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Theme

A Robotic System For Weeds Detection And Elimination

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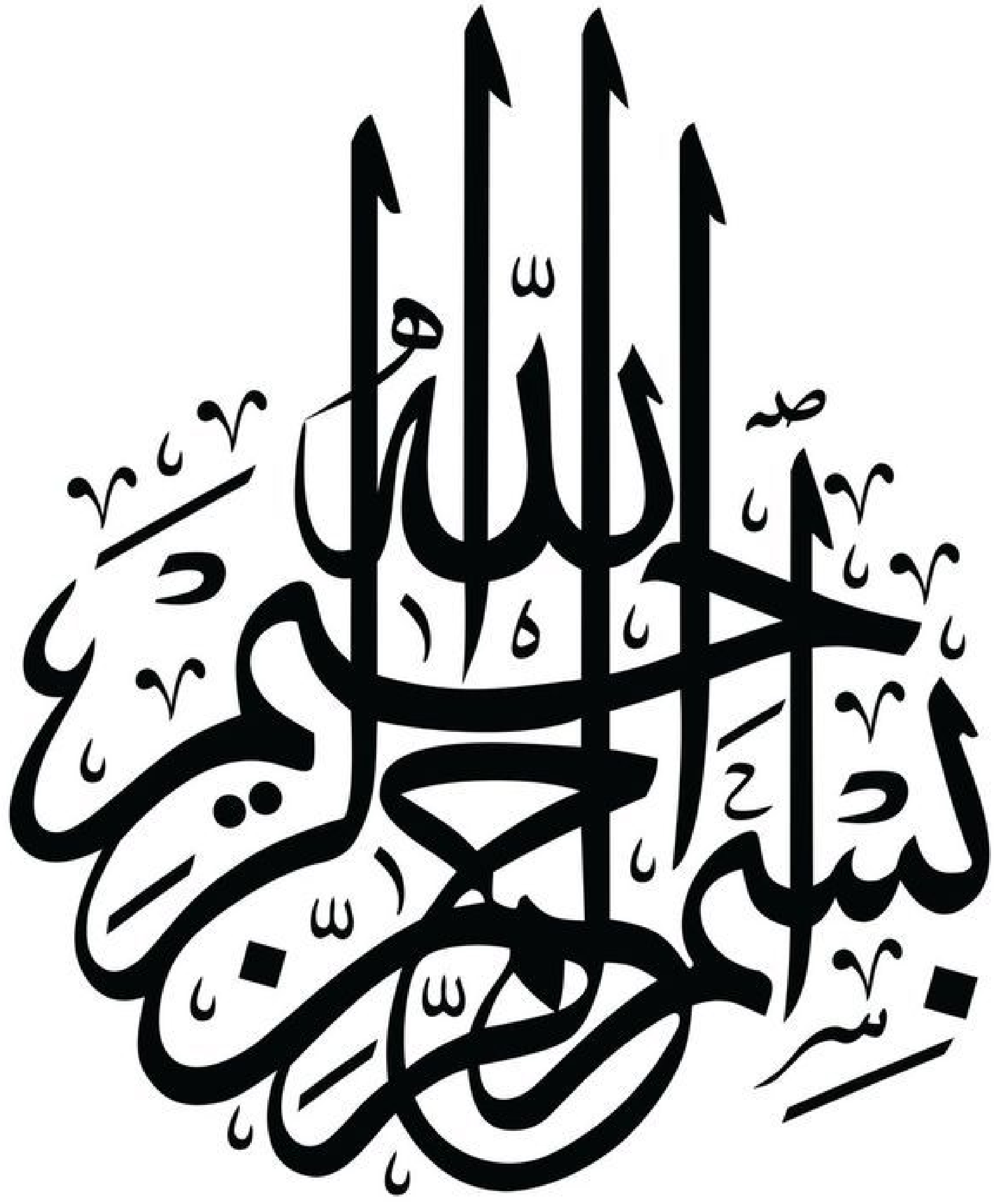
بسم الله الرحمن الرحيم

Dedication

First of all, we thank Almighty God for giving us the Strength, will and privilege in this humble work which I dedicate with the highest expressions of love and gratitude

To the one who took care of me with her eyes and kindness to the one who always accompanied me with her prayers to my mother

To the one who stood by me and encouraged me to persevere throughout my life to my father, the light of my path who worked hard to complete my academic career

To my honorable family each individual by name to my friends and loved ones and everyone who contributed to my success from near or far… to my classmates and to everyone who offered me a helping hand

Thanks

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To my beloved Family, Brothers and sisters For their
support and patient Also to myself, who worked hard and was
patient in order to accomplish this work
in the best possible way.

Abstract

In arid regions, like deserts, weeds pose a significant threat to farming, affecting productivity. Conventional weed control methods are labor-intensive and inadequate. The aim of the end-of-course project is to build a system robotic capable of detect and eliminate weeds. By leveraging advanced artificial intelligence methods and a range of mechanical and electronic tools, the intellegent agent detects weed presence through sensors. Based on this data, it decides whether to engage an automatic spraying mechanism for targeted weed elimination. This proposed solution offers a holistic approach, enabling timely intervention and resource optimization.

Keywords: desert Agriculture, Weeds, Artificial Intelligence, robotic, Mechanical and Electronic Tools, Intelligent Agent.

Resume

Dans les régions arides, comme les déserts, les mauvaises herbes constituent une menace importante pour l'agriculture, affectant la productivité. Les méthodes conventionnelles de lutte contre les mauvaises herbes demandent beaucoup de main d'œuvre et sont inadéquates. L'objectif du projet de fin de cours est de construire un système robotique capable de détecter et d'éliminer les mauvaises herbes. En tirant parti de méthodes avancées d'intelligence artificielle et d'une gamme d'outils mécaniques et électroniques, l'agent intelligent détecte la présence de mauvaises herbes grâce à des capteurs. Sur la base de ces données, il décide s'il convient d'activer un mécanisme de pulvérisation automatique pour une élimination ciblée des mauvaises herbes. La solution proposée offre une approche holistique, permettant une intervention rapide et une optimisation des ressources.

Mots clés : Agriculture du désert, Mauvaises herbes, Intelligence Artificielle, robotique, Outils Mécaniques et Electroniques, Agent Intelligent.

ملخص

في المناطق القاحلة مثل الصحاري، تشكل الأعشاب الضارة تهديدًا كبيرًا للزراعة، مما يؤثر على الإنتاجية. الأساليب التقليدية لمكافحة الحشائش كثيفة العمالة وغير كافية. الهدف من المشروع في نهاية الدورة هو بناء نظام آلي قادر على اكتشاف الأعشاب الضارة والقضاء عليها. ومن خلال الاستفادة من أساليب الذكاء الاصطناعي المتقدمة ومجموعة من الأدوات الميكانيكية والإلكترونية، يكتشف الوكيل الذكي وجود الأعشاب الضارة من خلال أجهزة الاستشعار. وبناءً على هذه البيانات، يقرر ما إذا كان سيتم تشغيل آلية رش الأوتوماتيكية للقضاء على الحشائش المستهدفة. يقدم هذا الحل المقترح نهجا شاملا، مما يتيح التدخل في الوقت المناسب وتحسين الموارد.

الكلمات المفتاحية: الزراعة الصحراوية، الحشائش، الذكاء الاصطناعي، الروبوتية، الأدوات الميكانيكية والإلكترونية، الوكيل الذكي.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GENERAL INTRODUCTION

The desert region presents unique challenges for agriculture due to its harsh environmental conditions and the prevalence of weed infestation. Weeds compete with crops for resources such as water, sunlight, and soil nutrients, leading to reduced yields and economic losses for farmers. Traditional methods of weed detection and elimination are often labor-intensive, time-consuming, and may involve the indiscriminate use of herbicides, which can have adverse effects on the environment and human health [1].

To address these challenges, there is a growing interest in developing intelligent systems for detect and eliminate weeds in desert regions. These systems leverage advanced technologies such as remote sensing, machine learning and robotics. By receiving data from sensors, these systems can provide real-time monitoring and decision support to farmers, enabling timely and precise weed management strategies [2].

An Intelligent Weeds Detection and Elimination Systems offers numerous benefits, including increased agricultural productivity, reduced herbicide usage, cost savings for farmers, and environmental sustainability. By effectively managing weed infestations, these systems contribute to the resilience and long-term viability of agriculture in the desert region, ensuring food security and livelihoods for local communities.

The importance of this study resides in merging nowadays technologies in the agriculture field in our deserted region as an effort to improve the overall process taking into consideration the hard conditions of this area, such as huge locomotion distance, soil nature, hot weather, and time. Without overlooking, of course, the importance of agriculture in Algeria's current economy. our topic will contain four chapters:

The **first chapter** will contain background on the topic at hand and more details about our motivations.

The **second chapter** will provide an overview of other research covering work similar to ours, going over the pros and cons of each study.

The **chapter three** will present the proposed system, which includes the development and implementation of an robotic system to detect and eliminate weeds, providing a comprehensive overview, and detailing all the details.

In the **chapter four** which is the last chapter presents the various mechanical and electronic tools as well as the programs that contribute to implementing the system and displaying the results obtained.

CHAPTER 1

OVERVIEW

Introduction

The term "robot" was first used in the 1920s by Czech writer Karel Čapek in his play "R.U.R." (Rossoms Universal Robots) [3], since then the field of robotics has witnessed significant development, thanks to advances in technology especially in the field of artificial intelligence [4], where robots have begun to play an increasing role in various areas of life, from simple tasks in factories to complex operations in the medical and scientific fields [5].

Intelligent artificial plays a crucial role in the development of robotics, the first robots were usually programmed to perform repetitive tasks in controlled environments [6]. However, as artificial intelligence advances, robots are becoming more autonomous and adaptable, they can perceive their environment, make decisions, and learn from their experiences [4].

In this chapter we will be defining the main elements and notions in our project along with the definition of our problem and the represented solutions in today's reality, trying to realize a new perception using what the technology is offering.

1.1 Artificial Intelligence

Artificial intelligence is considered one of the branches of computer science and one of the basic pillars on which the technology industry is based in the current era, the term artificial intelligence which is referred to by the abbreviation (AI), can be defined as the ability of digital machines and computers to perform certain tasks that mimic and resemble those performed by intelligent beings [7].

There are many proposed definitions of AI, each with its own concept, but most are roughly aligned around the concept of creating computer programs or machines capable of behavior we would regard as intelligent if exhibited by humans, John McCarthy a founding father of the discipline, described the process in 1955 as "that of making a machine behave in ways that would be called intelligent if a human were so behaving." [8].

1.1.1 History of Artificial Intelligence

In the first half of the 20th century, science fiction familiarized the world with the concept of AI robots, it began with the “heartless” Tin man from the Wizard of Oz, by the 1950s, turing suggested that humans use available information as well as reason in order to solve problems and make decisions, so why can't machines do the same thing? This was the logical framework of his 1950 paper, computing machinery and intelligence in which he discussed how to build intelligent machines and how to test their intelligence [9]. The idea of the test was based on answering the question: “Can a person discover that he is talking to a machine in a conversation that takes place for at least 5 minutes?” if he cannot tell that he is talking to a machine then the test has passed, regardless of whether the answers are correct or wrong, but what is important is that it simulates what a human might say, and this test has passed [10].

the period of the seventies and eighties witnessed a major stagnation in the field of AI, and this stage was called the “winter of AI.” However, in the year 1997, the sun of AI shone again [11].

1.2 Intelligent Agent

An intelligent agent (IA) is a term used in the field of AI to refer to an agent that is acting intelligently, this agent perceives its environment, acts independently in order to accomplish goals, and can potentially improve its performance through learning or the acquisition of knowledge [12].

An "agent" is defined in the book "AI: a modern approach" as anything that can be thought of as sensing its surroundings via sensors and acting upon that environment through actuators [12]. **Figure** 1.1 shows a demonstrative example of an agent with its components.

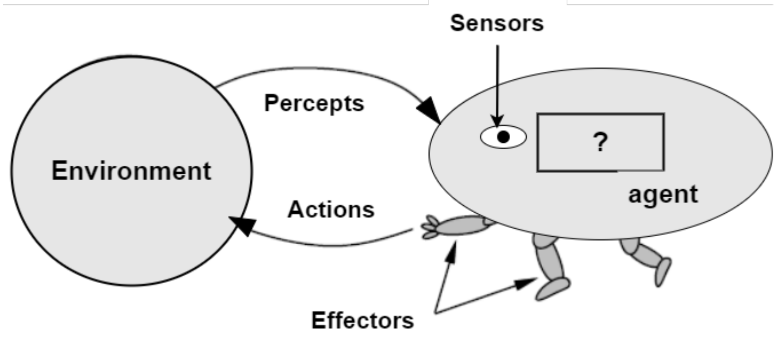


Figure 1.1: Agent

1.2.1 Intelligent Agent Characteristics

We can consider an AI tool as an AI agent when it has the following characteristics [13]:

- **Autonomy:** An IA operates without direct intervention from humans or others and has some kind of control over its actions and internal state.
- **Perception:** The agent function senses and interprets the environment they operate in through various sensors, such as cameras or microphones.
- **Learning:** They can learn and enhance their performance through machine, deep, and reinforcement learning elements and techniques.
- **Reasoning and decision-making:** IA are intelligent tools that can analyze data and make decisions to achieve goals, and use reasoning techniques and algorithms to process information

and take appropriate actions.

