causing pressure applied to the tube containing the fluids, therefor pumping the fluids into the desired area. [9]

2.2.2.3 Microcontroller and Extension Modules

Microcontroller – a small computer on a single integrated circuit that is used for a specific application and designed to implement certain tasks [10]. Microcontrollers can be used to program and control sensors, actuators and extension modules.

Wi-Fi Module – a self-contained SOC with integrated TCP/IP protocol stack that grants any microcontroller it is connected to the ability to access Wi-Fi networks [11].

LCD – stands for liquid crystal display, is a type of flat panel display technology that can interface with a microcontroller to provide a user interface and display data collected through sensors. LCDs come in different sizes.

2.3 Related Work

There are many systems that discussed and outlined hydroponics as an automated system with verities on what they are based, their components and what they provide.

Study 1 – LeafAlone Hydroponic System: This project created an automated hydroponic system that makes it easy for anyone to have their own hydroponic farm in their backyard. It allows the user to specify the plants they want to grow through a companion website. The settings specific to the plant are loaded to the microcontroller which controls the system by utilizing sensors (pH, EC, water temperature, water level, photosensitive) to collect data, and by using electronic liquid dispensing pumps to adjust the pH and nutrient levels according to the plant specific settings. It uses an air pump and oxygen filter to keep the water in the reservoir clean and oxygenated which deters bacteria and algae growth. The system also uses a camera that photographs the plants through their growth period, and sends it to the webserver to allow the user to see a time-lapse video of the plant growth through the website. It also sends the sensor data to the webserver for analysis and shows the user statistics about their plants in the form of graphs. The system is entirely powered by solar panels. The hydroponic technique used was deep water culture [6].

Study 2 – Design of Fully Automated Low-Cost Hydroponics System using LabVIEW and AVR Microcontroller: This project is a self-controlled intelligent hydroponic system that uses real-time data imported from an inexpensive AVR microcontroller used to monitor the system and automate actions needed to stabilize the hydroponic environment [13].

Study 3 – Fully Automated Hydroponic System for Indoor Plant Growth: this project aimed to improve the utilization of hydroponics as well as to create an environmentally independent system for indoor plant growth – Titan Smartponics. The Titan Smartponics accomplished automation by utilizing various microcontrollers, sensors and IoT technology for remote monitoring and control. It also developed a web and mobile application to view the readings and data collected to follow up plant growth and nutrition. [14]

Study 4 – Automated Hydroponics Greenhouse – Regulation of pH and Nutrients: this project aimed at creating a fully automated hydroponics greenhouse through monitoring

temperature in both water and air, relative humidity, water level, nutrient level and pH level. The system only uses the readings from the sensors to monitor plant growth and regulate water level, pH and nutrients, with the latter being its main focus. [15]

Study 5 – IoT Hydroponics Management System: system based on Internet of Things (IoT) for monitoring and management of the hydroponics garden is proposed. With the rising trend of IoT and through automation, the problems of managing these resources will be solved. This system aims to provide the ideal environment for plants to grow, a system where pH, water level, air temperature and relative humidity are constantly monitored. Additionally, with the use of simple mechanisms, this system provides controlled irrigation of water, and nutrient solution intake. Through the data gathered by the sensors and the use of cloud-based technology as the backend, information is stored, managed, applied and shared via internet by users. Management of resources in a hydroponics set-up would become easier and more efficient based on the success and results of this study Index Terms— IoT, sensors, web management, plants, hydroponics. [3]

Study 6 – An Automated Hydroponics System Based on Mobile Application: The purpose of design and develop the automation controlling and monitoring plant growth hydroponics system and evaluate the effect of using this prototype. This system is able to control significant environmental factors that affect plant growth including temperature, humidity, and water. The application system is automatically mixed the selected solution to obtain the desired value and also collects information about the amount of solution mixed at the time of planting and it can be used to estimate the cost of growing vegetables and calculate the profitability of each vegetable to make the decision to grow. This study demonstrates the successful application of plants grown with hydroculture to improve in pH sensor stability and the system works well in the automated mode. Index Terms—Automation control, monitoring, Internet of things, mobile application, and Hydroponics. [16]

Study 7 – The Design and Implementation of a Hydroponics Control System: This thesis was born out of the idea to make hydroponic food growing easier and cheaper, hydroponics is essentially the growing of plants without the use of soil. The idea of it being open source is also in keeping with the general community feeling surrounded by the hydroponic movement. The objective of the thesis was to create a working hydroponic controller, which is cheap and simple enough to build. It will monitor and control the key environmental ingredients needed for successful hydroponic growing, chiefly the pH, EC, air and water levels. Visual alarms will be raised if these go outside of predefined ranges. The controller will also be able to control external HW, such as lights, water heater and a water pump. A circuit board was developed, which will act as a shield for an Arduino 2560 board. The circuit board will help in the ease of building the system. It acts too, as a way of keeping the HW more stable, as wires will not come loose and interference will be minimized. The SW and HW design will be available for everyone to download. Knowledge of what is important in hydroponic growing was considered and these factors were used as inputs into driving the SW and HW requirements. UI usability studies were carried out to ensure that the controller would be enjoyable to use. Software design and software patterns were taken into use to make the SW more module and expandable. [17]

Similar Systems Comparison

Based on the similar systems mentioned earlier, the main essential parameters and components for hydroponic systems has been conducted and compared as shown in Table (2.1)

Table (2.1): Comparison of Similar Systems

System	Usability	Flexibility	Multi-language	Sensors			Other hardware					Functions			
				pH	EC	Distance	Microcontroller	LCD	LED	Pump	Wi-Fi module	F1	F2	F3	F4
1	√	√	N/A	√	√	X	√	X	X	√	√	√	√	√	X
2	√	X	N/A	√	X	X	√	X	√	X	√	√	X	√	X
3	√	√	√	√	√	X	√	√	√	X	X	√	√	√	√
4	N/A	N/A	N/A	√	√	√	√	X	X	√	X	√	√	√	X
5	√	√	N/A	√	X	√	√	X	X	√	X	√	X	√	√
6	√	√	N/A	√	√	√	√	X	√	√	√	√	√	√	√
7	√	√	√	√	√	X	√	X	√	√	X	√	√	X	√

---

[1] Control pH level

[2] Control nutrients concentration

[3] Control water level

[4] Notify user

Chapter Three: Hardware Analysis

and Design

3.1 Introduction

The HYPO project consists of mainly two parts, Hardware part and software part as shown in Figure (3.1).
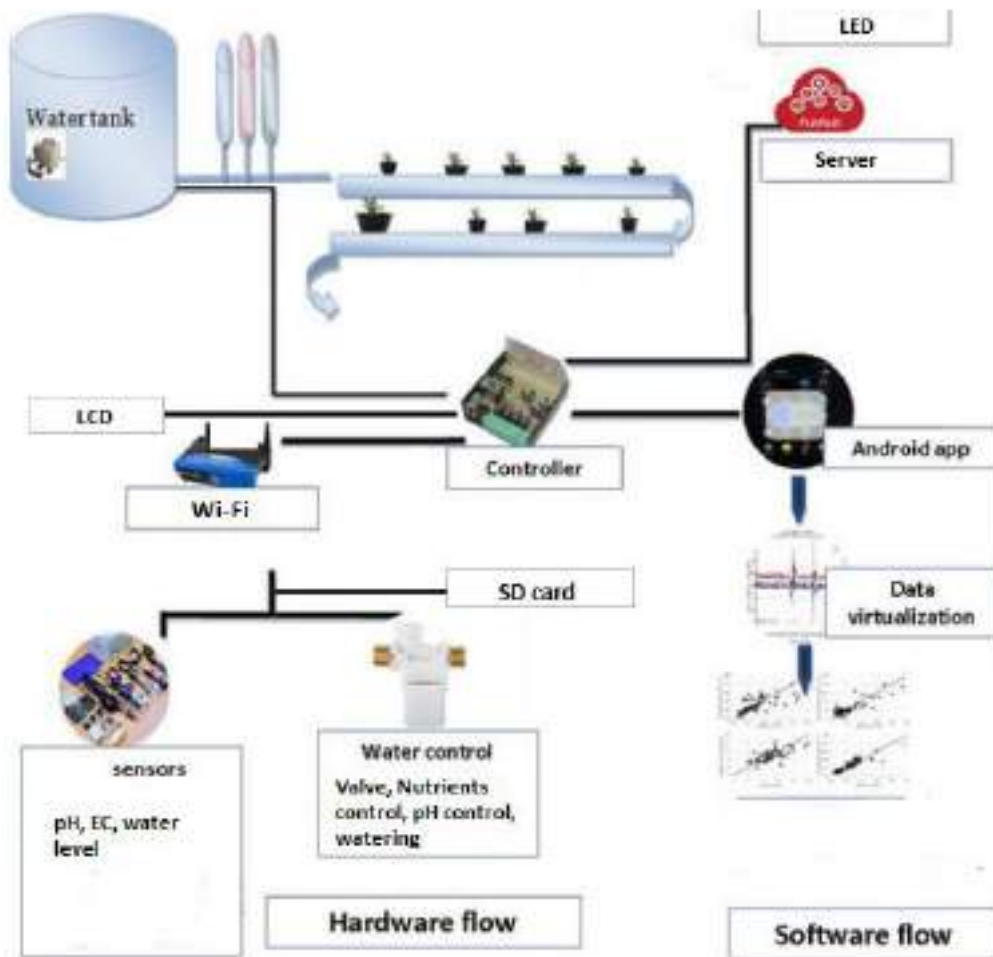
Figure (3.1): The Overall Block Diagram of HYPO

In this chapter, the design details of the growing environment, which is comprised of the hardware component are discussed. This chapter includes the analysis of the growing environment requirements, the system hardware, hardware controlling program and the simulation design.

3.2 Hardware Requirements Analysis

In this section the requirements which the growing environment should fulfill will be listed.

3.2.1 Functional Requirements

The functional requirements fall into control requirements and data requirements:

3.2.1.1 Control Requirements

CFR01: The hardware unit shall measure the EC of the reservoir water 10 minutes before the flood cycle.

CFR02: The hardware unit shall measure the pH of the reservoir water 10 minutes before the flood cycle.

CFR03: The hardware unit shall measure the water level of the reservoir 3 hours before the flood cycle.

CFR04: The hardware unit shall monitor the level of the nutrient solution 3 hours before the flood cycle.

CFR05: The hardware unit shall monitor the level of the pH equalizers levels 3 hours before the flood cycle.

CFR06: The hardware unit shall measure the level of the water in the growing tray to prevent it from overflowing during the flood cycle.

3.2.1.2 Data Requirements

DFR01: The hardware unit shall save the recorded measurements.

DFR02: The hardware unit shall send the saved measurements to a web server over a network connection to store the data.

DFR03: The hardware unit shall allow the user to view the recorded measurements on an LCD.

3.2.2 Nonfunctional Requirements

The SHCMS requires nonfunctional requirements such as reliability and correctness.

QR01: The hardware unit shall not fail more than two times within a month.

QR02: The hardware unit shall make accurate and precise measurements.

3.2.3   Assumptions and Constraints

3.2.3.1 Assumptions

- Availability of growing medium.

- Availability of nutrient solutions.

- Availability of Internet connection.

3.2.3.2 Constraints

- The system is limited to plants that don't need large areas or root support.

- The growing environment needs to be indoors, but it has to be close to an open place for the solar panel.

