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Automatic Weeding Robot Product Design

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Abstract

The mechanical control of weeds is nowadays the most promising technology for the enhancement of crop yielding. The chemical weeding is discovered not to be environmentally focused, dangerous for humans and animals' health and cause of herbicide-resistant foods. The development of informatics and electronics technologies in the last decade allows the intra-row weed technology to be the best solution in weed management. In fact, the combination of a mechanical weeder, a camera vision system and a control board permit the removal of weeds not only between two rows (inter-row weeding)

In this paper, an automatic mechanical weeding robot is designed, driven by four wheel motors and five rotating weedheads to weed four rows of crops at the same time. The model of selected motor is determined by calculation, and the vehicle chassis, wheel suspension and weeding mechanism are designed. The information fed back by the sensor is automatically controlled by the in-car computer for weeding. The charge can work for 8-10 hours at a time.

CHAPTER 1. GENERAL INTRODUCTION

Introduction

Vegetable crop production is a major contributor to the Chinese economy. In 2018, the output value was 11.72 billion US dollars, accounting for 13.85% of GDP, an increase of 3% over 2017. The total area harvested is 1.78 million acres.

At present, the promotion of modern agricultural fine production and Internet of Things technology combines huge market demand space, based on perception, the network platform of people, people and things, things and things is successful, modern agriculture quietly enters the Internet of Things era, intelligence The overall situation of agriculture. According to the data of the Institute of Quasi-Industrial Research, the potential market size of China's smart agriculture is expected to grow from US$13.7 billion in 2015 to US$2.68 billion in 2020, with a compound annual growth rate of 14.3%.

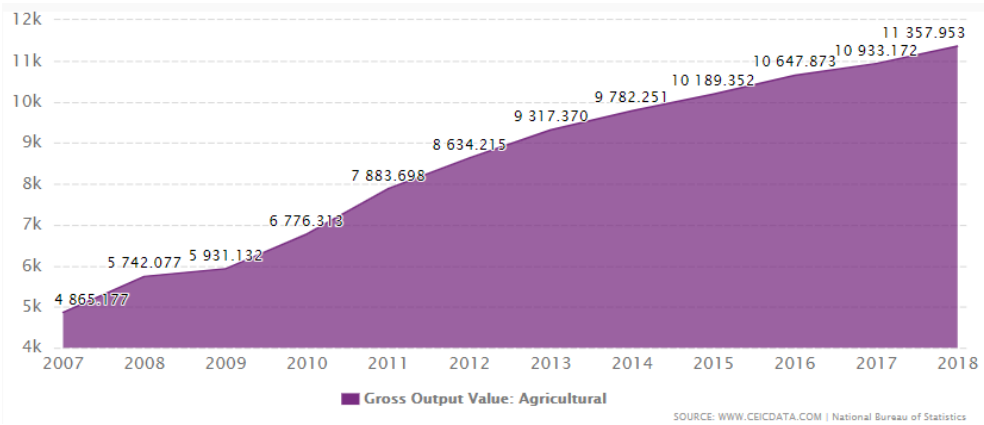


Figure 1.1: China's CN: GOV: Farming, Forestry, Animal Husbandry & Fishery (FF) from 1952 to 2018

Since the birth of agriculture, weeding has been the basic operation of vegetable harvesting. This is quoted in the many ancient literature collected on Canadian farm weeds, which even shows that we have been focusing on weed control before the Middle Ages. Plant growth is always accompanied by the growth of weeds. Both creatures need the same nutrients and sun extracted from the terrain. The sharing of resources can lead to the survival of weeds and the death of vegetables, which is a fierce competition for nutrients and resources.

In order to achieve high-yield vegetable production, good agricultural practices are required. One of the most important practices is the proper management of weeds. Weeds affect crop yields by competing for plant nutrients and resources (Slaughter et al., 2008; Iide et al., 2008). Weeds grow very fast compared to crops, and weeds can dominate if left untreated and managed.

Some people have adopted agronomic methods to improve crop competitiveness, such as growing viable crop seeds at relatively shallow depths and planting them immediately after weed control. This method prevents weed seeds from germinating before crops are planted and ensures that this approach ensures maximum crop yield and reduces weed infestation while minimizing any economic losses (Maxwell and O'Donovan, 2007). . If the canopy is closed and too much permanent light is shining on the ground where the weeds will germinate and grow, the above measures should be taken to control the weeds. However, weeds still need to be controlled during the crop production cycle.

Another method of weed control in practice is to increase the density of field crops. By planting crops in the field, the germination rate of weed seeds is reduced (Blackshaw et al., 2007). However, the distance between plants will decrease and may affect other field operations such as spraying fertilizer or harvesting.

Weed management is a strategy that uses the ecological knowledge of unwanted plants (ie weeds) to make the desired plant growth successful in specific agro-ecosystems (Ghersa et al., 2000). Currently controlling weeds is most effective, there are several ways to control weeds by using manual, chemical, mechanical or biological means.

This method was once and was achieved by bending over and pulling the weeds out of the soil with both hands. Then, from use to use-head, this method has evolved into manual Gianesi and Reigner (2007) reports that manual labor costs increased from $0.10 per hour in the 1940s to $1.00 per hour in the 1960s. . Until 2005, the rate was further increased to $10 per hour. In addition, problems such as back pain caused by continuous repeated bending result in avoidance of manual weeding. Therefore, weeding and hand weeding are prohibited.

In the presence of chemical weed control, mechanical weeding is the best choice for solving problems associated with manual weeding. There are many types of mechanical weeding tools on the market that use a variety of key technologies: by weeding, weeding and weeding. The weeds are buried by farming tools, usually on land. For weeding and uprooting of weeds, there are two types of machinery available: inter-row weeders and in-row weeders. Inter-row weeding is a method of weeding between planting rows. Weeding in rows is a method of weeding in plants. There are mechanical inter-row weeders on the market, such as inter-row cultivators, rotary tillers and basket weeders (Cloutier et al., 2007). The inter-role cultivator and the rotary cultivator are agricultural implements composed of suspended cutting blades that perform weed control. A basket weeder is a tool consisting of several rolled rectangular wires forming a circular basket. The effectiveness of weeding operations is often determined by a number of factors. For example, more aggressive operations often result in higher herbicidal effects, but often increase the risk of damage to crops.

There are also a variety of mechanical in-row weeders. Cloutier et al. (2007) and Wei De et al. (2008) reported the use of finger weeders and torque weeders. The finger weeder is a simple mechanical in-row weeder that uses two sets of truncated steel cones with rubber spikes or "fingers" pointing horizontally outward. The twisted weeder uses flexible spring teeth that are attached to the rigid frame and bent so that the two short segments can work closely and parallel to the work surface. They concluded that these machines will work effectively when using accurate and accurate steering. This is why these weed attachments are integrated with precision tiller machines. In addition, these machines can only perform weed control when the crop is not rooted, because if the above-mentioned in-row weeder is in contact with the crop, it will not damage the crop. This requirement makes it difficult to control weeds at the beginning of planting.

One of the most promising techniques for weeding in the line is the brush weeder. Cloutier et al. (2007) reported that the brush of the brush weeder is made of fiberglass and is flexible. These brushes can be rotated vertically or horizontally. It is also possible to add an operator to manipulate the brush to make the planting as close as possible to the crop without damaging the fennel. It is also possible to add fennel to manipulate the brush to grow as close to the crop as possible without damaging the crop.

Chemical-based weed control is widely used in modern agricultural systems. Implement conservation tillage measures to improve soil quality, minimize soil erosion or simplify crop management, and increase dependence on herbicides (Iaver et al., 2007). Herbicides in the mid-20th century helped reduce the dependence on mechanical weeders (Cloutier et al., 2007). Gianessi and Reigner (2007) report that during those years, the workforce became scarce and expensive, especially after the Second World War.

However, at present, it is becoming more and more difficult to ignore the use of herbicides in weed processing due to the effectiveness of weeds in controlling weeds while reducing yield losses. However, interest in mechanical weeding has increased due to concerns about the environment, the growing demand for pesticide-free products, and the growth of herbicide-resistant weeds (Upadhyaya & Blackshaw, 2007).

Biological weeding is a method of weeding a specialized herbivorous natural enemy that uses problematic plants in agriculture or in the natural environment (Blossey, 2007). Héraux et al. (2005) The use of allelochemical release organisms to control weeds in vegetable transplant fields. Hakansson (2003) reported the use of moths originating in South America to control Australian weeds, partial control of cactus plants. Biological methods have their place of success and failure, and some inconsistencies make this method not widely practiced.

Advances in computers and sensors have facilitated the automation of agricultural machinery, especially weeders. Through automation, weeding can be done electronically, reducing manual intervention and optimizing the power provided by the machine. Automated machines also offer possibilities. To identify weeds and crops, weeds are removed with precisely controlled equipment (Bakker, 2009).

Researchers have tried to apply automation technology to in-row weed control. Tillett et al. (2008) An automated weeding machine for detecting plants using computer vision and a rotating semi-disc for controlling weeds were tested. Astrand and Baerveldt (2002) developed an agricultural mobile robot that uses a vertically rotating weeding tool for weeding and is equipped with two cameras – a near-infrared filter camera for positioning crop rows and another for identification Color camera for crops. Cloutier et al. (2007) reported the head of the "srl Radis" developed in France. This automatic weeder uses light interception technology to detect crops and uses a control system to control the lateral movement of the head relative to crop rows and crops.

Grillpentrog et al. (2006) developed an autonomous in-row weeder based on RTK (Real Time Kinematics) GPS. The rotor weeder is controlled by an electro-hydraulic motor system that powers eight rotating tines that can be individually controlled to follow two different cusp trajectories. The machine has the same concept as a brush weeder, using a rotating tines or brush for weeding.

The automation of the rotating fork concept should be the next step as it has produced a good weeding effect. In addition, automation can help reduce labor, manual intervention, and time consuming issues associated with manual weeding. Accurate and reliable response and low maintenance costs.

CHAPTER 2. BACKGROUND

The increase in vegetable production is mainly attributable to increased consumer demand for nutritious and healthy food. Government programs (such as the National Fruit and Vegetable Program) encourage people to eat 4 to 6-1 / 2 cups of fruits and vegetables a day to promote good health and reduce the risk of health problems, contributing to this growth (Stewart and Lucier, 2009; CDC, 2011).

Weed management is very important in vegetable crop production and is considered one of the most important operations. Weeds are known to be very competitive in terms of moisture, sunlight and nutrients. Unfortunately, this competition will affect crop yields (Slaughter et al., 2008). Gianessi & Sankula (2003) reported that most crops require that the field be kept free of weeds during the first four to six weeks after sowing to prevent severe weed competition from early weed competition.

Throughout this chapter, herbicidal methods are evaluated by their efficacy, usually expressed as a percentage reduction in the area of weed plants or weed canopies before or after weeding. In the study, the percentage can indicate a decrease in the number of weed plants before or after the weeding operation or a decrease in the weed area before and after the weeding operation. Vanhala et al. (2004) developed a guide to physical weeding research and reported two methods for assessing herbicidal efficacy: using quantitative methods such as weed quantity, weed biomass and weed seed yield, depending on the type of weeds available in the field. These types of measures are ideal because they show the actual measurement of weed density or biomass at a certain point in time. Qualitative methods, such as visual estimation of weed control, are usually performed when the quantitative method is outdated. This is a quicker and easier way to do it, but it's hard to score and analyze it. The choice of whether to use qualitative or quantitative measurements depends largely on the time and resources required to conduct the assessment.

There are several ways to use weeding. Manual weeding is a method of uprooting weeds with bare hands or hand tools, while mechanical weeding requires a machine to control weeds. Chemical weeding uses herbicides to control weeds, and biological weeding uses other organisms to control weeds.

Manual weed Control

The earliest of all techniques, the simplest is manual weeding. Manual weeding begins with farmers using both hands to remove weeds. The technology then evolved into a hand tool, from stick to use-head (Cloutier et al., 2007). Manual weeding with human hands provides very effective weed control, but requires a lot of manpower and effort (Table 2.1). According to Gianessi and Reigner (2007), asparagus requires the shortest artificial weeding time of 12 Hever per hectare; onions require the highest manual weeding time of 158 hours per hectare. Compared to other crops (such as asparagus), the low rate of onion weeding is due to the smaller canopy of the onion, which allows more sunlight to penetrate the soil and is therefore more likely to produce weeds. The data in this table is based on a series of studies conducted by the US Department of Agriculture, the American Weed Science Society (WSSA), and the American Farm B Urea Association (AFBF) in the 1990s. Slaughter et al. (2008) pointed out that manual weeding only eliminated 65% to 85% of weeds in cotton production, mainly because workers mistakenly weeds for crops or weeds. It has also been reported that manual weeding with long handle ho will damage crops and also cause some weeds to be lost (Gianessi and Reigner, 2007). E-cutting is also time consuming and can cause injuries to the back of workers.

Figure 2.1: Hand weeding worker into a strawberry field in Oxnard, California

Earlier in California, hand-made ho heads were mainly used for weeding of most vegetable crops. Farm workers complained of permanent back injuries due to prolonged weeding. As a result, in 1975, Industrial grass weeding was banned by the California Industrial Safety Commission. The ban was extended in 2004 by the California State Occupational Safety and Health Standards Committee to manual weeding due to concerns about the health of farm workers. Organic crop growers are exempt from this ban because manual weeding is one of the few weeding methods available to them. Their chemical-free background. Walz (2004) conducted a national organic peasant survey and concluded that organic farmers believe that weeds are one of the main causes of weather-related losses, high input costs and high labor costs, leading to a reduction in profits. . Earthbound Farms, North America's largest organic producer, mentioned that weed control is a cumbersome and costly task because they rely on mechanical farming and manual weeding. Their farmers must spend $1,000 per acre to control weeds (EFO, 2011).

Table 2.1: Hand weeding work rates for different types of crops (Modified from Gianessi and Reigner, 2007).

Crop	Hand weeding (h/ha)
Asparagus	12
Broccoli	50
Carrot	35
Celery	149
Corn	12
Cucumber	74
Dry bean	40
Green bean	30
Green pea	30
Hot pepper	149
Lettuce	94
Mint	45
Onion	158
Peanut	15
Spinach	50
Sweet potato	59
Tomato	92

Mechanical weeding

As the degree of mechanization in agriculture has increased, weeding tools have been developed and these tools have been driven by animals such as bison and horses. Over time, these machines have evolved and adapted to the tractor as a source of draught. There are many types of mechanical weeders on the market that can use three main physical techniques to control weeds: (1) burying weeds, (2) cutting weeds, and (3) weeding. The burial of weeds is done through the use of farming tools (Gianessi and Sankula, 2003), usually the target of farming. The objectives of farming include reducing soil strength, covering plant debris, rearranging aggregates, and removing weeds. Weed cutting and root weeding are accomplished by mechanical tearing and destruction of weeds from the soil, usually by mechanical cultivation after crop planting and emergence. Most herbicides sold by manufacturers of mechanical weeders are designed to control weeds between rows or between rows (Cloutier et al., 2007). Only a few machines are designed for inter-row weeding or in-row weeding.

Mechanical Inter-row weeding

The type of weed control is often common and used by farmers who do not use herbicides. The purpose of inter-row cultivation is to plant as much inter-row area as possible without damaging the crop. Farming can destroy weeds by completely or partially burying weeds, eradicating weeds and destroying contact with the soil. However, there are limitations to using this method. Weed control can only be carried out early in the crop, as limited tractor and cultivator ground clearance and machine-plant contact can damage crops. Despite this, despite this, there are still a variety of farming tools that can be used for mechanical weeding.

Inter-row cultivators are the most commonly used machines for controlling weeds. The implement includes a tilling tool mounted on a toolbar that can be rotated or swept to move the soil, bury, cut or remove weeds (Figure 2.2). Sweeping cultivators use triangular or duck-footed blades that sweep under the soil but close to the soil surface. The width of the blades varies from as small as 5.1 cm (2 inches) to as large as 71.1 cm (28 inches). The cultivator type does not require any power output shaft power. The recommended speed of sweeping cultivators is 6.4 km / h to 11.3 km / h. Another type of cultivator is a rotary cultivator, such as a rotary tiller and a rotary tiller, which are commonly used for inter-row weeding, but the latter is more expensive because it has multiple functions including other farming applications. For example, strip planting into cover crops and preparing permanent plant beds; Ling tools use separate hanging inter-row gangs or saw blades, mounted on discs with parallel links; the width of the saw blade or knife is 12.7 cm is not equal to 152.4 cm (5 inches to 60 inches) and is reasonably configured. Can be used to cover tillage leaves to prevent crop damage. The recommended forward speed of rotary cultivators is 4 km / h (2.5 mph / h) to 8 km / h (5 mph) (Bowman, 1997).

Figure 2.2: Inter-row rotary cultivator for inter-row weed control (Tornado, 2011).

The basket weeder is a farm implement consisting of a rolling rectangular quarter-inch spring wire that forms a circular basket (Figure 2.3). The basket weeder is ground driven, which means it does not require any power other than the power supplied by the weeder. The water in the basket. The basket weeder will remove weeds from the soil surface without moving the soil into the crop line. The machine is suitable for moist soils with very low clay content. It performs sickness at a forward speed of 6.4 km / h (4 mph) to 12.9 km / h (8 mph) (Bowman, 1997).

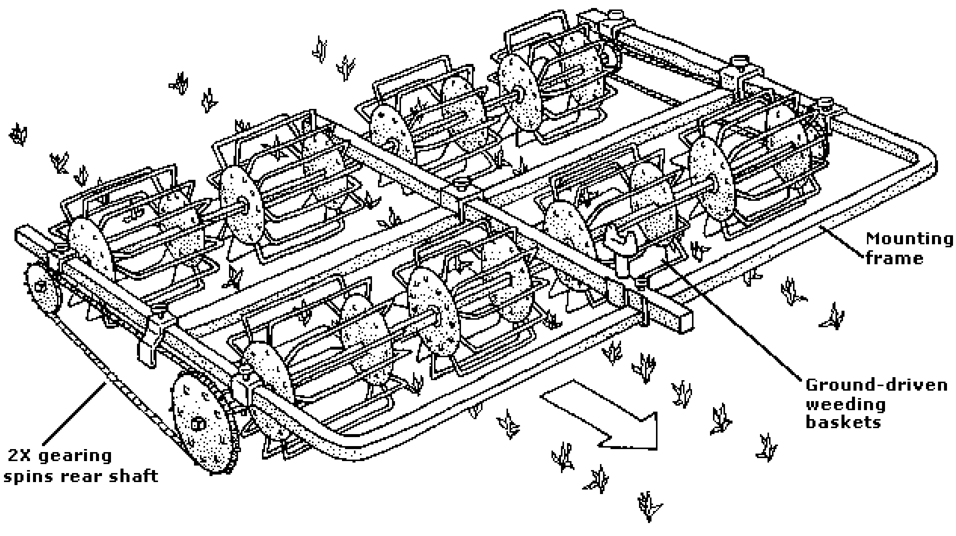


Figure 2.3: Basket weeder for inter-row weed control (Bowman, 1997).

Mechanical Intra-row weeding

Mechanical intra-row weeders

The first method is to use selective machines or additional tools that can weed in the vicinity of the crop. The goal of the weighing machine is to use two different methods depending on the crop density. The second method is to use a machine with a weeding tool that can be moved laterally to control the weeding of the crop canopy. Below are some of the machines reported to be effective in controlling weeds.

Finger weeder

The finger weeder is a simple mechanical in-row weeder that uses two sets of steel cones, rubber spikes or "fingers" attached to it. These fingers point outward at a certain angle. These finger weeders operate ground-driven rotating fingers from the side and down (Figure 2.4). Rubber fingers penetrate the soil and below the surface of the soil to remove small weeds near the fingers. Finger mechanisms perform best in loose soils, but perform poorly in wet hard crusts or compacted soils or in the presence of long stem residues. This type of herbicide is effective against young weed seedlings up to 25.4 mm (1 inch) high and interacts softly with deep-rooted crops. The recommended working depth is 12.7 mm (0.5 in) to 19.1 mm (0.75 in). The recommended forward speed for use with this weeder is 4.8 km / h to 9.7 km / h (3 to 6 mph). Alexandrou (2004) evaluated finger herbicides and obtained 61% of the weed efficacy results of in-row weeds killed in organic corn. However, one disadvantage of using this method is that the tractor must be manipulated very accurately to keep the finger mechanism as close as possible to the crop line (Bowman, 1997; Cloutier et al., 2007; Iide et al., 2008).

Figure 2.4: Finger weeder uses rubber spikes that are pointed at an angle towards the crop (weide et al., 2008).

Torsion weeder

A twisted weeder is another machine that can be used for weeding in the field. The twisted weeder uses the tines attached to the rigid frame and bends so that the two short tine segments are parallel to the soil surface and meet near the crop line. Allow crops to pass through the tines (Figure 2.5). The helical spring teeth allow the tip to bend around the contour of the soil and the surrounding crop. These herbicides have been tested for horticultural crops in Europe and North America and are very effective. Herbicides also reduce weed density to 60-80% of the original weed population. However, it also requires very precise steering with very low forward speeds and ultimately low working capacity. Torsional weeders are often used in conjunction with precision cultivators for efficient weeding (Bowman, 1997; Cloutier et al, 2007; Iide et al, 2008).

Figure 2.5: Torsion weeder uses flexible coil spring tines to sweep the weeds (weide et al., 2008).

Brush weeders

The brush weeder uses a flexible brush made of fiberglass or nylon that can be rotated about a vertical or horizontal axis. These herbicides are mainly used to eradicate and also bury and destroy weeds. A protective cover or protective cover can be installed to cover the crop from damage. The operator is required to manipulate the bushes to propagate weeds as close as possible without damaging the crop (Figure 2.6; Cloutier et al., 2007).