- **Reactive and Pro-active:** They can assess the environment and respond accordingly to achieve its goals, it can also be proactive by anticipating future events and taking actions in advance.
- **Communication:** They can communicate with other agents or humans using different methods, like understanding and responding to natural language, recognizing speech, and exchanging messages through text.
- **Goal-oriented:** They are designed to achieve specific goals, which can be pre-defined or learned through interactions with the environment.

1.2.2 Intelligent Agent Classes

IA are assembled into groups. based on their degree of perceived intelligence, capability, and the way of interaction. these types are given below.

Simple Reflex Agent

Only working on current perception, these agents do not consider the history of perception and that is why they are only successful when they have an environment that can be fully perceived, they are not adaptive to the environment and if something is not perceived in the current state, it will not be part of the action, responses are essentially based on a user initiating an event and the agent referring to a list of pre-set rules called "condition–action rule if condition then action[14]" and pre-programmed outcomes [15]. this type of agents is shown in the **Figure** 1.2.

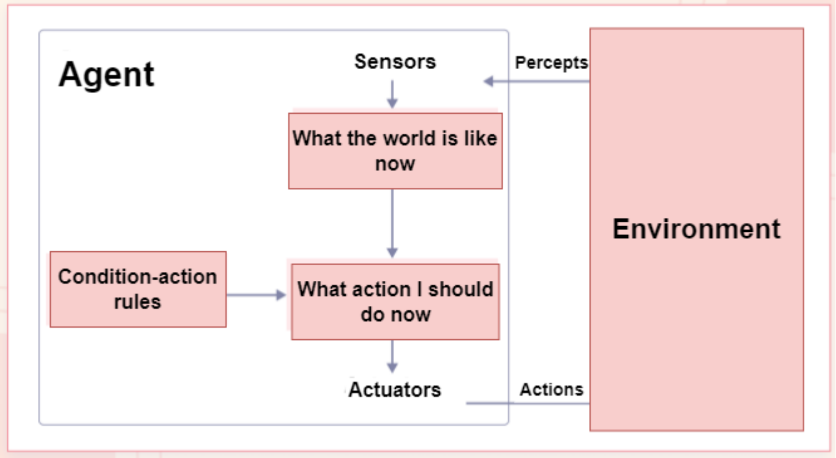


Figure 1.2: Simple Reflex Agent Structure

Model based reflex agent

The most effective way to handle partial observability is for the agent to keep track of the part of the world it can't see now, that is the agent should maintain some sort of internal state that depends on the percept history and thereby reflects at least some of the unobserved aspects of the current state, that is updated by knowing some information about how the world evolves, how do the agent's actions affect it [14]. This knowledge about "how the world works" called a model of the world, an agent that uses such a model is called a model-based agent [15]. this type of agents is shown in the **Figure** 1.3.

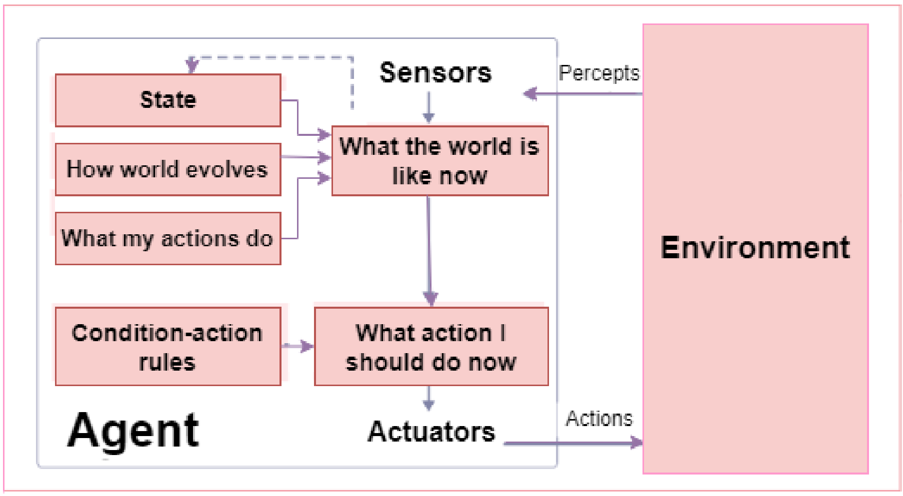


Figure 1.3: Model based reflex agent Structure

Goal based agent

Knowing about the current state of the environment is not always enough to decide what to do, in other words, in addition to describing the current state, the agent needs some kind of goal information which describes the desired situations of which research and planning are subfields devoted to finding action sequences that achieve these goals [14]. this type of agents is shown in the **Figure** 1.4.

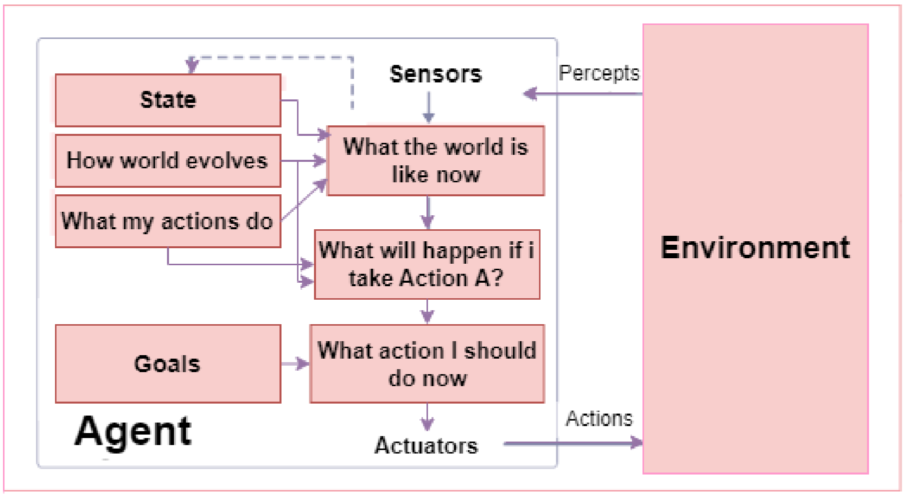


Figure 1.4: Goal based agent Structure

Utility based agent

While similar to goal-based agents, they boast the advantage of providing an extra utility measurement that rates potential scenarios on their desired results and then opts for an action that maximizes the outcome, rating criteria examples include variables such as success probability or the number of resources required, this also allows it the ability to trade off different factors before making a decision [15]. this type of agents is shown in the **Figure** 1.5.

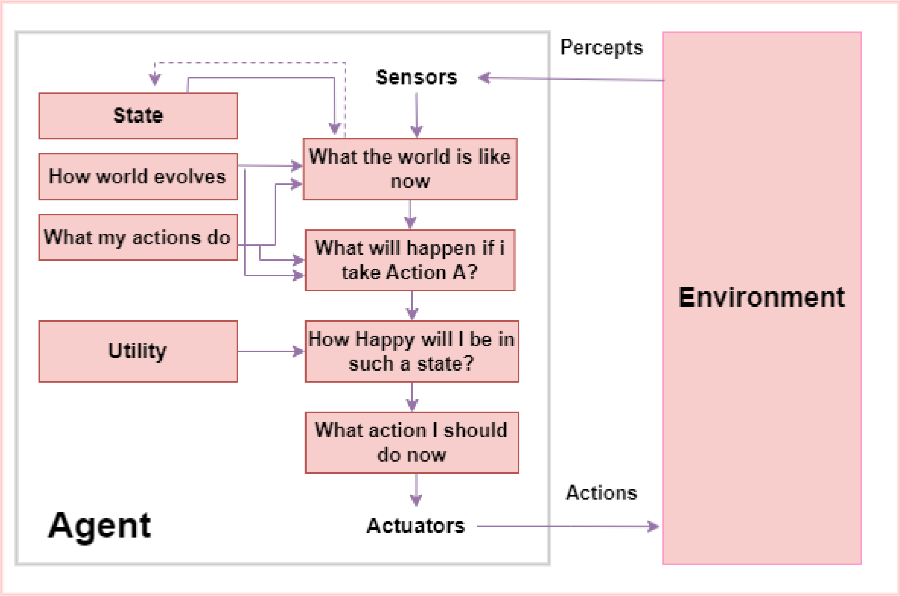


Figure 1.5: Utility based agent Structure

Learning Agent

An additional learning element means these agents can gradually improve and become more knowledgeable about an environment over time, it does so by taking feedback from whatever actions it has performed and adapting accordingly, of which this process requires the Learning Agent to have four components: the learning element (which learns from experience), the critic (which is the feedback system), the performance element (which decides the external action that should be taken), and the problem generator (which is a feedback agent that keeps history and makes new suggestions) [15]. this type of agents is shown in the **Figure** 1.6.

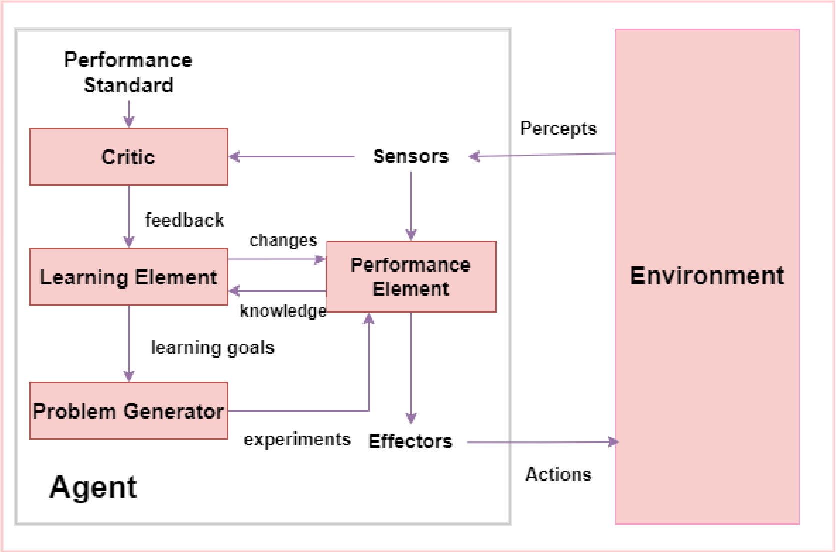


Figure 1.6: Learning Agent Structure

1.3 Robotics

Robotics is the interdisciplinary branch of engineering and science that includes mechanical engineering, electrical engineering, computer science and others, that involves the design, manufacture and operation of robots, the objective of robotics field is to create intelligent machines that can assist humans in a variety of ways, including performing tasks that are dangerous, repetitive, or require precision.s [16].

1.3.1 Types of Robotics

Robots are designed to perform specific tasks and operate in different environments. The following are some common types of robots used across various industries [17]:

Humanoid Robots

Humanoid robots are robots that look like or mimic human behavior, these robots usually perform human-like activities, and are sometimes designed to look like us, even having human faces and expressions, two of the most prominent examples of humanoid robots are Hanson Robotics' Sophia and Boston Dynamics' Atlas.

Industrial Robots

Industrial robots automate processes in manufacturing environments like factories and warehouses, these robots are made to handle heavy objects while moving with speed and precision, as a result, industrial robots often work in assembly lines to boost productivity.

Medical Robots

Medical robots assist healthcare professionals in various scenarios and support the physical and mental health of humans, these robots rely on AI and sensors to navigate healthcare facilities, interact with humans and execute precise movements and some of those robots can even converse with humans, encouraging people's social and emotional growth.

Agricultural Robots

Agricultural robots handle repetitive and labor-intensive tasks, allowing farmers to use their time and energy more efficiently, these robots also operate in greenhouses where they monitor crops and help with harvests, agricultural robots come in many forms, ranging from autonomous tractors to drones that collect data for farmers to analyze.

1.3.2 Benefits of Robotics

Robotic systems are highly desirable across various industries due to their numerous advantages, including increased accuracy, enhanced productivity, improved safety, rapid innovation, and greater cost-efficiency. Robots perform movements and actions with greater precision and accuracy than humans, and they can work at a faster pace without getting tired, leading to more consistent and higher-volume production. By taking on tasks in hazardous environments, they protect workers from potential injuries, thereby enhancing workplace safety. additionally, equipped with sensors and cameras, robots collect data that enables teams to quickly refine processes, fostering rapid innovation. The gains in productivity and efficiency also make robots a more cost-effective option for businesses compared to hiring additional human workers [18].

1.4 Desert Agriculture

desert agriculture is the farming of crops well-suited for arid conditions, such as sorghum, it is the type of agriculture whereby crops that normally withstand water stress conditions are grown so as to withstand hot and less water growing conditions [19].

1.4.1 Limits Of Desert Agriculture

- **Water Scarcity:** Limited availability of water for irrigation purposes. Poor irrigation practices also lead to increased soil salinity, which reduces soil fertility.
- **Extreme temperatures:** High temperatures during the day and cold nights can stress crops and stress workers, thus reducing productivity.
- **Limited Crop Variety:** Fewer crops are suitable for growth in arid conditions.