3.3 Hardware Unit Components

The hydroponic system relies on a number of sensors to give accurate measurements, e.g. water level, pH and EC. With a peristaltic pump to regulate water and control the dosing of pH and nutrients. The collected measurements can be displayed through LCD which interfaces with the microcontroller and later sent to the cloud server through Wi-Fi module that allows the microcontroller to access a Wi-Fi network. All these components connect to one microcontroller to be programmed using specific programs that deal with hardware components. The connection of these components with microcontroller, either as input or output is shown by the block diagram in Figure (3.2).
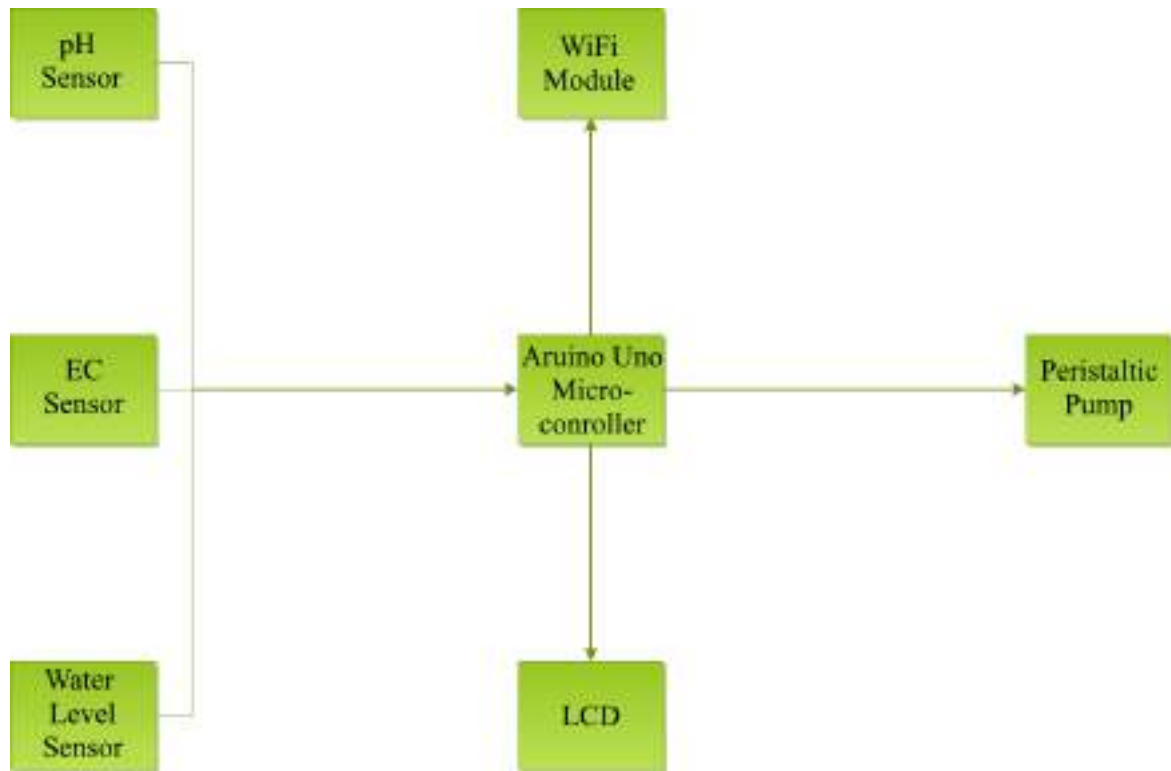
Figure (3.2): Hardware Unit Components

3.3.1 Hardware Components

3.3.1.1 Sensors

pH sensor (E-201-C) – the E-201-E pH sensor works on and input supply of 5V, with a pH detection concentration range from 0 to 14, in addition to $\leq$ 5s response time and $\leq$ 60s stability time. [18]

EC sensor (G1/2) – this EC sensor comes with measuring range of 0 – 2000 mu S/cm. [19]

Water Level Sensor – is mainly used to measure the water level and monitor sump pit. The water level sensor works in a very straightforward manner. The series of exposed parallel conductors, together act like as a variable resistor whose resistance varies according to the water level. The change in resistance corresponds to the distance from the top of the sensor to the surface of the water. The sensor produces an output voltage according to the resistance, which by measuring the water level can be determined [20].

3.3.1.2 Actuators

Peristaltic Pump (NKP-DC-B80) – it has a flow rate range of 5.2 – 90 ml/min with a relatively smaller volume and lower power dissipation. [21]

3.3.1.3 Microcontroller and Extension Modules

Arduino Uno Microcontroller - is an open source platform used to build electronics projects. It consists of both a programmable physical circuit board (often referred to as a microcontroller) and a piece of software, or an IDE (integrated development environment) that runs on your computer, and is used to write and download the computer code to the physical board. Arduino Uno is a controller board based on ATmega2560 (data sheet). It has 54 digital input / output pins (14 of which can be used as PWM output), 16 analog inputs, 4 UARTs (hardware serial ports), 16 MHz crystal oscillator, USB connection, power jack, ICSP header and a reset button [22]. Arduino Mega controller for automatic control Nutrient solution flow with logic. Precise control can also send data about the plant's liquid level (solution) to the Android smartphone from the owner of the hydroponic plant [23].

Wi-Fi Module (ESP8266) – it is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. This module has a powerful enough on-board processing and storage capability that allows it to be integrated with the sensors and other application specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry, including the front-end module, is designed to occupy minimal PCB area [24].

LCD (12864B V2.0) – a 128 * 64 pixel LCD display with a blue backlight and white foreground. The display is fully programmable and can display a combination of both graphics and text. It can operate in both parallel and serial (SPI) modes which can be configured by the external pin PSB. [25]

3.4 Hardware Unit Controlling Program

The hardware unit of the HYPO project controlling program consists of two main process, designing the algorithm of which the components will be programmed based on and the design of how the data will be processed and saved.

3.4.1 Algorithm

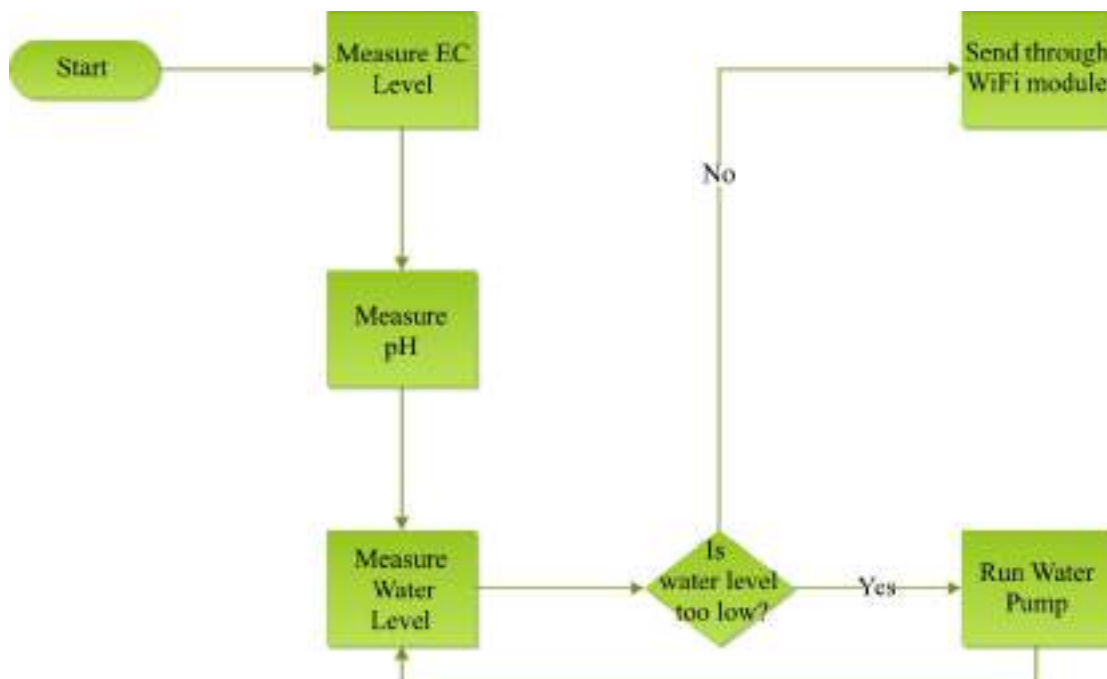The overall behavior of the hardware system is described by a flow chart shown in Figure (3.3).

Figure (3.3): Hardware Control System Flowchart

The Arduino script starts by collecting measurements from the EC and pH sensors in the growing tray. Then the water level sensor measures the water level in the tray if the water level is too low the water pump runs and refill the growing tray by transferring water from the water tank through a tube. Then the water level is measured again until and the process of measuring and refilling the tray is run until desired level is reached then all the measurements are sent to the server through the Wi-Fi module.

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3.4.2   Data Design

The information domain is transformed into several data structures which hold the sensor threshold data coming from the server and the sensor reading data coming from the sensors.

3.4.2.1 Data in Memory

The data in memory is housed in several struct data types. Figure (3.4) shows how the data is structured.
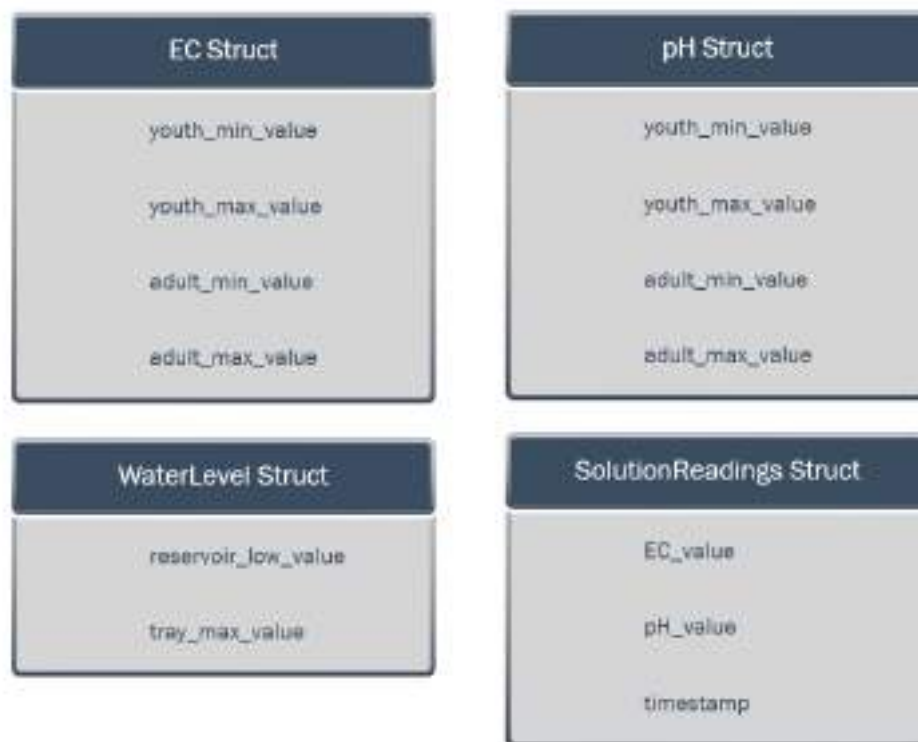
Figure (3.4): Structure of Data in Memory

3.4.2.2 Data in Storage

Data is stored temporarily in several JSON files on the Arduino memory module before it's sent to the server. This is because the Internet connection might sometimes be down, so data must be stored to avoid risk of losing the readings from the sensors. It would also be counterproductive to send the data to the server every time a reading is made.