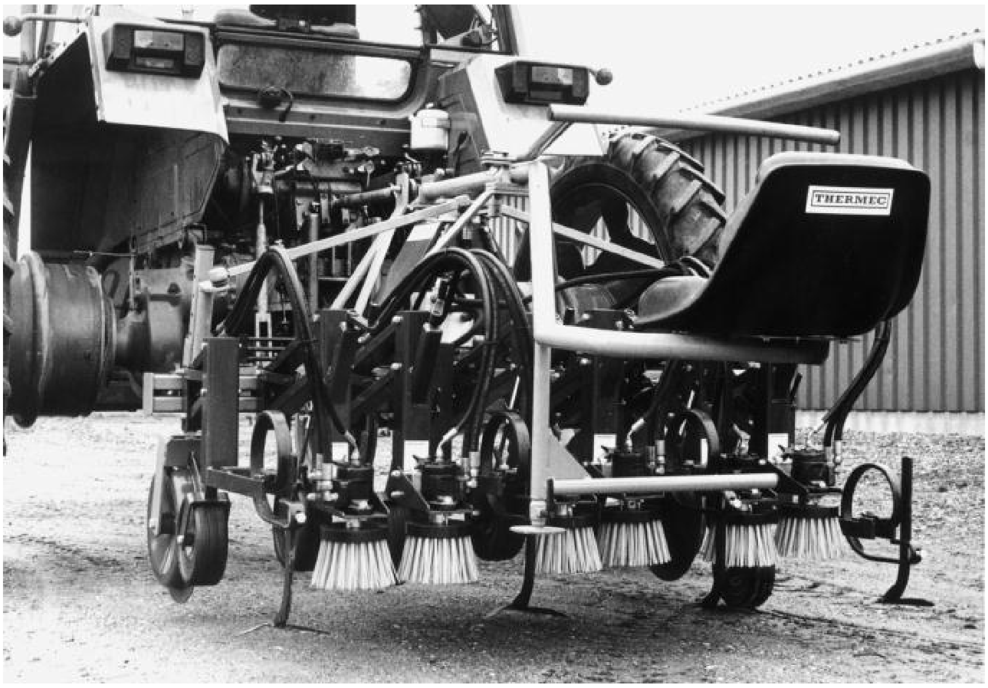


Figure 2.6: Vertical-rotating brush weeder use hydraulics and require an operator to control the brushes (Melander, 1997).

Fogelberg and Gustavsson (1999) studied the use of brush weeders to control weeds in carrots and reported that brush weeders are effective in the early growth stages of weeds, especially in the 2-4 true leaf stages. A working depth of 15 mm will uproot four to five to ninety percent of the weeds. They concluded that the main mechanism of weed control obtained by brushing weeding is uprooting, because brushing weeding exerts a greater root pullout force than the root anchoring force of weed plants.

Kouwenhoven (1997) also reported the study of brush weeders for in-row weed control. In an experiment conducted on corn and beet crops, it was determined that the brush mower had an optimum rotational speed of 240-360 rpm and rotated forward. The result of brush weeding with corn is more effective than manual weeding. However, it has been reported that sugar beet plants are damaged due to inaccurate manipulation and fine soil generated by brushing, and wet weather conditions, and weeds appear after weeding operations.

ECO-weeder

The ECO weeder is an in-line mechanical weeder that is mounted on a three-point suspension and is behind the tractor. It uses a tractor's power take-off (PTO) to drive the belt system, which uses tines to power two discs (Fig. 2.7), which is very similar to the brush weeder described above, but uses mechanical drives and does not require Any hydraulic power.Due to its low price and low maintenance costs, it is a good choice for small-scale vegetable growers. It is reported that the minimum tractor size required to power an ECO weeder is 14.7 kW (20 hp) when interacting with local farmers. The required PTO speed of 540 rpm still requires the operator to move the two rotating discs in the vertical direction of Tines into and out of the crop line. Farmers use a speed of 0.8 km / h (0.5 mph) to 2.4 km / h km. / h (1.5 mph), the rotational speed of the weeding element is estimated to be 150 to 300 Rpm, similar to the rotational speed of the brush weeder reported by Kouwenhov En (1997). Weeding machines can save up to 60% of weeding costs. Due to reduced labor requirements, manual weeding was carried out: two workers replaced eight workers (Univerco, 2011).

Figure 2.7: ECO weeder uses rotating weeding mechanisms with tines (Hillside Cultivator Company, 2011).

Chemical Weed Control

In the mid-20th century, the use of mechanical herbicides was reduced due to the introduction of herbicide sprays in North America and Europe (Cloutier et al., 2007; Hakansson, 2003). Due to the limited amount of labor and the high price, the use of herbicides has become more favorable, because after the Second World War, labor was becoming scarce because workers were more eager to work in cities than in rural areas, labor costs increased. As a result, labor rates increased from $0.10 per hour in the 1940s to $0.50 per hour in the 1950s and $1 per hour in the 1960s. In addition, the cost of using herbicides is more economical than standard practices such as mechanical tillage or manual weeding, helping to reduce yield losses (Gianessi and Reigner, 2007). Gianessi and Reigner (2006) reported that from 2001 to 2005, the cost of herbicides for vegetable crops increased slightly. They also reported that the cost of manual weeding has also increased, and the cost of manual weeding has increased from $8.75 per hour in 2001 to $10 per hour in 2005. Planting costs have also increased from $4.50 per acre to $5.84 per acre. Based on a 18.3 m (60 ft.) self-propelled boom sprayer, herbicide application costs are slightly lower, estimated at $4.00 per acre in 2001 and slightly increased to $5.21 per acre in 2005. These costs provide a reason why growers tend to use chemical weeding because of the cost advantage compared to manual weeding.

Spray the herbicide from a nozzle located on a tractor trailer or aircraft or helicopter. Weed control can be done on the line, between lines or in rows. Inter-row weeding involves the highest amount of herbicide (usually alachlor) from aircraft or large tractors, and there is no difference between cultivated plants and weeds. These applications pose a potentially significant ecotoxicological risk to non-target plants and associated pollinators.

Figure 2.8: On-the-row weeding through plane

In-row weeding is the most selective method of weeding in which herbicides are sprayed directly onto weeds from electric washing machines to avoid attacking plants. It is the most expensive technology and the most advanced technology. Another chemical weeding system consists of a fixed nozzle that pops up only when the nozzle is above the weed.

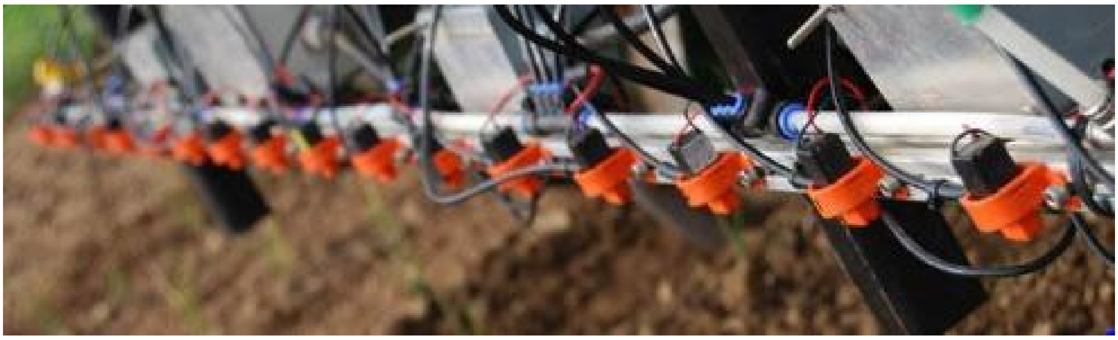


Figure 2.9: Intra-row chemical weeder with fixed nozzles

Both inline systems require a vision system that detects weeds and distinguishes them from seed plants.

Compared to mechanical farming, chemical weeding not only protects crops from weed competition, but also helps reduce crop yield losses. Mechanical farming has been difficult to cultivate in time because its fields hinder the entry of tractors and equipment, causing weeds to compete for nutrients in crops (Hakansson, 2003). Historical data presented by Gianessi and Reigner (2007) indicate that yields have increased due to chemical weeding. The researchers also showed that herbicides help increase corn and soybean yields.

However, interest in chemical weeding alternatives has increased due to environmental concerns, growing consumer demand for pesticide-free products, and improved herbicide resistance to weeds (Upadhyaya and Blackshaw, 2007). The use of herbicides is also increasingly restricted by pesticide use regulations, and consumer concerns and interest in organic foods are increasing (Slaughter et al., 2008).

The concentration of beetamine in the United States, in particular, ranges from 0.08 to 4.5 parts per billion (ppb) and is classified as a Class C pesticide by the US Environmental Protection Agency (USEPA), indicating limited evidence of carcinogenicity. Evidence for the bioaccumulation of alachlor in fish edible species as a detrimental effect of disease on growth and development raises concerns about its impact on human health. NIAB TAG, SRUC, Organic Research Center Elm Farm, Monsanto, Micron Sprayer Ltd, Tillett and Hague Technology Ltd, Garfords Farm Machinery and John Deere are investing in new alternative weeding methods. In a growing number of countries, consumer aversion to pesticides and their negative impact on the environment have led to restrictions on the acquisition and use of herbicides by the government. For the European Union (EU), the “EU Agricultural Pesticide Directive 91/414 / EEC” was proposed. According to Dirk A. G Kurstjens, although there are many different products, current herbicides use only 15–20 different modes of action, and only one new target has been commercialized in the past 20 years. Herbicide resistance has occurred in all known target sites, including 310 weed biotypes involving 10 glyphosate resistant weeds. It has been estimated that over the past decade, 100 new resistant biotype weeds have been resistant, due to the use of monoculture. Repeated use of several modes of action promotes the development of weed resistance, thereby reducing the effectiveness of chemical weed control. Weed communities have banned the use of glyphosate for 5-8 years, so other herbicides are needed to control weeds. However, these alternatives are rarely found, and the average time from synthesis to sale of new pesticides is 9 years or more.

Biological Weed Control

Biological weed control uses specialized insects (such as rye, sorghum, mustard, velvet beans, black walnut) to reduce weed growth or eventually kill them. It is known that these plant areas release chemicals that directly affect weeds by affecting weed growth and/or seed germination, or chemicals that indirectly affect weeds by affecting soil biology (eg, by inhibiting mycorrhizal vaccination potential) . This phenomenon is called allelopathy and can be used to destroy or inhibit weeds.

This environmentally friendly option has many advantages over other weed control. Farming can damage the soil structure or make the soil susceptible to erosion. In the long run, no synthetic herbicides are added to the environment, and the control effect is longer lasting and cheaper. Using this method for weed control is easier and/or more acceptable than in mechanical or chemical methods, in steep or sloping terrain or in environmentally sensitive areas such as rivers or lakesides. It offers interesting potential for weed management systems, but more research is needed to make the most of this technology in field conditions.

Other Forms of weed Control

There are other types of non-chemical weeding methods such as flame weeding, pneumatic weeding and laser weeding. These methods require additional energy to control weeds. For example, a flame weeder requires propane gas to generate heat, which increases the temperature of the weeds and burns the biomass of the weeds or the plant cells that cause the weeds to break and destroy the structure of the plants (Figure 2.10). Pneumatic weeders require the use of an air compressor that injects compressed air into the soil to loosen and uproot small weeds (Figure 2.11; Bond et al., 2003). Both methods have a large amount of energy requirements. Flame weeders require 28.2 to 131 liters of fuel per hectare (3 to 14 gallons of fuel per acre), depending on strength and coverage. Pneumatic weeders use a lot of power and require a 60kW tractor to generate high pressure to control weeds on sick crops. This is twice the power required for conventional excavation (Weide et al., 2008). However, they are all suitable for organic production systems because they use a chemical-free method with minimal interference to the soil.

Figure 2.10: A crop-row flame weeder using LPG gas to control weeds inside the crop row (Physical weeding, 2011).

Figure 2.11: Pneumatic weeder uses air to blow out weeds (weide et al., 2008).

Comparison Between Different weed Control Methods

Various types of in-row weed control methods can be used, resulting in different costs. Various mechanical weeding methods were compared to chemical weeding methods and conventional manual weeding methods based on Edwards (2009) and Gianessi and Reigner (2007) (Table 2.2). Edwards (2009) provides a report on estimating the cost of agricultural machinery. Manual weeding costs the most, at $312 per acre, while chemical weeding costs are the lowest. These costs are based on a labor cost of $12 per hour. Farmers tend to use chemical methods to control weeds only because of the huge cost differences. In addition, the herbicidal effect of chemical weeding can reach almost 90%. The lowest cost mechanical method that can be used is to reverse the weeder, which costs $22 per acre and produces almost 80% weed control. Manual weeding rates are based on manual weeding of lettuce (Gianessi and Reigner, 2007). The chemical weeding rate is based on a 6.1 m (20 ft.) boom sprayer operating at 9.7 km / h (6 mile / h). The operating speed of the finger weeder is based on an estimated operating width of 0.76 m (30 inches) and the operating speed of the twisted weeder is based on an estimated 0.18 m (7 inch) operating width of the single row twisted weeder. The working speed of the brush and ECO weeder is based on a double weeding mechanism, with a single row brush weeder and an ECO weeder with an estimated working width of 0.64 m (25 inches). The flame weeder operates at an estimated working width of 0.76 m (30 inches) based on the tractor mounted flame weeder.

Table 2.2: Comparison of different intra-row weeding machines with chemical, flame and manual weeding in terms of cost, operating speed, operating depth and weed control efficacy.

Method	Cost (USD/acre)	Work rate (ha/hr)	Operating Speed(km/hr)	Operating depth (mm)	weed control (%)
Chemical weeding	15	2.9-5.9	4.8-9.6	On surface	80-90
Torsion weeder	22	0.1-1.4	6.4-8.1	0-25	60-80
Finger weeder	38	0.3-0.6	4.8-9.6	10-40	55-60
ECO weeder	44	0.05-0.15	0.8-2.4	25-50	60-80
Brush weeder	74	0.1-0.3	1.6-4.8	25-50	60-80
Flame weeder	70-90	0.1-0.5	1.6-6.4	On surface	80-90
Manual weeding	312	0.01	NA	0-50	65-85

Automated Technology in weeding

Automation is defined as the technology, method, or system that operates and controls a process or machine without manual intervention and continuous operator input. Automation also optimizes the power provided by the machine, so electronic hardware, sensors, actuators and software are often used to replace the energy input in the process (Chancellor, 1981). Weed control, especially in the crop line, benefits not only from the intelligence of manual weeding, but also from the higher productivity associated with mechanical weeding. Automation technology has also been applied to weed control to combine the advantages of manual and mechanical methods. Through the use of automation, the machine can identify crops and weeds and remove weeds with precisely controlled equipment (Bakker, 2009). Slaughter et al. (2008) In the review of the automated robot weed control system, four core technologies required for automatic weed control were identified: (a) guidance, (b) inspection and identification, and (c) accurate weed control in the line. And (d) positioning. He also described several in-row weeding mechanisms for robotic drives. One of the mechanically based designs is the use of mechanical knives that can be quickly positioned into and out of crop rows.

Line navigation systems can use machine vision for crop line detection and/or global positioning system (GPS). Machine vision is able to identify crop rows at travel speeds from 2.5 km / h to 10 km / h and produces very small errors of 12 to 27 mm. At the same time, GPS can provide lateral positioning accuracy along the line with an RMS error of 6 cm and a maximum error distance of 13 cm (Slaughter et al., 2008). However, line guidance systems require the use of real-time kinematics (RTK) GPS-guided planting systems to grow crops, or use some type of geo-referenced mapping technique to map crop rows. The detection and identification of weeds and crops is a very difficult task in real time. Weed recognition technology relies on machine vision systems and image processing techniques described by Gonzales et al. (2004), such as biological morphology, spectral features and visual structure. Steward and Tian (1999) developed real-time machine vision weed detection for outdoor lighting conditions using the Environmental Adaptive Segmentation Algorithm (EASA). Tang et al. (2000) Color image segmentation using a binary-encoded genetic algorithm (GA) for outdoor weed identification under different lighting conditions.

Precise in-row weed control can be performed mechanically, chemically, thermally or electrically. Mechanical knives used in mechanical automatic weed control (such as automatic thinner) can be used to move in and out of the crop line, or to use a height that can be adjusted to height (Astrand and Baerveldt, 2002). The control of automated chemical herbicides (such as precision spray systems) was developed by spraying weeds in a spray system generated by a visual system using a separate spout (Lee et al., 1999). Electroweed control was developed by applying high pressure (15-60 kV) discharge or continuous current to small weeds using precise probe position control (Diprose and Benson, 1984; Blasco et al, 2002). Accurate thermal weed control involves the use of infrared sensors to detect weeds and automatically turn on weeds detected by flame nozzle combustion (Merfield, 2011).

Examples of Automated weeders

Tillett et al. (2008) The weeder was tested using computer vision to detect plants. The automatic in-row weeder uses a rotating semi-disc that rotates to avoid contact with the crop during weeding. The camera is mounted front and rear at the center of the implement at a height of 1.7 m so that the bottom of the field of view is vertically below the camera and the entire width of the bed can be seen over a length of approximately 2.5 m. Plant locations along the crop line and their position relative to the turntable were examined using computer vision (Figure 2.12). Experiments were carried out on cabbage plots using a 0.3 m in-row crop spacing and a forward velocity of 1.8 km / h (0.5 m / s). After transplanting (DAP), weeding treatment was performed on days 16, 23 and 33. The best results were obtained on the 16th and 23rd day after sowing, and the number of weeds decreased by 77% and 87%, respectively. However, after the next 2 weeks of weed re-growth and new germination, the number of weed plants after 16 DAP herbicide treatments was still reduced by 74%, while the number of weed plants after 23 DAP treatments was still reduced by 66. %. Under experimental conditions, studies have shown that early weed control successfully controlled subsequent weed regeneration and new germination. The machine was commercialized under the name Robocrop (Inman, 2011).

Figure 2.12: Automated weeder machine using hydraulics to rotate semi-circle discs that are used for weed control (Tillett et al., 2008).

Astrand and Baerveldt (2002) developed an agricultural mobile robot with vision-based perception for weed detection and subsequent control. The machine requires two cameras, a grayscale camera with a near-infrared filter to obtain a high-contrast image at the front to identify the position and orientation of the crop line, and a color camera to identify the location of the crop. Located in the center. The machine is facing down towards the soil (Figure 2.13). The weeding tool is a rotating wheel that is perpendicular to the crop line and is located at the back of the machine. When a gap between crops is detected, a pneumatic cylinder is used to lower the tool and provide some farming action in the crop-to-crop area. The weeding robot exhibits good sensing performance at a speed of 0.2 m / s. The crop line detection camera is able to identify crop rows with a +2 cm error based on the line recognition algorithm. Crop Detection Color cameras use image segmentation techniques to classify weeds and crops by color and shape characteristics to successfully detect crops. However, the herbicidal efficacy of the machine has not been reported. The study focuses more on crop detection and crop detection systems than on weed control.

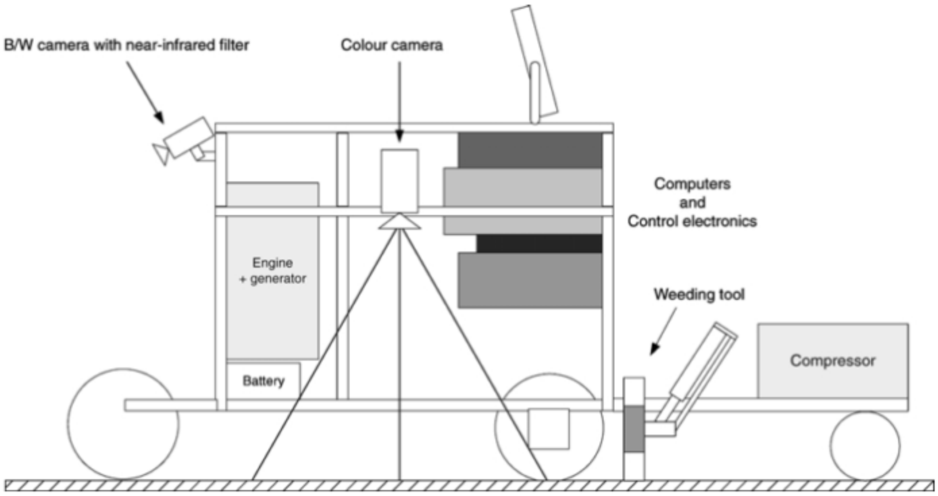


Figure 2.13: Major components of the mobile robot (Astrand and Baerveldt, 2002).

Cloutier et al. (2007) reported the in-weed weeder developed by the French company Sarl Radis (Fig. 2.14). The automatic weeder senses reflected light from the field surface to detect crops and uses a control system to control the movement of a head around the crop. It was originally developed for transplanted crops and can only be used if the weeds are much smaller than the crops. This is usually the condition for conventional weeding, in which case weeds are controlled and weeds are still small compared to crops. According to reports, the prototype works at a speed of 3 km / hr. Farmers Guardian (2007) reported that the Dutch Applied Plant Research Organization is continuing to develop the prototype, hoping to achieve a speed of 4-6 km / h and effectively control the weeds of higher populations between crops.

Figure 2.14:Sarl Radis intelligent weeder from France uses an automated hoe that moves in and out of the crop row (Cloutier et al., 2007).

Griepentrog et al. (2006) Developed an autonomous in-row weeder based on RTK (Real Time Kinematics) GPS to locate the weeder relative to the crop seed map developed at the time of crop planting. The weeder uses a rotary weeding mechanism that is rotated by an electrohydraulic motor. The mechanism consists of eight tines with an outer diameter of 0.234 m (Fig. 2.15). These tines can be individually controlled to follow two different cusp trajectories. An inactive track trace can be described as a cycloid curve, where the curve is tracked by points on the circumference of the circle as the circle rolls on a straight line. Another trajectory is where the tines move in and out of the crop line. The study claims that the rotor weeding mechanism has the ability to control weeds in crops until the soil is as close to the crop as possible without damaging them. The herbicidal effects of these tines are achieved by uprooting, weeding soil cover and cutting roots. Parameters that achieve a particular tilling effect include the ratio of forward speed to rotational speed, the diameter of the tines, the number of tines, the shape and design of the tines, and the lateral offset from the crop row. The machine is connected to an automatic tractor driven by an RTK GPS. The lateral movement of the weed mechanism and the activation of the rotor tines are based on the seed map of the previous seeding operation.