1.5 Weed

A weed is a plant considered undesirable in a particular situation, growing where it conflicts with human preferences, needs, or goals. Plants with characteristics that make them hazardous, aesthetically unappealing, difficult to control in managed environments, or otherwise unwanted in farm land, may all be considered weeds [20].

1.5.1 Reasons why weeds are considered a problem

Weeds compete with crops for essential resources such as water, nutrients and light as they use the same nutrients as crop plants, greatly damaging plantations and reducing their productivity. they also serve as habitats for agricultural pests and diseases, acting as reservoirs for pathogens that threaten crops. Furthermore, weeds can disrupt harvesting operations, leading to inefficiency and increased labor time. effective weed management requires additional labor, machinery, herbicides, and other control measures, thus raising the overall cost of agricultural production [21].

1.6 Problematic

Before the advent of technology, farmers' problem with weeds was a major challenge that hindered their productivity and threatened their crops. They were growing densely in the fields, depleting natural resources such as water and nutrients from the soil, reducing the quantity and quality of crops. Farmers were forced to use traditional and arduous methods to combat them, which requires great effort and a long time. In addition, reliance on chemical pesticides posed a threat to the health of farmers and the surrounding environment. This situation made it difficult for them to maintain sustainable productivity, and increased the economic challenges they faced, as the cost of weed control consumed a large portion of their limited income. So, **what** methods they were use? and **how** can the problems of the farmers be solved with current technological advances?

1.6.1 Existing Systems

The fight against weeds began with the beginning of agriculture, some existing systems use herbicides, manually removing in case of significant spread, and plowing... but all these of methods require significant time and labor, necessitating specific equipment, technical skills, and high cost. the **Figures** below 1.7 1.8 1.9 show some existing systems.

1.6.2 Proposed Solution

To solve this problem, we propose to develop an robotic system based on artificial intelligence to detect and eliminate weeds with high efficiency. This system aims to provide a comprehensive and

Figure 1.7: Using Pesticides

Figure 1.8: Hand Weeding

Figure 1.9: plowing

sustainable solution to the challenges facing farmers using the latest technologies, with a focus on environmental and economic sustainability. The proposed system has many advantages that make it an effective and viable solution.

Conclusion

In conclusion, the chapter provided a comprehensive foundation for the general concepts related to the development and implementation of a robot for detecting and eliminating weeds, trying to clarify and offer a background about the project, it also pointed out the technological basis and the tools contributing to the development of robot to perform their tasks perfectly.

CHAPTER 2

LITERATURE REVIEW

Introduction

Having robots that detect and eliminate weeds is necessary. First to improve farming and improve food quality. Second, reducing the hard work of humans saves time as farmers will not need to be on the farm also reduces the negative impact on the crop and soil caused by these weeds. With increasing awareness of the importance of fighting them, this domain has seen remarkable development in recent years. In this chapter, we present a comprehensive review of previous works, to explore the different techniques and approaches used and identify their respective strengths and weaknesses.

2.1 Related Works

Many research studies have been conducted on weed detection and elimination robots, where these systems have adopted various methods to manage weeds effectively and sustainably. Including the use of advanced technologies such as machine learning and AI to control it in a targeted manner without affecting crops.

2.1.1 Systems Classification

Numerous systems were built from basic ones to more technologically advanced ones. All trying to achieve one big goal, a better robot. Those robots can be classified according to some criteria:

1. Control system.
2. Weed removal method.
3. Incorporated Sensors.

Control system

In the realm of robotics, control systems play a crucial role in determining how robots interact with their environment and accomplish tasks. There are various approaches to control systems, each with its distinct advantages and limitations.

- **Manual Control:** Humans operate the robot using a remote control, which provides direct control but requires constant attention.
- **Pre-Programmed Path:** The robot follows a pre-determined path for autonomous work, which is suitable for repetitive tasks in structured environments but lacks adaptability.
- **Real-time Path Planning:** The robot automatically navigates and adapts its path based on sensor data and detected weeds, ideal for complex environments but requires advanced processing power.

Weed removal method

Robotic technology has revolutionized weed control by enhancing precision and efficiency. Various innovative approaches now allow for targeted weed management, reducing the reliance on broad-spectrum herbicides and minimizing environmental impact.

- **Mechanical Removal:** Robotic arms equipped with tools such as brushes or tillers physically remove weeds, often targeting specific areas identified by a detection system. This method is accurate and reduces herbicide use but may damage the soil or desired plants.
- **Laser Weeding:** High-powered lasers deliver targeted bursts of energy, destroying weeds with minimal impact on the surrounding soil or crop. This method is fast and effective but requires careful control to avoid damaging desired plants and can be expensive.
- **Spot Spraying:** Robots use fine nozzles to spray herbicides directly onto selected weeds, reducing overall herbicide use and minimizing non-target application. This method balances effectiveness and accuracy.

Incorporated Sensors

Sensors can be defined as a devices that detect the changes in the physical world. Those changes or inputs can be light, motion, photo. The output generated usually signaled and converted so human can read it. There are so many types of sensors. Those types can be classified as analog sensors and digital sensors.

- **Analog Sensors:** Are designed to provide a continuous output signal that is proportional to the measured quantity, they operate on the principle of changing voltage or current in response to the physical stimulus they detect [22].
- **Digital Sensors:** In contrast to analog sensors, convert physical measurements into discrete digital signals, typically represented as binary numbers (0s and 1s), they employ various techniques such as analog-to-digital conversion to convert analog inputs into digital outputs [22].

2.1.2 Literature Survey

In this section we are going to mention and classify existing robots, trying to present for each the methodology, advantage, disadvantage and the name.

Bonirob

BoniRob was developed by students at the university of osnabrück along with bosch companies and the german agricultural company amazone that is equipped with four wheels that can be steered independently of each other, allowing flexible movement and navigation on rough terrain. It is also carried a four-channel multispectral camera and a red, green, blue and depth (RGB-D) sensor to capture detailed information about the crop. Additionally, GPS, LIDAR and wheel encoders are available, resulting in around 5TB of data. it uses a tool to perform mechanical weed control, driving a screw into the soil to remove the plant [23].

Figure 2.1: Bonirob

- **Advantage**
  - handles large fields easily.
  - High accuracy in eliminating weeds.
  - It does not negatively affect the fine structure of the soil.
- **Limitations**
  - High initial and Maintenance cost.
  - Its mechanical method in eliminate weeds may not be suitable for all types of weeds or agricultural tasks.
  - Collecting a large volume of data requires robust data storage and management solutions and processing it efficiently can be resource-intensive.

Ecorobotix Robot

EcoRobotix Robot, illustrated in Figure 2.2, is a four-wheeled robot powered by two electric motors, with wheels designed to ride on off-road surfaces, so it could traverse any farmland with relative ease. It has solar panels on top to generate a continuous source of power for the internal battery, allowing it to run as long as there is daylight, thus removing the need to snap and recharge at the end of the day. It weighs approximately 130 kg. An onboard camera, RTK GPS and a series of sensors allow you to identify crops and keep it on a travel course, as well as detect the presence of weeds between crops. The herbicide is then sprayed over the target plants, so they are treated individually [23].

Figure 2.2: Ecorobotix Robot

- **Advantage**
  - High accuracy in eliminating weeds.
  - Continuous Power Supply.
  - Low Weight so It does not negatively affect the fine structure of the soil.
- **Limitations**
  - High initial and Maintenance cost.
  - Dependence on weather as long periods of cloudy weather may affect the robot's ability to operate optimally.
  - The reliability of the RTK sensor under different field conditions can affect the robot's ability to maintain an accurate travel path.

Smart Pesticides Robot

The proposed system does not rely on sensors. Rather, direct control via the remote control allows the user to direct the robot to spray weeds at a distance of more than 1000 meters for the duration he chooses via a button on the control device for a distance of up to a maximum of 1 km. The robot uses a microcontroller Arduino uno to perform all tasks, Also it relies on the NRF24 module to supply power to the robot [25].

Figure 2.3: Smart Pesticides Robot

- **Advantage**
  - Control is very simple.
  - The robot has a simple and user-friendly design.
  - Easy to maintain and repair.
- **Limitations**
  - Relying on battery power.
  - It relies on constant user control.
  - The automation is limited in that it cannot make independent decisions about weed location or optimal routing.

AVO by Ecorobotix

The Proposed system is a solar-powered autonomous robot designed for precise crop spraying. Its interchangeable batteries enable 10-hour workdays, covering up to 10 hectares. AVO is equipped with Lidar and ultrasonic sensors for obstacle detection and navigation, and it follows a pre-programmed path using its GPS. Its software adapts to various crops, and a mobile app allows for easy control, it has a safety strip that stops the robot if it comes into contact with people or obstacles, and its lightweight design minimizes soil compaction [26].

Figure 2.4: AVO by Ecorobotix

- **Advantage**
  - Reduced pollution from spray drift through the use of specialized panels, nozzles, and adjuvants.
  - Covers large areas (up to 10 hectares) with long working hours (10 hours per day) thanks to solar power and interchangeable batteries.
  - Safety features like a stop mechanism and lightweight design minimize risks for people and the environment.
- **Limitations**
  - High initial and Maintenance cost.
  - Robot efficiency may be affected on cloudy days or areas with limited sunlight.
  - Limited ability to adapt to different weeds.

LaserWeeder

The Proposed system is an advanced robotic weeding system uses 42 High-resolution cameras, equipped with independent weeding modules, each featuring 30X 150W CO2 lasers with millimeter precision. These lasers are capable of firing every 50 milliseconds, ensuring efficient and precise weed removal. Additionally, the system includes bedtop lighting that is effective in all conditions, making it versatile for various agricultural environments. LaserWeeder operates on tracks and is powered by Nvidia GPUs, enabling optimal performance and adaptability in different farming scenarios [27].

Figure 2.5: LaserWeeder

- **Advantage**
    - Lasers leave the soil microbiology undisturbed, unlike tillage or spraying.
    - The system boasts millimeter precision.
    - The system includes effective overhead lighting, making the system able to operate day, night and in all weather conditions.
- **Limitations**
    - High initial cost.
    - The system requires regular maintenance and technical updates to ensure optimal performance.
    - The system does not work independently it must be linked with tractors.

AgBot II

The robot consists of two side-units connected by the implement unit. The side units house the batteries and drive train as well as other electronics. The implement unit houses a herbicide tank, a small fertiliser sprayer, and a one metre wide weeding array. The robot has a state-of-the art planning, guidance, navigation, communications, and motion control sys-tem taht deduces his position, velocity, heading, desired path. Weeds are detected and classified using a vision-based system with a ground-facing camera and image processing computer. Once detected, the system triggers either mechanical or spray modules attached to the underside of the robot platform to eliminate it [28].

Figure 2.6: AgBot II

- **Advantage**
    - High accuracy in eliminating weeds.
    - It does not negatively affect the fine structure of the soil.
    - The robot works autonomously and automatically.
- **Limitations**
    - High initial and maintenance cost.
    - Limited compatibility with crops.
    - Relying on a vision-based system as the effectiveness of the detection may be affected in bad weather conditions.

FarmDroid FD20

This research [29] aims to develop a system that enables a robot to identify and eliminate harmful weeds. The system consists of an autonomous robot that runs on four solar panels that converts sunlight into power for its two batteries, reducing CO2 emissions and uses RTK signals to determine its location. It does not rely on a camera or sensors to remove weeds. Rather, precision during planting ensures that the location of each plant is accurately identified and thus the process of eliminating weeds can begin at a very early stage.

Figure 2.7: FarmDroid FD20

- **Advantage**
    - It does not negatively affect the fine structure of the soil.
    - The robot works autonomously and automatically.
    - Solar powered.
- **Limitations**
    - High initial and maintenance cost.
    - Limited compatibility with crops.
    - The reliability of the RTK sensor under different field conditions can affect the robot's ability to maintain an accurate travel path.

Verdant Robotics Robot

This research [30] aims to develop a system that enables a robot to identify and eliminate weeds. Verdant's system clips on to the back of a tractor, to make autonomous agronomic decisions in real time. This system uses multi-view geometry camera systems, hyperspectral cameras, inertial sensors, light detection and ranging (lidar), kinematic sensors, and global positioning system (GPS) when it's available. Through algorithms and mapping, this whole array of sensors infers the state of the outside world, also detects weeds, which are eliminated using Sharpshooter smart sprayer.

Figure 2.8: Verdant Robotics Robot

- **Advantage**
    - handles large fields easily.
    - High accuracy in eliminating weeds.
    - Multiple advanced sensor technologies.
- **Limitations**
    - High initial cost.
    - The system requires regular maintenance and technical updates to ensure optimal performance.
    - The system does not work independently it must be linked with tractors.

2.1.3 Comparative Analysis Between Robots

The following table presents a comparison of several robots designed to detect and eliminate weeds, developed using advanced technologies in robotics and artificial intelligence.

