Autonomous University of Queretaro

Engineering Faculty

# “Voice Activated Robotics Application Using Off the Shelf Home Automation Components”

**Thesis**

Presented as a partial requirement for a degree in Automation Engineering with specialization in Instrumentation and Process Control.

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Universidad Autónoma de Querétaro
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**Tesis**

"Voice Activated Robotics Application Using Off the Shelf Home Automation Components"

Que como parte de los requisitos para obtener el grado de Ingeniero en Automatización con especialidad en Instrumentación y Control

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## Resumen

El Internet de las Cosas (IoT por sus siglas en inglés) es una nueva tecnología que ya está cambiando el mundo en el que vivimos al interconectar objetos físicos que pueden recopilar o transmitir información a nosotros y entre ellos. En este trabajo, con el uso del IoT, se presenta un vehículo utilitario semiautónomo con componentes de automatización (inteligentes) asequibles, el sistema consiste del hardware y el software. Para el software que comandará y controlará el vehículo, hay una aplicación web habilitada para dispositivos Android, y también los applets (aplicaciones inteligentes) que se pueden activar con el Servicio de voz Alexa. El hardware consiste en dispositivos de control de automatización asequibles y de bajo costo que operan el cortacésped semiautomático y activado por voz al mismo precio o menos que un cortacésped común. El producto final de este trabajo es un vehículo que servirá como una demostración de un proyecto de robótica y también como un vehículo utilitario. El vehículo se puede controlar a través de comandos de voz y es capaz de moverse en cuatro direcciones a cinco velocidades diferentes. El cortacésped es capaz de moverse a una velocidad promedio de 35.7 m / min entre sus cinco velocidades en pasto, y a una velocidad promedio de 20.80 m / min y 16.29 m / min en piso y concreto respectivamente. Los sensores ultrasónicos probaron su fiabilidad al detener la cortadora de césped a una distancia promedio de 7.3 cm de los diferentes obstáculos presentados. Este trabajo contribuye al conocimiento existente sobre el Internet de las Cosas al proporcionar un vehículo semiautónomo capaz de ser controlado a través de la nube tanto con comandos de voz como a través de una aplicación web, actualmente, se ha hecho un trabajo limitado para combinar estas tecnologías.


Palabras clave: Internet of Things, Robotics, Alexa, Autonomous Vehicle, Voice Control.

**Abstract**

The Internet of Things is a new technology that is already changing the world in which we live by interconnecting physical objects that can collect or transmit information to us and to each other. In this work, with the use of the IoT, it is presented a semi-autonomous utility vehicle using off-the-shelf home automation (smart) components, the system consists of the hardware and software. For the software that will command and control the vehicle, there is a web app enabled for Android devices, and also the applets that can be triggered with the Alexa Voice Service. The hardware consists of inexpensive home automation control devices that operate the semi-automated and voice activated lawn mower at the same price or less than a common ride-on lawn mower. The final product of this work is a vehicle that will serve as a demonstration of a robotics project and also as a utility vehicle. The vehicle can be controlled through voice commands and is capable of moving in four directions at five different speeds. The lawn mower is able to move at an average velocity of 35.7 m/min among its five speeds in grass, and at an average velocity of 20.80 m/min and 16.29 m/min in floor and concrete respectively. The ultrasonic sensors proved their reliability by stopping the lawn mower at an average distance of 7.3 cm of the different obstacles. This work contributes to existing knowledge on the Internet of Things by providing a semi-autonomous vehicle capable of being controlled over the cloud both with voice commands and through a web app, currently, there is limited work done combining these technologies.

Keywords: Internet of Things, Robotics, Alexa, Autonomous Vehicle, Voice Control.