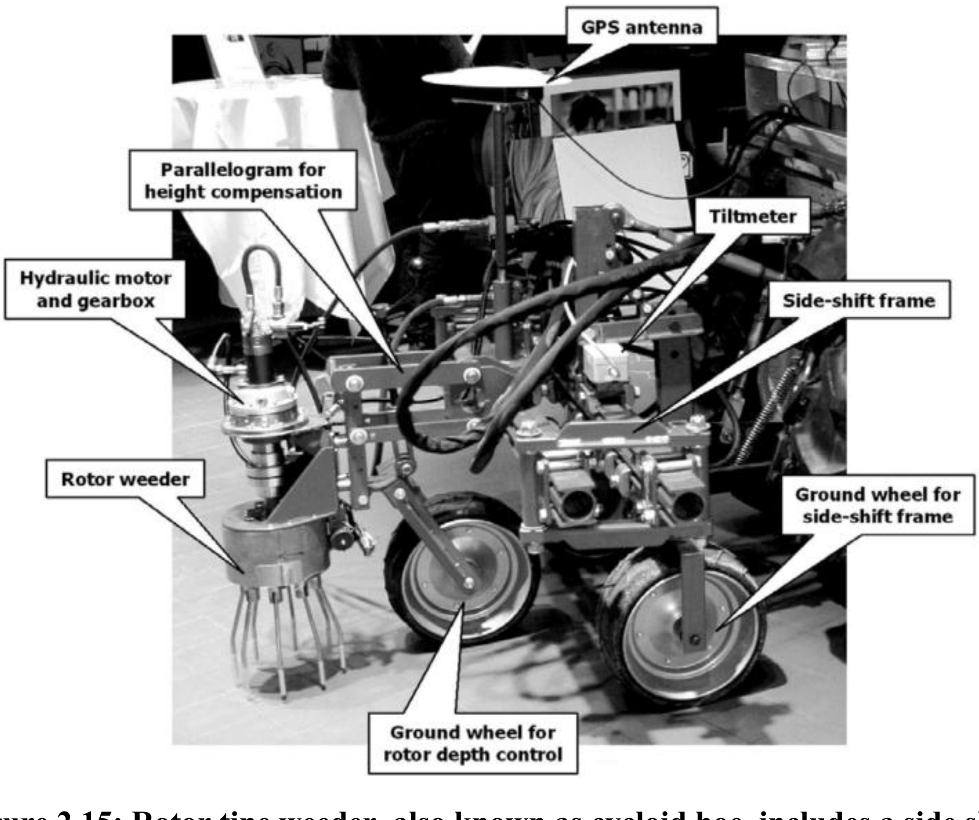


Figure 2.15: Rotor tine weeder, also known as cycloid hoe, includes a side shift mechanism for lateral control and ground wheel for depth control (Griepentrog et al., 2006).

Unmanned vehicle with automated weed system

Farming machinery tools are constantly being improved, and the current trend is the development of automated guidance systems. This approach will lead to self-directed, self-motivated and autonomous machines that will grow crops with minimal operator intervention. Within this range, one or more cameras will be used for real-time image acquisition and analysis. A GPS-based positioning system will be used to map the location of crops and weeds. With the help of sensors, the tillage system will be able to selectively control weeds in the crop line, which will allow the machine to separate crops from weeds and selectively eliminate weeds.

Simon Blackmore of Harper Adams University College insists that 80% of the energy entering farming suggests the manipulation of large tractors and the damage they cause to crops across crops. The proposed solution is for agricultural light and small machinery, such as driverless cars, self-propelled, autonomous, low-power machines. Even considering the fixed costs of machinery and maintenance, the use of such robots for agricultural tasks such as weeding can reduce the cost for field operations. Blackmore, citing Danish research on concrete agriculture, concluded that these agricultural robots, called agricultural robots, can cut the cost of weeding by half. In the agricultural robot, Carre Anatis manufactured by Agri Machinery uses a ho head fixed to the frame to perform inter-row weeding. A total of three heads, one for each row. In contrast to the previously described machine, the machine's particularity is unmanned and powered by 3 batteries (with 4 hours of autonomy and 4 hours of charging time). A hybrid version with generator can also be used.

Figure 2.16: Carre Anatis

Another project for fully automated robots is the IBEX project. IBEX is co-financed by Innovate UK, whose mission is to identify and eliminate weeds that are sprayed on remote hillsides that are inefficient or impossible to use with tractors or quad bikes. The car continues to drive. The achievable terrain has a slope of up to 45 degrees; it can pass through dirt and lush vegetation, including bracken. It combines the use of sensors and Bayesian machine learning software to fully understand its surroundings. It excels at independent navigation, covers preset user target areas or optimizes routes using data acquired by itself. It provides an always active camera and data link that allows administrators to intervene when needed.

Figure 2.17: IBEX agribot

Hortibot was developed by the Danish Institute of Agricultural Sciences (a branch of the University of Aarhus, Denmark). This is an unmanned vehicle that detects weeds through a vision system and then selectively sprays herbicides on it.

Figure 2.18: Hortibot

The machine described in this paper is an unmanned vehicle that can be used to provide in-row weed control using a spatula. Carre Anatis is the only machine that provides mechanical weeding, but it is a type of interline control. Weed control has not been developed.

The AgBot II is an innovative agricultural robot prototype designed and manufactured by Queensland State University researchers and engineers and heavily funded by the Queensland Government. AgBot II forms part of a new generation of crop and weed management mechanisms designed to work in autonomous communities in wide-area and horticultural crop management applications. Robotic cameras, sensors, software and other electronic devices enable it to navigate the fields, fertilize, detect and classify weeds and mechanically or chemically kill weeds, providing farmers with a tool to help reduce operations. Cost and efficiency losses.

Figure 2.19: AgBot II

CHAPTER 3. INTER-ROW WEEDER DESIGN PROCESS

From the literature review outlined in Chapter 2, some important design and requirements can be seen. This chapter contains the design process for the in-row weeder. The design process first lists the design goals and then selects the weeding mechanism by analyzing and discussing several design concepts.

In order to start the design process, several design goals and requirements for the weeder were set.

- The weeder will be used for weeding of vegetable crops.
- Weeding machine will be used for large-scale vegetable crop production.
- The weeder should be able to control weeds with minimal damage to crops.
- The goal of herbicides is to control weeds in the early stages of growth, as weeds are easily distinguished in the early stages of growth.
- The overall size of the weeder should not be too large, as it will be transported long distances by ordinary trucks.
- The weeder can be towed by its own power system.
- Because the weeding operation can be done with less power than previously tested, the weeding mechanism will use electric rather than fluid power.

Design Concept

The design requirements for selecting a weeding mechanism are:

a) Effective weeding mechanisms should be able to weed, bury and cut weeds at the same time.

b) The working diameter of the weeding mechanism should be as small as possible in order to operate within the crop line.

c) The working depth of the weed mechanism should not exceed 50.8 mm (2 inches) because the early weeds did not reach the soil.

Four weeding concept concepts are considered as design alternatives:

1. Saw-teeth mechanism

The mechanism uses a rotating circular saw blade (hole saw) mounted on a vertical shaft and rotated by a vertical axis. In the presence of weeds, this mechanism is reduced to the soil to destroy weeds. The size of the weeding mechanism is small, so it is easy to move in and out of the crop line. However, it may not produce a good weeding effect because although it easily penetrates deep into the soil, it still requires a lot of force to move the weeding mechanism laterally or forward.

2. Flat blade mechanism

The mechanism uses flat blades mounted on a vertical axis and oriented horizontally. In the case of weeds, the rotating mechanism is lowered into the soil. This mechanism is similar to the mechanism used in mobile, backpack weeders or herbivores. This concept is very effective for weeding, but it is not effective for burying and weeding. It only cuts weeds on the surface of the soil.

3. Nylon brush mechanism

This mechanism uses multiple nylon brushes to attach to the disc. With this concept, the mechanism can be more in contact with weeds, making it a good potential for higher weed control. It also buryes and uproots on weeds as it removes weeds from the soil. This concept requires low speed because it has a larger mechanical surface area in contact with the soil than other weeders. However, due to the cleaning effect, this concept produces more dust, especially in dry soil conditions.

4. Flexible tine mechanism

The mechanism uses a plurality of flexible steel teeth that are attached to the disc and oriented vertically or offset from the vertical plane by 10 to 20 degrees. This mechanism can uproot, weave and cut weeds as weeds rotate. The speed requirement depends on the number of tines used, and an increase in the number of spikes will reduce the speed requirement. This mechanism is similar to the nylon brush mechanism except that it uses a small amount of steel teeth to reduce dust generated during operation.

Decision matrices were developed to study different mechanisms with specific criteria (Table 3.1). The criteria for selecting the most appropriate mechanism are the ability to weed, the ability to weed, the ability to bury weeds, the ability to produce less dust, the ability to handle soil depths up to 50.8 mm, and the ease of handling. As can be seen from the decision matrix, the flexible tipping mechanism is the best choice because it satisfies all six conditions. Nylon brushes meet five criteria but do not meet the requirements for creating low dust levels. This is because the cleaning effect of the brush produces a lot of dust under dry soil conditions. The sawtine mechanism does not meet two criteria, namely weeding ability and ease of operation. Because this mechanism will require a lot of force to move the weeding mechanism laterally after it has penetrated into the soil. The flat blade mechanism meets the fewest conditions, with only three conditions. This mechanism does not allow the weeds to be uprooted or buried because it only cuts weeds on top of the soil.

Table 3.1: Design decision matrix to choose the most suitable mechanism to be used on the intra-row weeder based on six criteria.

	Mechanism			
Criteria	Saw teeth	Flat blade	Nylon brushes	Flexible tines
Ability to cut weeds	✓	✓	✓	✓
Ability to uproot weeds	X	X	✓	✓
Ability to bury weeds	✓	X	✓	✓
Ability to create less dust	✓	✓	X	✓
Ability to work at 50.8 mm soil depth	✓	X	✓	✓
Easy maneuverabilit y	X	✓	✓	✓

After considering these concepts, the principle of a flexible tine mechanism similar to that used by the ECO weeder was used because it produced less dust than the nylon brush used in the weeder mentioned in Chapter 2. Entering the soil, it can cut, remove and bury weeds at the same time. Due to the advantages of brush weeders using rotating brushes, the rotary weeding mechanism is highly valued.

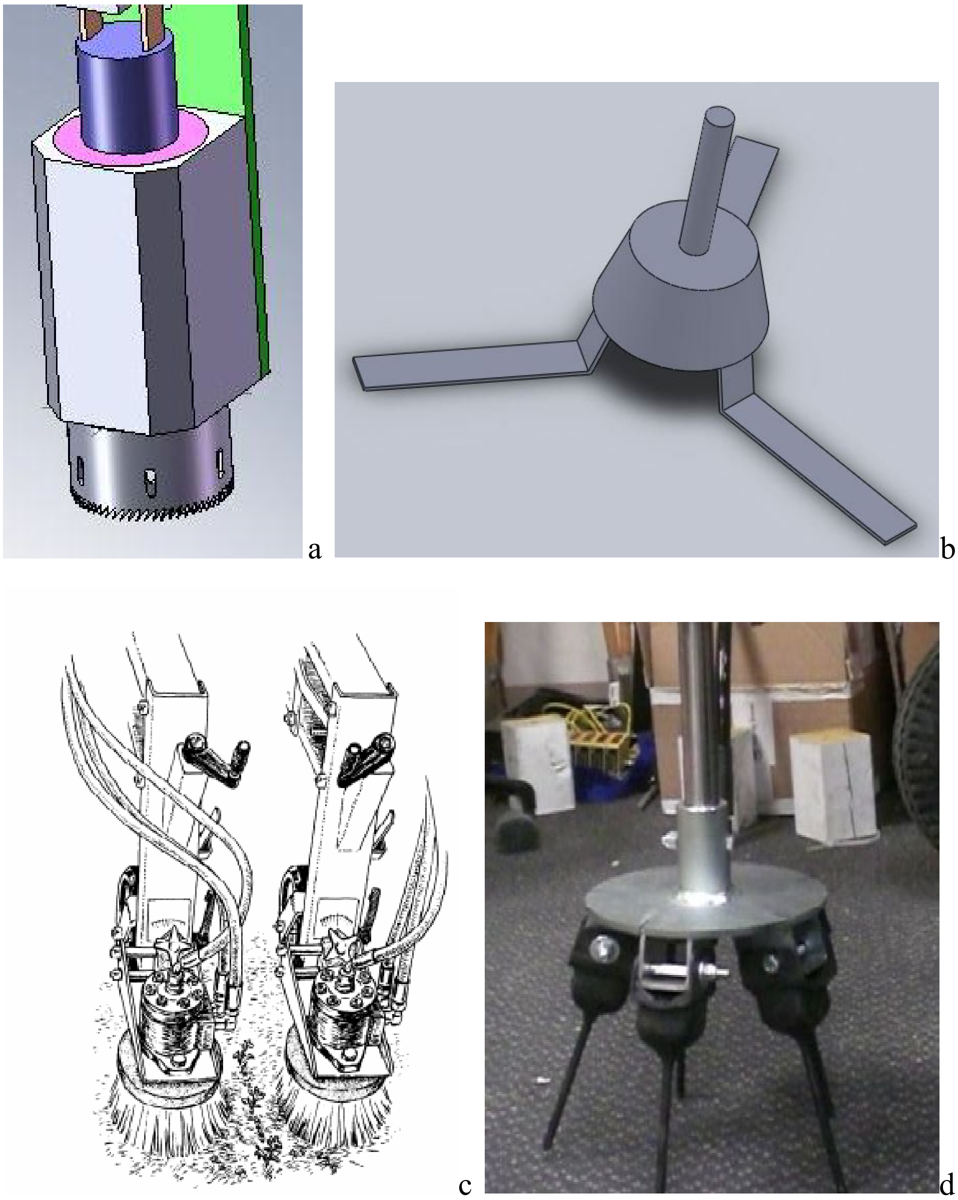


Figure 3.1: Different types of weeding mechanisms considered to be used for weed control. a) saw teeth b) flat blades c) nylon brushes d) flex tines.

In Chapter 2, the brush weeder and the ECO weeder are identified as having the ability to weed, cut and bury weeds, and can achieve 60% to 80% of the weeding efficiency of weed plants at a forward speed of 1.6 to 4.8 km / H. However, the brush weeder concept described in the literature requires the operator to control the movement of the brush in the crop row (Cloutier et al, 2007; Melander, 1997; Fogelberg and Gustavsson, 1999; Kouwenhouven, 1997). In the research project documented in this paper, the movement of the flexible tip-tine weeding mechanism is automated, rather than relying on the operator to control the brush. Brush weeders are described in (Cloutier et al, 2007; Melander, 1997). In the study, a motor system was used to rotate the flexible teeth. As mentioned in the previous chapter, the electrical system hydraulic system has been selected for a variety of reasons, including:

a) Electrical systems have faster response times than hydraulic systems.

b) More precise control of the electrical system compared to hydraulic systems

c) Power consumption can be easily monitored when using an electrical system to understand the effects of soil depth, actuator speed and other factors on the required power.

d) The electrical system will not leak and will not cause soil pollution.

Weed Control Mechanism and Actuation System

The main design work is devoted to the design of weed control mechanisms and actuation systems. The following considerations were considered when designing the system:

1) There should be two actuators on each side of the crop to remove or destroy the weed plants on the left and right sides of each row of crops.

2) In order to control weeds, motors with high torque at low speeds should be used.

For motors, two known types, stepper motors and servo motors, can be used. The stepper motor uses a plurality of tineed electromagnets or pole stators that are arranged around a rotating sun gear that will move the teeth through a tine or a step, according to which the servo motor is a normally DC motor. A permanent magnet assembly with a central rotary commutator receives current. This current will flow through the magnet, generate a magnetic field, and rotate the commutator to produce torque, then rotate the motor shaft. Since I decided to use the electrical system for the weeding execution system, the DC servo motor was chosen instead of the stepper motor for the following reasons:

a) Servo motors are more efficient than stepper motors because stepper motors consume a lot of power even without a load.

b) The servo motor uses a closed loop system, which means that the motor system includes feedback on the data, such as speed control and positioning. The stepper motor uses an open-loop system, and the controller will issue commands that rotate at a specific speed without knowing the actual speed at a particular load.

c) Servo motors produce high power output even in small size, while stepper motors can only produce low power due to size and weight.

In determining the most suitable DC servo motor, I studied two types of brushed DC motors and brushless DC (BLDC) motors. A brushed DC servo motor is a typical DC servo motor in which a commutator equipped with a brush rotates between permanent magnets. As the name suggests, in a BLDC motor, an external switch that is synchronized with the rotor position is used to replace the rotational motion of the brush with a rotating permanent magnet rotor. For the following reasons, I decided to use a BLDC motor instead of a brushed DC motor:

a) Since the brushes pressed against the commutator must be replaced periodically, the brush DC motor requires more maintenance. BLDC motors do not require this type of maintenance because they do not use brushes.

b) Compared to brushed DC motors, BLDC motors can generate more power in a compact size.

c) Downstream pressure control is also considered to be self-adjusting. The spring mechanism will likely ensure that the weeding mechanism remains in contact with the soil.

Mathematical Model of the Actuation System

Kinematics

Kinematic Analysis

To estimate the soil forces that will act on the drive system, a single-tine soil dynamics model developed by Godwin and Odogherty (2007) was used. The model is based on the work of Godwin and Spoor (1977), Godwin et al. (1984) and Wheeler and Godwin (1996). The model has been implemented in a spreadsheet that calculates the draft and vertical forces acting on a single tines in the soil. The soil parameters used in this model are soil bulk density and cohesion. The tine parameters used in the model are tine working depth, tine width, rake angle and speed. The rupture distance ratio, m, is the ratio of the forward soil rupture distance to the critical depth. The N factor is an infinite factor obtained by interpolation of the rake angle, ranging from 20 to 130 degrees and the internal friction angle of the soil (range 0 to 0). 45 degree). Calculate the calculated value of the soil force acting on the tines by the value of the power P; the tip width W of the crescent side of the soil failure mode; the lateral force, S; and the lateral destructive force Q, using the following formula,

$$P = \gamma {d_c}^2 N_\gamma + c d_c N_{ca} + q d_c N_q \tag{1}$$

$$W = w + d_c\left(m - \left(m - \frac{1}{3}\right)\right) \tag{2}$$

$$S = \gamma v^2 N_a d_c / g \tag{3}$$

$$Q = \frac{w_c N_c}{d - d_c} + \frac{0.5(1 - \sin\phi)\gamma w N_q}{d - d_c} \tag{4}$$

where γ is the soil bulk density, in kN/m^3; d is the working depth, in m; d_c is the critical depth, in m; cohesion is the, c in kN/m^3; q is the soil surcharge, in kN/m^3; w is the tine width, in m; m is the rupture distance ratio; g is the gravitational acceleration, in m/s^2 and ϕ is the internal friction angle, in degrees. All N are obtained by interpolation of rake angle, α in degrees.

From which the draft force (D) and the vertical force (F) can be obtained by

$$D = (PW + S(w + 0.6d_c))\sin(\alpha + \delta) + Q + c_a w d_c \cos\alpha \quad (5)$$

$$V = -((PW + S + (w + 0.6d_c))\cos(\alpha + \delta) + c_a w d_c \sin\alpha) \quad (6)$$

P is obtained from (1), W is obtained from (2), S is obtained from (3), and Q is obtained from (4), where α is the anteversion angle. Ca is the soil interface adhesion in kN / m3; δ is the interface friction angle (in degrees).

Using the spreadsheet containing the cusp model, the water intake required to move the 90 degree rake at the lateral velocity obtained was estimated. The soil parameters of the friction soil and the viscous soil provided by Wheeler And Godwin (1996) were used because no actual soil data were available. There was no significant change in traction between the different velocities, but there were differences between the different soils (Figure 3.2). For this simulation, the average of the maximum forces from the two soils is . As a result, a draft force of 40 N was obtained. For modeling, a weeding mechanism with 4 tines was chosen, so the total draft force is 160 N.

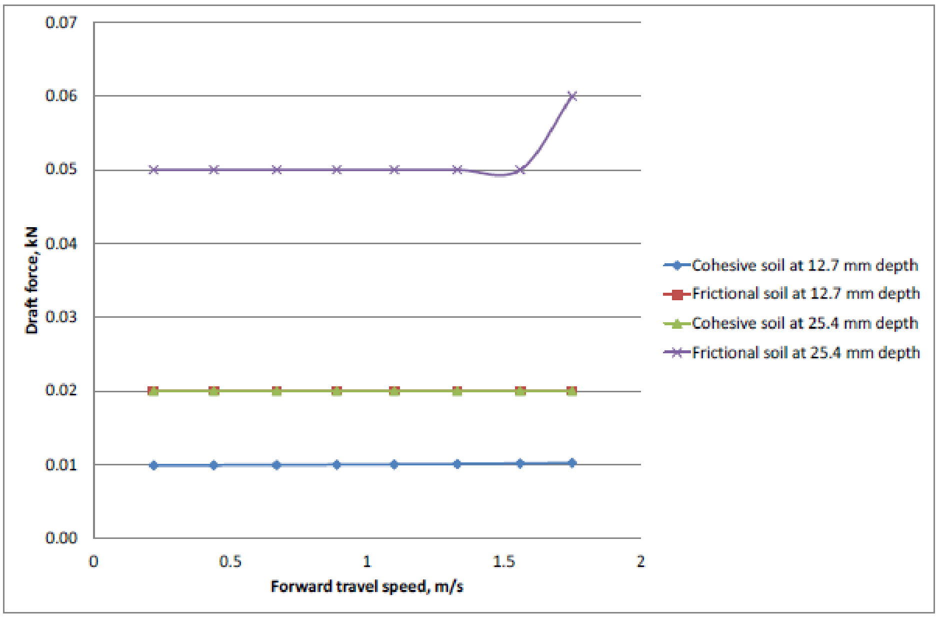


Figure 3.2: Draft force of cohesive and frictional soils with different travel speeds.

In order to determine the motor that is most suitable for rotating the weeding mechanism, the draft force obtained using the single tine model is used. Calculate the torque required by the weeding mechanism motor using the following formula:

$$\tau = F_{soil} * r \quad (7)$$

where F_{soil} is total draft force for 4 tines and r is the weeding mechanism radius.

Based on work done by Kouwenhoven (1997) and communication with Iowa vegetable growers when using the ECO weeder, the motor's target maximum speed is

500 rpm. The compact BLDC motor NEMA GM86BLF 115B-430 was chosen to handle 2.1 N-m power at 3000 rpm. The motor is paired with a 6:1 reduction gearbox to produce a torque of 12.6 N m with a motor speed of 500 rpm.