Chapter Four: Software Analysis and Design

4.1.   Introduction

The software side of the HYPO project consists of two main parts: the actual app which can be referred to as the client side, and the server which provides the services needed by the app as well as connecting the hardware unit with the software unit. All the software related designs are discussed in this chapter.

4.2.   System Architecture

The HYPO project system architecture can be referred to as a layered system. Of which each layer provides a set of services. These layers as shown in figure (4.1).

Figure (4.1): HYPO System Architecture

4.3.   Software Design

In this section the usecase diagram and the usecase description is overviewed.

4.3.1.   Usecase Diagram

The usecase diagram shows the main functions that the application is to provide to users. As in figure (4.2).
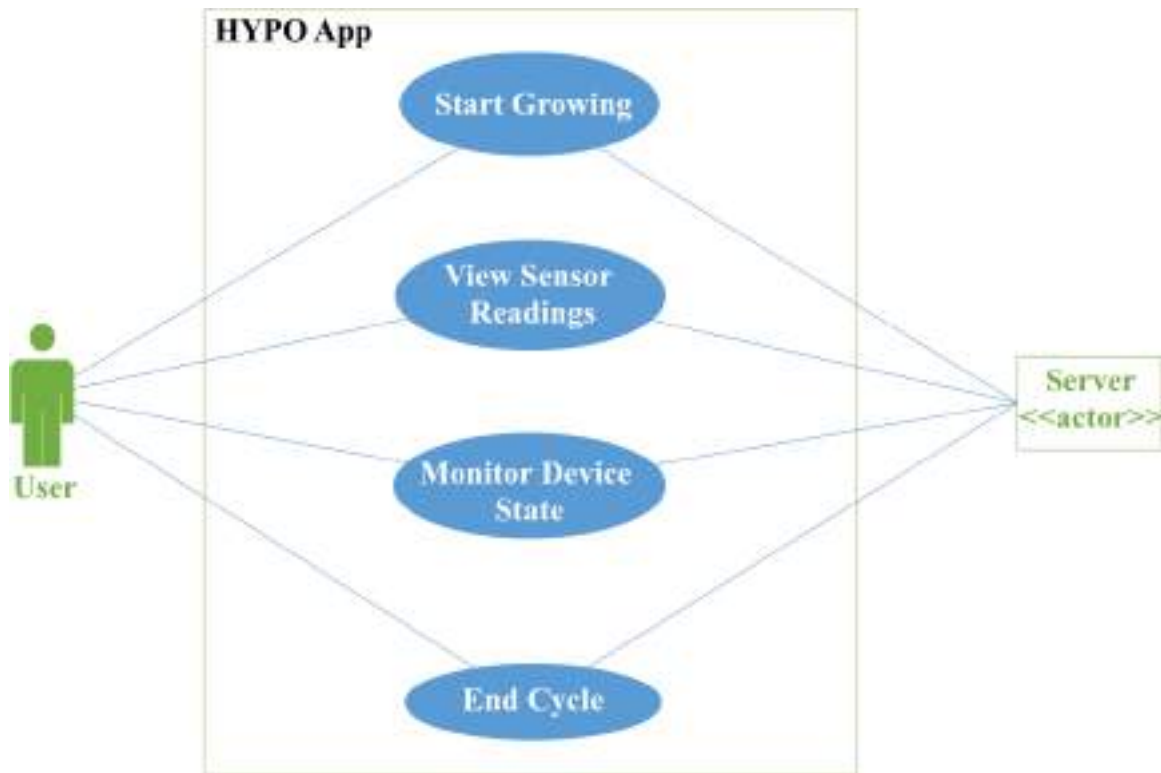
Figure (4.2): Usecase Diagram

4.3.2. Use Case Description

The following tables describe the use case diagram in more detailed way and show the flow

of each use case process.

1. Start Growing

Table (4.1): Start Growing Usecase Description

Use case name: Start Growing	ID: 1	Importance level: Important
Primary actor: User		**Use case type:** Overview, Essential
Stakeholders and interests: User User – wants to grow plants		
Brief description: This use case describes how we create a new environment and start growing.		
Trigger: The user logs in or signs up into the application. **Type:** Internal		
Relationships: 　　　**Association:** Application User		

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Include:	
Extend:	
Generalization:	

Normal flow of events:

1. The user opens the application.
2. The user has a choice of logging in or signing up. (A-1)
3. The user is redirected to the home page.
4. The user presses the start growing button.
5. A list of plant groups is then displayed to choose from. (A-2)
6. After choosing the plant group, a list of plant types in that group is displayed and the user can choose the desired type. (A-3)

Alternate/ Exceptional flows:

A-1: If the user already has an account the user is asked to enter the username and password, if not, the user can choose to sign up and create a new account or exit the application.

A-2: If the desired plant does is not found, the user can either choose another group or stop growing.

A-3: If the required plant type is not found in the specified group the user can either choose another type, search in another group or stop growing.

2. View Sensor Readings

Table (4.2): View Sensor Readings Usecase Description

Use case name: View Sensor Readings	**ID:** 2	**Importance level:** High
Primary actor: User		**Use case type:** Overview, Essential
Stakeholders and interests: User User – wants to view sensor readings.		
Brief description: This use case allows the system to display the sensors' readings in a chart in the application and allows the user to view these readings and keep track of their plants' status.		
Trigger: The user opens monitor page. **Type:** Internal		

Relationships:
     Association:
     Include:		

| Extend: |
| Generalization: |

Normal flow of events:

1. The application user opens the application to keep track of their grown plants and monitor their growth.

2. The plant status (pH and EC values changes) is shown.

S-1: if the user wants to view the plant overall status in home page.

S-2: if the user wants to view the plant status in detail in monitor page.

SubFlows:

S-1: Overall status

1. The user opens the home page.

2. The pH and EC levels are shown as statistics.

3. The user can choose to view the sensors' statistics over a specific period of time (hourly, daily, weekly or monthly).

S-2: Detailed Status

1. The user goes to monitor page.

2. **Each sensor's current reading is shown.**

3. Monitor Device State

Table (4.3): Monitor Device State Usecase Description

Use case name: Monitor Device State	ID: 3	Importance level: High
Primary actor: User		**Use case type:** Overview, Essential
Stakeholders and interests: User User – wants to view device state		
Brief description: This use allows the user to monitor device's parameters.		
Trigger: Open monitor page **Type:** Internal		

Relationships:
 	
    Association:
 	
    Include:
 	
    Extend:
 	
    Generalization:		

Normal flow of events: 1. The user opens the monitor page. 2. The application asks the server to get the device's parameters. (A-1)		

| 3. | Server responds. |
| 4. | Application displays the data. |

Alternate/ exceptional flows:
A-1: Couldn't connect to server, the application shows error message.

4. End Cycle

Table (4.4): End Cycle Usecase Description

Use case name: End Cycle	**ID:** 4	**Importance level:** Low
Primary actor: User		**Use case type:** Overview. Essential
Stakeholders and interests: User User – wants to end cycle		
Brief description: This use case allows the user to end the growing cycle.		
Trigger: Plant dies or ripens. **Type:** Internal		

Relationships:
 	
    Association:
    Include:
    Extend:
    Generalization:		

Normal flow of events: 1. The user opens the home page of the application. 2. The user then under the plant information card clicks on the End cycle link. 3. The application then will communicate the server to terminate the growing cycle and won't display anymore sensor readings.		

4.4.   Database Design

In the following the main entities of the database are shown along with their attributes and how each entity relates to the other entity. The database design is shown in figure (4.3).
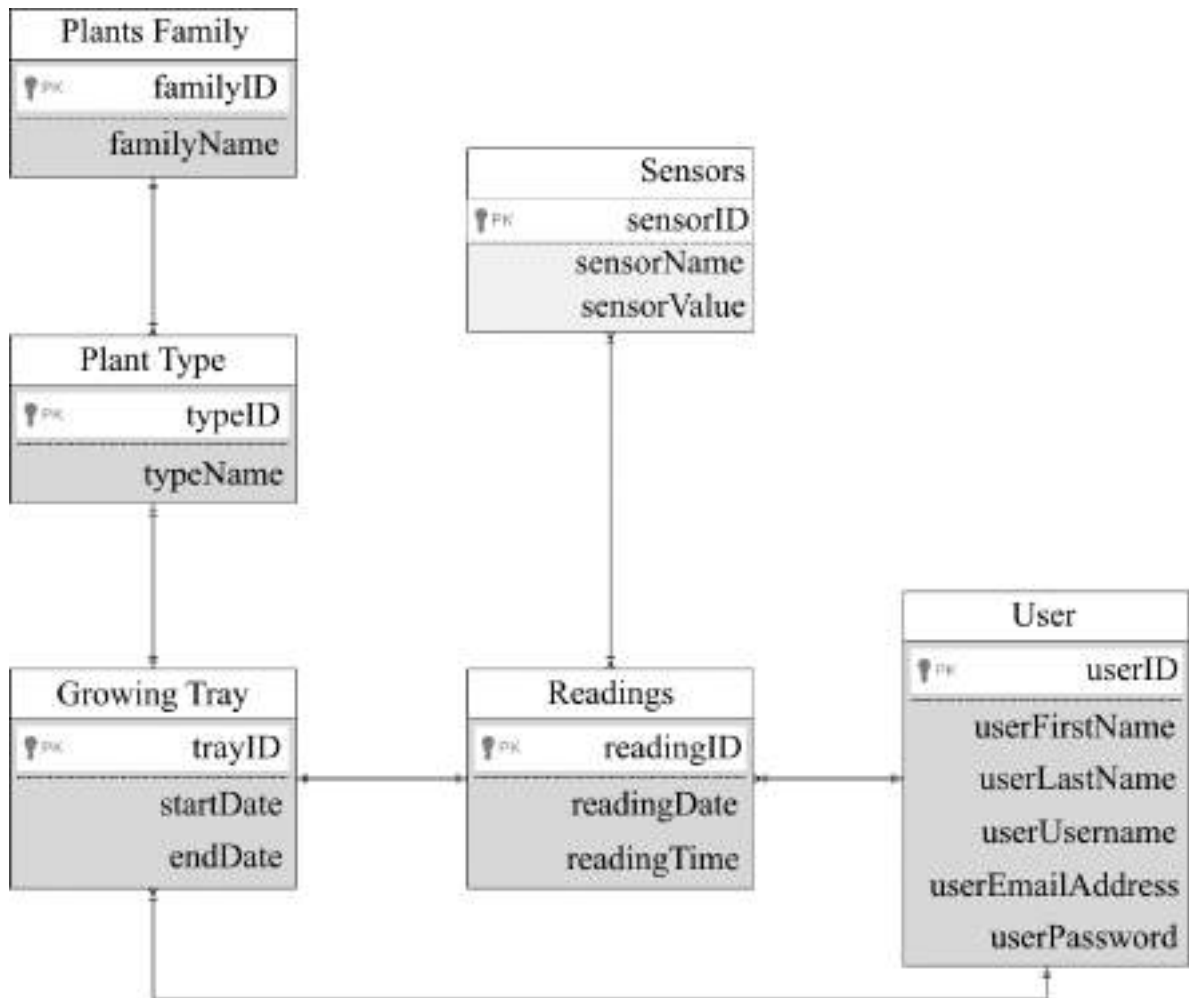
Figure (4.3): Database Design

4.5. System Flow Design

In this section the usecase diagram and the usecase description is overviewed.

4.5.1.   Activity Diagram

The Activity Diagram shows the different activities the software goes through.