Features	**Control System**	**Weed removal method**	**Technology Level**	**Manufacturing cost**	**Sensors**
Bonirob	Real-time path planning + Manual control	Mechanical removal	Advanced	High	multispectral camer + RGB-D sensor + LIDAR + GPS
Ecorobotix Robot	Real-time path planning + Pre-programmed path	Spot spraying	Advanced	High	camera + RTK
Smart Pesticides Robot	Manual control	Spot spraying	Basic	Low	/
AVO by Ecorobotix	Real-time path planning + Manual control	Spot spraying	Advanced	High	multi-camera vision system
Laser Weeder	Manual control	Laser weeding	Advanced	High	42 High-resolution cameras
AgBot II	Pre-programmed path	Spot spraying + Mechanical removal	Advanced	High	vision-based system with camera
FarmDroid FD20	Pre-programmed path	Mechanical removal	Advanced	High	RTK
Verdant Robotics Robot	Manual control	Spot spraying	Advanced	High	multi-view geometry camera + hyperspectral cameras + inertial sensors + lidar + GPS

Table 2.1: Comparison of Weeds Detection and Elimination Robots

Conclusion

The advancement of technology in agriculture and the adoption of autonomous robots to remove weeds and seize agricultural opportunities is best demonstrated by reviewing previous work, in which we explored the technologies and challenges of developing these robots, and by understanding the barriers and advantages we found that many lessons and ideas can be learned. This contributed greatly to the construction of the robot for our study.

CHAPTER 3

PROPOSED SYSTEM

Introduction

In this chapter, we will review the development of an innovative robotic system to detect and eliminate weeds with high efficiency. We will also provide a comprehensive overview of the system, the methodology it relies on, and how the integration of artificial intelligence contributes to its work. The proposed system relies on the latest sensing, guidance and control technologies, allowing it to operate autonomously and accurately determine weed locations. In this chapter, we will focus on presenting the algorithms used to process data and make decisions for effective weeding. These algorithms aim to improve the system's accuracy and efficiency, contributing to improved agricultural productivity and reduced reliance on harmful chemicals.

3.1 Overall System Architecture

To understand the complexities of our system and its operational dynamics, exploring its overall architecture is indispensable. as shown in **Figure** 3.1, the system architecture acts as a blueprint, coordinating the complex interaction between sensors, actuators and intelligent agents, to achieve an efficient and accurate process of weed detection and elimination.

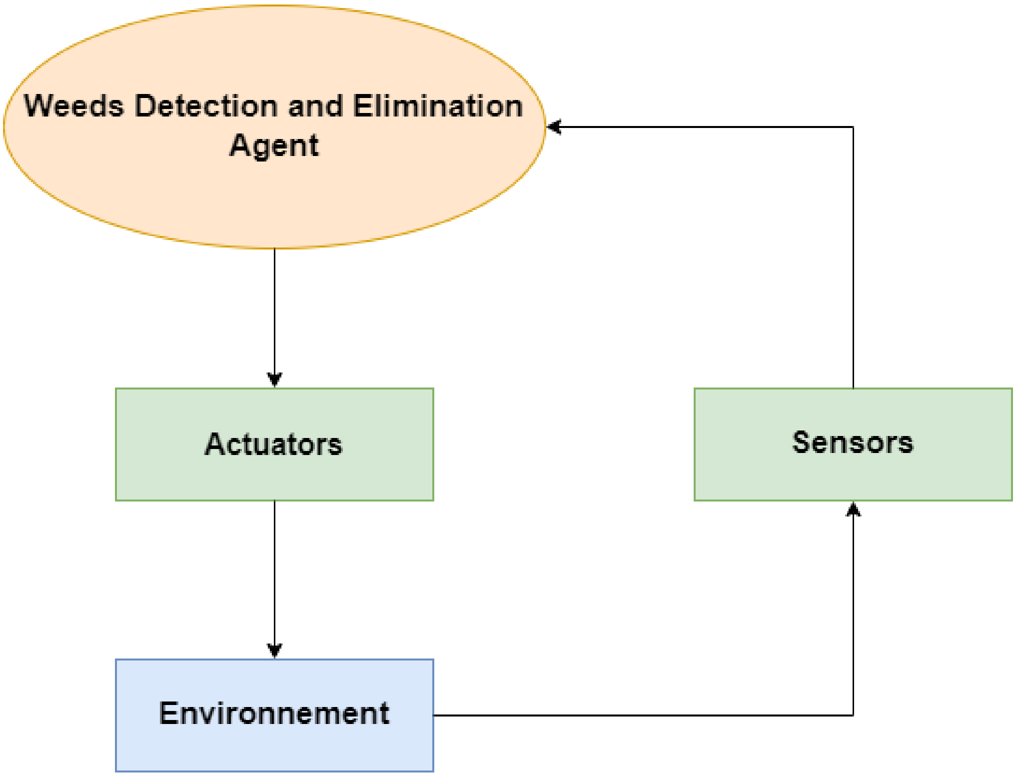


Figure 3.1: Overall System Architecture

3.1.1 Environment

The target environment in our system represents the space of agricultural fields in which the agent updates its state using sensors and interacts with it using actuators. This environment is complex and dynamic, requiring the robot to interact with a variety of factors and variables. Therefore, the robot must be designed and programmed to deal effectively with these factors in order to achieve the required performance. The agent's goal in this environment is to detect and eliminate weeds effectively and accurately, while maintaining crop safety and increasing the efficiency of agricultural operations.

3.1.2 Sensors

To achieve the system's functions effectively, the robot needs appropriate sensors that enable it to control itself and perform tasks efficiently. These sensors are the robot's sensory eyes, enabling it to better recognize and understand the surrounding environment, ensuring smooth performance and response to incoming commands. sensors can be defined as devices or components that can detect and measure physical properties in the surrounding environment, which provides the essential data that the robot needs to understand its surroundings, make necessary decisions, and perform actions accurately and effectively. in our case , the camera is the only sensor.

3.1.3 Actuators

The actuators are the direct equipment that makes the interaction of the agent in the environment possible. They converts decisions issued by the controller into actual and executive movements in the environment, allowing the robot to perform various tasks.

In our robotic system, the motor and the pump are the only parts that represents the actuators, as it allows control of movement and accuracy in performing the required actions.

3.1.4 Weeds Detection and Elimination Agent

The weed detection and elimination robot interacts with the environment through the camera. receives the sensors data and processes it to determine if there are objects in the image using a deep learning model to make the appropriate decision. If there is an object in a frame that is classified as a weed, it will send commands to the actuators to execute the specified movement. This cycle is repeated as the robot moves along the space, with the agent receiving updated information from the camera and making decisions based on the artificial intelligence algorithm.

3.2 Model development pipeline

In this section, we outline the complete pipeline for our weed detection system shown in **Figure** 3.2, from data collection to making predictions. The pipeline consists of the following key steps:

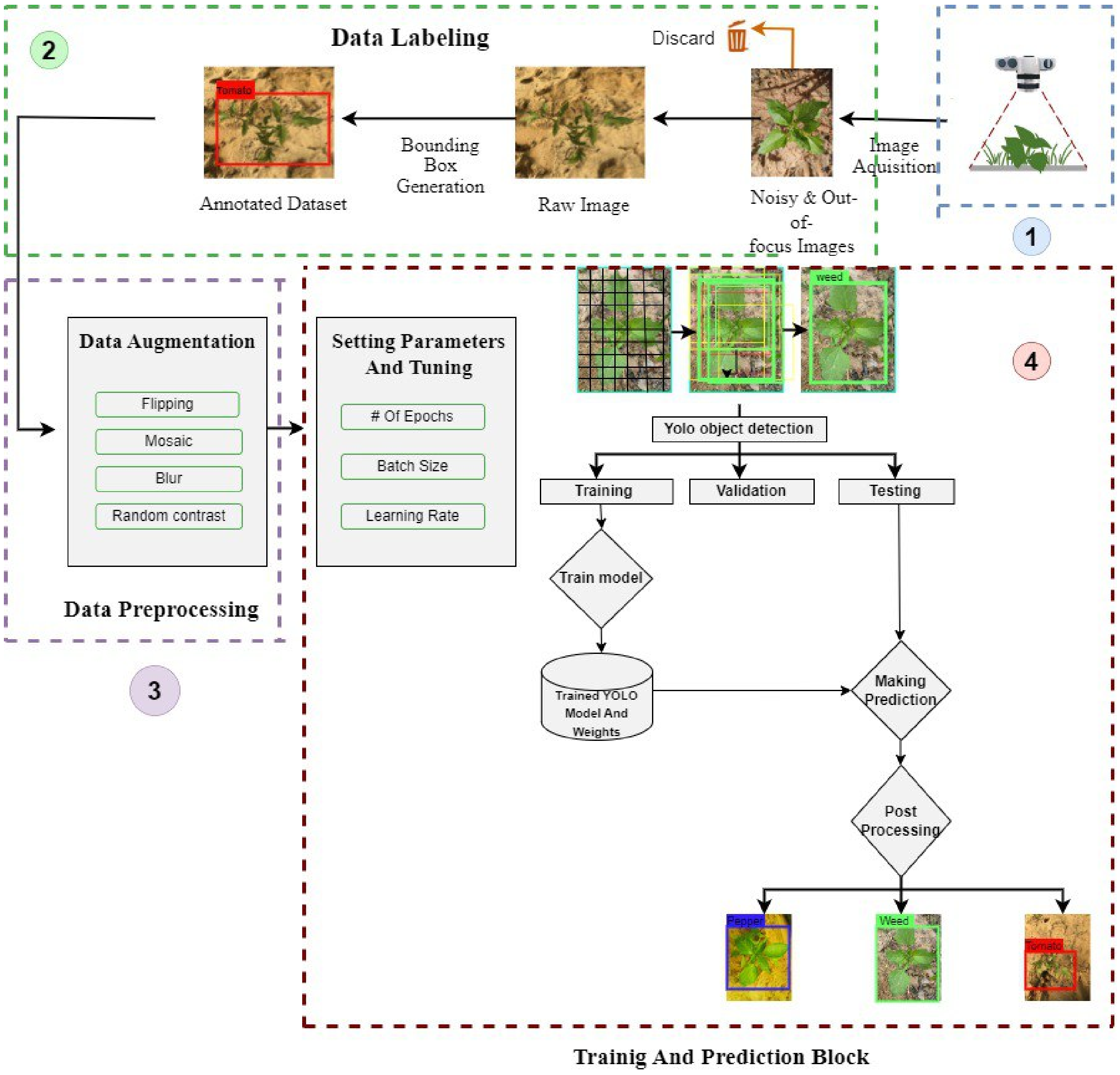


Figure 3.2: Weed Detection Pipeline

The diagram above illustrates the comprehensive pipeline we followed, which includes data collection, data preprocessing, model selection, model training, and prediction. Below, we provide detailed descriptions of each step.

3.2.1 Preparing the Dataset

Choosing the Dataset

To develop a robust model, selecting an appropriate dataset was crucial. We consulted with agricultural engineers to identify the prevalent weed species in our region, Wilaya Oued Souf, across different seasons. The experts identified *Chenopodium murale* as a common and persistent weed in our locality and beyond. We also inquired about the types of crops that *Chenopodium murale* typically grows with, ensuring that our model and robot could effectively distinguish the weed from the crops. This information was crucial for training our model to accurately detect *Chenopodium murale* amidst the crops. They advised us on the crops frequently co-existing with this weed, which included tomatoes and peppers. Given their similar shapes and colors, especially tomatoes, these crops presented a suitable challenge for our detection model. Consequently, we planted these crops to create a realistic and comprehensive dataset.

The Planting Process

The planting process was conducted at Echahid Hamma Lakhdar University's plastic house as shown in fegure 3.3 . We planted 100 tomato and 100 pepper saplings, arranging them in orderly rows to mimic typical agricultural practices. The plants were maintained under controlled conditions with daily watering provided through a drip irrigation system. This setup ensured uniform growth and health of the plants, crucial for capturing consistent and high-quality images for our dataset.

Figure 3.3: Growing Pepper and Tomato Plants in Greenhouses

3.2.2 Data Collection

To train our model effectively, we employed a systematic data collection process aimed at capturing a wide range of real-world agrarian scenarios. The primary dataset (**Figure** 3.4) was generated at the Plastic House at Echahid Hamma Lakhdar University, supplemented by additional images from various farming sites in different localities.