MODEL		GM86BLF 80-430	GM86BLF 105B-430	GM86BLF 115B-430	GM86BLF 130-430
Number of pole				4 Poles	
Number of phase				3 Phase	
Rated voltage	Volt	48	48	48	48
Rated speed	RPM	3000	3000	3000	3000
Rated torque	Oz-in	143	258	300	356
	Nm	1	1.8	2.1	2.5
Rated current	A	8.3	14	17	18.3
Rotor power	Watt	314	550	640	785
Peak torque	Oz-in	426	800	900	1068
	Nm	3	5.6	6.3	7.5
Peak current	A	25	42	51	55
Back E.M.F	V/KRPM	13.7	13.7	13.3	13.3
Rotor inertia	kg.cm²	1.2	2.3	2.6	3.2
Body length	mm	80	105	115	130
Weight	Kg	2.3	3.4	3.8	4.3

Figure 3.3: NEMA motors table

Simulation of tine rotary motion

A tine kinematics model was established to estimate how many tine paths affect the tine working area at different travel speeds and speeds, which is the soil area affected by the teeth. O'Dogherty et al. A similar model was developed (2007), but more focused on the kinematics of the rotating disc than on the rotating tines.

The purpose of this modeling and simulation work is to achieve the minimum speed required to achieve good tillage coverage at different driving speeds. Good tillage coverage means that the tines of the weeding mechanism will pass at least once in the same area as the front tines.

Tine kinematic model

The time t (in seconds) it takes to move forward at a certain travel speed

$$t = \frac{d}{v} \tag{8}$$

Where d is the travel distance in meters and v is the forward speed of the weeder in m/s.

At the same time, the tine will move in an angular direction, ψ , in radians, given by

$$\psi = \omega t \tag{9}$$

where ω is the angular velocity, in rad/s.

Tine Initial Position

The angle between each tine, θ, in radians, is given by

$$\theta = \frac{2\pi}{n} \tag{10}$$

where n is the number of tines.

For the tine movement, the general equations of converting polar coordinates to Cartesian coordinates were used.

For tine 1, n = 1, the position is

$X_o=0$ (11)

$Y_0= r$ (12)

where r is given by

r = weeding mechanism radius + tine radius (13)

For the other tines, the X_i and Y_i positions are given by

$X_i= r \cos \phi_i$ (14)

$Y_i= -r \sin \phi_i$ (15)

for the angle, ϕ, given by

$$\phi_i = (n-1)\theta - \pi/2 \tag{16}$$

Tine Moving Positions

For the first tine, the position at the next interval, ti is given by

$Xi= r \cos \phi + d\ i$ (17)

$Yi= r \sin \phi$ (18)

where ϕ is given by:

$$\phi_i = \frac{\pi}{2} - \psi i \tag{19}$$

and ψ is from (2) and i=1,2,3,…..,i.

For other numbered tines, the next position is given by

$X_i= r \cos \phi_i +d\ i$ (20)

$Y_i = -\, r \sin \phi_i$ (21)

where ϕ is given by:

$$\phi_i = ((n-1)\theta + \psi i) - \frac{\pi}{2} \quad (22)$$

Soil Working Zone Model

The model developed by Wheeler & Godwin (1996) was used as a reference for estimating the working area of the tooth. The tines working area is the area of soil disturbance caused by the sharp tooth work at a specific soil depth. When the soil is cultivated by sharp teeth, the weeds in the tines working area will be uprooted, buried or felled, and as a result, the weed canopy in this area is disturbed and the weed canopy is reduced. According to (Godwin & O'dogherty, 2007), the herbicide drive system developed by (Ahmad et al., 2011) uses a sharp tooth that is considered to be a narrow tines because the aspect ratio (d / w) is between 1 and 6. . Using this as a reference, use the model (Figure 3.4). Within a certain working depth d and a certain blade width w, the model shows that the width of the working area is almost the distance d from the left and right sides of the tines.

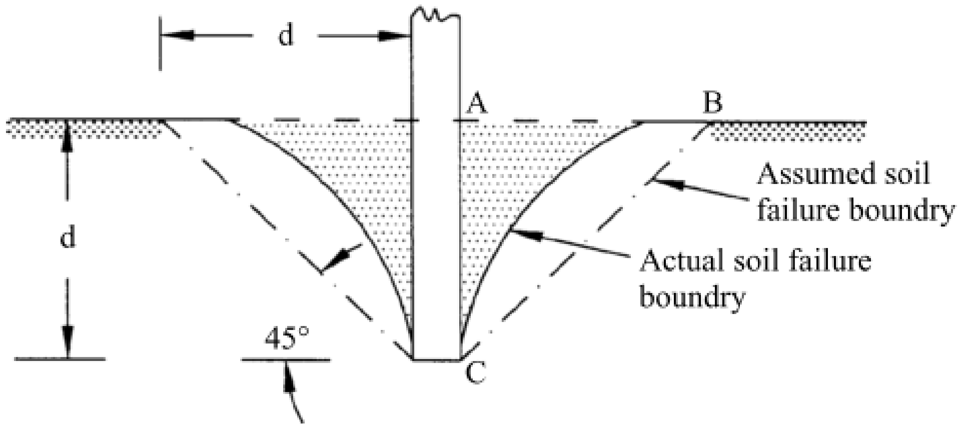


Figure 3.4: Cross-section of typical tine failure soil profile with working depth, d and tine width, w (Wheeler and Godwin 1996).

The tines were tested in the experimental diagram. Using a working depth of 25.4 mm (1 inch), preliminary tests showed that the width of the working area of the pointed tin was only 12 mm (0.5 inch) on either side of the tines. However, this width is affected by dry weather and low soil moisture content. The distance between each of the tines is targeted at the same distance. The soil is also very hard and too dry, making it difficult for the sharp teeth to enter the soil..

In order to determine the working area of a certain number of rotating tines, a predefined value must be used for the above equation. Three different travel speeds (0.8 km / h, 1.6 km / h and 2.4 km / h) were tested using a weeding mechanism with five tines. As noted above, the goal is to achieve a minimum angular velocity of the sharp-tooth weeding mechanism required to achieve an acceptable working area that overlaps or contacts between each tines.

Assumptions and Limitations

1. The simulation results are only applicable to the soil conditions used during the initial experiment. If the tines are used for different soil conditions, the actual work area should be re-evaluated.

2. The tines movement is considered to be a perfect circular motion without any obstacles, such as rock. This situation makes modeling easier.

3. Since the working depth also affects the time working area, the working depth is considered to be constant at 25.4 mm.

Simulation Results

The five-tine weeding mechanism allows the teeth to work at a diameter of 22.9 cm (9 inches). According to the simulation results, the same distance is obtained between each fork path, and the rotation speed must be increased for each increase of the travel speed. Simulations were only performed over a short range of travel to view a clear view within the path distance of each tines.

When the slowest travel speed of 0.8 km / h was observed, the minimum effective speed required was observed to be 200 rpm (Fig. 3.5a). When the driving speed is increased to 1.6 km / h, the required minimum speed is also increased to 350 rpm (Fig. 3.5b). The fastest travel speed for simulation is 2.4 km / h, and the minimum speed required for effective weeding is 500 rpm (Figure 3.5c).

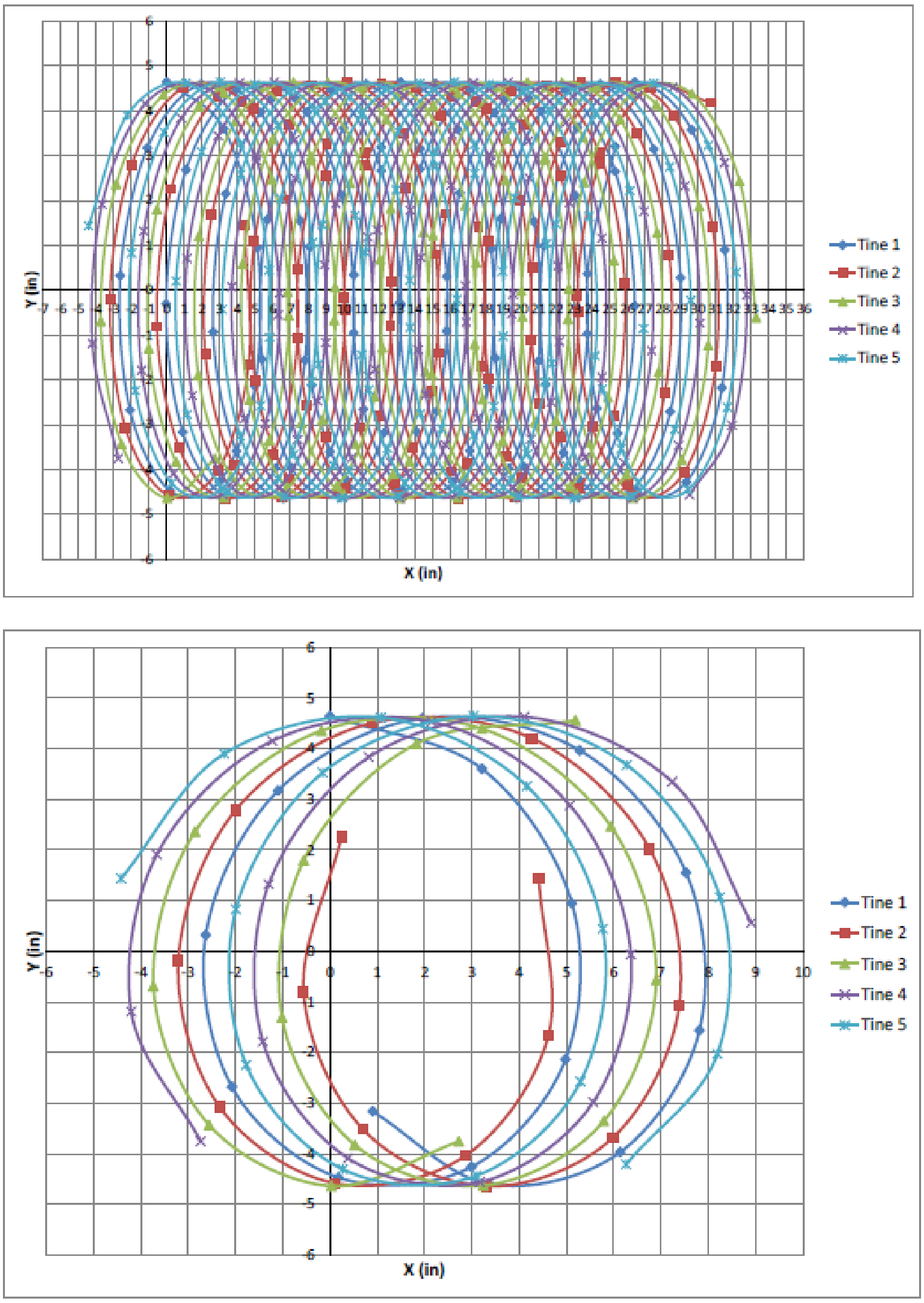
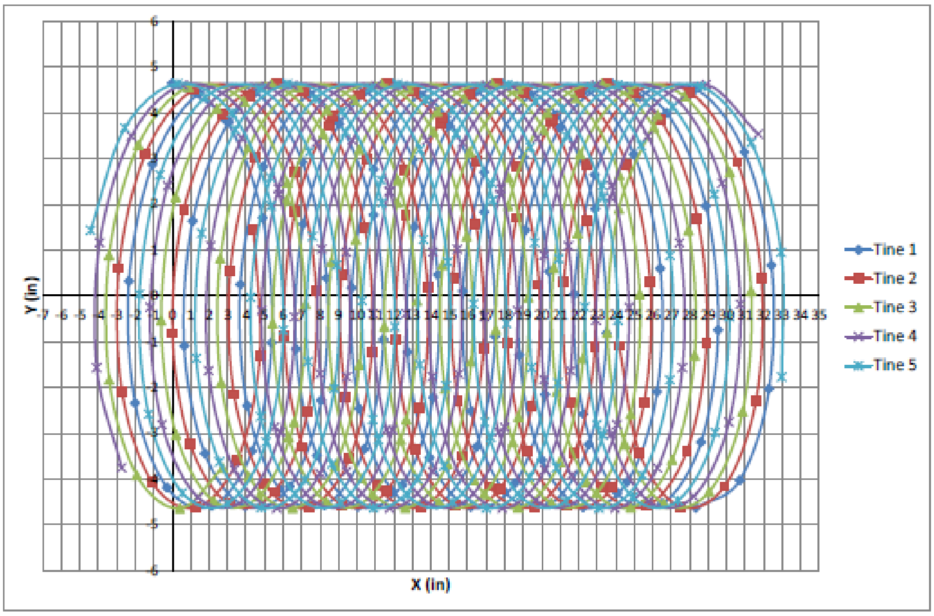


Figure 3.5a: Tine movement for 5 tines at 0.8 km/h travel speed and 200 rpm rotational speed. Top figure shows tine movement for a horizontal distance of 76.2 cm (30 in.) and bottom figure shows a detailed figure of the distance between each tine path which was more or less 12.7 mm (0.5 in.).



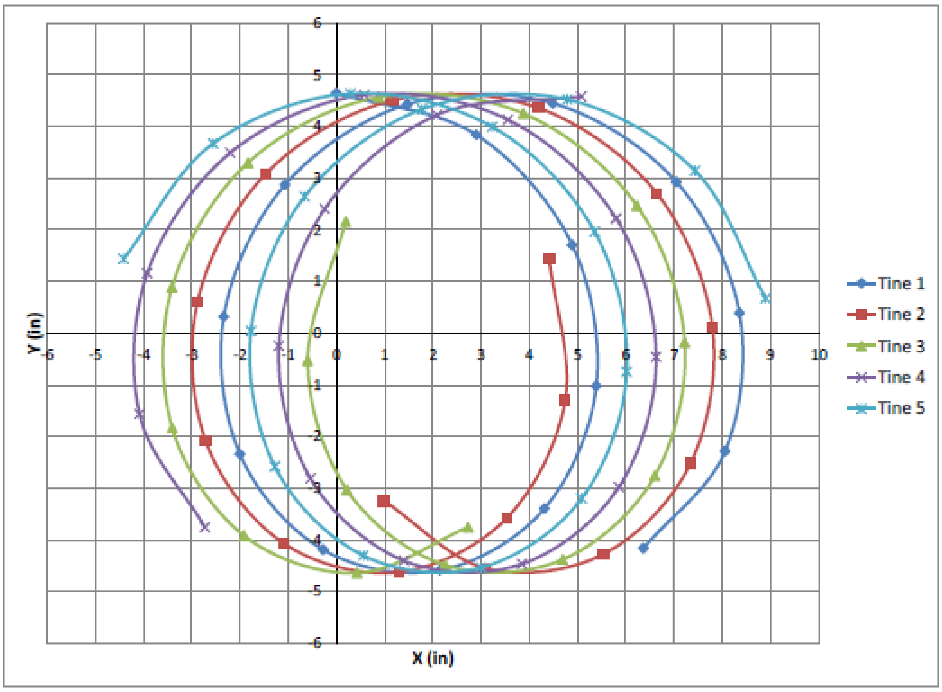
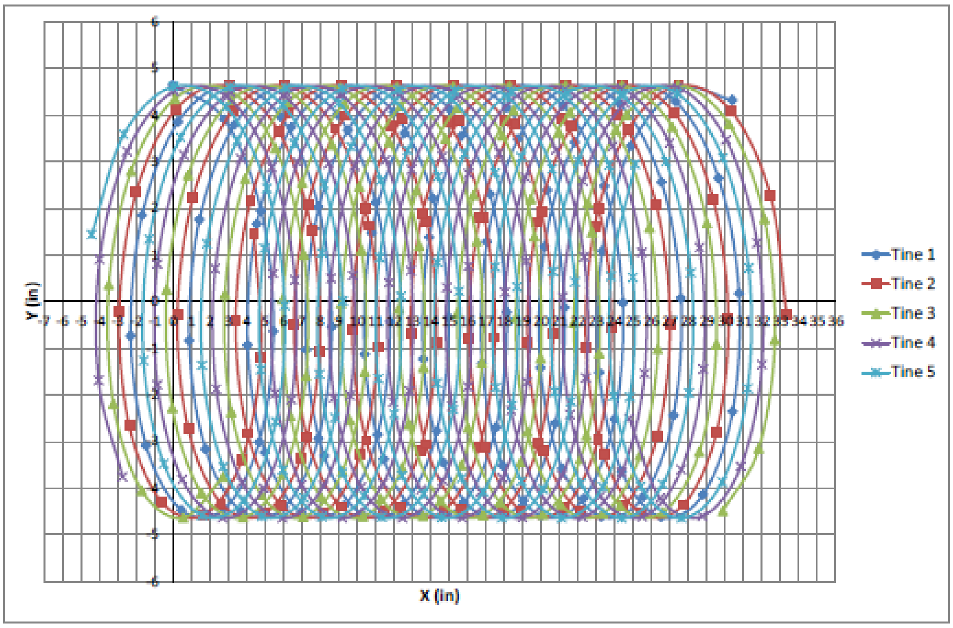


Figure 3.5b: Tine movement for 5 tines at 1.6 km/h travel speed and 350 rpm rotational speed. Top figure shows tine movement for a horizontal distance of 76.2 cm (30 in.) and bottom figure shows a detailed figure of the distance between each tine path which was more or less 12.7 mm (0.5 in.).



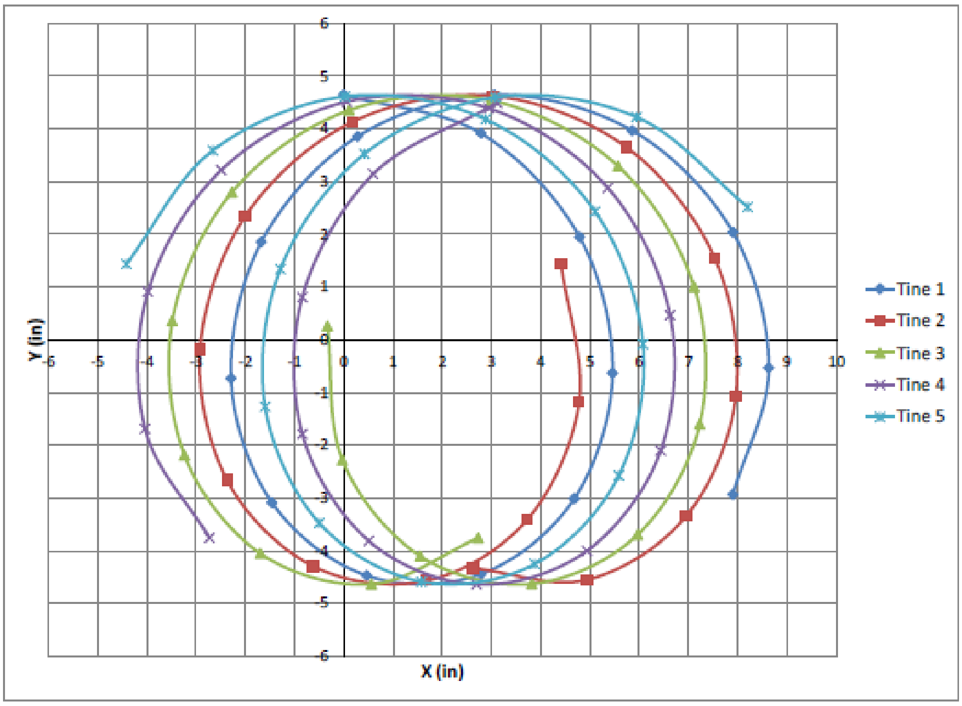


Figure 3.5c: Tine movement for 5 tines at 2.4 km/h travel speed and 500 rpm rotational speed. Top figure shows tine movement for a horizontal distance of 76.2 cm (30 in.) and bottom figure shows a detailed figure of the distance between each tine path which was more or less 12.7 mm (0.5 in.).

According to the above simulation values, the head of the weeding mechanism is designed with four sharp tine and the size is reduced to 20 cm to avoid damage to broad-leaved vegetables such as sugar beets, and some torque requirements can be reduced. Cut the ends of the bevel with two pieces of steel 2 mm wide and 40 mm thick to sharpen the head and then bend it 85 degrees to form a weed head. Such a diagonal line is easier to cut into the soil during weeding, and the roots of the weeds are cut off, thereby achieving the purpose of turning and weeding. The weeding mechanism can be accomplished by connecting the coupling to the selected brushless motor and reducer kit.

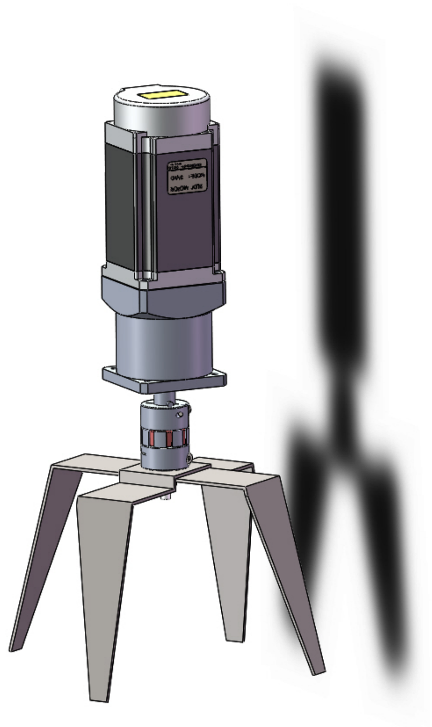


Figure 3.6: Weeder head

CHAPTER 4. INTER-ROW WEEDING ROBOT DESIGN PROCESS

Robot Problem statement

Development and construction of automated robotic beets or corn for controlling weeds in inter-row crops such as weeds. The robot can be divided into four main modules:

1. A vehicle as a platform for carrying e.g. weeding tools for inter-row weeding. The vehicle could be equipped with the control modules described below.
2. A control unit that provides the necessary control signals for vehicles and tools through vision, GPS and other necessary sensor inputs.
3. A GPS module that provides the vehicle with its global location in real time.
4. The vision system detects the location of the crop relative to the location of the vehicle.

The main goal of the project is to develop vehicles and control units and possibly use different sensor technologies.

The vehicle

Automated driving vehicles should be developed to test different sensor systems and tools in the field. The vehicle should be able to drive in field conditions, in which case it may be subject to irregular interference in accordance with the prescribed route.