   1. **Registration**
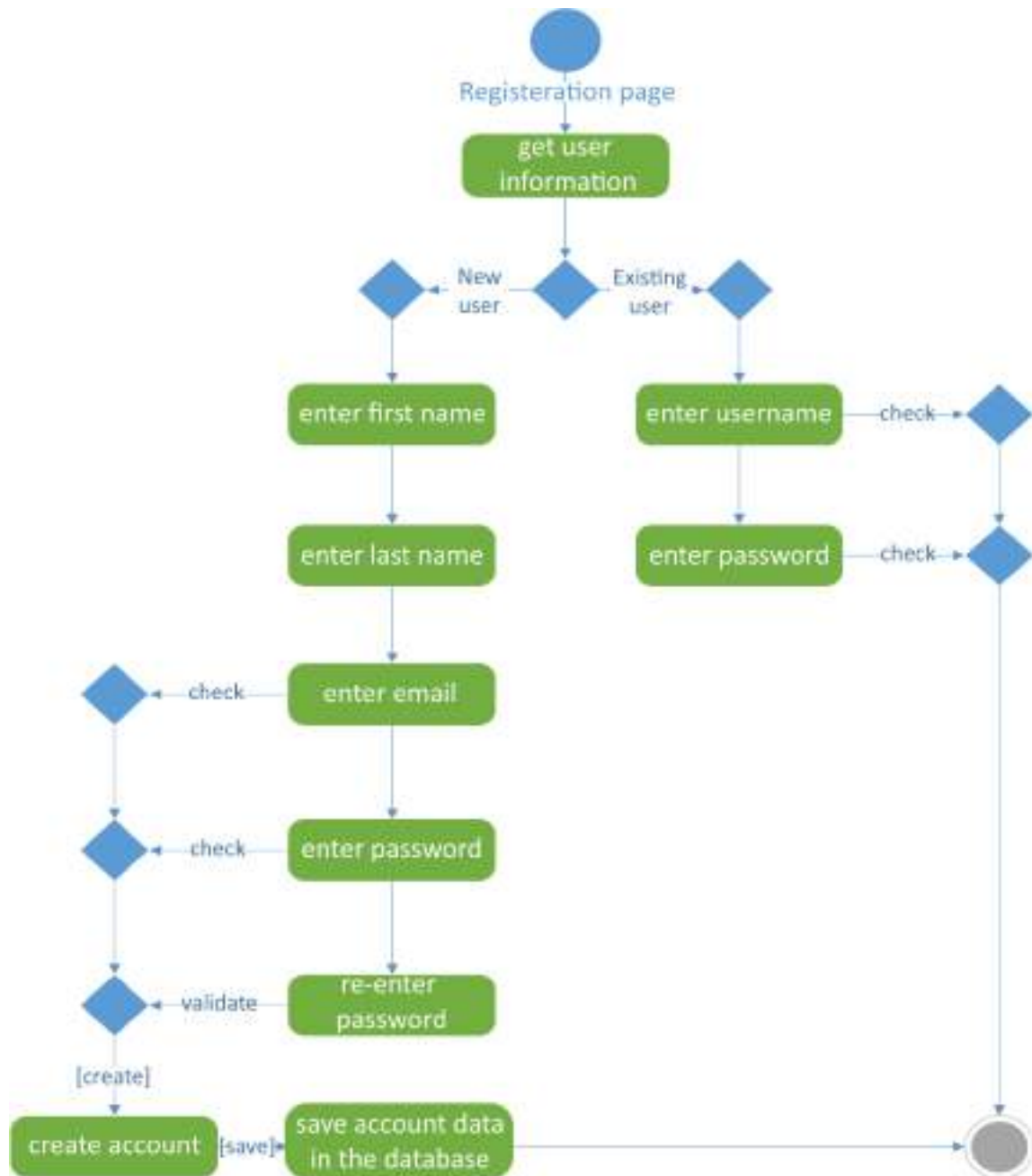
Figure (4.4): Registration Activity Diagram