**Dedications**

*To my mother Claudia, who has always given me her love and support. That throughout my life has always pushed me forward and has shown me the value of the work.*

*To my father Mayolo, the best teacher that I have had in the classroom and in life, my example of constancy and dedication. Thank you for advising me and serving me as a guide to becoming the person I am now.*

*To my godfather Alvaro and to my uncle Noel who since childhood have given me advice and support and have always inspired me to go further.*

*To all my family, for their unconditional love, for being the fundamental pillar of the person who I am, in all my education, both academic and life, for their unconditional support flawlessly maintained over time.*

*To my friends, that we supported each other in our professional studies and that I will carry with me always.*

*To those people that I love so much that during my career were always close to me pushing me to achieve greater goals.*

*Finally to the professors, those who marked each stage of my journey, who were mentors, teachers, and friends for me,*

*As a testimony of eternal gratitude for the achievement of my career which is for me the best heritage.*

*To all, with affection.*

**Dedicatoria**

*A mi madre Claudia, que siempre me ha brindado su cariño y apoyo. Que a lo largo de mi vida me has impulsado siempre hacia adelante y me has mostrado el valor del trabajo.*

*A mi padre Mayolo, el mejor maestro que he tenido en las aulas y en la vida, mi ejemplo de constancia y dedicación. Gracias por aconsejarme y servirme como guía para convertirme en la persona que soy ahora.*

*A mi padrino Álvaro y a mi tío Noel quienes desde niño me han dado consejo y apoyo y que han sido para mí  siempre un ejemplo a seguir.*

*A toda mi familia, por su amor incondicional, por ser el pilar fundamental en todo lo que soy, en toda mi educación, tanto académica, como de la vida, por su incondicional apoyo perfectamente mantenido a través del tiempo.*

*A mis amigos, que nos apoyamos mutuamente en nuestra formación profesional y que llevaré conmigo siempre.*

*A esas personas que tanto quiero y que durante mi carrera estuvieron siempre cerca de mí impulsándome a lograr metas más grandes.*

*Finalmente a los maestros, aquellos que marcaron cada etapa de mi camino, que fueron para mí, mentores, profesores y amigos,*

*Como testimonio de eterno agradecimiento por el logro de mi carrera que es para mí la mejor herencia.*

*A todos, con cariño.*

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Filled with satisfaction I am ready to present this thesis, as it represents the culmination of a cycle, a cycle that required a lot of effort and dedication, which was filled with challenges that led me to demand and to give the best of myself.

I would like to express my gratitude to all those people who in some way influenced the culmination of this project.

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# Contents

# CHAPTER 1.

## 1. Introduction

The Internet it's now a widespread technology that has been around for a while, but it's been mostly the product of people, so all the data, images, recordings, games, books, etc. was created by people and for people. To this day, the internet is one of the most important and relevant technologies ever invented. The Internet is like a digital fabric that's woven into the lives of society in one way or another. This Internet of people changed the world, but there's a new one emerging, and it's already changing the world again. This innovative Internet it's not anymore just for people, now it's focused on connecting things, and that's why it's named The Internet of Things (IoT). The IoT refers to the networked interconnection of physical objects through the use of embedded sensors, actuators, and other devices that can collect or transmit information about the objects themselves. The mash-up of captured data from these devices can then be analyzed to optimize products, services, and operations. With smart objects, it is possible to go beyond the services that can be provided by an isolated embedded system. A smart object can be defined as an embedded system that is connected to the Internet [1][6][7].

IoT has been around for a long time, lots of companies have been using sensors and networks to provide and get information about the location of their devices, how they're being used, their condition, and the state of their environment since the 1990s. With the progress made in the 2000s with the Internet connectivity, and paralleled with the widespread use of mobile devices and applications, this helped to create what we now know as IoT. Other factors include the emergence of cloud computing as a way to store and process large volumes of data cost-effectively [3][8].

ABI Research's latest data on the Internet of Things shows that there are more than 10 billion wirelessly connected devices in the market today; with over 30 billion devices expected by 2020 the IoT translates into a trillion dollars industry [2][5], and it goes far beyond lights, smart meters, smartphones, and wearables, this shows that the trend of connecting our devices to the Internet it's already here.

When considering an IoT-based application, there are some challenges that need to be addressed both technologically and in the society. One of the central issues is making a full interoperability of interconnected devices possible, providing them with an always higher degree of smartness by enabling their adaptation and autonomous behavior, while guaranteeing trust, privacy, and security [4]. Nowadays the IoT-enabled devices have enormous capabilities, and they are mostly small, one key challenge that needs to be addressed is the power consumption. Many IoT applications need to run for extended periods of time, and it's required that they will work for as long as possible, IoT devices need longer battery lifetimes, smaller batteries or even energy harvesting for battery-less applications [12].