The control unit

The control software is intended to be executed on a PC physically connected to the vehicle. Interface cards, serial and parallel ports will be used to communicate with peripheral devices. The control software will be developed using a high-level programming language and will run on the Windows operating system. It was chosen because of flexibility and a large number of available interface cards with drivers. Motor control and advanced path control are designed to be solved by classical methods such as PID control.

The GPS module

The RTK / GPS device is capable of delivering 1 to 5 cm accuracy at 5 Hz.

Vision

The development of vision systems is not the main goal. Therefore, I want to simplify the vision system so that it can identify spots on the ground that are in good contrast to the ground. It should be possible to replace the simple module with a more advanced module for crop identification in the field.

Analyses and Product Specification

-Design

Designed a fully automatic weeding robot for use on large areas of cultivated land.

-Production

The production of robot parts should be as simple as possible, the production method is simple, the cost is low, and the wearing parts are easy to replace and update.

-Use

The vehicle should be able to operate at approximately 0.5-1 m / s and travel approximately 8 - 10 hours between charges.

The accuracy of the vehicle must be within ±5 cm to drive without compromising the field crop. In crops with large spacing, the demand is not very high. However, if the vehicle is traveling accurately, it will be easier to control the tool, or even without having to control the tool relative to the vehicle.

The size of the vehicle should be such that it can produce inter-row crops with a line spacing of 350 mm. The distance between the vehicle chassis and the ground should be 500 mm to allow crops to pass under the vehicle.

The vehicle should be able to turn at a smaller turning radius on the front of the car.

-Input

Vehicles should be able to use the RTK / GPS position for steering, such as corn fields or beet fields.

-Output

Vehicles should be able to carry different tools for field weeding or data collection.

-Users

Mainly for large-scale agricultural production farmers or agricultural companies, reducing agricultural production workload, making agricultural production more modern and intelligent, making agricultural production more precise and controllable.

-Environment

After weeding, the vehicle should be able to work in the field. Able to cross the ridge

-Safety

It is important that the vehicle be used safely to avoid injury. Second, it is important not to damage the vehicle or cause damage to the surrounding environment.

-Transport

Should be able to transport robots on trailers or trucks.

-Destruction

The electronic equipment should be removed separately, but the disposal will not create any special requirements for the vehicle design.

The overall principal concept

This chapter will document considerations regarding vehicle principles and mobile robot concept selection. The principles considered are: traction, steering, size, power and control architecture.

Traction

Traction mode has a great impact on vehicle steering and terrain characteristics, cost and power consumption.

Wheels, tracks, feet or air cushion

The foot is not feasible for this robot; therefore, the technology is not yet mature.

Air cushions can damage crops and generate a lot of dust, which covers crops and places high demands on the dust resistance of vehicles..

Track-type tractors are very common on large farms, large fields, and almost no road transport because of their low ground pressure and the traction of the drawbars on soft soil is very good. These characteristics are not as important for mobile robots because the important characteristics of mobile robots are steering accuracy, low power consumption and low cost. Developing tracks for robots is also a daunting task for this project.

Wheels are inexpensive, and because there is little need for drawbar pull and load carrying capacity, greater sinking and ground pressure are not important. The soil conditions in the field after sowing are usually also suitable for wheeled vehicles, so the wheels are selected for traction.

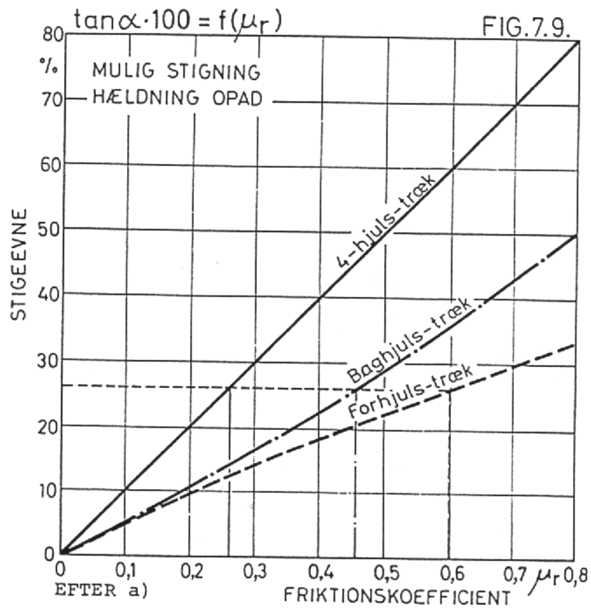


Figure 4.1: Climbing capability of vehicles with FWD, RWD and All-WD.

The graph in Figure 4.1 shows the relationship between possible climb and friction coefficient, and it can be seen that 4-WD provides the best grip. This is because the overall weight of the vehicle creates traction between the wheels and the road. The second best is the rear wheel 2-WD, because part of the weight of the front wheel is on the rear wheel when driving uphill.

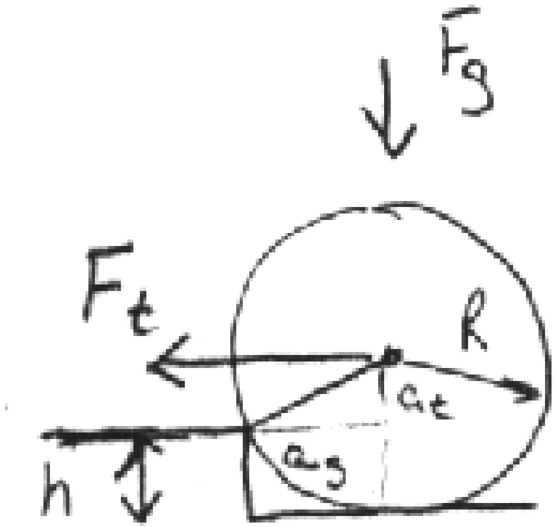


Figure 4.2: A towed wheel passing an obstacle.

In Figure 4.2, a towed wheel is shown being dragged over the obstacle. The momentum equation around point A shows that it is necessary to use a larger force Ft to increase the normal force on the wheel Fg. It can be seen that when the height of the obstacle is as high as the radius of the wheel, the force will be infinite. When the obstacle is larger than the wheel radius, the maximum force of the drive wheel is equal to the force Fg. However, if the obstacle is too high, the wheel will have no grip unless the wheel is pushed toward the obstacle. For optimal terrain performance, four-wheel drive is necessary because all wheels can help the vehicle overcome obstacles.

Steering

It is important that the vehicle must be able to turn very accurately in the crop line and minimize damage to the crop. The advantages and disadvantages of different steering strategies are discussed below.

Differential steering

The principle of differential steering is to make the speed of the left wheel different from the speed of the right wheel. The speed difference will cause the vehicle to turn. This method of use is very different on all-wheel drive vehicles compared to two-wheel drive vehicles, as discussed in the following paragraphs.

All-wd

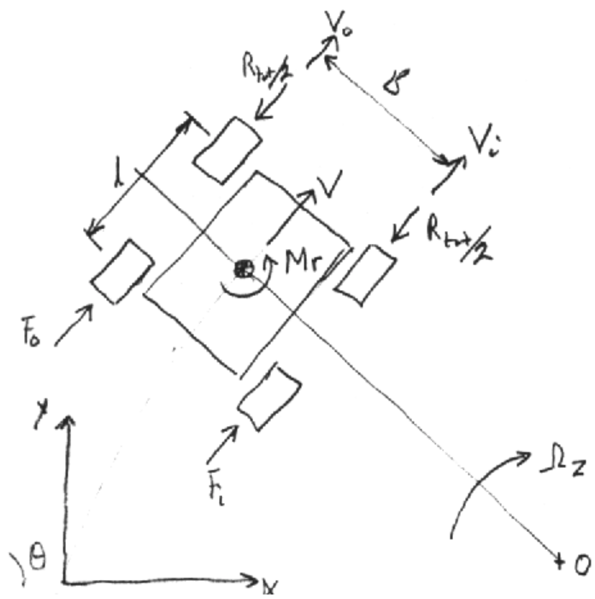


Figure 4.3: Principle of All-WD differential steering.

Differential steering is often used for vehicles that should be very maneuverable in difficult terrain. Vehicles using this steering method can turn on the spot and the method is often seen on earth moving equipment. The construction of the transmission is also simple because the wheels on one side rotate at the same speed and the position and orientation of the wheels are fixed. This suggests that it may be a possible solution for weeding robots, but this method also has some major drawbacks. When cornering, the vehicle also turns around the vertical axis through the center of the vehicle, which means the wheels must slide sideways. This consumes a lot of power to turn the vehicle. This method is also not suitable for dead reckoning due to excessive slip, which invalidates the odometer data. Damage to crops is also likely to occur. The wheels will dig out viable weed seeds that will germinate. Due to these shortcomings, I chose not to use differential steering full WD (slip steering).

2-wd

One or more casters support the vehicle when using 2WD differential steering. Vehicles using this steering method can turn on the spot. This method is commonly used in robotics, such as AGV because of its excellent operability. But because the casters are not suitable for off-road driving.

When the vehicle turns, the casters must be dragged. Even a small obstacle requires a large force from the drive wheel because the momentum arm from the center of the turn to the caster.

Articulated steering

The principle of joint steering is to change the angle between the front and rear axles of the vehicle. The disadvantage of this method is that the tool space between the front and rear axles is small. Poor turning stability can also be a problem due to lateral movement of the center of gravity. The advantage is that the structure is simple and the performance of subsequent lines is good.

Changing heading of wheel(s)

This is the principle that most road vehicles use for steering. When ignoring the forces on the vehicle, Ackerman describes the ideal relationship between the angles of the outer and inner wheels during cornering. If the relationship between the wheel angles follows the Ackerman equation, the geometrically induced tire slip will be eliminated. (Ignore centrifugal force, so it is only suitable for very low cornering speeds.) Low geometry-induced tire slip is critical for good odometer data and precise steering.

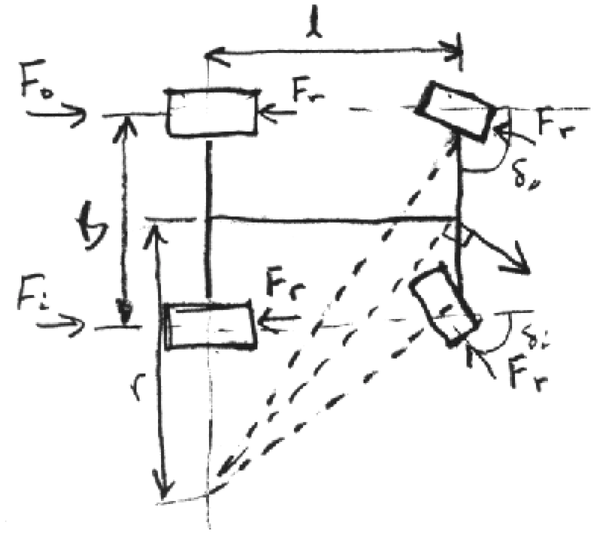


Figure 4.4: Principle of Ackerman steering.

The Ackerman criterion is difficult to implement mechanically because it is highly nonlinear. Therefore, on most vehicles, the steering angle is only close to the Ackerman criterion for small steering angles. However, the deviation from Ackerman does not necessarily mean that the steering geometry is not optimal at high speeds under actual driving conditions.

If the vehicle is not all-wheel drive, the problem is the same as the model with casters. When the towed wheel hits an obstacle, it must have a large force to turn. If the wheels for steering are towed, they may encounter the problem of gripping in loose soil to turn the vehicle. This will cause the wheels to slip resulting in lower steering accuracy.

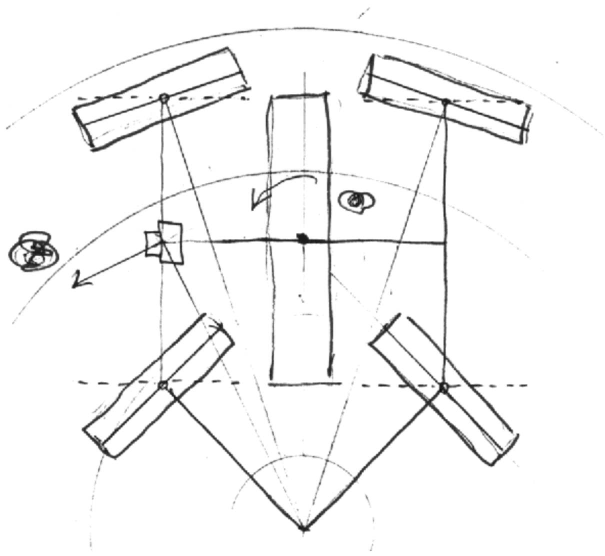


Figure 4.5: Placement of wheels on the robot.

If the vehicle is full WD, it will have very good off-road performance. The vehicle can be steered only along one or all axes. If the weeding robot can steer on all axes, it is possible to obtain a very small turning radius. If the steering of the rear and front wheels is symmetrical around the middle of the vehicle, the wheels will follow the same track at the fixed turn (Fig. 4.5). Therefore, the vehicle needs a small space between the rows to accurately follow the row. The disadvantage of all-wheel steering is that construction and control become more complicated.

All-wheel Ackerman steering was chosen due to the possibility of obtaining good odometer data, precise steering and a small turning radius.

Dimensions

The vehicle selected four wheels placed on each corner of the rectangle, the length of which is parallel to the crop line. This configuration provides good stability and the rear wheels can operate in the track of the front wheels, which reduces rolling resistance. This configuration is shown in Figure 4.5.

Gauge

There are several restrictions on the size of the vehicle. It should be able to travel in rows with a distance of 350 mm between rows, such as beets. Cornfields also focus on weeding. Therefore, it is advantageous for the vehicle to travel at an angle of 350 mm between rows of rows. Beets are broad-leaved, so the wheels should not be too close to the center of the row and damage the beets.

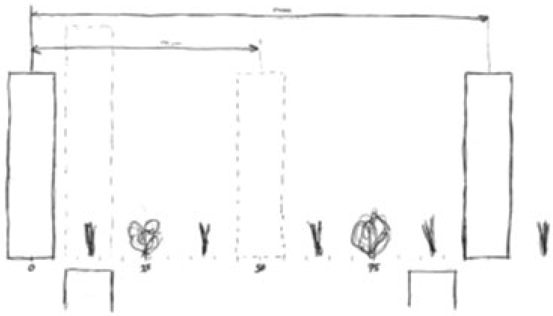


Figure 4.6: Necessary wheel gauge for in-row driving in corn and beet fields

Because robots are designed for large-scale planting, they should be able to cover more crops each time they work. Taking 350mm planting as the standard, assuming that I can weed 4 or 5 rows of crops at a time, the wheel width of the robot should be between 1450-1750mm, and the whole robot should be able to be transported by ordinary truck, and the external size should be less than 1800mm, so choose A wheelbase with a wheelbase of 1450mm removes weeds on both sides of the crop.

Placement of tools and loads

The tool should be placed in the most stable position and at an optimal distance from the ground. The best position is in the middle of the wheelbase, where obstacles and irregularities can cause minimal movement of the tool.

Tools

The vehicle should be capable of testing using a variety of tools such as weeding, spraying, collecting crop data and soil samples. This design only considers the use of rotary weeding.

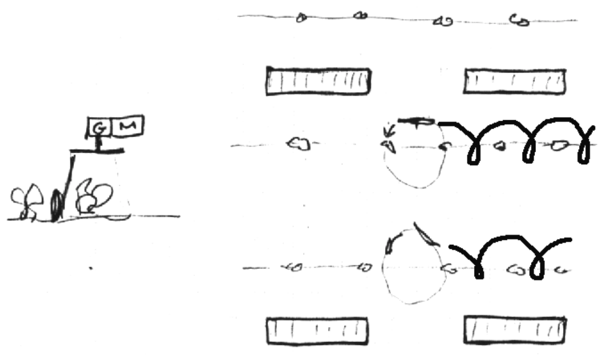


Figure 4.7: Rotating hoe

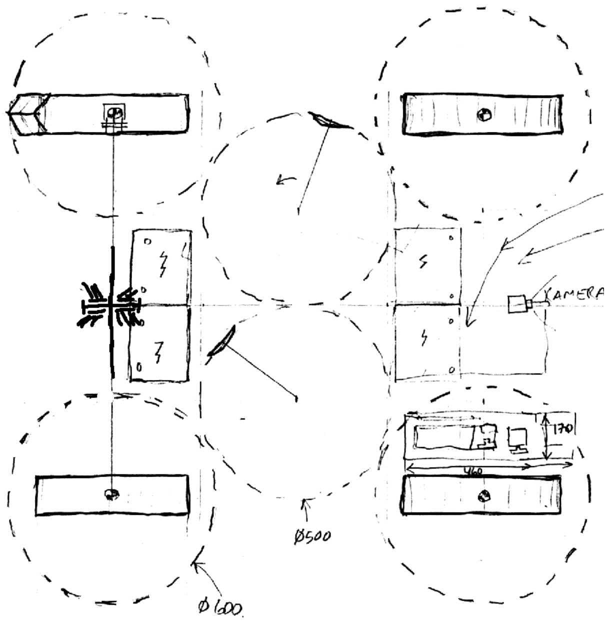


Figure 4.8: Dimensions

Control Architecture

Sensors

GPS system

In our preliminary investigation, I found that the affordable GPS system was not accurate enough (DGPS accuracy is 1-5m). In order to achieve a satisfactory accuracy of 1-5 cm, a carrier phase differential GPS (also known as RTK) device would be required.

Orientation

It is important to understand the direction of the vehicle, not only to understand the direction, but also to understand the inclination of the two directions. For example, GPS only returns the position of the GPS antenna. I need to know the roll angle, pitch angle and compass angle to convert the antenna position to a control point. Compass angle (yaw angle) is also important for maneuvering the vehicle.

Gyroscope

The gyroscope can measure the direction of all three axes. Gyroscopes are sensitive to the rotation of the Earth (unless they have built-in compensation) and must be initialized in a known direction. The advantage is that it is not sensitive to acceleration.

Accelerometers

T There are various techniques for measuring acceleration. By measuring the angular velocity on three axes, it can find the direction relative to the direction at initialization. This is similar to gyroscopes, and some manufacturers refer to accelerometers as electronic gyroscopes.

Magnetometer

A 3-axis magnetometer can be used to measure the stadium. The effect of the magnetic declination and deviation caused by the local magnetic field is measured.

To calculate the heading from the magnetic field, you need to get the data from the inclinometer (tilt sensor).

Inclinometer

Inclinometer measures the angle of gravity on two axes.

Vision

By far the most successful way to find plants is to use a camera. Usually, it looks at the infrared spectrum, and the appearance of the plant is clearly visible from the background. There are already systems that can detect plants in use.

In the Department of Control and Engineering. They have used the CMOS camera in their previous visual projects, so we don't have much decision. However, it does not look at the infrared spectrum and therefore can only detect paper plants. A good contrast with the background. However, the CMOS camera is the best technology for controlling applications.

Distributed control

For data communication in commercial or industrial applications, the CAN bus is typically used when there are a large number of sensors providing data for a large number of cells. The CAN bus is a distributed network system. All units connected to the bus have access to all data on the bus. The sensor will send data on the bus with priority and unique ID. All other recipients can then decide whether or not to use this data. The advantage is that the wiring is simple because only one set of cables can be connected to all devices. The disadvantage is that all units connected to the bus require a microcontroller. Unless you buy it in bulk, it will make it expensive.

Centralized control

An inexpensive and flexible solution is to connect all control signals to the interface cards in the PC. All connections between the sensor and the sensor data user are performed by the PC and all calculations are performed in the software. This makes it easy to make changes, just by making changes in one place. PC also provides users with an information-rich interface.

I chose to use a PC because it will be used as the basis for many future projects.

Position

Correct the position of the vehicle by gps real-time positioning, and adjust the distance between the body and the crop in combination with the camera screen.

Path

The robot should be able to follow the list of waypoints. For example, it can be a list of crop locations generated at the time of sowing. However, the waypoints can also be generated by the onboard vision system and the position of the plants seen can be calculated in flight. The vehicle does not have to travel directly between the two road signs. In particular, it may not be sharp enough to go directly to the next waypoint. This can happen at the end of the crop line, it should rotate 180° and return to the next line.

Motors and power supply

Motors

Vehicle motors must be easy to control, supply and install. It is also preferred that they can be used for testing indoors. DC motors best meet the above requirements. The DC motor can be used indoors and powered by a battery. The power amplifiers and gears of DC motors are off-the-shelf products, making them a flexible and easy to install solution.

Power supply

The vehicle should be completely autonomous and therefore have its own power source. The power supply should be able to drive the DC motor and computer. Choose the battery for your vehicle because it's the easiest to install and should be able to provide power for 8 to 10 hours of testing.

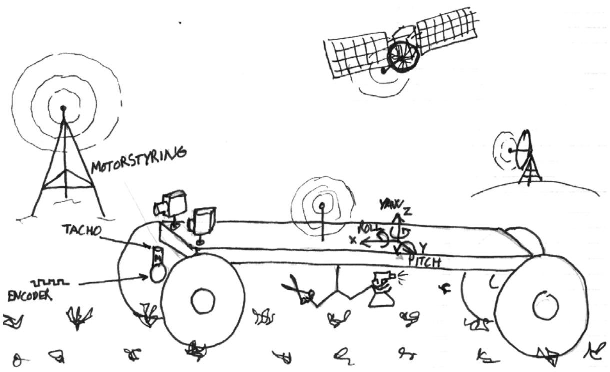


Figure 4.9: General version.

The mechanical design

IIn this chapter, the mechanical design will be based on the main decisions in the previous chapter. First, the steering and drive gear principles for implementing 4-WD and 4-WS on a vehicle will be determined. In the second paragraph, the wheel module will be designed. The chassis will then be designed and finally the assembly of the vehicle's mechanical components will be discussed. General requirements and standards for mechanical design:

- In-row driving in fields with a ground clearance on minimum 500 mm
- Space for different types of tools and sensors
- Possible to implement and design within this project.
- Protection of electronics etc.
- Flexibility

Steering and drive gear

In this paragraph, the principle of mechanical implementation of the 4-WS and 4-WD general principles will be determined.