2. Growing Environment
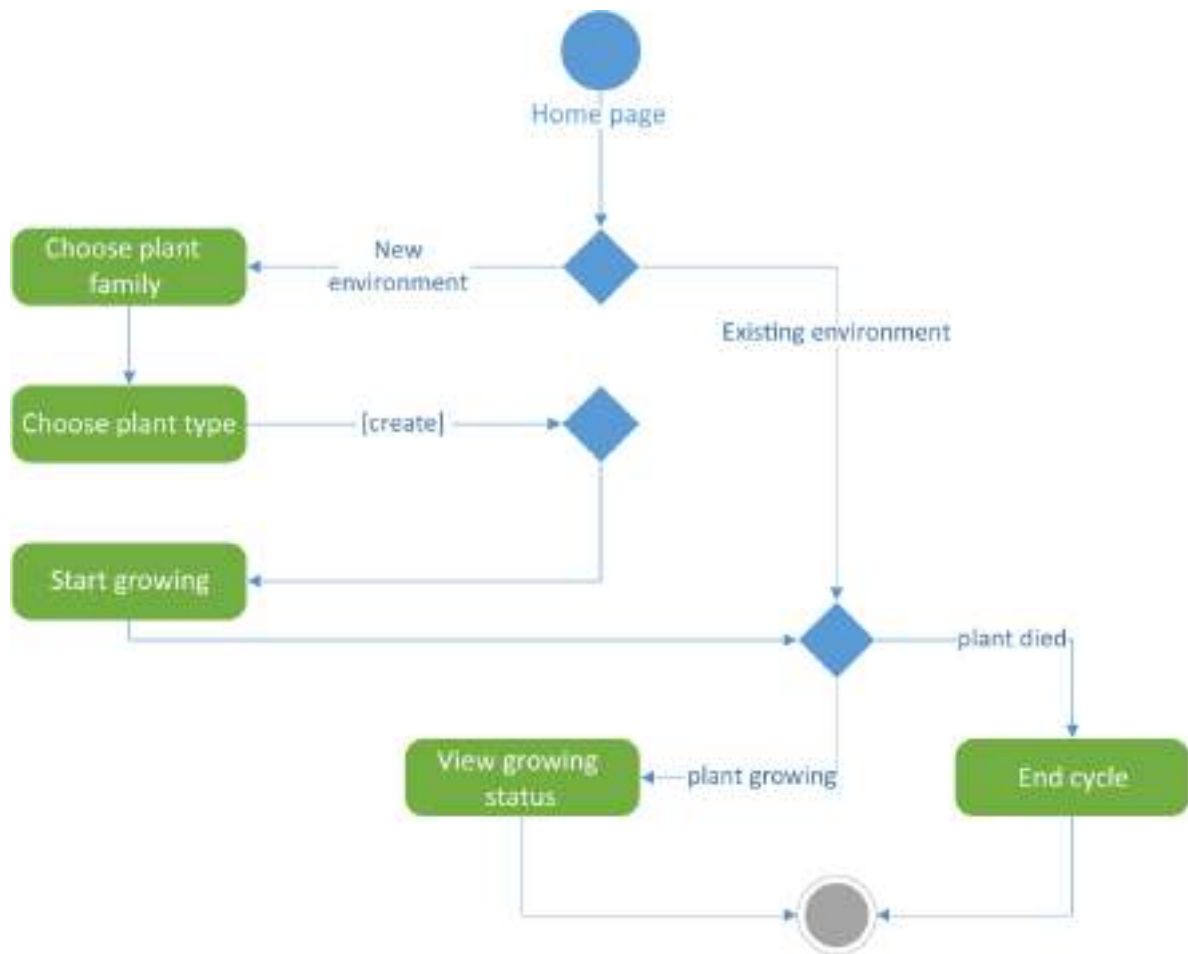
Figure (4.5): Growing Environment Activity Diagram

3. Monitoring
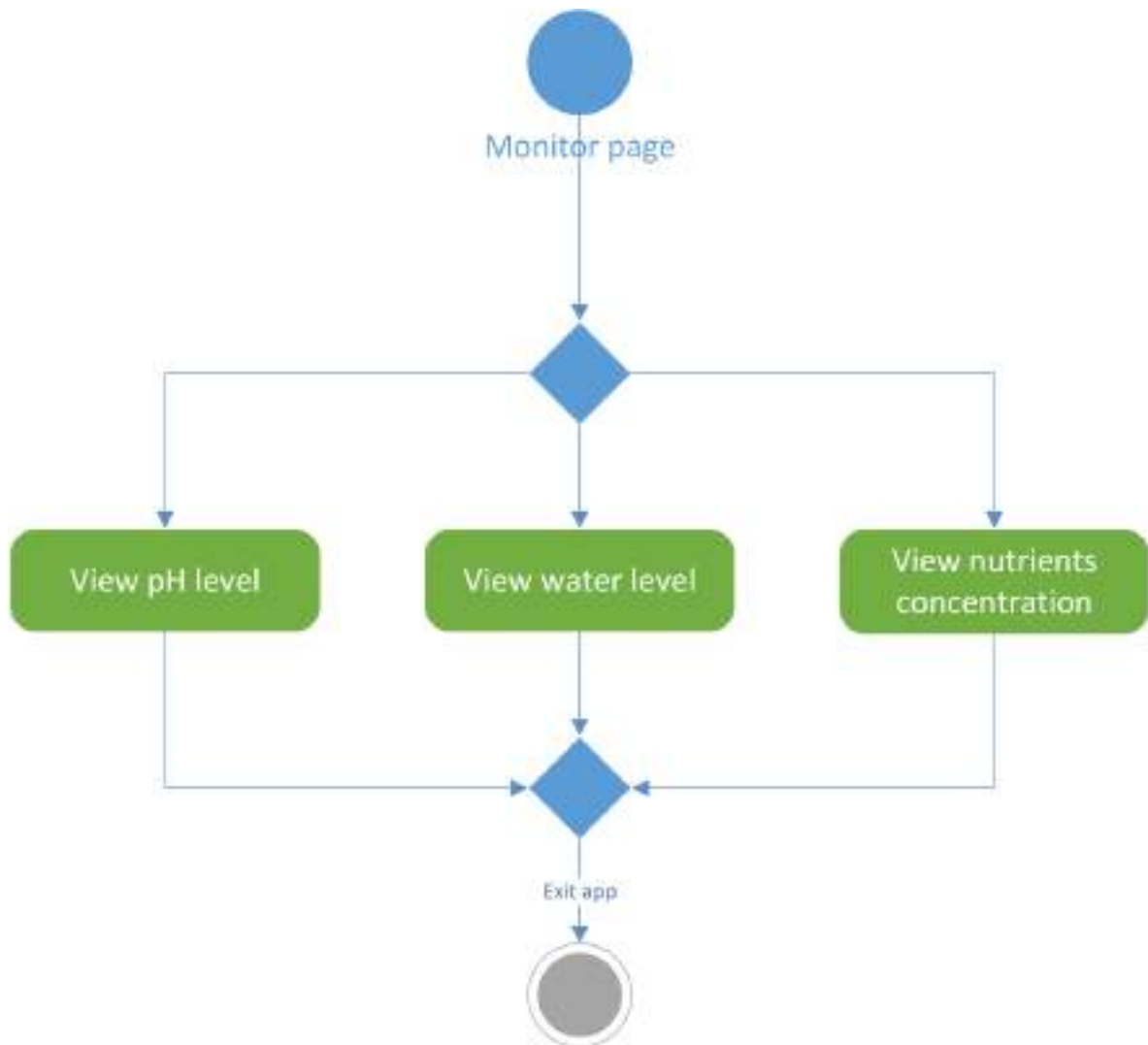
Figure (4.6): Monitoring Activity Diagram

4.5.2.   State Diagram

The state diagram shows the different states which the plant go through during its growing cycle. Shown in Figure (4.7)
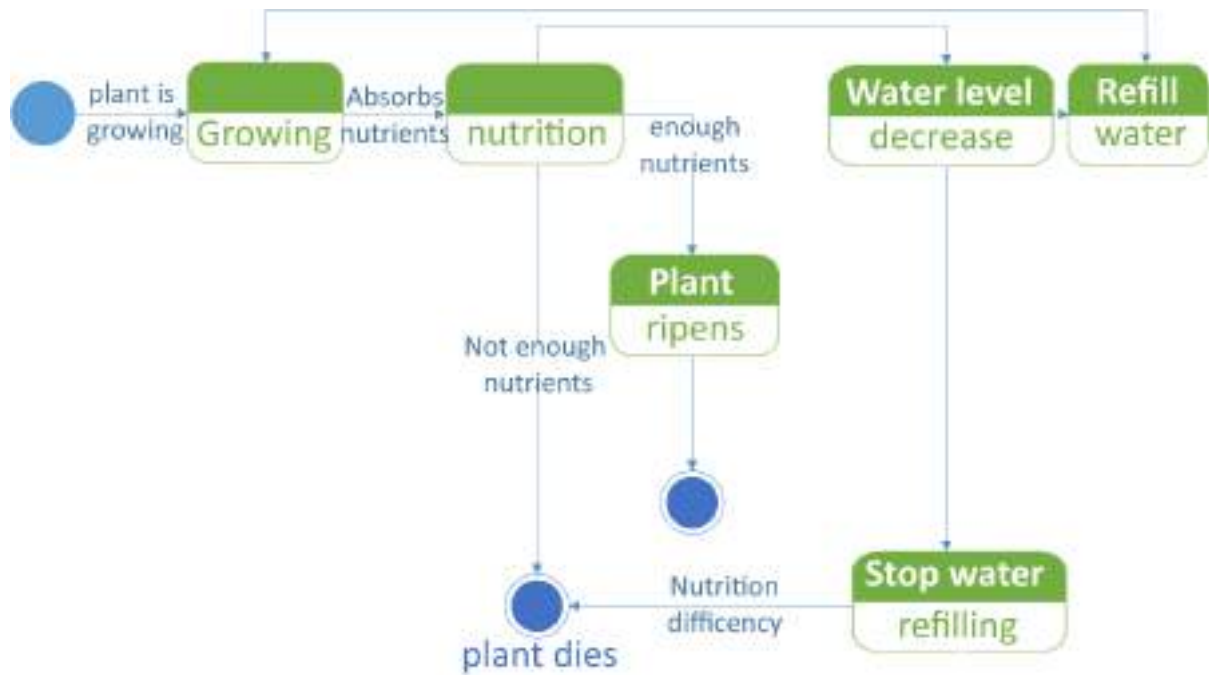
Figure (4.7): State Diagram

4.6.   User Interface Design

1. Login and Signup

This page allows the user to create a new account, login and access the application. As shown in Figure (4.8) and Figure (4.9).

Figure (4.8): Login Interface Design
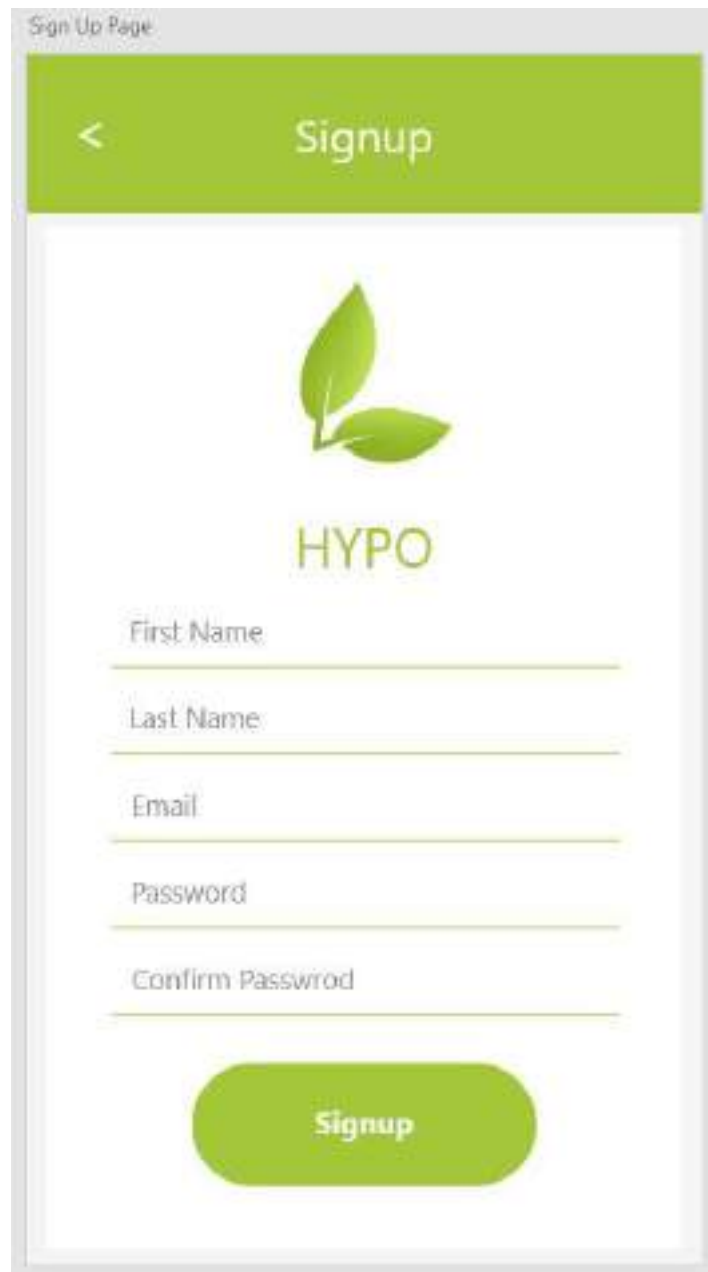
Figure (4.9): Signup Interface Design