IoT has the potential to transform the way the world works, and with the digitization of machines, vehicles, and other elements of the physical world this is getting possible. To get the full potential of IoT applications, it is required to innovate in technologies and business models. If we expect a fully developed IoT that may transform our lives, then it's critical to encourage interoperability between systems, ensure security, and protect privacy and property rights. The Internet of Things can begin to reach its full potential especially if companies, developers, and everyday users embrace this new trend and start to work together [5][8]. So much needs to be done before we can make a real IoT connected global environment but one thing is for sure, if we make it, it definitely will change our world.

The purpose of this chapter is to introduce the reader to the Internet of Things (IoT), showing its main characteristics, background advantages and challenges. Also, the reader will be introduced to Voice Services with a special focus on Alexa. The chapter one it's closed with a description of the project, objectives, and its relevance.

On chapter two we will examine the elements that will be used for the project, their features, and importance. Additionally, it will be explained the functioning and operation of these elements in the system.

On the third chapter, the reader will be able to see the methodology of work, flux diagrams, and connections. Implementation and overall view before tests will be available too.

On the fourth chapter, the obtained results will be presented, as well as the appropriate remarks and comments. The reader will also be able to study the user manual and to check safety considerations. There will be a troubleshooting guide too in case it's needed. Conclusions and possible applications will also be discussed in the last chapter.

### 1.1. Internet of Things

Kevin Ashton coined the term Internet of Things in the context of supply chain management in 1999 [16]. This is now an old definition of IoT since in the recent years the definition has a bigger perspective covering more applications like transport, communications, automotive and transportation, healthcare and utilities in general. In Figure 1. InFigure 1 we can see a schematic of the interconnection of objects, where according to the impact of the data generated the application domains were chosen.

Since the development of the first network in the world, the ARPANET in the 1960s [17], the Internet has exponentially grown from a small academic and military concept to a worldwide network that host services, information and has more than a billion users with no sign of any possible decrease in its numbers [7].

Nowadays, technology allows us to make electronic devices that are small, cheap and powerful; this makes possible to expand the capabilities of what we know as the Internet. A smart thing in the IoT can be almost any object that can be assigned an IP address and provided with the ability to transmit and receive data over the Internet. but the key feature that a smart thing has is that it has the means to sense physical phenomena (e.g., sound, level, weight, temperature, light) or means to affect the physical world (actuators).