Ackerman steering

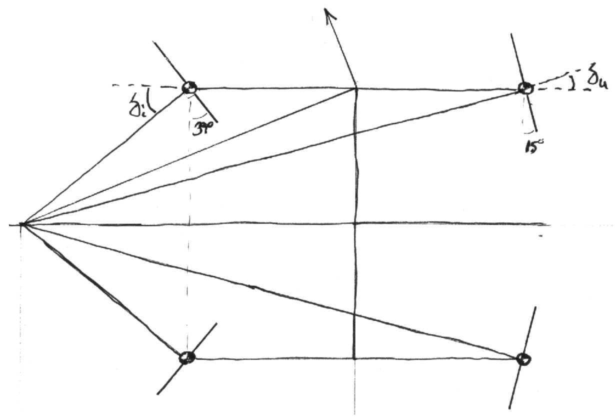


Figure 4.10: Ackerman steering.

The principal steering concept chosen is 4-ws and Ackerman steering, because of flexibility, possibility of good odometer data, good steering precision and a small turning radius. The Ackerman steering geometry is shown on Figure 3.1 and the relation between the wheel angles are given in the formula below.

$$\cot\delta_\mu - \cot\delta_i = \frac{B}{L},\ B \approx 1450mm,\ L \approx 1450mm \qquad (23)$$

Equation (23) shows that the relationship between the wheel angles is non-linear and is a function of the wheelbase (L) and the kingpin (B). The size of the vehicle is chosen, and the width is very large compared to the length, even at smaller steering angles, the difference between the wheel angles is large, see Figure 4.10. This makes it difficult to design a steering gear to avoid geometrically induced tire slippage, which can result in poor odometer data and inaccurate steering.

Implementing 4-WS Ackerman steering

The requirements and standards for a good steering wheel solution are:

• Good compliance with the Ackerman theorem.
• Acceptable play or backlash.
• Safe and reliable.

-Motor to position each wheel

An electric motor and a gear or a linear actuator can be placed on each wheel to change the wheel direction.

Advantages:

Using closed-loop computer control should be a good fit for Ackerman. Changes in steering strategies, such as sideways steering or dimensional changes, can be easily accomplished by software. If the construction allows, the steering angle can be rotated 360°. The flexibility of this approach will be a great benefit for the study of field manipulation. Mechanical design is not complicated and can save shop time. The solution is very compact and connected via wires. Reduced complexity of the design chassis due to fewer constraints on the design.

Disadvantages:

There is no mechanical connection between the steering wheels, but since it works in the field at low speeds, the safety risk is considered small. Buying all electronic and mechanical components is very expensive. It may be problematic to follow the Ackerman in real time, and then geometrically induced tire slippage cannot be avoided [BERN].

-Steering rod

Traditional steering gear used on most road vehicles, where the steering wheel is connected to the steering wheel, Figure 4.11.

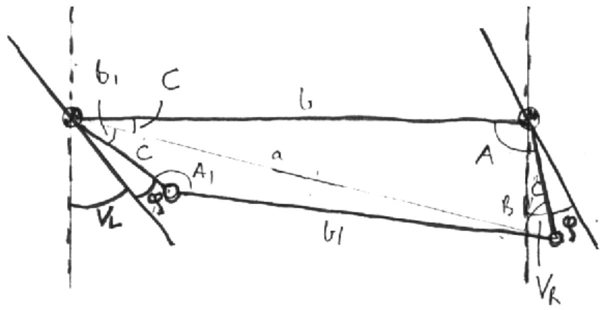


Figure 4.11: Conventional steering mechanism.

Advantages:

When driving forward, the wheels are always well aligned and the geometry causes a small slip. Steering can be controlled with just one input.

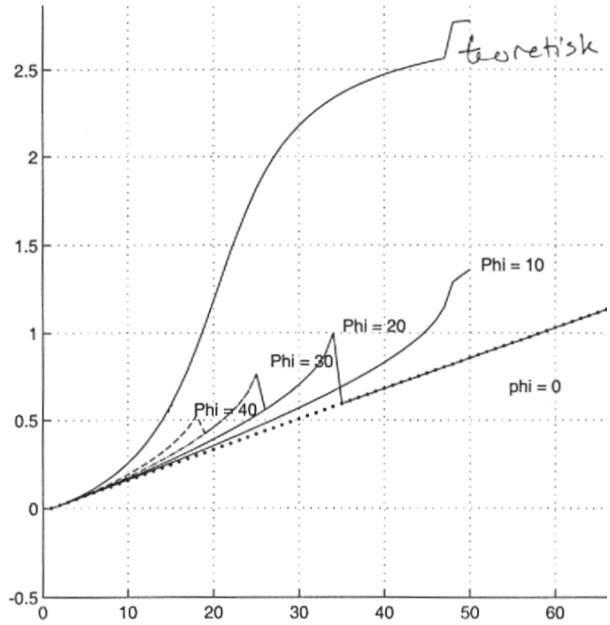


Figure 4.12: Matlab plots showing the results for the conventional steering gear.

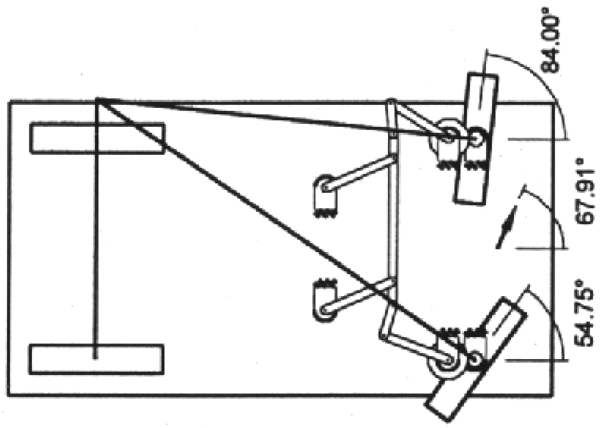


Figure 4.13: Mechanism for Ackerman steering.

Disadvantage:

For a typical vehicle with a length/width ratio of approximately 2, the steering gear is well compliant with Ackerman. Typical results are shown in Figure 4.12. It can be seen that for such vehicles, the steering gear compliance is very poor. With Ackerman. The outer wheel angle VR and the geometric angle φ are inputs, and the inner wheel angle VL is the output. Different geometries have been calculated in Matlab, but a fairly simple solution that is well compatible with Ackerman has not been found. Although it fits well with Ackerman, see Figure 4.13. However, these mechanisms are very complex and take up a lot of space.

-Guide way or special designed guide wheels

The guide rail with the desired path is moved linearly by the actuator so that the wheel angle is correct. This can also be done by a steering wheel designed to make the steering wheel at right angles.

Advantages:

Can fit well with Ackerman.

Disadvantages:

It is difficult to design and operate the mechanism with little friction, no play or backlash.

-Differential gear

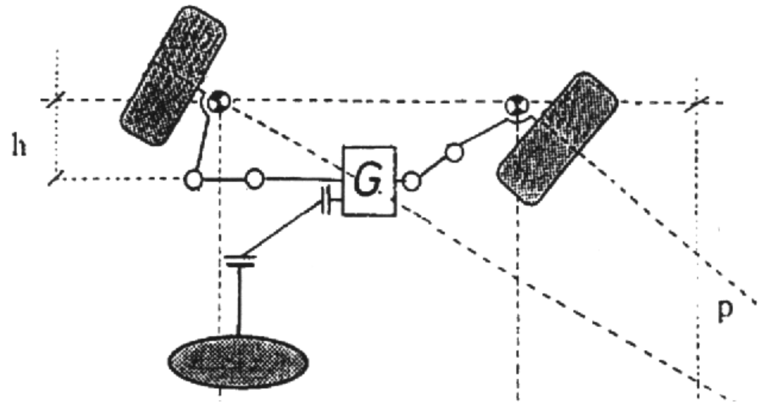


Figure 4.14: Ackerman compliance achieved with differential gear.

A differential gear can be designed to provide each wheel with the desired angle of rotation according to Ackerman's method, see Figure 4.14.

Advantages:

The compliance with Ackerman is very good and the alignment of the wheels is also very good. The wheels are also mechanically connected.

Disadvantages:

The mechanical design is very complicated and is a project in itself. Making at the IKS workshop will be very difficult and time consuming. This may make us unable to achieve our goals.

-Connection of front and rear axle steering gear

Researched the following principles.

Connection by steering rods

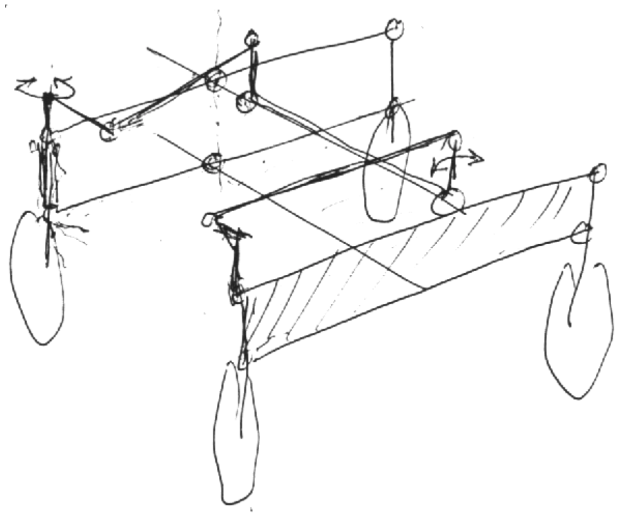


Figure 4.15: Connection of the front and rear wheels with steering rods.

The rod is connected to the rotation of the front and rear wheel king pins, see Figure 4.15.

Advantages:

Can be made from standard components.

Disadvantages:

When the front shaft is slightly rotated due to an obstacle, the joint must be placed so that the steering angle does not change. Connection takes up a lot of space.

-Steering motors for each wheel

Each steering wheel has its own steering wheel connected to the main pin.

Advantages:

Lateral movement will make it possible to position and orient the vehicle more precisely in the row. This method is very flexible because the steering strategy is implemented in software. Flexible wire placement.

Disadvantages:

The price of parts will be high and the control of vehicles will be more complicated..

-Wire connection

Wires connect the kingpins.

Advantages:

Big flexibility of placement of connection and simple to implement

Disadvantages:

Might give problems with backlash and play.

-Hydraulic connection

Hydraulic motor or actuator for steering.

Advantages:

The gap can be small and the hose is very flexible to place.

Disadvantages:

Hydraulic components are very expensive and must be operated to pump the system.

Choice of 4 wheel steering principle

After studying the various possibilities of implementing Ackerman and connecting the front and rear wheel steering, I chose to use 4 motors for steering. Since all options are in the software, you can provide maximum flexibility. This will provide an opportunity for various tests of the on-site steering method. The front, rear and all-wheel steering can be tested. The point at which the wheel turns can be placed anywhere, not just on a straight line including the front axle, rear axle or vehicle center point.

Design of the driving transmission

Transmission and motor

Since the 500 mm ground clearance is large and the wheel diameter is in the range of 350 mm to 500 mm, it is more complicated to transfer the transmission to a normal motor. Ordinary motors will also require the use of a differential between the front and rear wheels and the front and rear axles. This will be very expensive, heavy, complicated and reduce transmission efficiency.

Another possibility is to use an electric motor to drive each wheel and then control the speed of each wheel according to its turning radius by closed-loop computer control. This principle has been chosen for gearboxes and motors.

Wheel module

The wheel module now has its own steering motor and drive motor, which makes the system very flexible.

Wheel module

In this section, the mechanical concept of the wheel module will be designed in detail. The overall principle and quantitative structure of the vehicle have been determined. The module (wheel module and chassis module) should now be specified and the interface between the modules determined.

Quantitative structure

The wheel module consists of a wheel with a drive motor, a steering motor and two motor sensors. Since a large ground clearance and a very narrow wheel structure are required to drive between the rows of crops, the kingpin is placed above the center of the wheel, and the deflection of the steering mechanism is said to be zero, see Figure 4.16.

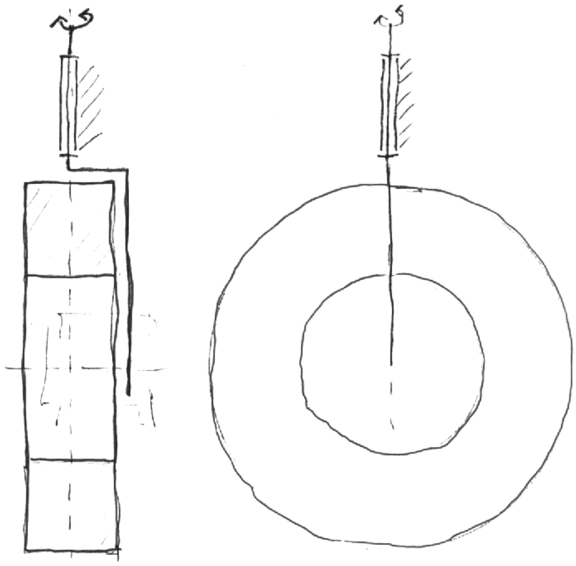


Figure 4.16: Placement of kingpin with zero offset.

This structure has many advantages. The force feedback into the steering system is minimal. The steering motion on one wheel has the least effect on the steering of the other wheels. The zero kingpin offset also results in the lowest power requirement for steering. If the kingpin is placed on the side of the steering wheel, the steering motor will have to transmit a constant torque to maintain the direction, which will cause the motor to malfunction. The disadvantage is that the larger the distance between the bearing and the load impact point will produce a larger bearing force, but this is not a major problem.

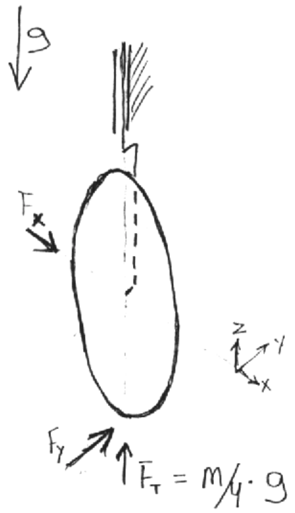


Figure 4.17: Forces reacting on the wheel module.

When designing a mechanical system, it is necessary to consider two things: normal working conditions and worst case.

Under normal conditions, the system should be able to operate as specified, and it may be important to observe deflection and dynamics. In the worst case, it is important to recognize that avoiding failures in all situations is not feasible or economical. It is important to anticipate what might happen to the system and design system failures in the best possible way. The most important thing is to try to avoid danger to people, and then design systems that invalidate inexpensive parts, such as screws.

Mechanical design is always a trade-off between conflicts of interest, such as light weight and high strength. The vehicle must be lightweight to minimize energy consumption and motor and battery costs.

The force acting on the wheel module is shown in Figure 4.17. In the next two paragraphs, the normal force and the worst case force will be estimated, and then in the third segment, the force will be updated because the choice of motor will limit the allowable force.

Normal working conditions

The forces under normal operating conditions are primarily attributable to the weight of the vehicle, the traction of the motor and the steering of the wheels.

The force Fx is mainly due to traction, and μ is the estimated rolling coefficient:

$$F_x = \frac{m}{4} \times g \times \mu \approx \frac{1200kg}{4} \times 9.81m/s^2 \times 0.25 \approx 735.75N \quad (24)$$

The force Fy is mainly attributed to the centripetal force at the turn. As the centripetal force increases, the resultant force will be closer to the outer wheel when cornering. The entire force will act on the outer wheel before the vehicle turns. The following assumes that these forces are evenly distributed between all four rounds:

$$F_y = \frac{m}{4} \times \frac{V^2}{r_{turn}} \approx \frac{1200kg}{4} \times \frac{\left(2 {}^{m}\!/_{s}\right)^2}{1.45m} \approx 827.58N \quad (25)$$

The force Ft is mainly due to the gravity:

$$F_t = \frac{m \times g}{4} \approx \frac{1200kg \times 9.81 {}^{m}\!/_{s^2}}{4} \approx 2943N \quad (26)$$

Worst-case conditions

I estimate the worst case the vehicle should be able to cope without damage.

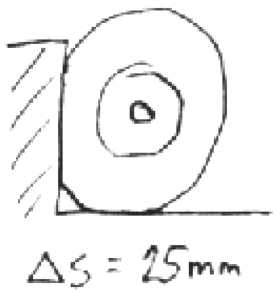


Figure 4.18: Deformation of the tyre, when hitting an obstacle with 1 m/s.

Fx, worst case

If the vehicle hits an obstacle at a speed of 1 m / s, see Figure 4.18. In my opinion, this will cause the tire to deform by Δs = 25 mm and cause a linear decrease in speed, resulting in an average velocity of Vave = 0.5 m / s. This is only an estimate and will depend to a large extent on the expansion rate of the tire and tire material.

The time for the vehicle to slow down will be:

$$t=\frac{\Delta s}{V_{ave}}\approx\frac{0.025m}{0.5{}^{m}\!/_{s}}\approx 0.05s \tag{27}$$

The deceleration:

$$a\frac{\Delta V}{\Delta t}\approx\frac{1{}^{m}\!/_{s}}{0.05s}\approx 20{}^{m}\!/_{s^2} \tag{28}$$

The resulting force:

$$F_{x,worstcase}=m\times a\approx 1200kg\times 20{}^{m}\!/_{s^2}\approx 6kN \tag{29}$$

(This could also have been found by an energy approach)

This assumption is not very accurate and depends to a large extent on the inflation rate of the tire, but it implies the magnitude of the force.

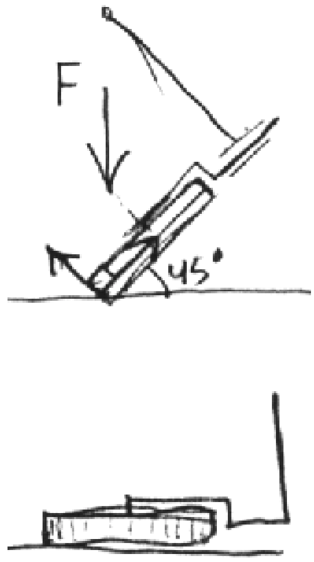


Figure 4.19: Forces if the vehicle is tilted.

Fy, worst case

The vehicle is lifted up in one side or tilting, see Figure 4.19. The maximum static force will be:

$$F_{y,worstcase}=\frac{m}{2}\times g\approx\frac{1200kg}{2}\times 9.81{}^{m}\!/_{s^2}\approx 5.89kN \tag{30}$$

The vehicle is unlikely to receive strong power in the Fy direction.

Ft, worst case

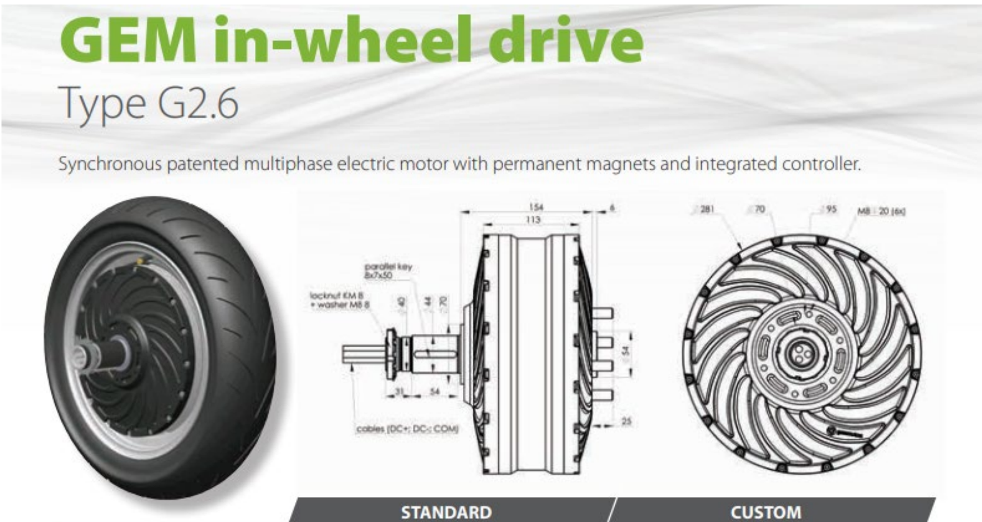
The vehicle is lifted and dropped.

The force at which the drop is from the height of h = 0.25 m is calculated using the energy method, but is assumed to be the same as Fx (worst case).

$$F_{t,worstcase}=\frac{\frac{m}{4}\times g\times h}{\Delta s}\approx\frac{\frac{1200kg}{4}\times 9.81{}^{m}\!/_{s^2}\times 0.25m}{0.025}\approx 29.43kN \tag{31}$$

Since dynamic forces are difficult to estimate, the worst-case forces will be designed for the vehicle: Ft, worst case = Fx, worst case = 6 kN.

Later in the design process, I chose to use the gemmotors-G2.6 hub motor. According to GEM's description of the product and the mechanical data listed, the hub motor can meet these needs.



	STANDARD	CUSTOM
Nominal power	6 kW	5 ~ 9 kW
Nominal torque	175 Nm	175 ~ 250 Nm
Peak power (20 sec)	7.5 kW	7 ~ 12 kW
Peak torque (20 sec)	205 Nm	200 ~ 340 Nm
Speed	1000 rpm at 48 V	390 ~ 1300 rpm
Battery-to-wheel efficiency	up to 90%	up to 92%
Voltage	48 V	40 V ~ 75 V
Wheel rim	13" integrated rim	≥12" integrated or ≥13" standard car rim
Mounting	one side	one or two sided
Cooling	air	
Dimensions	width 160 mm, diameter 281 mm	
Active motor weight	17 kg	
Total motor weight	25 kg	
Standard functions	torque regulation, regenerative braking, high fault tolerance	
Signal interface	CAN	
IP Protection	IP 67	
Temperature range	- 40 ~ 60 °C	
LEV Applications	scooter, motorbike, three-wheeler, micro car, golf-cart, service vehicle, agricultural and industrial vehicle	
Additional features	speed regulation, complementary functional safety, software customization	

Figure 4.20: Design using motors GEM-G2.6.

Wheel

The wheels of the vehicle should have good grip on bare soil in the field. The rim must be a minimum of 13 inches to fit the GEM motor.

Figure 4.21: Tire 3D model .

The tire has a circumference of 430 mm and a width of 172 mm.

The main shaft of the motor is bolted to the rigid suspension of the entire wheel by means of a flange sleeve. Since the robot is mainly operated in a relatively flat field, the ground is relatively flat and soft, and the vehicle is not moving fast, the suspension is designed as a one-piece.