2. Home Page (Start Growing)
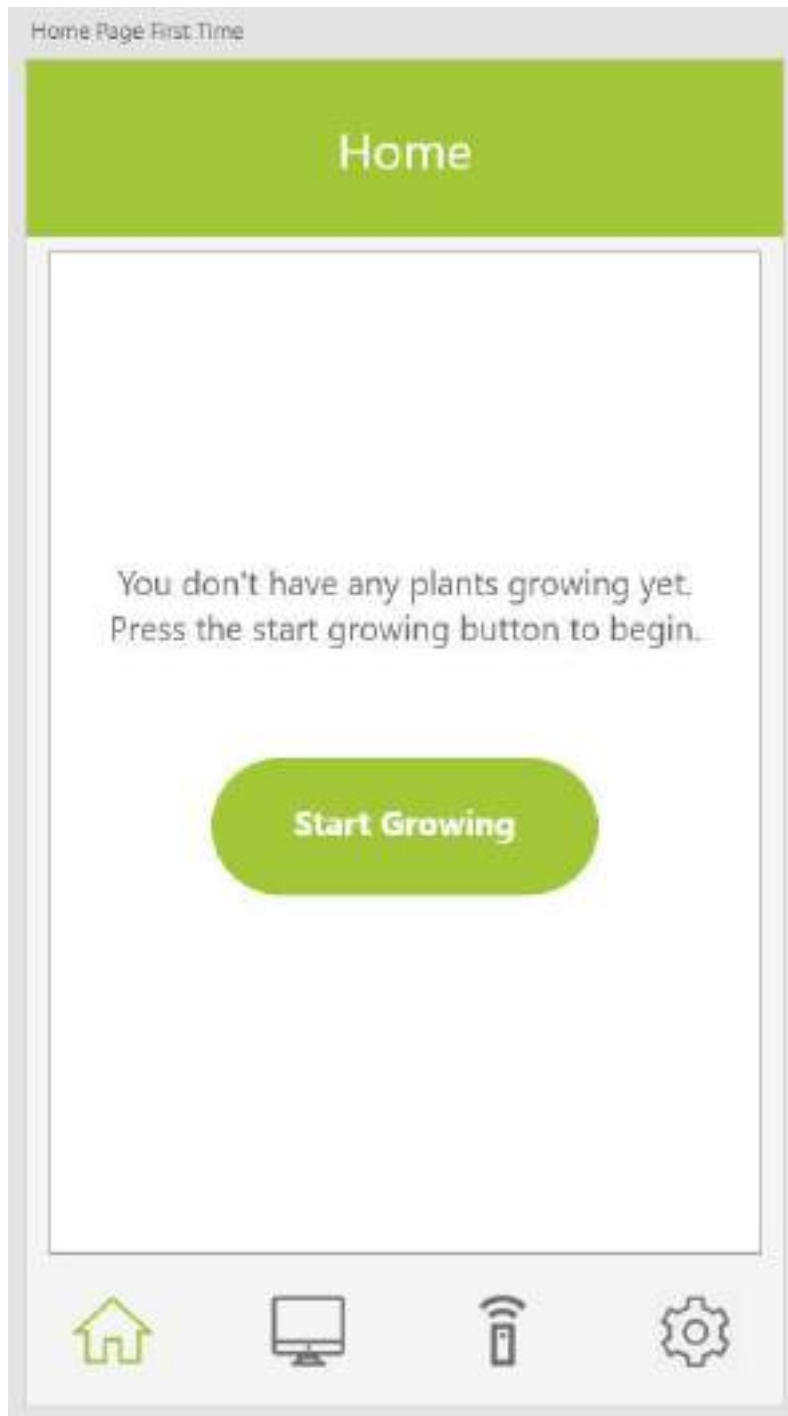
Figure (4.10): Home Page Interface Design

3. Choose Plant Group

Figure (4.11): Choose Plant Group Interface Design

4. Home Page (Growth Cycle)

Figure (4.12): Home Page After Growing Interface Design

5. Monitor
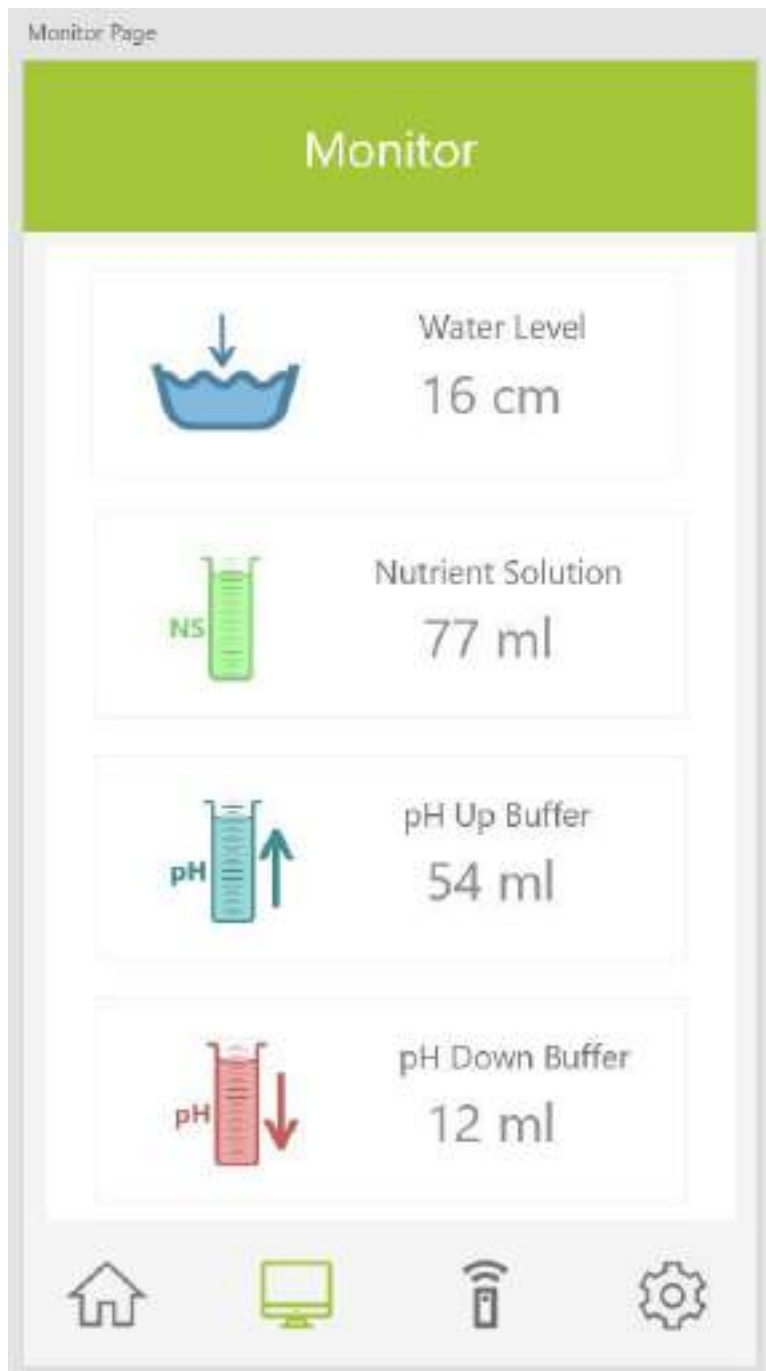
Figure (4.13): Monitor Interface Design

6. Settings
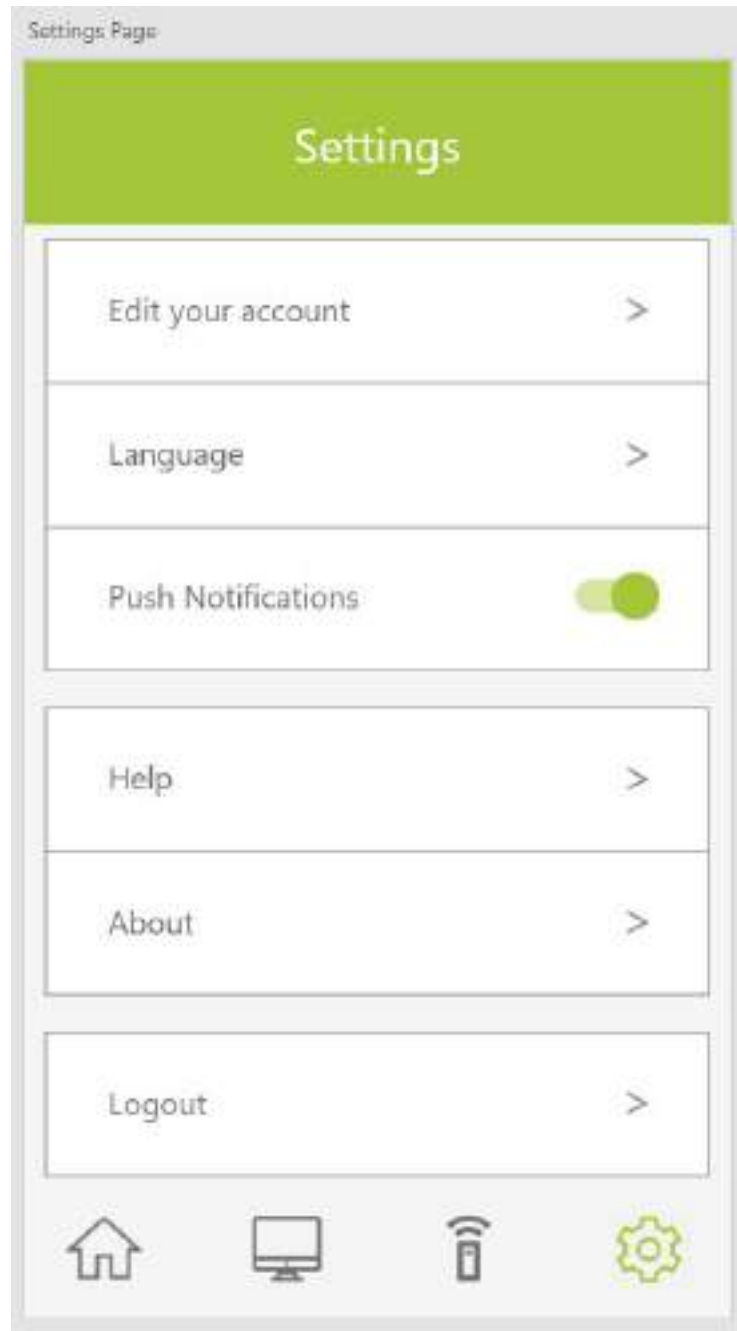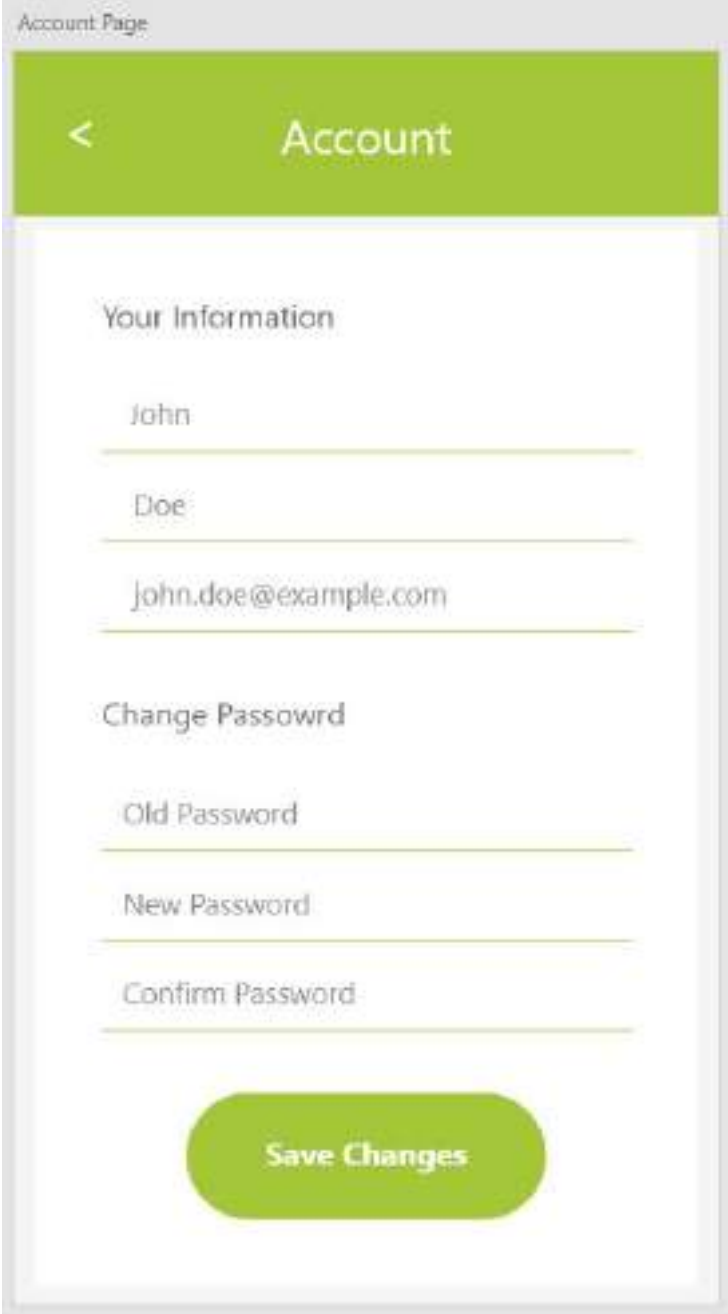
Figure (4.14): Settings Page Interface Design

7. Account

Figure (4.15): Account Interface Design

Chapter 5: Implementation and Testing

5.1.   Introduction

In this chapter the application in runtime and related processes will be reviewed.

5.2.   Implementation

1. Login

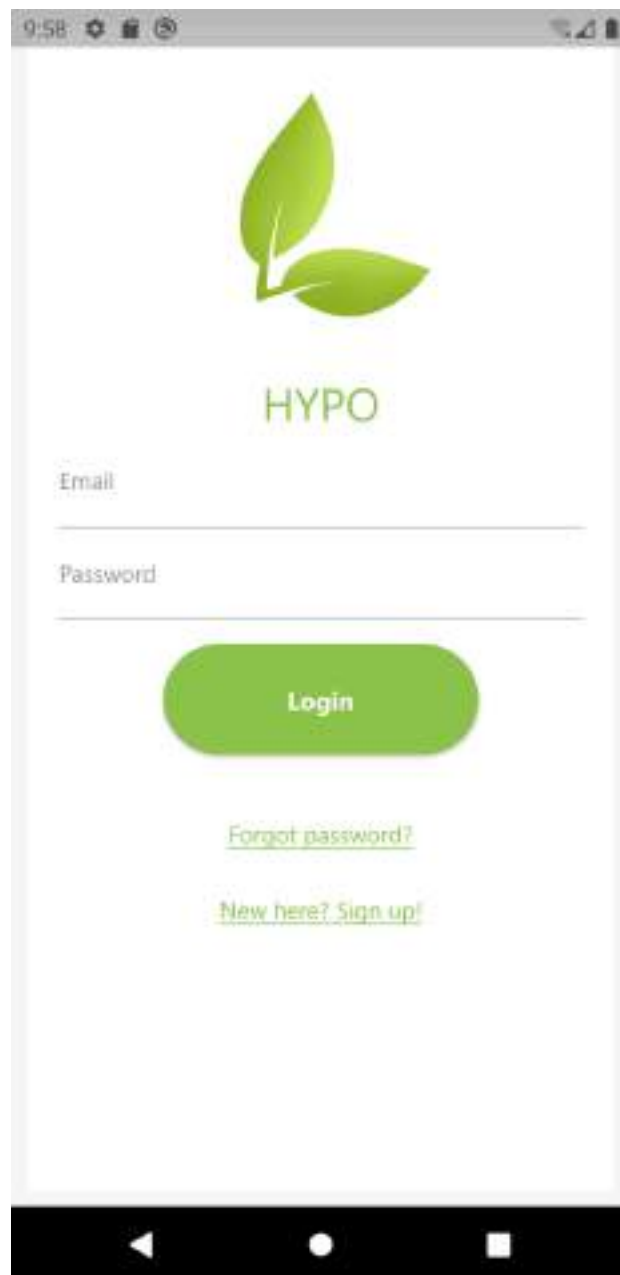Figure (5.1) shows the interface for user login.