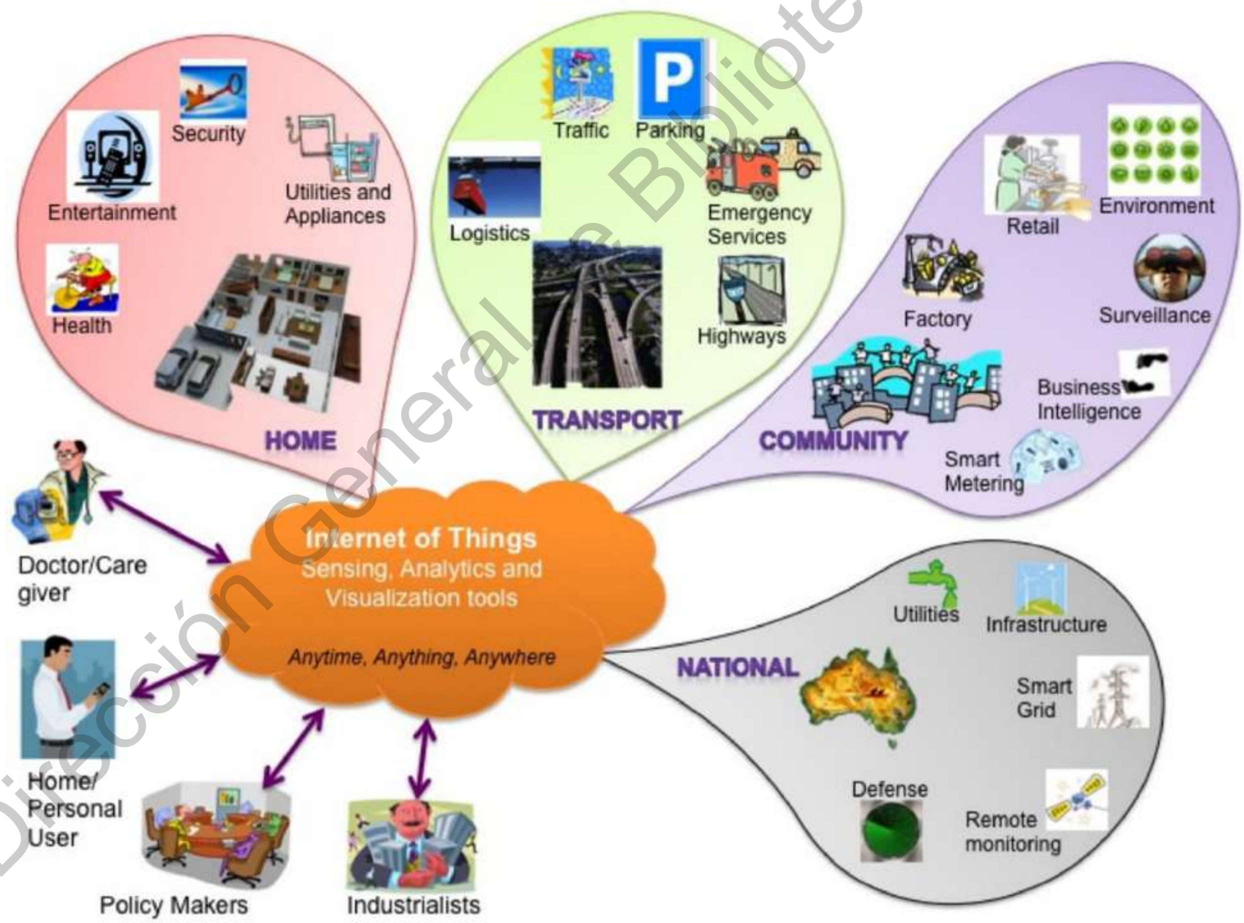


*Figure 1. Internet of Things schematic showing the end users and application areas based on data [14].*

### 1.1.1. Why now?

According to the Gartner's IT Hype Cycle of 2016 (Figure 2), it can be seen that the Internet of Things platform has been identified as one of the emerging technologies. A Hype Cycle is a way to represent the emergence, adoption, maturity, and impact on applications of specific technologies [14]. We can see that the Gartner's IT Hype Cycle (Figure 2) forecast that IoT will take 5 to 10 years for fully market adoption. As we can see, there are more technologies that are based on the IoT in the innovation trigger such as Virtual Personal Assistants, Smart Workspaces, Smart Robots, and Connected Homes all of them with the same period of adoption 5 to 10 years, this can give us a good forecast of where the users and companies are putting their bet on the development of new technologies.