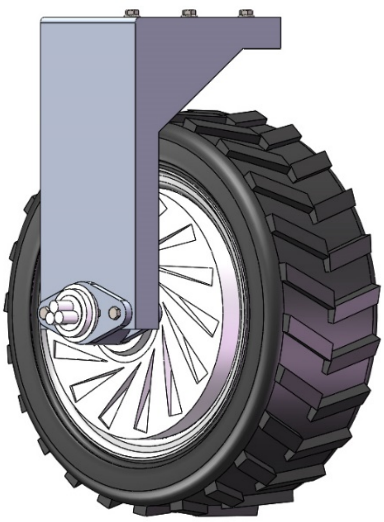


Figure 4.22: Tires and suspension

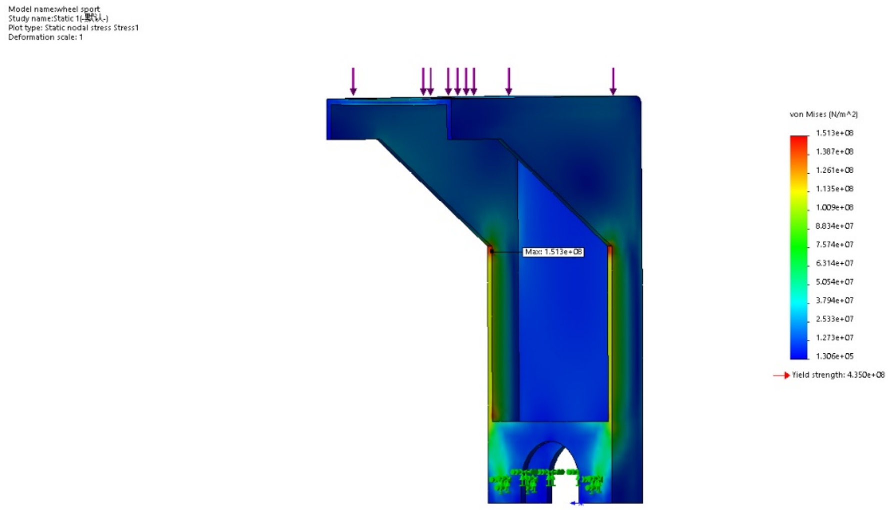


Figure 4.23: Suspension strength check

Check the wheel suspension and select the material for the aluminum alloy 7050 commonly used in modern bodies. The locking point is the flange connected to the motor shaft, and the pressure of 3500N is applied to the upper surface of the steering system connection, because each wheel is about 300kg. After calculation, as shown in the figure, even at the weakest point, the red area in the figure is far from the material's own yield limit of 4.35e + 08. It is much smaller than the yield strength of the material, so the workpiece can be competent.

Steering mechanism

Requirements and standards for good implementation guidelines:

- Low cost
- Capable of driving outdoors. Protected against rain and dust.
- Little play or backlash
- Low complexity

Transmission and control loop

In this paragraph, the mechanical components used to implement the steering mechanism will be selected and the correct dimensions calculated.

Power requirements

It is necessary to estimate the torque required to steer the vehicle. Many parameters affect power requirements, such as caster angle and camber angle. However, the kingpin here is vertical, just above the center of the hub, which eliminates many of the conventional parameters. A convenient way to calculate the maximum torque required for steering is to calculate the torque required to steer on dry and clean concrete under static conditions. Usually this is the heaviest steering load.

$$T = Wf\sqrt{\frac{I_0}{A} + e^2} \approx 2940N \times 0.7\sqrt{\frac{0.6135}{2.5434}} \approx 133Nm \tag{32}$$

f = 0.7, effective friction coefficient
I0 = polar moment of inertia of tire print
e = 0, kingpin offset
A = tire print area

The exact shape of the tire footprint is unknown, so it is assumed to be circular and the diameter is equal to the nominal tire width, see Figure 4.24.

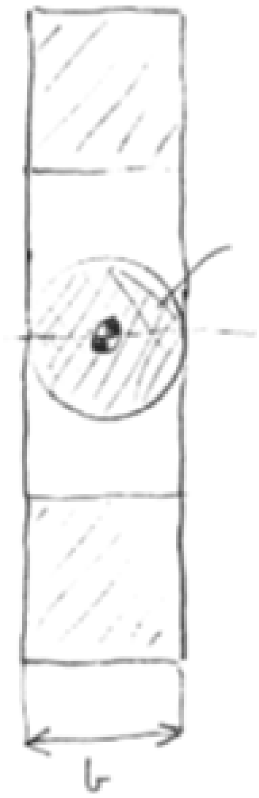


Figure 4.24 Assumed tire print.

Steering motor

Demands and criteria's for choosing steering motors.

• Price
• Power requirement 133 Nm
• Intermittent service
• The steering response (velocity) should be minimum 90 degrees/s with a 133 Nm load
• Output shaft, which is easy to attach the kingpin to.
• Possibility of attaching encoder to the motor or gear

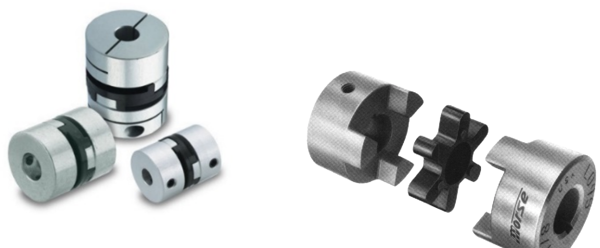
Choose JIE brushless DC motor with a reducer to meet the above requirements, Rated voltage 48 volts, could output torque 180Nm after gear unit.

Figure 4.25 JIE brushless DC motor with reducer

Coupling

Gear bearings can only withstand torque and therefore cannot be used to support the kingpin. Since it is not possible to perfectly align the motor shaft with the kingpin, it is necessary to use a coupling between the motor shaft and the kingpin. Requirements and criteria for choosing the right type of coupling:

- Little backlash
- Able to transmit a torque on 150 Nm
- High torsional stiffness
- Low price
- Compact
- Parallel misalignments up to 0.25 mm
- Easy to adapt



a **b**

Figure 4.26 a; Oldham coupling, b; jaw coupling

two types are chosen as the best for this application, see Figure 4.26.

The Oldham coupling was chosen because of its zero backlash, small size, high torsional stiffness and very low restoring force resulting in lower bearing loads. The caliper shaft attachment was chosen because it is best suited for reverse torque and vibration applications. The disc is acetal because it has higher torsional stiffness and longer backlash life than nylon discs. The reason for choosing boring wheels is that they have a protective coating and are non-abrasive, with a long service life of 2-3 times and no backlash life.

Sensor for the steering motors

To control the steering angle of each wheel, position feedback must be provided on the kingpin, gear or motor. The encoder is the best choice for position feedback. The most common is the incremental quadrature encoder, which only gives relative position and orientation. Here, I want to measure the absolute steering angle, so I need an encoder with an index. The US-digital, which also provides a drive motor encoder, has an encoder with an index and resolution of 2048 counts per revolution. The encoder is easy to install and protected by a rugged enclosure. They can be used on shafts with a diameter of 2 mm or more. Up to 1" and easy to align. They can also provide a PC ISA-BUS interface card for 4 encoders, which will make implementation simple.

Bearings

The kingpin has to be fitted in two bearings.

Forces

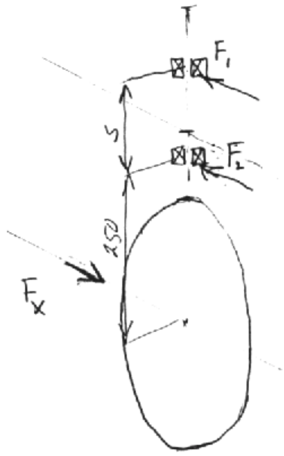


Figure 4.27 Bearing forces

The maximum force acting on the kingpin bearing is shown in Figure 4.27. In the worst case, the load must be transmitted to the chassis through the kingpin bearing..

The worst case horizontal load on the wheel module is Fx, the worst case = 6 kN, the worst case axial load is Ft, and the worst case = 6 kN. The radial bearing force is calculated by using the momentum balance formula. The length from the center of the wheel to the lower bearing is estimated to be l = 250 mm. The length between the bearings is s = 100 mm. The signs of horizontal reactions F1 and F2 are not important.

$$F_1 = \frac{F_x \times 1}{s} \approx \frac{6kN \times 0.25m}{0.1} \approx 15kN \quad (33)$$

$$F_2 = \frac{F_x \times (l + s)}{s} \approx \frac{6kN \times (0.25m + 0.1m)}{0.1m} \approx 21kN \quad (34)$$

The worst case vertical load Ft is only assumed as the axial load of one of the bearings.

$$F_a = F_{t,worstcase} \quad (35)$$

If the vehicle is hoisted, it must bear the axial load of the bearing caused by the weight of the wheel module..

$$F_{a,weight} = m_{wheelmodule} \times g \approx 29kg \times 9.81 \, {}^{m}\!/_{s^2} \approx 0.284kN \quad (36)$$

Bearing type

Different types of bearings can be used as the main pin bearings. I found that there are two types of bearings that need to be carefully inspected: self-lubricating plain bearings and ball/roller bearings.

Cheap sliding bearings can withstand large static loads and can easily handle smaller speeds. The only drawback is the relatively high coefficient of static friction, which is approximately six times that of a ball or roller bearing. This non-linearity should be avoided or minimized in the control system. The friction in the bearing is secondary, as compared to wheel ground friction.

Ball or roller bearings have a very low coefficient of friction and good load carrying capacity. This is a very common and long lasting solution. The kingpin is subjected to axial and radial loads. Many different bearing configurations can solve this problem, but if deep groove ball bearings are used, the upper and lower bearings can be of the same type and size..

The best way to ensure bearing alignment is to make the bearing housing one piece on a lathe or milling machine. In order to obtain the lowest weight, good strength and bearing tightness, it is preferable for this application to make a thin-walled part that is symmetrical about its axis of rotation.

For the kingpin housing, two deep groove ball bearings are selected and made into a thin-walled part that can be machined from a blank tube.

Bearing size

The diameter of the kingpin must be calculated before finding the right bearing. The rule is that when the part will withstand the worst-case load Fx (worst case), no yielding will occur. This load causes the maximum bending moment Mb to be just below the lower bearing.

$$d=\sqrt[3]{\frac{32\times M_b}{\pi\times\sigma_{0.2}}}\approx\sqrt[3]{\frac{32\times 6kN\times 0.25m}{\pi\times 235MPa}}\approx 0.04m \tag{37}$$

d is the diameter of the kingpin just below the bearings, σ 0.2 is the yield stress

A trade-off is made between bearing cost and weight and the above criteria, with a main pin diameter of 40 mm. The bearing 6308 is selected from the SKF general catalogue, and this special bearing is manufactured in large quantities and is therefore very inexpensive. The bearing has a seal that should be built into it to prevent dust from contaminating the bearing. The dynamic load rating is C = 42.3 kN and the static load rating is C0 = 24 kN. C0 is greater than the worst-case force in the radial direction F2 = 21 kN, which occurs when the kingpin does not rotate, so it can cope with the worst-case static conditions in the radial direction. The axial bearing capacity of deep groove ball bearings is: Fa = 0.5 x Fr, so the maximum axial force Fa = Ft can be easily dealt with, and the worst case = 6 kN.

Figure 4.28 SKF 6308 bearing

Steering mechanism, Part design

A bearing with an inner diameter of 90 mm and an outer diameter of 98 mm is used to mount the bearing and protect the coupling. One end of the coupling is fixed to the steering motor reducer. The inner coupling of the sleeve is connected to the output shaft of the reducer and the steering king pin, respectively. The other end of the kingpin is embedded in the tire suspension and bolted to the suspension by steel plates so that the rotation of the tire is controlled by the control system to control the rotation of the motor so that the four wheels individually control the steering.

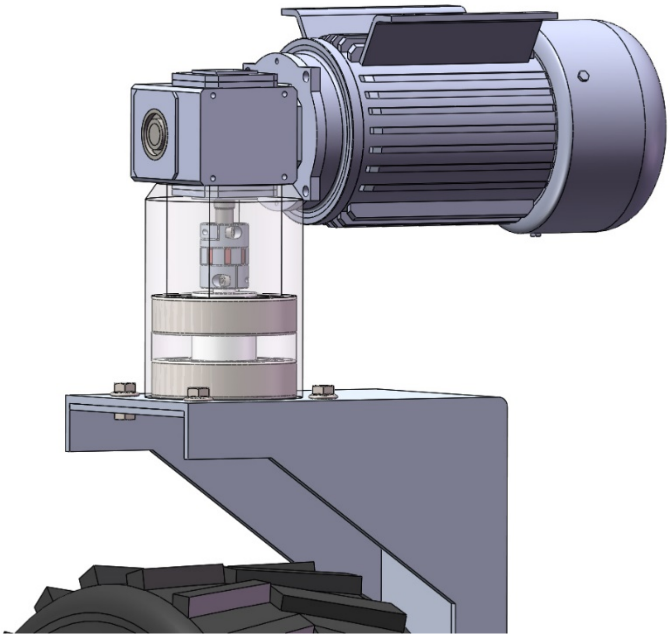


Figure 4.29 Steering mechanism model

Figure4.30 Steering mechanism model explode view

Chassis

In this part, the mechanical concept for the chassis will be designed in detail.

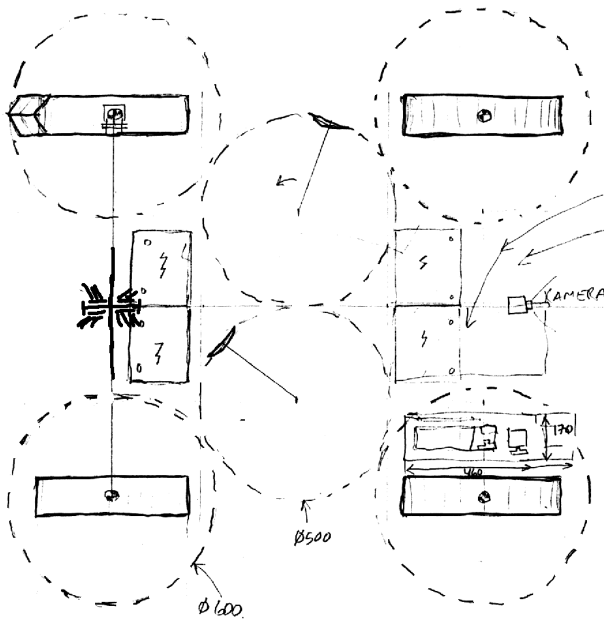


Figure4.31 Overall principle and quantitative structure

General Principles and Summary of Overall Quantitative Structure

The main structure of the vehicle is shown in Figure 4.30. The kingpin is located just above the center of the wheel and the distance between the centres of the kingpins is 1450 mm both in the longitudinal and transverse directions. There is space in the middle to accommodate different types of tools. The ground clearance between the wheel modules should be 500 mm.

Quantitative structures

As noted above, the general principles, structure and dimensions have been determined, and the position and shape of the chassis components will be determined herein.

Components which must be placed

The first step is to find the dimensions and special requirements for the placement of the different components.

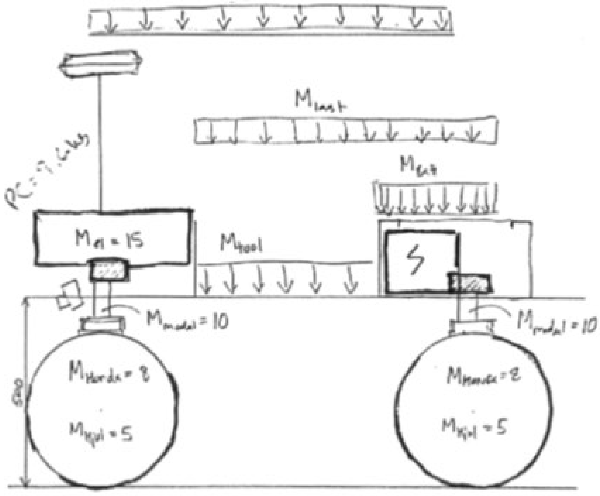


Figure4.32 Overall load

Batteries

The battery used for this application must be able to provide an almost constant current for 8 to 10 hours. Ordinary car batteries can only supply large currents in a short period of time. Therefore, I need to use a traction battery that can provide constant current for a long time..

In particular, the power consumption of a steering motor is difficult to estimate because power consumption depends to a large extent on how much initiative the motor must have to eliminate ground irregularities and other disturbances.

The robot requires a total of five weeding motors, four steering motors and a control motor that controls the lifting of the weeding mechanism, as well as four drive motors that drive the wheels. The power of the weeding motor is 640W, the power of the steering motor and the lifting motor are the same, and the power is 1500W. However, it is not used continuously. It consumes power only after a forward operation is completed, so it is difficult to calculate accurately. The wheeled motor is rated at 6 kW. It cannot be fully loaded when running at low speed for a long time.

Ordinary home computers have a power of 40W (not always running at full capacity), and the rest (such as cameras and sensors) require a total of about 20W.

Figure4.33 Common electric vehicle battery

Select a lead-acid battery for each battery of 12V / 20Ah, each weighing 6.5kg, assuming the required number of batteries is n.

Assuming a speed of 1.6km / h during operation, it is estimated that the body weight outside the battery is about 700kg.

$$P_{wheel} = Fv = ((700kg + 6.5kg \times n)g\mu + 200N) \times 1.6km/h \tag{38}$$

$$P = P_{wheel} + P_{weeder} + P_{pc} \tag{39}$$

$$t = \frac{Wh \times n}{P} = \frac{240Wh \times n}{((700kg + 6.5n) + 200N) \times \frac{1.6}{3.6}) \ + 60W + 650W} \tag{40}$$

When t = 10, n = 70 is obtained, i.e., under the assumed operating conditions, 70 selected batteries can be stably operated at a speed of 1.6 km / h for ten hours. The vehicle is designed to work 8-10 hours at a time. Taking into account the unpredictable power consumption, the final selection of 76 battery packs is suitable for the entire car, with a total weight of about 500kg.

The battery is the heaviest part of the robot and has a large influence on the weight distribution of the vehicle. It should be placed close to the center of the vehicle.

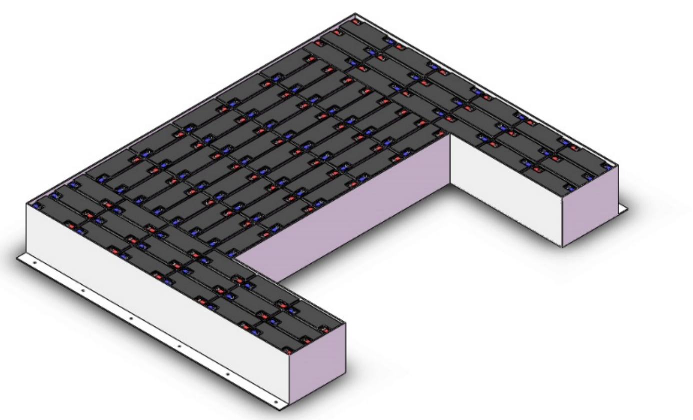


Figure4.34 Group of vehicle battery

The entire battery is designed to balance the weight of the battery and to reserve space for computers and GPS devices. The battery compartment is secured to the chassis by the lower edge screws on both sides.

RTK/GPS

Trimble's RTK / GPS equipment can be placed on a rover (robot) for outdoor use and good protection against water, dust, etc..

The equipment for the rover is:

• GPS Total Station 4700, integrated GPS receiver and radio modem, see Figure 4.33.

• GPS antenna without ground plane

• Radio antenna

• Stand for the GPS antenna made of a 500 mm long aluminium tube with a diameter on 1" equal to 25.4 mm. The stand can be extended with more tubes.

Figure 4.35 GPS Total Station 4700

The GPS antenna should be placed so that no part of the vehicle is blocked by

GPS signals. The antenna must be placed in a stable position to avoid vehicle dynamics problems.

Compass

The guide is very sensitive to hard iron deformation and magnetic fields generated by electrical equipment. Initially, it was difficult to find the correct position of the compass, and the position of the compass was underestimated and placed on the GPS antenna mount.

Computer

The exterior dimensions of the cabinet are: 520 x 512 x 185 and weighs 9.6 kg. In addition, the wires must be connected to the computer in approximately 80 mm of free space to access the connection and disconnect the cable. Since all control signals are connected to the computer, the computer takes up the most space and should be placed in the center to avoid wiring problems.

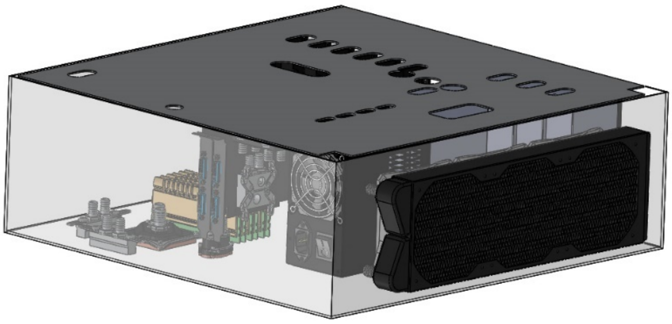


Figure 4.36 PC box

Camera

Since the itinerary is for four crops, four cameras are needed below the frame to scan the crops. Two extra front cameras are required at the front of the vehicle to get the path information, but the two cameras can be mounted on the vehicle's casing.

Figure 4.37 Coms camera

Part design

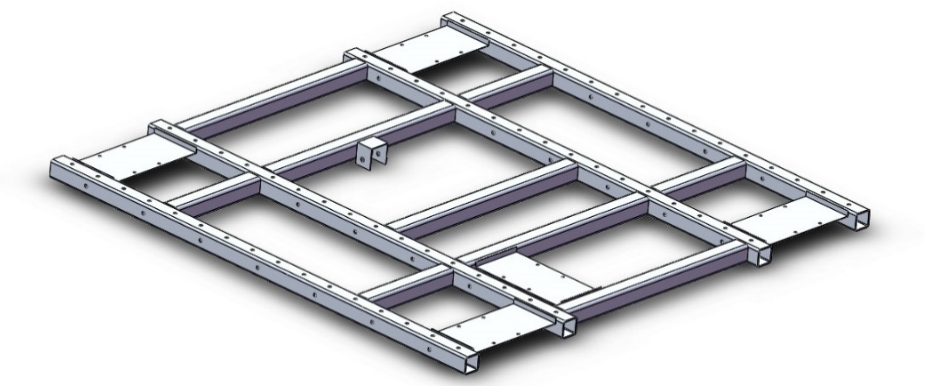


Figure 4.38 Chassis

The substrate consisted of 50x50 square steel. The raw materials were cut into four lengths of 1450 mm in the longitudinal direction, and then four kinds of 300 mm and five kinds of 650 mm steel were welded separately. The five steel plates were bent to a size of 300 x 146 x 17 mm as a fixed point to connect the four wheel assemblies and the motor of the lifting mechanism. The intermediate piece is part of the subsequent fixed support spring and is also integrally connected to the ground plate by welding.