Figure (5.1): Login Interface

2. Home (Before Growing)

In figure (5.2) the home page after logging into the application for the first time is shown, as noticed no plants are grown yet.
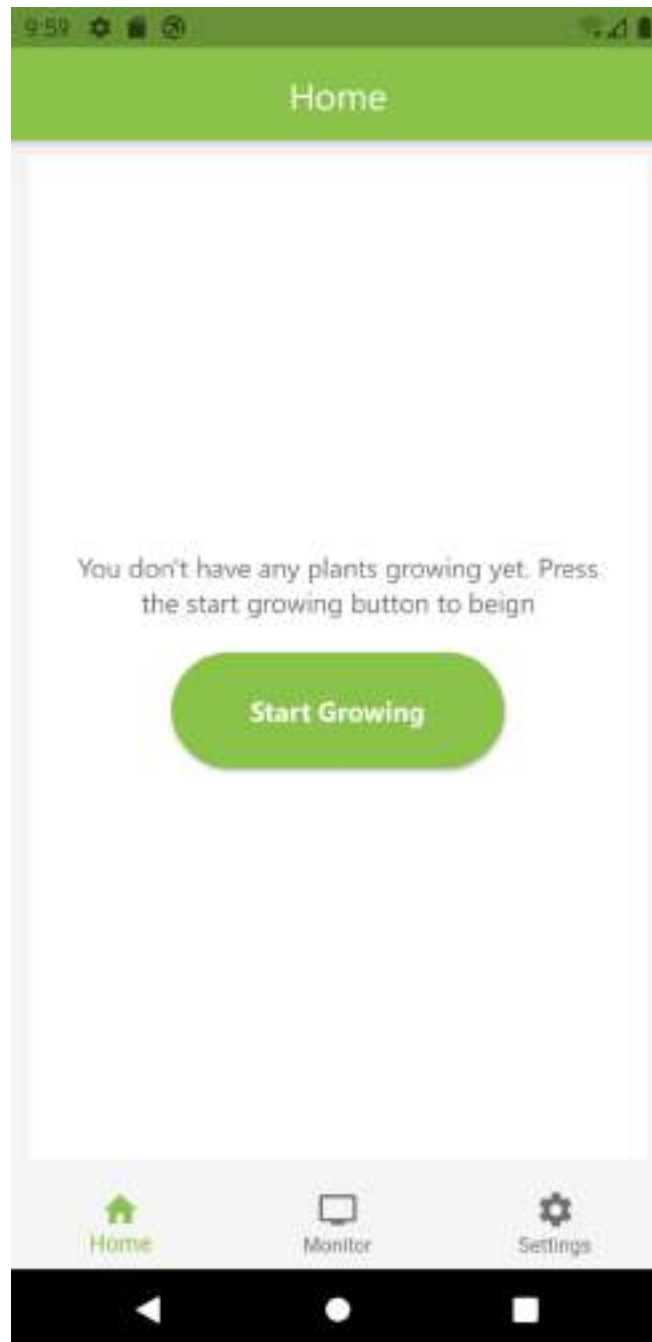

Figure (5.2): Home Interface Before Growing

3. **Choosing Plant Group**

   Figure (5.3) shows the interface for choosing a plant group, which appears after clicking
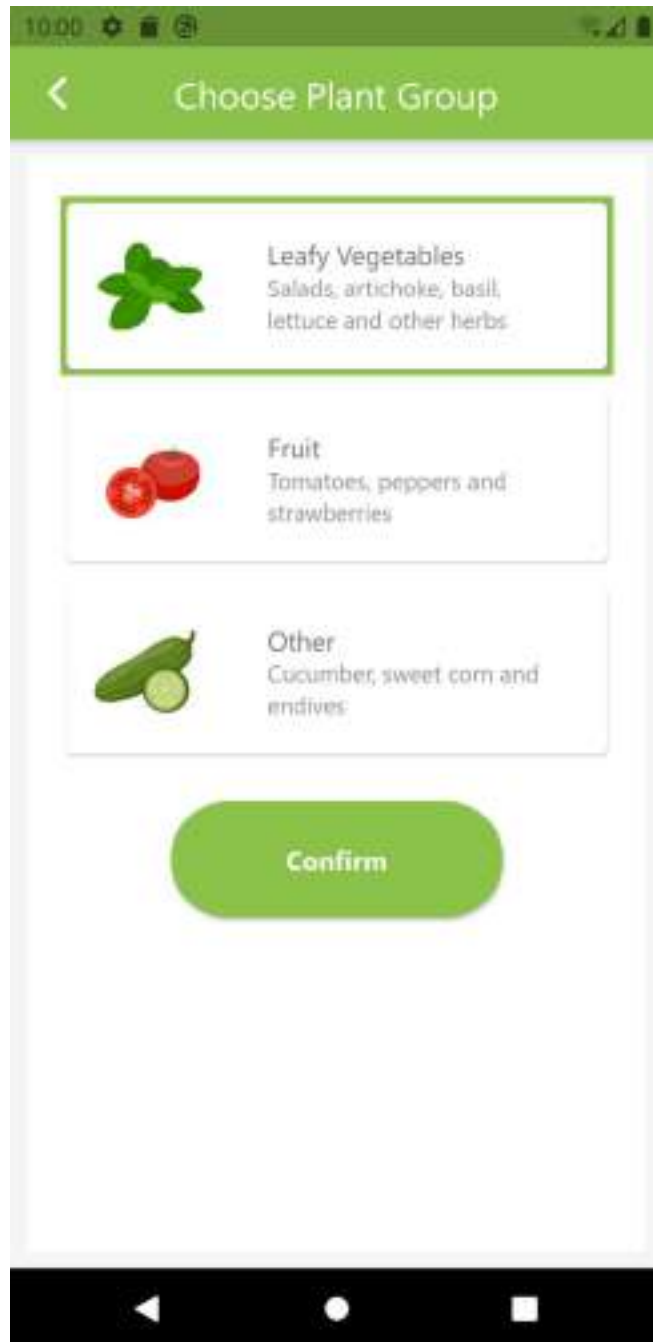
   the (Start Growing) button in figure (5.2).

Figure (5.3): Choose Plant Group Interface

4. Home (After Growing)

After choosing plant group and growing the plant, statistics on the plant growth are
displayed these statistics show the pH and EC absorption over a specified period of time.
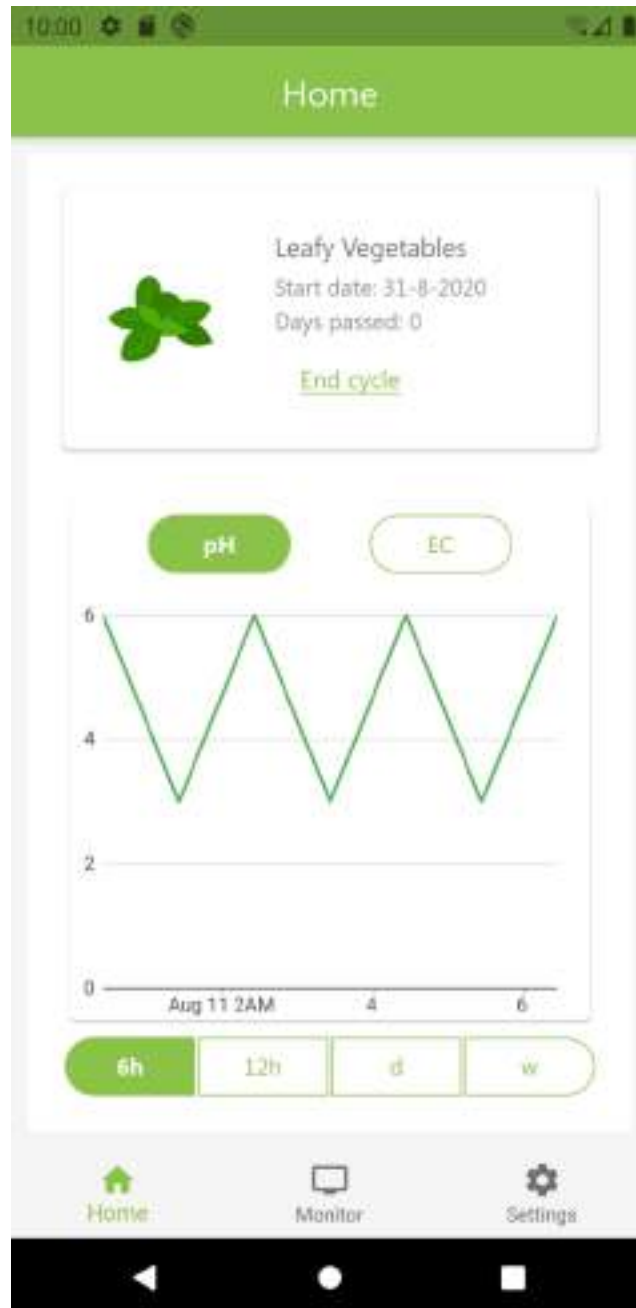

Figure (5.4): Home Interface After Growing

5. Monitor

Figure (5.5) shows the monitor where current sensors' readings are displayed.

Figure (5.5): Monitor Interface

6. Settings

Figure (5.6) shows the settings page which allows the user to edit their account, change the application language, logging out, etc.