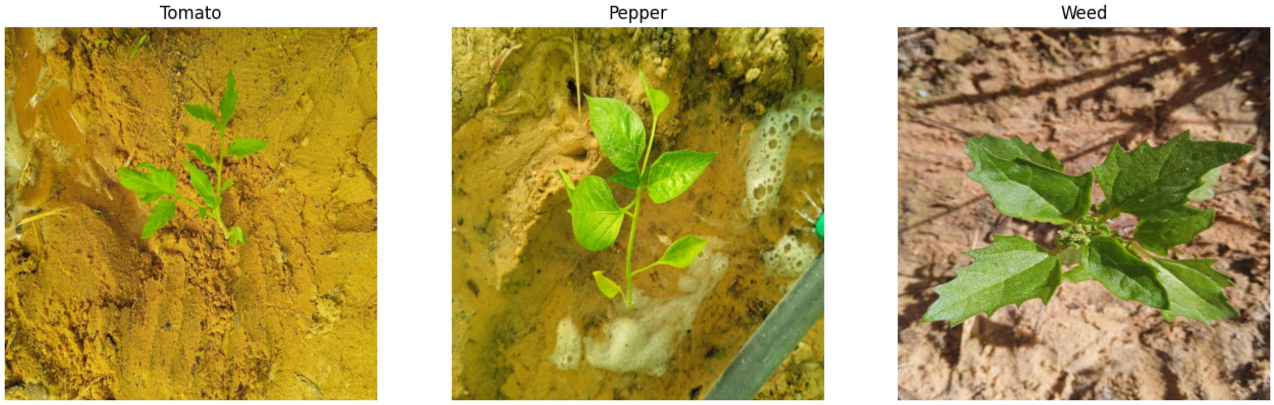


Figure 3.4: Sample images of a Chenopodium Murale, pepper and tomato

Images of the tomato and pepper plants were captured every three days from November 2023 to March 2024 to document their growth under different conditions. We varied the time of day (morning and afternoon) and the perspectives (all sides, especially from above) to ensure a diverse and comprehensive dataset. This approach allowed us to record the plants' development stages and the varying appearances of *Chenopodium murale* as it grew alongside the crops. Our data collection leveraged four smartphones for diverse image capture. A primary 13-megapixel sensor with high resolution (4128 x 3096 pixels) captured intricate details. The remaining phones, all 13-megapixel with f/2.2 apertures and 28mm lenses, offered consistent field of view and varied low-light performance due to differences in sensor size and pixel microns. The final phone, boasting a 12-megapixel sensor with an f/1.8 aperture, provided exceptional low-light capture with PDAF and OIS for clear images in all conditions.

Data Splitting

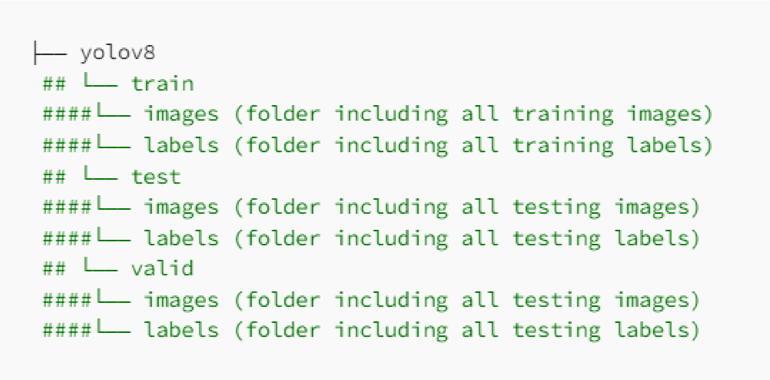
After gathering a useful real-world agricultural dataset, let's divide it in a way that will allow our models learn better from these images. This is where we conduct data splitting which is vital for constructing a high performing weed detector on our smart robot. We have up to 3000 samples per category ensuring harmonized data distribution between Classes Weed, Pepper and Tomato. we strategically divided the dataset into train 70%, valid 10%, and test 20% sets as shown in **Table** 3.1.

Subset	**Number of Images**
Training	**6076**
Validation	**711**
Testing	**1465**

Table 3.1: Distribution of Dataset

Data Labeling

Next, the images were labeled to provide ground truth annotations for training the weed detection model. On the makesense.ai platform makesense.ai [31] and roboflow platform roboflow.com [32]. the labeling process took place in which the efficient annotation of weeds, peppers and tomatoes was possible. During the process of weed labeling, we concentrated on determining and marking boundaries of each individual weed as they appear in the **Figure** 3.5. This necessitated creating rectangles around each separate weed plant or multiple plants grouped together. The annotations were formatted into YOLO format, this format makes use of one text file for each object with a single line for each that indicates the object's class label, center coordinates (normalized), and width and height of its bounding box (also normalized).



```
├── yolov8
 ## └── train
 ####└── images (folder including all training images)
 ####└── labels (folder including all training labels)
 ## └── test
 ####└── images (folder including all testing images)
 ####└── labels (folder including all testing labels)
 ## └── valid
 ####└── images (folder including all testing images)
 ####└── labels (folder including all testing labels)
```

Figure 3.5: Dataset File Structure

3.2.3 Data preprocessing

Once the data was collected, it underwent preprocessing to enhance the model's performance. This included annotating the images with bounding boxes around the weeds and crops, normalizing the pixel values, and augmenting the data through transformations such as rotations, flips, and adjustments in brightness and contrast. **Figure** 3.6 represents the processing pipeline diagram of the system.

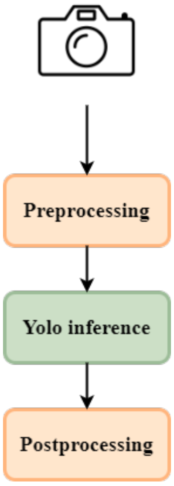


Figure 3.6: Image processing pipeline high-level diagram

Image Resizing

Images are typically resized to a specific size required by the YOLOv8 architecture. In many YOLOv8 implementations, the default input size is 640x640 pixels. This resizing ensures consistency and compatibility with the internal operations of the model.

Image Normalization

Raw pixel values in images usually range from 0 to 255. However, for training deep learning models, it's beneficial to normalize these values to a smaller range, often between 0 and 1 (or -1 and 1 depending on the implementation). This normalization helps improve the stability and convergence of the training process.

Data Augmentation

While meticulous data preprocessing is essential for YOLOv8 training, we can further empower the model by incorporating data augmentation techniques. These techniques artificially expand the size and diversity of our training dataset by creating variations of existing images. This is illustrated below in **Figure** 3.7 for training weed detection model.

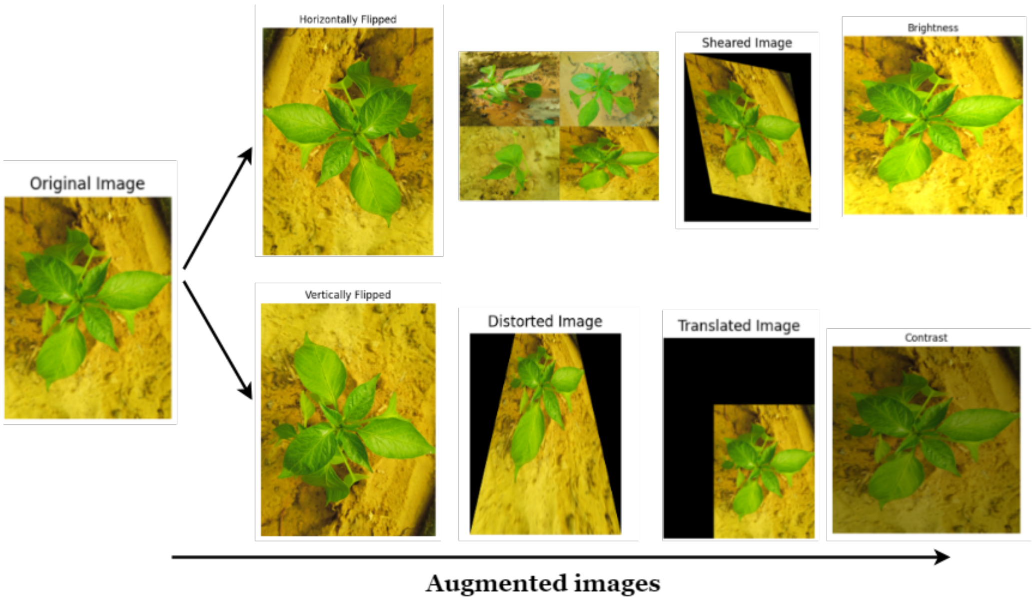


Figure 3.7: Data augmentation techniques applied

We Create more instances by apply a set of transformations to the images, including:

1. **HSV augmentation:** It involves adjusting the hue with 5%, saturation withe 0% and value with 20% in the image to create variations, enhancing model robustness by introducing diverse training data.
2. **Flipping:** It used to flips an image horizontally or vertically, adding additional diversity by producing horizontally or vertically flipped copies of the original images.
3. **Perspective Distortion:** Aims to simulate real-world viewing angles, enhancing model adaptability to varied perspectives.
4. **Scaling:** Refers to resizing the image, either enlarging or reducing it with 5%, maintaining its aspect ratio or not.
5. **Rotation:** It is the process of rotating the image by an angle of 20 degrees around its center point.
6. **Translation:** It has various use cases, such as aligning two images together or stitching images in panoramic shots. it is commonly used to augment data for training deep learning models.
7. **Shearing:** it is a linear transformation that distorts an image along one of its axes with 3%.

Training the YOLOv8 Model

We used the following code to train the YOLOv8 model. The training process involved running for 100 epochs with the specified configuration.

```
from ultralytics import YOLO

model = YOLO('yolov8n.pt')

results = model.train(epochs=100, cfg='Downloads/default.yaml')
```

Model Training Parameters

To ensure good performance, we carefully selected the following training parameters:

- **Epochs:** 100 epochs were used to allow the model sufficient time to learn the features from the dataset without overfitting.
- **Batch Size:** A batch size of 16 was chosen to balance memory usage and training speed.
- **Learning Rate:** The learning rate was initially set to 0.001, with a scheduler to reduce it as training progressed, facilitating convergence.
- **Optimizer:** We used the Adam optimizer, known for its efficiency in handling large datasets and adjusting learning rates dynamically.
- **Loss Function:** YOLOv8n uses a combination of classification, localization, and confidence loss to optimize object detection.

Figure 3.8 below illustrates the class distribution of our dataset, providing an overview of the frequency of each class, which is crucial for understanding the dataset composition and ensuring balanced training of the model.

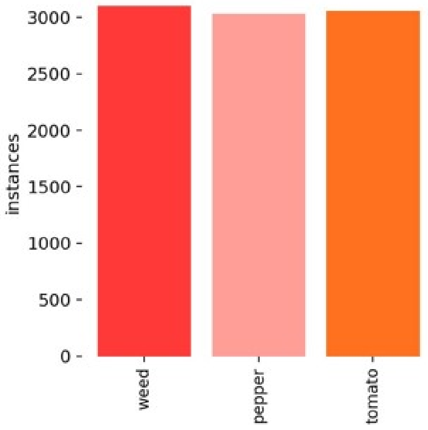


Figure 3.8: Class distribution in the dataset.

Data Postprocessing

After an image is processed by YOLOv8, a raw output is produced which needs to be fine-tuned to yield final object detections. This process, referred to as post-processing, aims at reformatting the model's raw predictions to make them human-readable. By cleaning up YOLOv8 output, it becomes possible to receive trustworthy and specific objects detections. The following is a detailed explanation of some cardinal post-processing procedures we followed in YOLOv8.

Decoding Predictions YOLOv8's raw output contains various elements like bounding box coordinates, confidence scores, and class probabilities. The post-processing stage decodes these elements and converts them into a format that specifies:

- **Bounding Boxes:** The location and size of the detected objects.
- **Class Labels:** The predicted class (type) of each detected object.
- **Confidence Scores:** The probability that the model's detection is correct.

Non-Maximum Suppression (NMS) : The algorithm YOLOv8 is a little too excitable: it often makes several predictions for the same object sometimes with overlap between various detections, NMS on the other hand can help resolve such issues through an analysis of confidence scores by ignoring boxes at an intersection whose estimated probability would be less than that observed in another box. This way we only have the most probable results.

Thresholding : Yolo by itself gives a confidence score to each detection which signifies the level of certainty the model has with regards to its detection. Using this post-processing capability, wecan define the minimum confidence score that it ought to have. If there are any detections whose confidence score falls below this limit, we drop them off. Therefore, there are no detections reported unless they beat your threshold for confidence in results.

3.2.4 Evaluation Metrics

Intersection Over Union : Intersection Over Union (IoU) score refers to the accuracy of the predicted bounding boxes. The obtained bounding box and the real bounding box are compared as shown in **Figure** 3.9, with this comparison process, the IoU score is obtained [33].

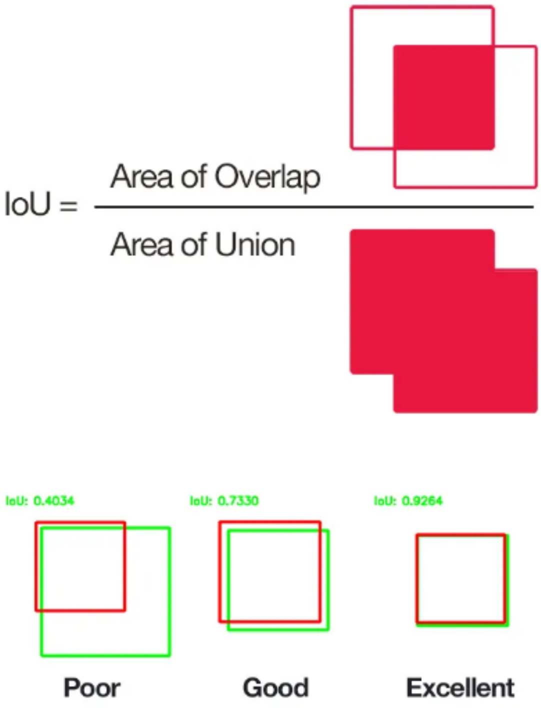


Figure 3.9: Intersection Over Union

Mean Average Precision (mAP) : Mean Average Precision (mAP) is a commonly used metric for evaluating object detection models. It calculates the average precision across different classes and is often used to measure the overall performance of a model. The formula for calculating mAP is given by:

$$\text{mAP} = \frac{1}{n}\sum_{i=1}^{n}\text{AP}_i$$

where n is the number of classes and AP_i is the Average Precision for class i.