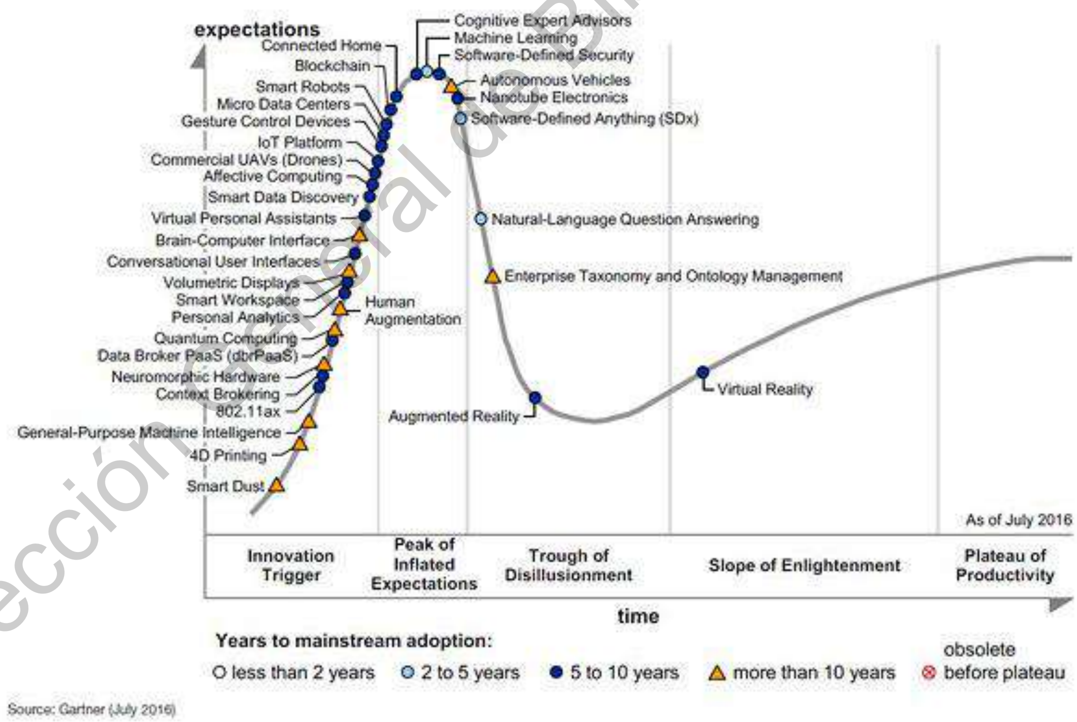


*Figure 2. Gartner 2016 Hype Cycle of emerging technologies [18].*

IoT is already transforming industries, business, and health care in innovative ways to offer new services that can deliver additional profits to both sides; suppliers and users [61][62]. Right now is the best moment to jump on this new trend and start to develop technologies.

### 1.1.2. Opportunities

The infrastructure for a widespread IoT should be efficient, reliable, scalable, secure and trustworthy, but also it needs to be widely applicable and must take social and political expectations and economics consideration into account. To this day some problems have already been solved, and many companies and academics are putting their efforts to work and develop a better integrated and organic IoT.

- Low-cost: Nowadays the cost of technologies, connectivity, data, and sensors is declining while the computing and processing power is increasing. Companies like Cisco, IBM, and Google provide data storage with high-bandwidth at low cost and the cost of connectivity have declined at a rate of 15% per year [19].
- Internet Protocol v6 (IPv6): This is a new standard that comes to solve the problem of IPv4 address exhaustion. The IPv4 has almost 4.3 billion addresses available that with the exponential growth of the Internet is now all assigned, the top-level exhaustion occurred on 31 January 2011 [20][21]. This new Internet Protocol has been designed to use a 128-bit address to offer 340 undecillion ($3.4x10^{38}$) unique IP addresses [13]. With this amount of unique addresses available the problem of addressing schemes is one of the problems solved in the IoT structure.

- Technological Advances: The semiconductor industries are developing newer and advanced processors at lower prices. As an example, the microprocessor ARM Cortex-M3, use only about one-tenth of the power that most 16-bit processors used only two years ago and this at about three-quarters the price [1].
- Demand: Right now, there is a settled market for smart devices such as smart watches, smart thermostats smart lights and this market is growing each year as technologies get advanced and cheaper. The demand for smart things will only grow from this point, and some studies value a potential economic impact of the IoT between $3.9 trillion to $11.1 trillion dollars per year in 2025 [5].
- Standards: The growing interest in IoT over the past five years has made that software, hardware, and networking companies work together with industry associations and academic parties to develop formal standards for IoT [8]. The Industrial Internet Consortium Working Groups was formed by big name companies such as Cisco, AT&T, and IBM to coordinate and establish the priorities and enable technologies of Industrial Internet to accelerate market adoption and drive down the barriers to entry [22]. The Application Programming Interfaces (APIs) that enable basic commands and data transfer among the IoT devices have been standardizing as well.

### 1.1.3. Challenges

Despite the fact that IoT has such a big potential, companies and users must outdo several concerns and challenges that are holding back the growth of IoT.