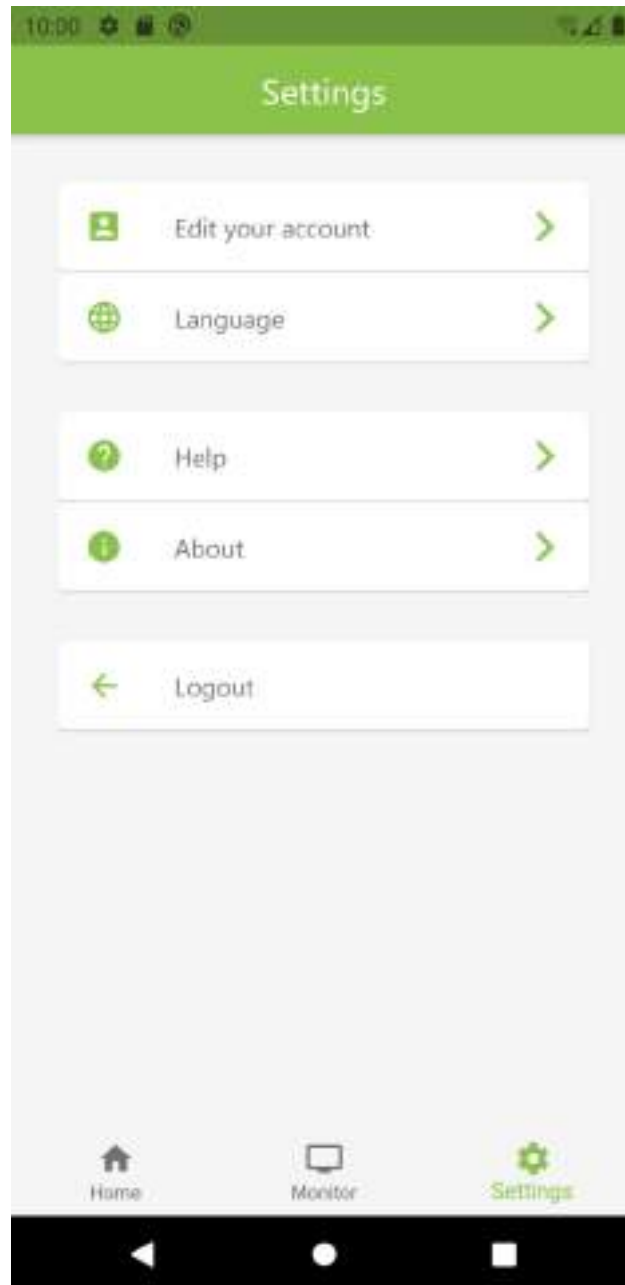*Figure (5.6): Settings Interface*

7. Editing Account

The interface in figure (5.7) shows the option for account edition which can be accessed through the settings page in figure (5.6).
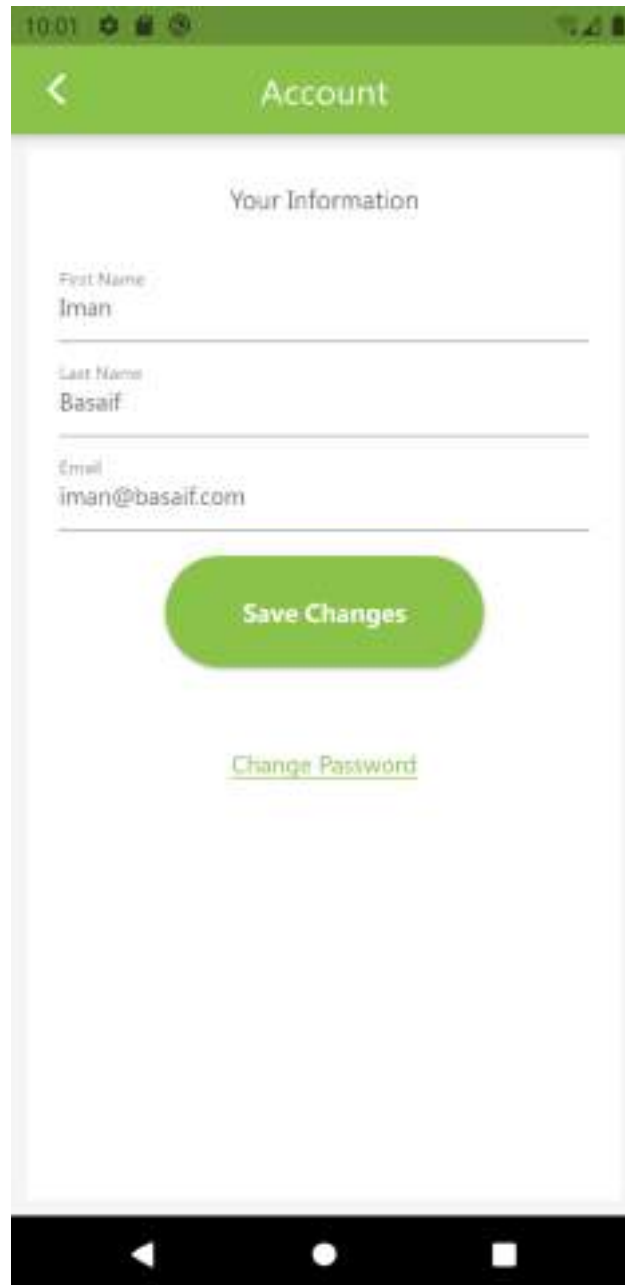

Figure (5.7): Account Interface

8. **Changing Password**

   Figure (5.8) shows the changing password option which appears after clicking on (change
   password) in the account page that was shown previously in figure (5.7).
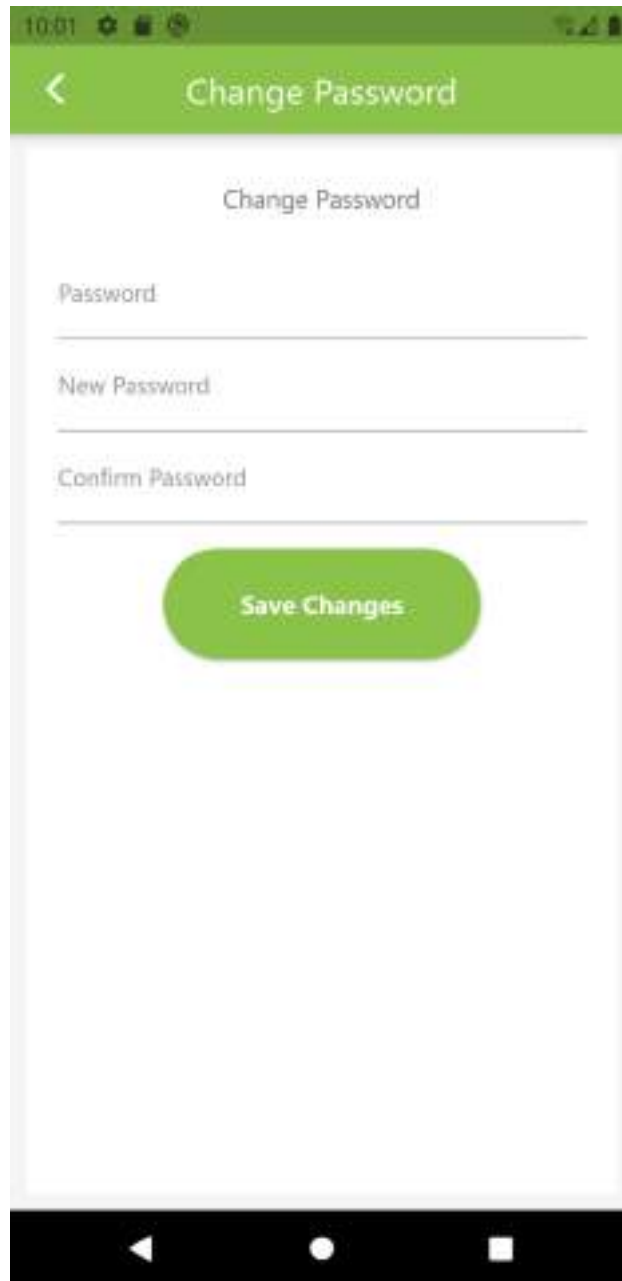

Figure (5.8): Change Password Interface

Chapter 6: Conclusions and Recommendations

6.1.   Introduction

In this chapter we conclusions and recommendations of the project will be discussed.

6.2.   Conclusions and Results

- The aim of HYPO is to automate the monitoring process of hydroponics system that is capable of fulfilling the following objectives and monitor nutrients and PH levels and concentration also provide statistics on PH level and plant growth and regulate water and finally allow user to access growing environment data anytime through application

- All goals were achieved

- Project methodology :The incremental model has been chosen for the methodology of this project because the project can be neatly divided into two well defined system : the growing environment system ,which is comprised of the hardware component (sensors , microcontroller and actuators) the mobile application and the server (the mobile application is for both android and iOS platforms). Each one of these systems is developed in its own increment respectively. It is better to develop each system in its own iteration rather than develop both of them simultaneously.

6.3.   Recommendations

The future development of the HYPO project aims to:

- Control: It is added to have a pump operation

- Language: So that the conversion to the Arabic language

- Notifications: So that notices are sent to the user

7. References

[1] D. H. Jung, H. J. Kim, W. J. Cho, S. H. Park and S. H. Yang, "Validation testing of an ion-specific sensing and control system for precision hydroponic macronutrient management," *Computers and Electronics in Agriculture,* vol. 156, p. 660–668, 2019.

[2] P. Luthfy Romadloni, "Rancang Bangun Sistem Otomasi Hidroponok NFT (Nutrient Film Technique)," *e-Proceeding of Applied Science,* vol. I, no. 1, pp. 75-84, 2015.

[3] C. J. G. Aliac and E. Maravillas, "IOT Hydroponics Management System," *IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology,Communication and Control, Environment and Management,* pp. 1-5, 2018.

[4] T. Asao, Hydroponics - a standard methodology for plant biological researches, Rijeka: InTech, 2012.

[5] B. Turner, "How Hydroponics Works," HowStuffWorks.com, 20 October 2008. [Online]. Available: https://home.howstuffworks.com/lawn-garden/professional-landscaping/hydroponics3.htm. [Accessed 22 November 2019].

[6] J. Loomis, K. Al Charif and M. DiLeonardo, "LeafAlone hydroponics system," University of Central Florida, Orlando, 2014.

[7] V. Chari, "How do pH probes work?," Quora, 18 November 2016. [Online]. Available: https://www.quora.com/How-do-pH-probes-work. [Accessed 22 January 2020].

[8] DFRobot, "BEST EC SENSORS FOR HYDROPONICS GARDENING," CityOS, 2020. [Online]. Available: https://cityos.io/best/13748/Best-EC-sensors-for-hydroponics-gardening. [Accessed 22 January 2020].

[9] Wikipedia, "Peristaltic pump," Wikipedia, 19 December 2019. [Online]. Available: https://en.wikipedia.org/wiki/Peristaltic_pump#Applications. [Accessed 22 January 2020].

[10] M. Brain, "How Microcontrollers Work," HowStuffWorks.com, 1 April 2000. [Online]. Available: https://electronics.howstuffworks.com/microcontroller1.htm. [Accessed 21 January 2020].

[11] Arduino, "Getting started with the Arduino Uno WiFi," Arduino, 10 Februray 2018. [Online]. Available: https://www.arduino.cc/en/Guide/ArduinoUnoWiFi. [Accessed 21 January 2020].

[12] Future Electronics, "Micro SD Card Module," Future Electronics, 2020. [Online]. Available: https://store.fut-electronics.com/products/micro-sd-card-module. [Accessed 21 January 2020].

[13] S. Adhau, S. Rushikesh and K. Kowdiki, "Design of fully automated low cost hydroponic system using LabVIEW and AVR microcontroller," in *IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS)*, Pune, 2017.

[14] V. Palandea, A. Zaheera and K. George, "Fully Automated Hydroponic System for Indoor Plant Growth," *Procedia Computer Science,* vol. 129, pp. 482-488, 2018.

[15] K. Lundin and O. Olli, "Automated hydroponics greenhouse," KTH Royal Institute of Technology, Stockholm, 2017.

[16] K. Kularbphettong, U. Ampant and N. Kongrodj, "An Automated Hydroponics System Based on Mobile Application," *International Journal of Information and Education Technology,* vol. 9, no. 8, pp. 548-552, 2019.

[17] M. Griffiths, "The Design and Implementation of a Hydroponics Control System," Oulu University of Applied Sciences, 2014.

[18] e-Gizmo Mechatronix Central, *pH Sensor E-201-C,* e-Gizmo Mechatronix Central, 2017.

[19] DHgate, "Dedicated G1/2 probe for CM-230 Conductivity Monitor Conductivity meter Plastic electrode with Pin&plug," DHgate, 2020. [Online]. Available: https://www.dhgate.com/product/dedicated-g1-2-probe-for-cm-230-conductivity/402021716.html#seo=WAP. [Accessed 22 January 2020].

[20] A. Aqeel, "Introduction to HC-SR04 (Ultrasonic Sensor)," The Engineering Projects, 5 October 2018. [Online]. Available: https://www.theengineeringprojects.com/2018/10/introduction-to-hc-sr04-ultrasonic-sensor.html. [Accessed 15 January 2020].

[21] Kamoer fluid tech, *NKP peristaltic pump,* Shanghi: Kamoer fluid tech.

[22] farnell, "Arduino Uno," [Online]. Available: https://www.farnell.com/datasheets/1682209.pdf. [Accessed 16 January 2020].

[23] N. A. K. J. T. T. a. M. I. S. P Sihombing, "Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android," *Journal of Physics: Conference Series,* vol. 978, no. 1, pp. 12-14, 2018.

[24] SparkFun Electronics, "WiFi Module - ESP8266," SparkFun Electronics, 2020. [Online]. Available: https://www.sparkfun.com/products/13678. [Accessed 21 January 2020].

[25] MACFOS, "12864B V 2.0 Graphic Blue Color Backlight LCD Display Module," MACFOS, 2020. [Online]. Available: https://robu.in/product/12864b-v-2-0-graphic-blue-color-backlight-lcd-display-module/#tab-description. [Accessed 21 January 2020].