Precision : Precision measures the accuracy of positive predictions. It is the ratio of true positive predictions to the total number of positive predictions made by the model. The formula for precision is given by:

$$\text{Precision} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}}$$

Recall : Recall measures the ability of the model to correctly identify all relevant instances. It is the ratio of true positive predictions to the total number of actual positive instances in the data. The formula for recall is given by:

$$\text{Recall} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

F1 Score : The F1 score is the harmonic mean of precision and recall. It provides a single metric that balances both precision and recall. The formula for the F1 score is given by:

$$\text{F1 Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

3.3 Conclusion

In conclusion of the third chapter, it becomes evident that designing and developing a robote to detect and eliminate weeds requires comprehensive project planning. The technical details of these plans have been elaborated upon, including the algorithm to be employed to achieve the specified objectives.Understanding the functioning of the robot effectively is also crucial, with hypotheses proposed on how to achieve this goal efficiently, including the utilization of advanced technology and efficient data analysis. Despite the anticipated challenges, such as costs and potential technical issues, achieving the project's objectives is entirely feasible. By executing the plans meticulously and taking necessary measures to address any potential obstacles, we can attain positive outcomes and deliver a system that meets the expected performance and interaction standards.

CHAPTER 4

IMPLEMENTATION AND DISCUSSION RESULTS

Introduction

In the final chapter, we delve into the array of mechanical and electronic tools, alongside the software programs, that form the backbone of our system's implementation and the presentation of our results. This chapter serves to illuminate the intricate integration of hardware and software that brings theoretical designs into practical, functioning reality. From the mechanical components that form the physical structure to the electronic circuits that power them, and the software that orchestrates their operation, each element plays a crucial role in ensuring the system's effectiveness and reliability. This detailed exploration not only highlights the technical prowess involved but also showcases the synergy between different technologies that culminates in the successful realization of our objectives.

4.1 Objectives

We aim in our project to achieve several objectives such as:

- Design the general structure of the robot.
- Identify intra-row weeds accurately using the concept of object detection in Deep Learning.
- The robot will eliminate the weeds by directing a herbicides sprayer above it.

4.2 Requirements

- Knowledge in Python programming language.
- Knowledge in G Code.
- Internet connection.
- Knowledge in Raspberry Pi.
- Knowledge in Arduino.
- Knowledge in electronics.
- Knowledge in mechanic.

4.3 Working Environment

To prepare the various work steps and evaluate the system's effectiveness and performance, we utilized a computer with particular specifications, as detailed in **Table** 4.1.

Name	**Parameter**
Processor	Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz 1.80 GHz
Memory	16 GB
Server model	HP 8th Gen
OS	Windows 10 Pro 22H2 19045.4412

Table 4.1: System Information

4.4 System Hardware Components

The system is composed of three primary sections: the electronic, mechanical, and software aspects. These elements work together to allow the robot to perform detection and elimination tasks smoothly and efficiently. Below we will provide a detailed discussion of the various mechanical and electronic tools that achieve this, as well as the software that ensures optimal functionality.

4.4.1 Raspberry Pi

Raspberry Pi is a small computer that resembles a PC motherboard, but all the components are already on it (CPU, memory, wireless module, USB ports, network, etc.). It can run various operating systems and can be used in many projects (electronics, robotics, retro-gaming, and more) [35].

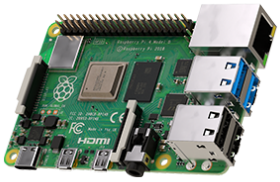


Figure 4.1: Raspberry Pi

Key Features of the Raspberry Pi

We chose the Raspberry Pi as the microcomputer in our system for several benefits [36], including:

- **Processing Power:** Raspberry Pi's computational prowess opens the doors to AI, image recognition, and other data-intensive applications.
- **Versatility:** Raspberry Pi can function as a complete computer, enabling web connectivity, data storage, and advanced computations alongside robotics tasks.
- **Connectivity:** Raspberry Pi boasts a range of connectivity options, including Wi-Fi, Bluetooth, Ethernet, and USB ports, making it suitable for networked and IoT applications.

4.4.2 Arduino UNO

The Arduino Uno is an open-source microcontroller board used in robotics for real-time control tasks by allowing users to write code with C++ language in integrated development environment and it is compatible with Windows, macOS, and Linux [37].

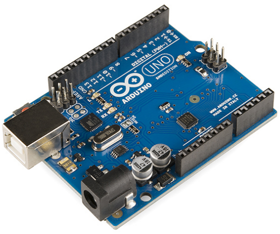


Figure 4.2: Arduino Uno

Key Features of the Arduino UNO

arduino uno has many advantages that made us use it in our system [36], including:

- **Simplicity:** Arduino's intuitive environment allows for quick experimentation and easy integration of hardware components.
- **Cost-Effective:** Arduino boards are affordable, making them accessible for hobbyists and small-scale projects.
- **Real-Time Control:** Arduino's real-time capabilities are suitable for applications that require precise control, such as motor control and sensor interfacing.

4.4.3 CNC Shield for Arduino UNO

The CNC Shield is an extension board for Arduino that allows you to control stepper motors for various Computer Numerical Control (CNC) machines. In simpler terms, it gives Arduino the power needed to run machines like 3D printers, laser cutters, and CNC mills [38].

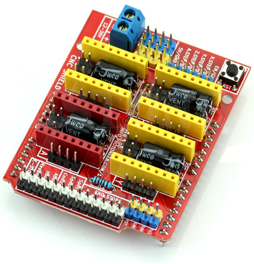


Figure 4.3: CNC Shield

4.4.4 Camera v1.3

This sensor is like the eyes of a robot, enabling it to “see” and understand its surroundings accurately. It is also small in size and connects directly to the Raspberry Pi.

Figure 4.4: Camera v1.3

4.4.5 Power supply 12V 250W

It refers to a device that provides electrical current at a voltage of 12 volts and a capacity of up to 250 watts, which are suitable for the components and devices used in our project.

Figure 4.5: Power supply 12V 250W

4.4.6 Male-to-female cables

It act as adapters, with the male connector plugging into a device and the female connector receiving a plug from another cable or device, allowing us to establish connections between them.

Figure 4.6: Male-to-female cables

4.4.7 NEMA stepper motor with drive

A nema stepper motor with drive is a precision motor used in robotics, and CNC machines. it converts electrical pulses into precise mechanical rotation, controlled by the drive for accurate positioning and movement.

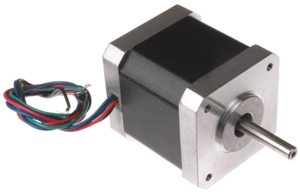


Figure 4.7: NEMA stepper motor with drive

4.4.8 Endstop

this sensor act as safety limits and reference points for the robot. They tell the Arduino when the robot has reached the edge of its movement in a specific direction, preventing crashes and helping it know its position.

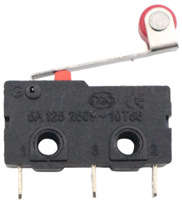


Figure 4.8: Endstop

4.4.9 Channel Relay Module Shield

They can be used to control devices such as lights, fans, motors, solenoids, etc. 5V relay has three high voltage terminals which connect to the device you want to control. The other side has three low voltage pins which connect to the Arduino [40].

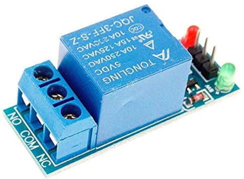


Figure 4.9: Channel Relay Module Shield

4.5 Wiring

Installing the wiring that connects the mechanical and electronic components of the system shown in Figure 4.10.

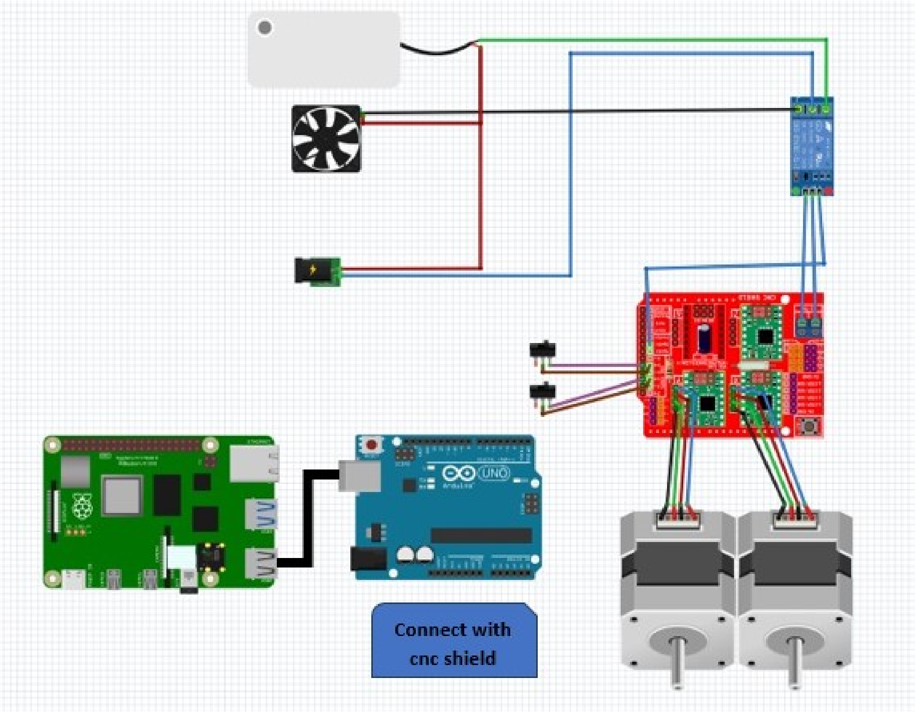


Figure 4.10: System Wiring

4.6 Software Implementation

In this section, we will present the software components that we will use in this project.

4.6.1 Python

Python is an interpreted, object-oriented, high-level programming language with dynamic semantics, Python supports modules and packages, which encourages program modularity and code reuse [41].

4.6.2 Python Libraries

To prepare the environment for the weeds detection project on Raspberry Pi, the following libraries and tools were installed:

1. **Ultralytics**
   Ultralytics is the home for cutting-edge, state-of-the-art computer vision models for tasks like object detection. Besides providing implementations of these models, Ultralytics also provides us with out-of-the-box workflows for training, fine-tuning, and applying these models using an easy-to-use API [42].
2. **OpenCV**
   Open source computer vision and machine learning software library. it was built to provide a common infrastructure for computer vision applications [43]. By using it, one can process images and videos to extracting necessary data for decision-making.
3. **NumPy**
   It is a Python library for working with efficient multidimensional arrays, It offers a faster and more powerful way to handle numerical data compared to python's built-in lists [44].
4. **PyTorch**
   Open source machine learning (ML) framework based on python programming language and the Torch library. it is an open source ML library used for creating deep neural networks and is written in the Lua scripting language [45].
5. **Picamera**
   This package provides a pure Python interface to the Raspberry Pi camera module for Python 2.7 (or above) or Python 3.2 (or above) [46].

4.6.3 Visual Studio Code

Visual Studio Code is a powerful source code editor that runs on desktop and on the web and is available for Windows, macOS, Linux, and Raspberry Pi OS [47].

4.6.4 Arduino IDE

The Arduino Integrated Development Environment is a programming program that will interface between the Arduino board and the software. The Arduino IDE contains a compiler that converts programming language into machine language that can be understood by the Arduino board [48].

4.6.5 GRBL

An open source, embedded, high performance g-code-parser and CNC milling controller written in optimized C that will run on a straight Arduino [49].

4.6.6 G Code

It is the most popular CNC programming language. They are responsible for the movements of CNC machines relative to different axes such as X, Y, telling them where to start, how to move, and when to stop [50].

4.6.7 PySerial

PySerial is a Python package that facilitates serial communication. A computer running Python with the PySerial package installed can communicate with external hardware [51].

4.7 System Design and Architecture

Designing and assembling the weed detection and elimination robot presents an exciting engineering challenge. The robot is mainly constructed from V-slot aluminum extrusions and aluminum gantry plates, see Figure 4.11 and Figure 4.12 with the help of fasteners such as screws and screwdrivers needed to secure the pieces in place.

Figure 4.11: Gantry Plates

Figure 4.12: V-slot Aluminum

- The assembly process started with the two V-slot aluminum, one for X Axis with a length of 0.5 meters and the other one for Y Axis with a length of 0.55 meters. we installed the X-axis with the Y-axis in a T-shape using aluminum gantry (as shown in Figure 4.13). and then mounted the kit on the top of body of the robot to allow the sprayer to move freely and appropriately over the weed.

Figure 4.13: X-axis rail with the Y-axis

- We installed all the mechanical and electronic components necessary for the movement of the robotic system as mentioned in the **section** 4.5 on the robot body.

  Where we should keep the position of the camera in a fixed place to do the mapping between the coordinates from the camera and the coordinates in the real environment.