RTK/GPS equipment

The GPS antenna is supplied with a 500 mm long bracket with a diameter of 25.4 mm. The GPS antenna must be placed so that other devices do not block the signal from the satellite to the antenna. Finally, the antenna mount is mounted at the rear of the vehicle and connected to the ground through a metal bayonet.

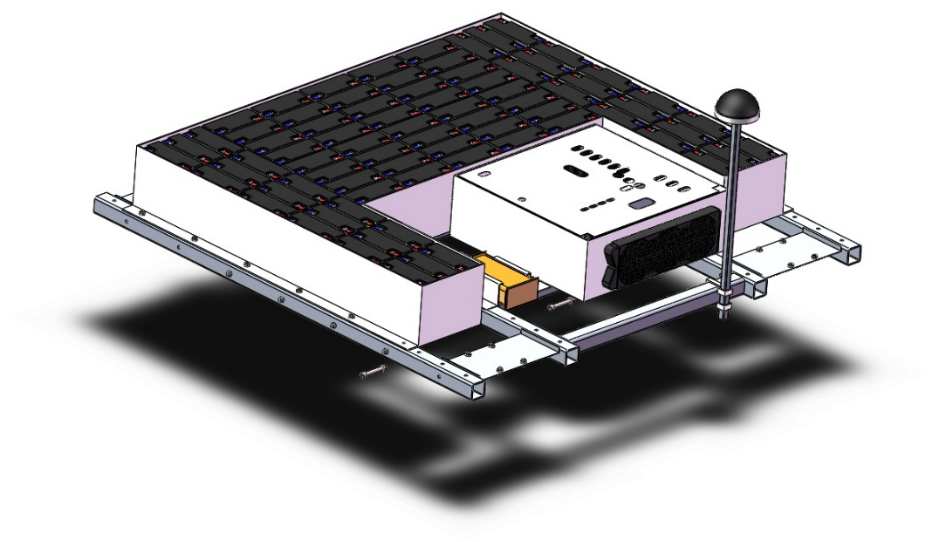


Figure 4.39 Chassis with installation component

Weeding tool

As mentioned earlier, the vehicle chassis is designed to weed four times at a time, requiring a total of five rotating mechanisms to work simultaneously. The entire organization must achieve a 20-50 mm ability to stably penetrate into the soil during work, while leaving the ground completely when it needs to be turned or does not require weeding to make the vehicle turn and shift smoothly.

The motor and handpiece of the weeder have been selected in Chapter 3. This section describes the assembly of the entire mechanism.

A U-shaped steel insert housing measuring 50 x 50 is used to mount an electric motor with a housing height of 255 mm. The main body uses U-shaped steel with a length of 1500 and another U-shaped steel with a main body length of 300 mm. The U-shaped steel with the open end is fixed to the housing by bolts. The five sets of weeders have a spacing of 350 mm, which corresponds to the crop spacing. A small steel plate is mounted on a casing in the middle as a component that is connected to the spring mechanism.

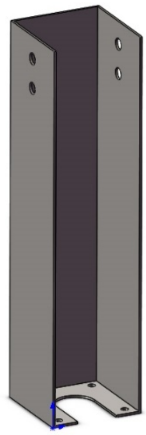


Figure 4.40: Weeding mechanism motor housing

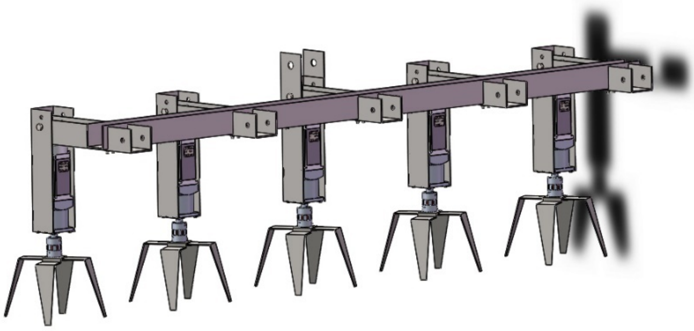


Figure 4.41: Weeding mechanism

Figure 4.42: Weeding mechanism explode view

In order to raise the weeding mechanism, another electric motor is needed to complete the work.

The two ends of the second and fourth sets of weeders are respectively fixed with four rod mechanisms consisting of 450 mm long rods to form a parallelogram with the chassis so that the motor can drive one of the rods to rotate to drive the entire mechanism upward and downward. . A spring mechanism is mounted in the middle between the motor housing and the ground so that the weeding mechanism can penetrate into the ground to resist the whole, thereby ensuring that the weeding mechanism is in contact with the ground by 20-50 mm. Working status. Complete the weeding work. The rod connected to the output shaft of the motor reducer is connected to the same coupling as the previous one.

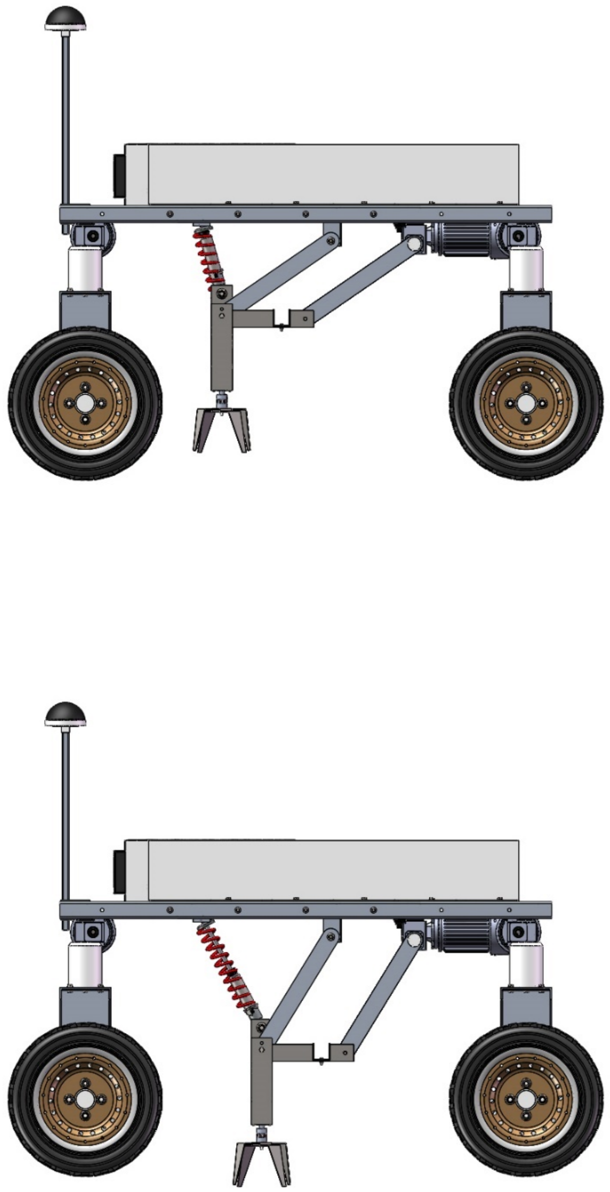


Figure 4.43: Weeding mechanism lifting mechanism

Cover shell

After research, the shell first needs to assume the function of installing the headlights and the front camera. Second, an alarm light is needed at the top to allow the user to remotely tell if the vehicle is working properly. Secondly, the rear needs emergency start and emergency brake buttons, and a touch screen is required to command the robot.

Figure 4.44: Front view of the outer casing

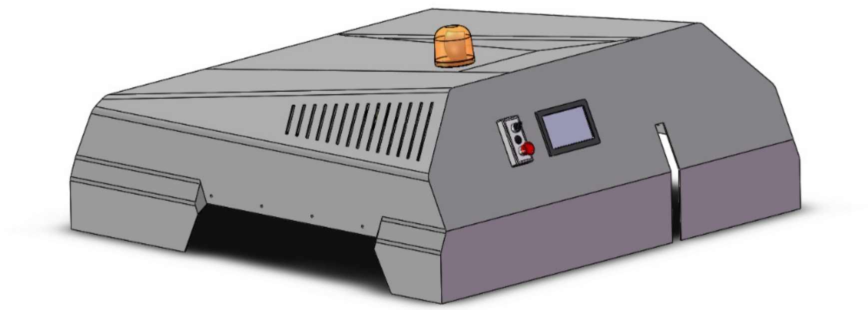


Figure 4.45: Rear view of the outer casing

The shape of the enclosure consists of five beveled corners with grille on the front and sides to accommodate internal batteries and main cabinets to prevent damage due to excessive internal temperatures. The tailgate is about one meter high from the ground and is very convenient for personnel to operate.

The outer casing is formed of a plastic material by a rotational molding process and integrated. It is secured by screw holes on both sides and the steel frame of the chassis.

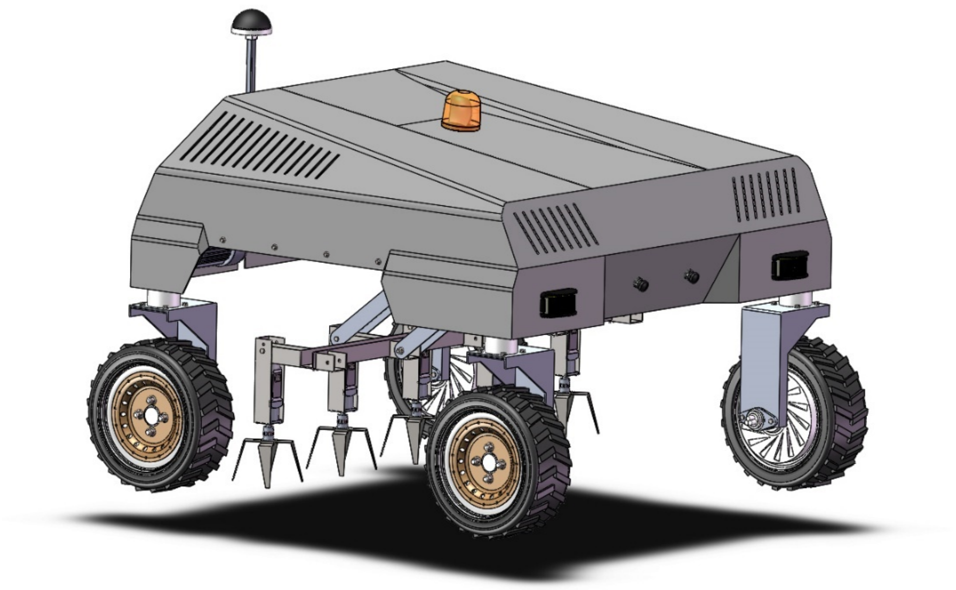


Figure 4.46: Automatic weeding robot

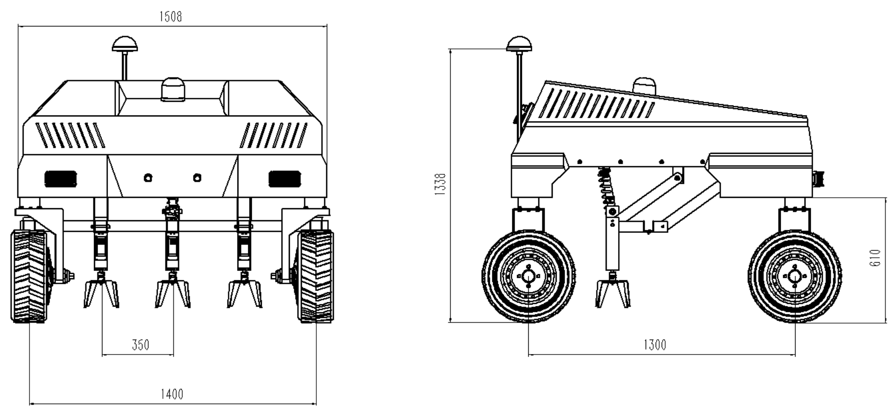


Figure 4.47: Automatic weeding robot dimension

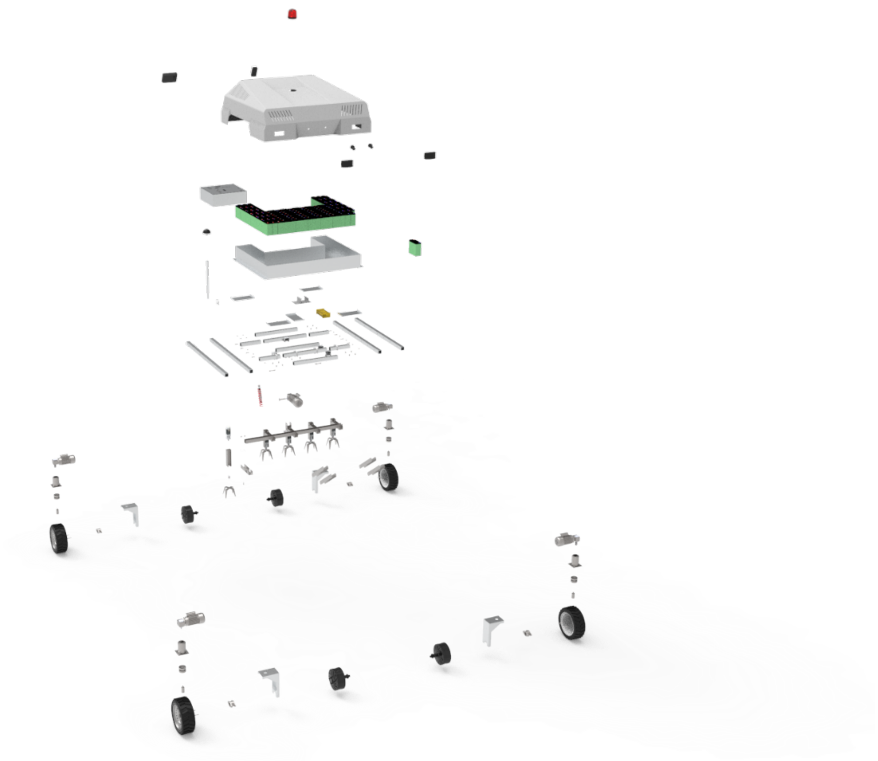


Figure 4.48: Automatic weeding robot explode view

CHAPTER 5. SOFTWARE

Of course, the robot also has a very important part in the programming and design of the control system, but I am not in this industry can not design and develop this part, only the possible control system can be shown in the figure according to the reference picture.

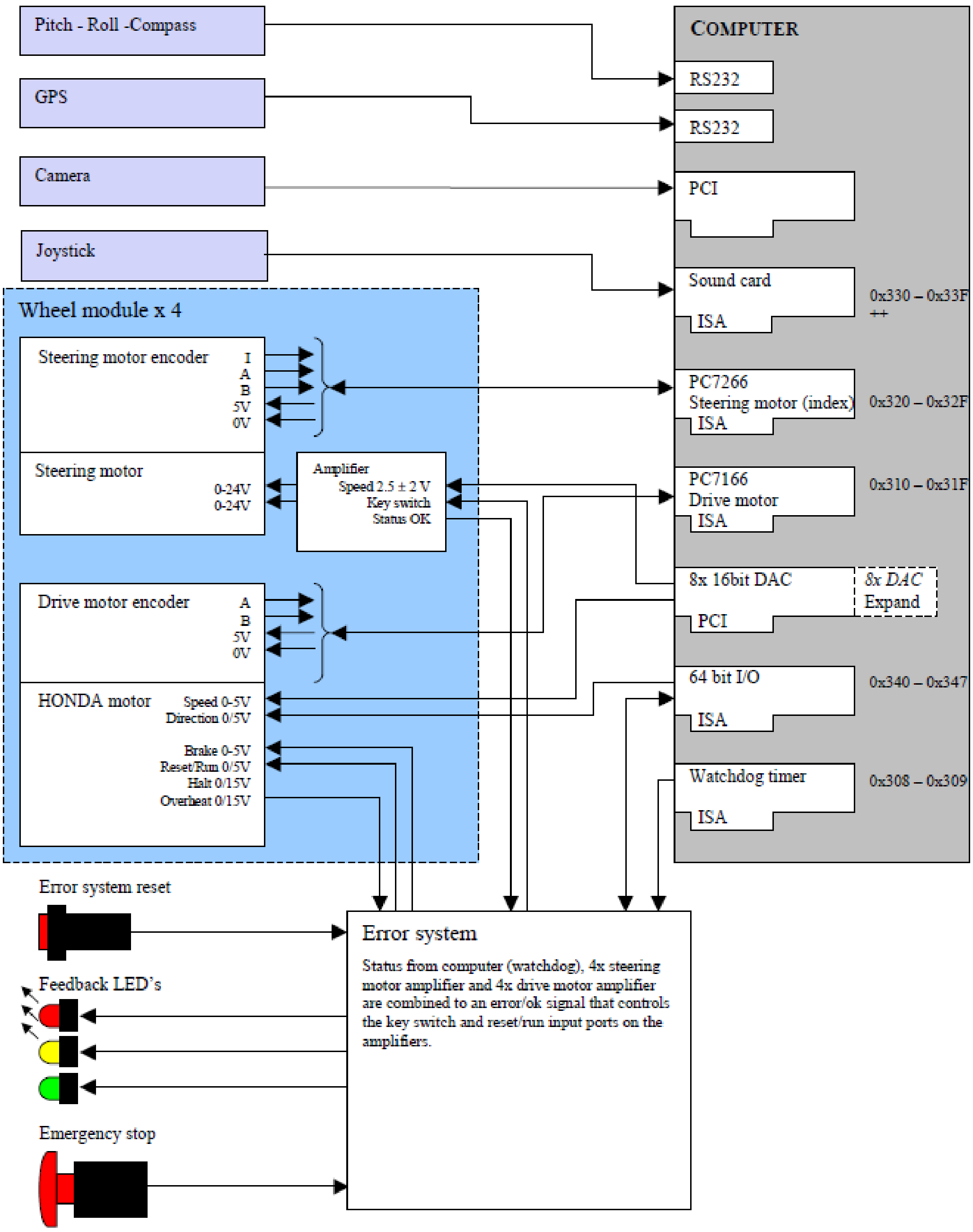


Figure 5.1: An overview of the control connections

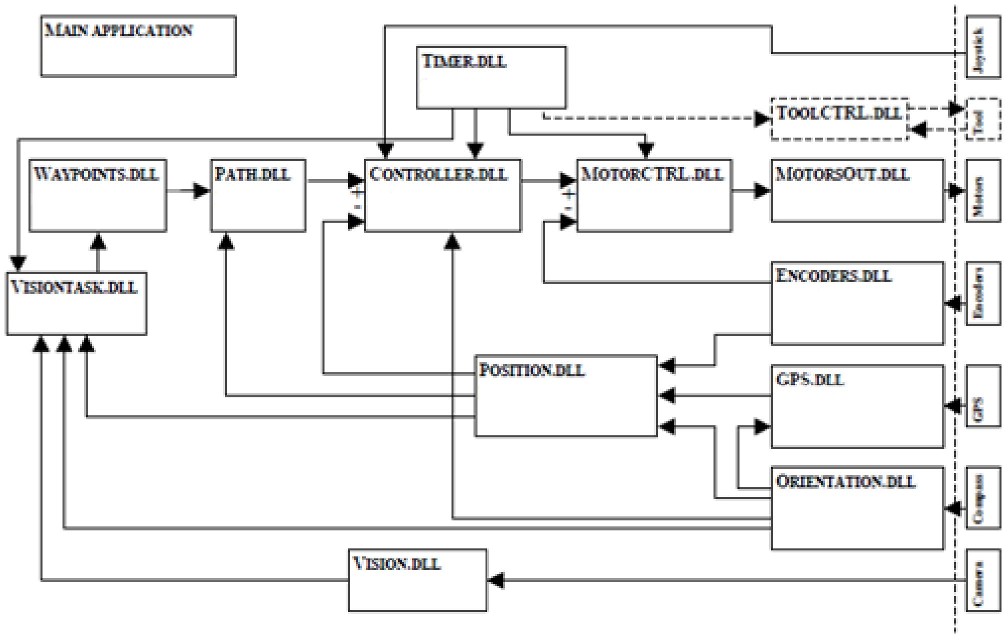


Figure 5.2 An overview of all software modules and their connections.

The previous section introduced two control methods. The control sequence is explained here. First, the vehicle travel system should be controlled separately from the weeding system..

The driving system should use the information obtained by the front-end camera to guide the wheeled motor to advance or stop at a steady speed. At the same time, the distance between the head of the weeder and the plant obtained by the camera at the bottom of the vehicle is used as a steering motor. Adjust the distance between the hoe and the crop to prevent damage to crops. At the end of the four-row crop, four motor-controlled steering motors are controlled to work together to complete the steering and enter the next four crops for the next phase of work.

When the vehicle reaches the end, the hoist motor should also start working. The motor must overcome the resistance of the support spring to lift the weeding mechanism off the ground so that the vehicle can be steered smoothly. After the steering is completed, the weeding mechanism will be lowered to continue the new weeding work.

CHAPTER 6. GENERAL CONCLUSIONS

The purpose of this study was to design an automated robot that could be used for weeding on large farms. First, weeds are an important factor affecting vegetable yield, especially in the first 5-6 weeks of growth. Therefore, at this stage, timely weeding and reducing nutrients consumed by weeds can enable better production of vegetables and increase the economic value of agricultural products.

The entire robot is driven by four wheels with drive capability, powered by 76 lead-acid batteries, and weeded using a weeding mechanism driven by a brushless motor. The robot can perform weeding operations on both sides of the four rows of crops at a time. The battery reserve can provide 8 to 10 hours of support for the entire robot, and one machine can serve 300 acres of land within three weeks.

In addition to improving the control program, subsequent robots can upgrade the weeding tools and should also be able to provide features such as data collection and replace more tools to enrich product features. The intelligent agricultural market is vast. The proportion of GDP in agriculture in various countries is relatively stable. Agricultural intelligence can better increase the yield and quality of crops, and there may be more choices for growing varieties.

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