- Interoperable technologies: There are many companies, developers and industries working with IoT each one is using the technologies and protocols that better suits them. This works in a local environment but IoT it's meant to be a global solution, this is why there is a need to create standards and protocols that enable interoperability between all the devices. Without standards, it's difficult for organizations to combine applications and devices that use different technologies and operate with different networks and protocols. It's required to ensure that smart objects can interact with multiple services and with other smart objects.
- Data management issues: With IoT comes the creation of a remarkable amount of data that has never been seen. With this, the storage, ownership, and handling of data become a critical issue. By 2012 the Internet consumed up to 5% of the total energy generated in the world [14] and this number is only growing up as the need to be always connected does. The network traffic and data storage need the energy to work, and this energy needs to come from a clean source if we want to make IoT a clean, affordable technology.
- Privacy and security: Security is a critical component for enabling the widespread adoption of IoT devices and applications. If the users don't have a guarantee of confidentiality and safe storage of their information, it seems unlikely that they will adopt IoT in their everyday lives. It's essential that only authorized entities can access and modify the data. This is important for everyone from industries to house automation and healthcare. A solution for ensuring data confidentiality must be developed so IoT can be widely accepted.

- Simplicity and control: With billions of expected devices connected and working at the same time, it's essential to have the connectivity to hold and make flow all the information generated. Some smart things have lots of sensors and applications, to make progress with IoT it is required to control and send all information while keeping smart things simple and intuitive. IoT is intended for everyone, and that's why it should be about accessing information that the user wants, not irrelevant or generic data that is not required. These capabilities are almost about to be realized with the strong data analysis that takes locations, interest, and likes of users, this enhances the performance of smart devices, but the privacy and personal information must always be taken into account.

### 1.2. Voice Services

The voice command recognition started at the end of the 1970s with the project "Put that there" [24]. On this project, the commands are used to interact with a computer. The system allows users to paint figures in a graphic interface using phrases of the natural language. This project revolutionized the way people interacted with computers and, since then, many projects have emerged working with voice commands.

A voice recognition system is a computational tool able of processing the voice signal emitted by the user, and recognize the information contained in it, translating then into text or commands that can execute an action or a process. On the process, there are many technologies and sciences involved, such as physiology, acoustics, signal processing, artificial intelligence and computer science. With the boom of smartphones, the interaction through voice commands have been improving; a user can ask for information, keep a conversation and execute commands.

One example of these systems is Siri, the personal assistant of Apple [25] which can be used to send messages, place calls, and make dinner reservations. Siri works hands-free, and it's one of the most advanced voice assistants that it is available. To Android users, there is Google Assistant [26] that has been updated to compete with Siri, with Google Assistant it's possible to ask questions, set alarms, send messages, access to music and much more. The gesture and voice recognition are elements that more companies are trying to implement in all their new products. Nowadays there are many low-cost devices that have the capabilities to offer this kind of functions, and some high-end devices take these services to the next level providing an organic intelligent environment.

One personal assistant that has gained a lot of popularity since its release on 2014 is Alexa [27] from the developer Amazon. Alexa is an intelligent personal assistant capable of make to-do lists, set alarms, play music and provide weather and traffic information as well as interact with households items over the cloud.

### 1.2.1. Amazon Alexa

Alexa is the personal assistant from Amazon, and it's the brain behind the Amazon Echo (Figure 3) [28] and other Alexa devices [29]. Amazon has made the interaction with Alexa quite simple; the user needs to ask a question or makes a command and Alexa will respond instantly. Alexa is hosted in the cloud so the more you use it, the smarter it gets, and also because of this it can give the user updates and can control devices in real time.

Most devices with Alexa are activated with a wake-word (such as Echo); while other ones require the user to push a button to activate Alexa's listening mode. For now Alexa it's available only in English and German.

Some of the key features of Alexa are [29][30]:

- Alexa can play music from big streaming services like Amazon Music, Spotify, Pandora, and more.
- Amazon Alexa enabled devices like the Amazon Tap and Amazon Echo have 360º omnidirectional audio speakers.
- Most of the Alexa enabled devices are hands-free.
- Their built-in microphone can hear the user from across the room with far-field voice recognition, even while music is playing or people are speaking.
- The Alexa Voice Service can answer questions, read the news, report traffic and weather, read audiobooks, give info on local businesses, provide sports scores and schedules
- It can control lights, fans, switches, thermostats, garage doors, sprinklers, locks, and more with compatible connected devices.
- It constantly gets smarter and adds new features.