- Finally, We used a sprayer installed on x-axis V-slot aluminum that can be controlled by the arduino.

4.8 General Architecture of the System

The system we introduce is a weed detection and elimination robot. **Figure** 4.14 shows the overall framework robotic system and the collaborative functioning of its components. As presented below, the weeding robot system collects images using the camera from the crops row. The Raspberry Pi will process the images by doing some pre-, post-processing operations on each frame and then detect if there are objects in the image using the deep learning model to make the appropriate decision. If there are no objects in the image classified as weeds, the Raspberry Pi will not send any data about the object position to the Arduino. If there an object in a frame classified as a weed, then the microcoumputer will send the position of weed to the microcontroller, which in turn will send signals to motors to move precisely above the weed location, then the microcontroller sends signal after a while to turn on the sprayer for specific amount of time.

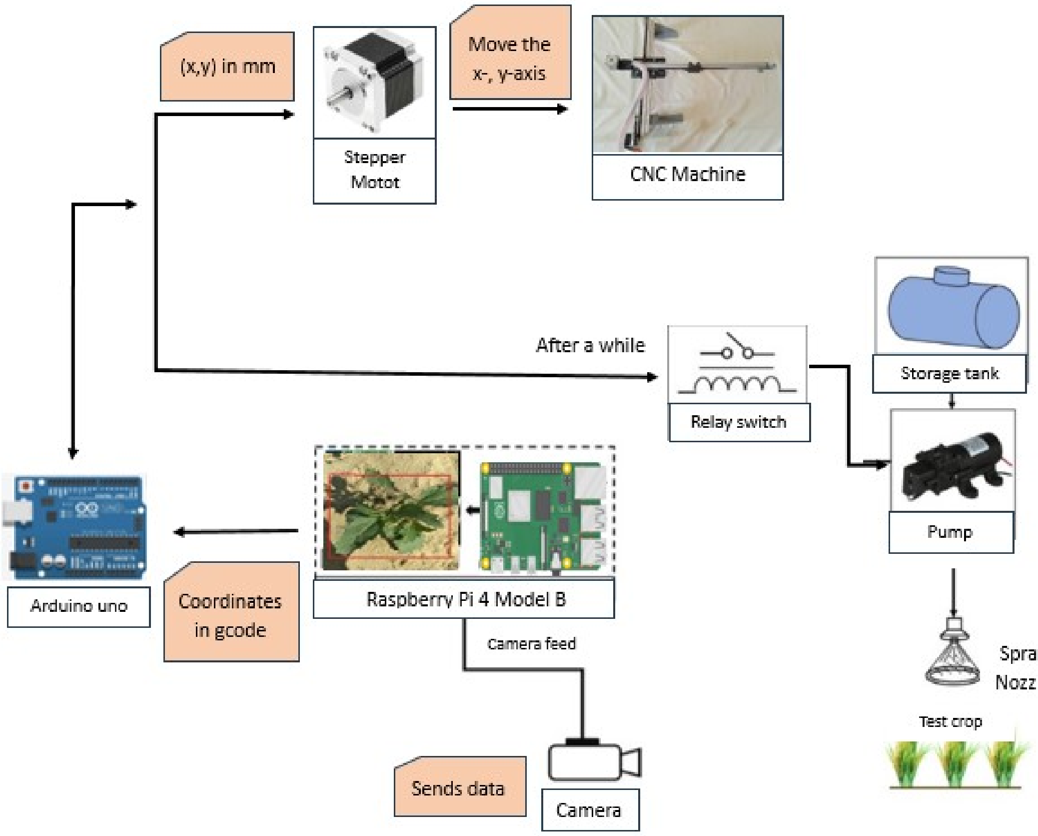


Figure 4.14: General Architecture of the System

4.9 Implementation

After completing the assembly of the pieces and assembling the electronic and mechanical components of the robot, it is now time to test, implement and move the robot in order to detecte and eliminate weeds intelligently by following the programming steps included in it. Below we will mention the total steps required for this.

4.9.1 Setting Up and Configuring the Robotic System

- The first thing we need to do is to ensure that the development environment is set up and the necessary libraries are downloaded for the Raspberry and Arduino and image processing to work well which was mentioned in **section** 4.6.
- Then we have to configure the camera to be connected to the Raspberry Pi by using the Picamera and OpenCV libraries in order to carry out the detection process and for the robot to be aware of the current state of the environment.

4.9.2 Communication between Raspberry Pi and Arduino

raspberry pi and Arduino communicate using USB cable via a serial communication protocol using the pyserial library in Python. The Raspberry Pi is then configured to open a serial connection with the Arduino. Once the connection is successfully established, the Raspberry Pi can send G-code commands to the Arduino.

```
serial_port = '/dev/ttyACM0'
baud_rate = 115200



try:
    ser = serial.Serial(serial_port, baud_rate, timeout=1)
    time.sleep(2)
except serial.SerialException as e:
    print("Serial port error:", e)
    exit(1)
```

4.9.3 Perception System

- The process begins with a camera capturing real-time video of the agricultural fields, and then captures a frames (images) from the video stream and stores it as variable. The captured frame is then resized to a width and height of 640 pixels. This resized image is processed and analyzed using the YOLOv8n algorithm, which identifies the location of the plants in the image and labeling it with bounding boxes for detected objects, class labels (weed, pepper or tomato), and confidence scores (how certain the model is about the predictions).

```
picam2 = Picamera2()
picam2.start()

try:
    image = picam2.capture_array()
    image = cv2.resize(image, (640, 640))
    image_rgb = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)

    time.sleep(5)

    results = model.predict(image_rgb)
```

```
    annotator = Annotator(image)
    class_colors = [(0, 0, 255), (0, 255, 0), (0, 165, 255)]
```

- after the model identfy the plant as weed, The center of the bounding box is then calculated and sent to the Arduino.

```
detected_weeds = []
for r in results:
    boxes = r.boxes
    for box in boxes:
        b = box.xyxy[0]
        c = int(box.cls)
        label = model.names[c]

        if c == 0:

            x_center = (x + w) / 2
            y_center = (y + h) / 2
            detected_weeds.append((x_center, y_center))

            annotator.box_label(b, label)
```

The following **Figure** 4.15 shows how to calculate the center location of the plant bounding box in the frame.

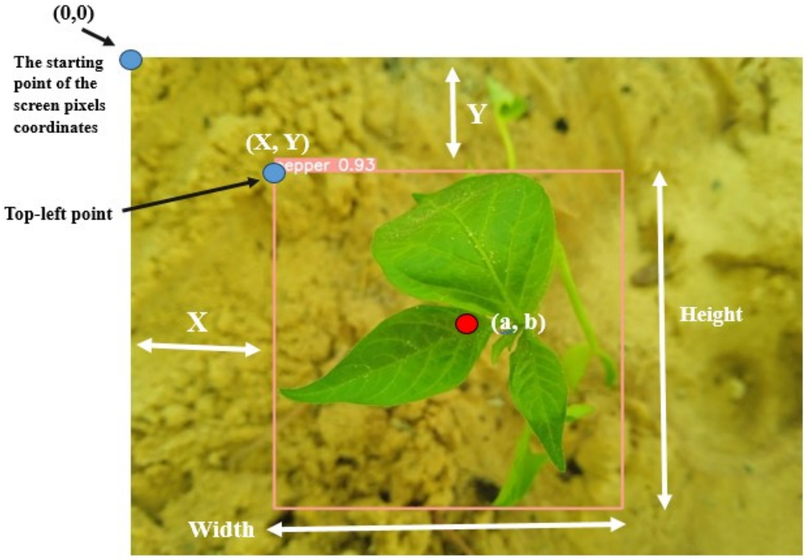


Figure 4.15: Object Bounding Box Location on Screen

As shown in figure 4.15 , we can calculate the center point coordinates (a, b) as follow:

- Calculation the x-axis of Center Point: $a = \frac{x+width}{2}$
- Calculation the y-axis of Center Point: $b = \frac{y+hieght}{2}$

4.9.4 Sending G-code Commands

G-code commands are sent from the Raspberry Pi based on the coordinates of the center of a bounding box on the x and y axes in a pixel.

```
for weed in detected_weeds:
    x_center_gcode, y_center_gcode = weed

    gcode_command = f"$X\nG1 X(x_center_gcode) Y(y_center_gcode) F2000\
       nM4\nG04 P1\nM3"
    print("Generated G-code instruction:")
    print(gcode_command)

    gcode_command += ’\n’

    ser.write(gcode_command.encode())

    response = ser.readline().decode(’utf-8’).strip()
    time.sleep(8)
```

Where **G01** represents the command to move in a straight line at a specific feed rate or speed, and **X(x_center_gcode)** and **Y(y_center_gcode)** indicate the value of the coordinates of the center of the bounding box on the x and y axes, and **F** indicates the moving speed.

4.9.5 Integrated weed removal module

- After the Raspberry Pi sends the coordinates of the center point to the Arduino. the Arduino reads the incoming characters and then sends the command to the stepper motors using the GRBL library to move to the specified point.
- The weed that will be eliminated first if there is more than one weed in the frame is determined based on the coordinates of the center of the bounding box, so that the center whose x-axis coordinate value is smallest is reached first.

- After a period of sending the command to the stepper motors, the Arduino sends a command to the pump, which in turn activates the sprayer for a specific period of time. Once the command is executed, it returns to the starting point.

4.10 Result

This section presents the findings from our experiment, focusing on performance metrics of the machine learning model developed for the weed detection and elimenation robot. The results are detailed to provide insights into the performance of the system, supported by quantitative data and visual representations, to give a comprehensive understanding of the outcomes and validate the success of our approach.

4.10.1 Evaluation Metrics

After training, we evaluated the model's performance using various metrics. The plots below show the training evaluation metrics over the epochs.

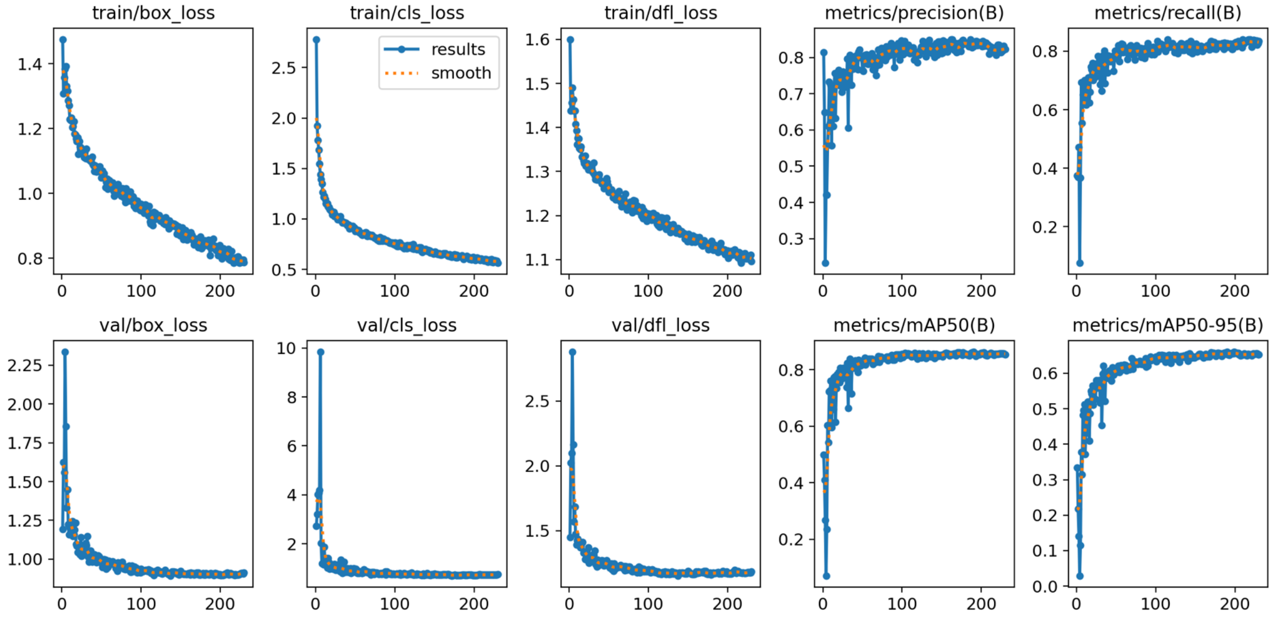


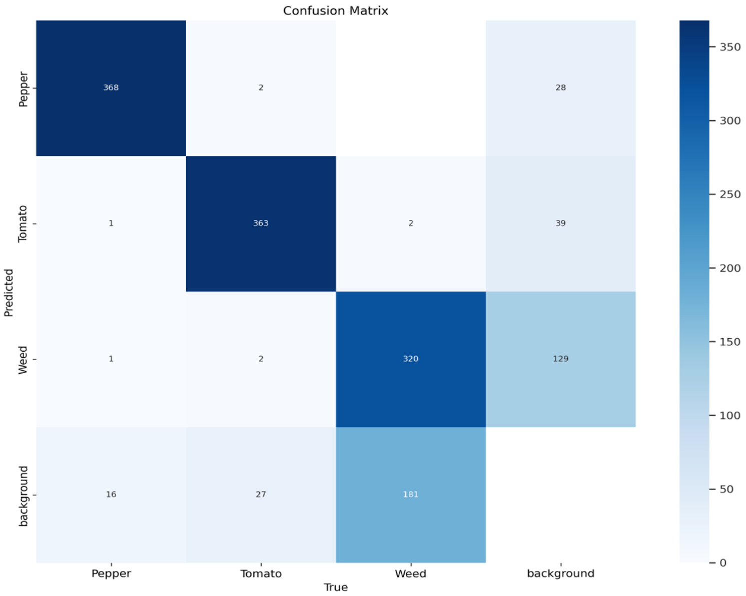
Figure 4.16: Evaluation Metrics Plot

- mAP50 (B) indicates how accurately the model detects Class B objects when using the 50% IoU criterion to determine correct detections. In our case it reaches 0.86913.
- Box loss is the extent of the differences between the expected and actual coordinates of the bounding box on the plant. In our case it reaches 0.5.
- Both precision and recall measure the accuracy of positive predictions made by the model.

In our case it reaches 0.86538 for Precision and 0.73854 for Recall.

4.10.2 Confusion Matrix

It shows how the model performed in predicting the four classes compared to the actual cases.



Predicted \ True	Pepper	Tomato	Weed	background
Pepper	368	2		28
Tomato	1	363	2	39
Weed	1	2	320	129
background	16	27	181	

Figure 4.17: Confusion Matrix

The final form of the weed detection and elimination robot is represented in **Figure** 4.18.

Figure 4.18: Robot to detect and eliminate weeds

4.11 Discussion

In the end, we obtained good results and many advantages of our system, including:

- Real time control.
- detect plants smartly.
- Eliminate weeds automatically using a sprayer.
- Compatibility with artificial intelligence.
- Good integration between many mechanical and electronic devices.
- Adaptability.
- Low price.

with all these good results and features, this does not prevent the system from having some negatives and some challenges in its completion, including:

- The difficulty and great time spent collecting data, and the diversity of the harmful herb that was studied and the great similarity between its types negatively affected the accuracy of the results obtained.
- the lack of capital and time allocated for this project, led to not reaching some of the goals set from the beginning of the project.
- Difficulty in dealing with electronic and mechanical tools, as our expertise lies primarily in artificial intelligence and programming. This led to delays in assembling the robotic arm and multiple failed attempts to operate it.

4.12 Conclusion

The final chapter reviews the various mechanical and electronic tools in addition to the programs that contribute to implementing the system and presenting the results obtained. Through this chapter, it is demonstrated how these components are integrated to achieve the system objectives effectively and accurately. These tools and software are a vital foundation in building an integrated system capable of efficiently detecting and removing weeds, enhancing agricultural productivity and reducing costs and reliance on chemicals. The results presented in this chapter represent evidence of the successful integration between the various components of the system and its ability to operate in real agricultural environments.

GENERAL CONCLUSION

In conclusion, the development and implementation of the weed detection and elimination robot present a promising solution to the challenges faced by farmers in weed management. Through using the latest artificial intelligence techniques and various mechanical and electronic tools, the robot offers an efficient and environmentally friendly approach to weed control.

The robot's ability to accurately detect weeds, coupled with its precision in herbicide spraying, contributes to significant reductions in herbicide usage, labor costs, and crop damage. Additionally, its autonomous operation reduces the need for human intervention, allowing farmers to focus on other essential tasks while ensuring effective weed control.

The robot parts were designed after being printed, and then we assembled the parts and completed the missing pieces. Afterwards, the electronic and mechanical tools were integrated to obtain the final robot. The system uses an Yolo v8 algorithm to make the smartest decision based on the weeds state. The system was implemented using Arduino IDE with CNC shield and Raspberry Pi 4 with a variety of other devices and sensors connected to them to ensure control and smooth operation of the system. It can be divided into two main parts:

1. **the robot part** includes the actual robot and all the mechanical and electronic parts that control its movement.
2. **the programming part** controls directing the movement of the robote and making the necessary decisions.

What distinguishes our system from other systems is the low cost and automation plus the high precisensuring, powerful performance, and easy maintenance and development. An other advantage is the simplicity and performance in real time.

Throughout theion, various chapters, we explained the system engineering, faced limitations, and achieved objectives.

BIBLIOGRAPHY

[1] “ Management and Development of Agricultural and Natural Resources in Egypt’s Desert “ By Abdelazim Negm and Ahmed A. Elkhouly On 2021. Publisher: Springer International Publishing.

[2] Automated Weed Detection: AI-Enhanced Solution for Weed Control By Neil Sahota. Last Access 27-06-2024 `https://www.neilsahota.com/automated-weed-detection-ai-enhanced-solution-for-weed-control/`.

[3] “Protected agriculture.” By Merle H. Jensen Alan J. Malter. Publisher: World Bank.

[4] Advances in Artificial Intelligence for Robotics, Last Access 27-12-2023 `https://www.researchgate.net/publication/377385099_Advances_in_Artificial_Intelligence_for_Robotics`.

[5] Trung Tran. 6 Typical Examples of Robots in Everyday Life, Last Access 27-12-2023 `https://www.agriculture.com/machinery/tractors/verdant-robotics-runs-precision-ag-farming-as-a-service`.

[6] Unimate ROBOTS: Your Guide to the World of Robotics, Last Access 27-12-2023 `https://robotsguide.com/robots/unimate`.

[7] “ Artificial Intelligence And Machine Learning “ By Kim, J.-L. On 2023. Publisher: IOS Press.

[8] “ Artificial Intelligence What Everyone Needs to Know “ By Jerry Kaplan On 2016. Publisher: Oxford University Press.

[9] “ The History of Artificial Intelligence “ By Rockwell Anyoha and harvard universty On 2017.

[10] “ Introduction to Artificial Intelligence “ By Mariusz Flasiński On 2016. Publisher: Springer International Publishing.

[11] AI winter, Last Access 28-12-2023 `https://en.wikipedia.org/wiki/AI_winter`.

[12] “ Intelligent Agent Fundamentals and Applications“ By Fouad Sabry On 2023. Publisher: One Billion Knowledgeable.

[13] Hiren Dhaduk, What is an AI Agent? Characteristics, Advantages, Challenges, Applications, Last Access 2024-01-01 `https://www.simform.com/blog/ai-agent/`.

[14] “ Artificial Intelligence A Modern Approach Third Edition “ By Stuart Russell and Peter Norvig On 2016. Publisher: Pearson.

[15] Avik Choudhuri. Types of intelligent agent, Last Access 2024-01-05 `https://www.probecx.com/en-au/blog/types-of-intelligent-agent`.

[16] Kinza Yasar, Katie Terrell Hanna. What Is Robotics? | Definition from WhatIs. techtarget Last Access 2024-01-05 `https://www.techtarget.com/whatis/definition/robotics`.

[17] Sam Daley. What Are Robots? Robotics Definition & Uses. builtin. Last Access 08-01-2024 `https://builtin.com/robotics`.

[18] Sienna Roberts. Advantage and Disadvanatages of Robotics. Last Access 11-01-2024 `https://www.theknowledgeacademy.com/blog/advantages-and-disadvantages-of-robotic/`.

[19] What is desert agriculture? Last Access 25-5-2024 `https://wikifarmer.com/what-is-desert-agriculture/`.

[20] Weed. Last Access 17-01-2024 `https://en.wikipedia.org/wiki/Weed`.

[21] Frick, E. Johnson, Weeds - when are they a problem? Last Access 17-01-2024 `https://www.dal.ca/faculty/agriculture/oacc/en-home/resources/pest-management/weed-management/organic-weed-mgmt-resources/weeds-problem.html`.

[22] Analog vs. Digital Sensors: Unveiling the Differences and Applications. Last Access 01-02-2024 `https://www.linkedin.com/pulse/analog-vs-digital-sensors-unveiling-differences-khadar-baba-shaik`.

[23] Gustavo José Querino Vasconcelos, Gabriel Schubert Ruiz Costa, Thiago Vallin Spina and Helio Pedrini. Low-Cost Robot for Agricultural Image Data Acquisition Last Access 2024-02-12 `https://www.mdpi.com/2077-0472/13/2/413`.

[24] Cécile Julien. Débuts prometteurs en grandes cultures pour Ecorobotix. Last Access 2024-02-12 `https://www.terre-net.fr/innovation-et-technologie/article/133739/debuts-prometteurs-en-grandes-cultures-pour-ecorobotix`.

[25] IoTFever. Pesticide Robot | Agriculture Robot Last Access 2024-02-13 `https://www.instructables.com/Pesticide-Robot-Agriculture-Robot/`.

[26] AVO by Ecorobotix, Last Access 15-02-2024 `https://agtecher.com/product/avo-by-ecorobotix/`.

[27] LaserWeeder implement, Last Access 15-02-2024 `https://carbonrobotics.com/laserweeder?trk=article-ssr-frontend-pulse_little-text-block`.

[28] " Robotic weeding from concept to trials " By Tristan Perez, Chris McCool, Owen Bawden,Jason Kulk. Last Access 27-06-2024 `https://core.ac.uk/reader/144867420`.

[29] “ Proceedings of the 6th Symposium on Agri-Tech Economics for Sustainable Futures “ By Karl Behrendt and Dimitrios Paparas and Anne WAMBUI Mumbi and Nigel Hill On 2023. Publisher: HAU Publications (Ebooks).

[30] Alex Gray. Verdant Robotics runs precision ag farming as a service, Last Access 2024-02-20 `https://www.agriculture.com/machinery/tractors/verdant-robotics-runs-precision-ag-farming-as-a-service`.

[31] makesense.ai. *makesense.ai*. Last Access 28-03-2024. `https://www.makesense.ai/`.

[32] roboflow *roboflow.com*. Last Access 28-03-2024. `https://roboflow.com/`.

[33] Bulut, Sema Zeynep. "A Brief Overview of R-CNN, Fast R-CNN, and Faster R-CNN." Medium. Available online. Last Access 28-03 2024 `https://semazeynepbulut.medium.com/a-brief-overview-of-r-cnn-fast-r-cnn-and-faster-r-cnn-9c6843c9ffc0`.

[34] "A Comprehensive Review of YOLO Architectures in Computer Vision: From YOLOv1 to YOLOv8 and YOLO-NAS." By Guoqing Chao and Xianzhi Wang On 2023. Publisher: eprint arXiv:2304.00501.

[35] Patrick Fromaget. What is a raspberry pi? (hardware, software, goal & usage), Last Access 02-04-2024, `https://raspberrytips.com/what-is-a-raspberry-pi/`.

[36] Bansari Kikani. Arduino vs. raspberry pi for robotics: Navigating the perfect choice. LinkedIn, Last Access 02-04-2024 `https://www.linkedin.com/pulse/arduino-vs-raspberry-pi-robotics-navigating-perfect-choice-kikani`.

[37] Arduino. Last Access 24-04-2024 https://www.arduino.cc/.

[38] Sami Hamdi. Mastering DIY Projects with the Arduino CNC Shield: A Comprehensive Guide. Sidi Bouzid, Tunisia: Robotics for beginners. Last Access 04-04-2024 https://roboticsforbeginners.com/mastering-diy-projects-with-the-arduino-cnc-shield-a-comprehensive-guide/.

[39] " Mastering DIY Projects with the Arduino CNC Shield: A Comprehensive Guide. Robotics for beginners " By Sami Hamdi On 2024.

[40] 5V Relay Module — SunFounder Ultimate Sensor Kit documentation. Last Access 09-04-2024 https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/components_basic/25-component_relay.html.

[41] Python (programming language). Last Access 15-04-2024 https://en.wikipedia.org/wiki/Python_(programming_language).

[42] Ultralytics. Last Access 15-04-2024 https://docs.wandb.ai/guides/integrations/ultralytics.

[43] OpenCV. Last Access 15-04-2024 https://en.wikipedia.org/wiki/OpenCV.

[44] What is NumPy? Last Access 15-04-2024 https://numpy.org/doc/stable/user/whatisnumpy.html.

[45] Kinza Yasar. What is PyTorch?. TechTarget. Last Access 15-04-2024 https://www.techtarget.com/searchenterpriseai/definition/PyTorch.

[46] picamera. Last Access 15-04-2024 https://picamera.readthedocs.io/en/release-1.13/.

[47] Martin Heller. What is Visual Studio Code? Microsoft's extensible code editor. Last Access 18-04-2024. https://www.infoworld.com/article/3666488/what-is-visual-studio-code-microsofts-extensible-code-editor.html.

[48] Qu'est ce qu'Arduino IDE ? Comment l'utiliser ? Comment Programmer sur Arduino ? Last Access 18-04-2024. https://arduinofactory.fr/arduino-ide/.

[49] Grbl. Last Access 18-04-2024. https://github.com/grbl/grbl.

[50] G M: CNC. Rapid Direct. Last Access 18-04-2024. https://www.rapiddirect.com/ar/blog/g-and-m-codes/.

[51] PySerial.Last Access 22-04-2024 `https://clouds.eos.ubc.ca/~phil/docs/problem_solving/11-Python-and-External-Hardware/11.01-PySerial.html`.