*Figure 3. Amazon Echo [27].*

### 1.3. IFTTT

If This Then That or IFTTT (Figure 4) is a free web service that combines numerous other web apps into one place and then can perform some actions given a certain set of rules [31][32]. IFTTT was created by Linden Tibbets, Jesse Tane, Scott Tong, and Alexander Tibbets and launched it on September 7, 2011. By 2015 users were creating about 20 million recipes each day [38].

*Figure 4. If This Then That logo [32].*

### 1.3.1. How does it work?

IFTTT is an easy way to automate tasks that might otherwise be repetitive or unable to talk to each other. To make it work, users are guided through a process to make recipes, where some event in one device or service automatically triggers an action in another [40][41].

- Channels: Also known as Services describe a series of data from a specific web service such as Gmail or Facebook [39]. They can also describe some actions controlled with certain Application Programming Interfaces (APIs). In the last case, they can represent information like weather or traffic. There are particular triggers and actions in each channel [32].
- Triggers: They are elements that "trigger" the action. For example, from a specific location, you can receive a notification based on how far are you from home.
- Actions: They are the output that results from the input of the trigger [31].
- Recipes: Also known as Applets, they are the combination of two channels using a trigger and an action [40].
- Ingredients: It's the data available from a trigger [33].

## 1.4. Justification

The motivation of this work is to apply automation engineering skills to develop a fully functional demonstration of a small semi-autonomous utility vehicle that can be a cheaper option that the ones that are right now in the market. Autonomous utility vehicles like a lawn mower are now available on the market in a price range from $1000 to $2500 USD [42][43] and none of them can be controlled with voice commands or Cloud Computing. There is a growing market that is asking for cheaper smart devices and that is one goal that wants to be achieved with this project. Nowadays settled companies are taking advantage of this market but with smaller and cheaper electronic components it's viable to build a vehicle making an integration of robotics and electronics with open-source programming on the cloud. The final product of this project will be a voice commanded utility vehicle that will be able to perform the actions of a common lawn mower, and since it's going to be based on open source components, it will serve as a demonstration of a robotics project for children and people who are not related to these fields.

## 1.5. Thesis Statement

### 1.5.1. Hypothesis

It is possible to develop a small semi-autonomous utility vehicle using off-the-shelf home automation (smart) components based on an open-source, cloud-based electronics platform and operated through voice commands.

### 1.5.2. Aim

Implement an Internet of the Things paradigm in order to create a semi-autonomous vehicle oriented to home applications.

### 1.5.3. Specific Goals

1. To study the Internet of Things.
2. To study the Alexa Voice Service.
3. To develop a small utility vehicle operating over the cloud.
4. To have proper knowledge about the sensor and components being used.
5. To command the vehicle over Amazon Alexa’s cloud system.

# CHAPTER 2.

## 2. Theoretical Foundation

### 2.1. System Elements

#### 2.1.1. Lawn Mower

As a base, a Black & Decker's electric lawn mower model CM1836 [52] will be used, as shown in Figure 5.

*Figure 5. Black & Decker's electric lawn mower [52].*

Features

- Helps to reduce the carbon footprint at releasing zero emissions.
- Rechargeable 36V battery and highly efficient motor allow the user to mow up to 1/3 of an acre on a full charge.
- 18 inches blade.
- Clean electric power means no oil changes, tune-ups or trips to the service station.

- Easy to start, and quiet too.
- Adjust the height of all four wheels at once with the pull of a lever.
- Charge time at 100%: 12hrs.
- Charge time at 60%: 4hrs.
- Weight 62 lbs.

### 2.1.2. Particle Photon

Particle's Internet of Things hardware development kit, the Photon, provides everything it's needed to build a connected product. Particle combines a powerful ARM Cortex M3 microcontroller with a Broadcom Wi-Fi chip in a tiny thumbnail-sized module called the PØ (P-zero) [44][46]. The Particle has a solid 3.3VDC SMPS power supply, RF and user interface components to the PØ on a small single-sided PCB called the Photon. This kit is open source, which means that it can be programmed and adapted to the project.

The Photon (Figure 6) comes in two physical forms [45]: with headers and without. Since the Photon Relay Shield will be used, the Photon with headers will be required.

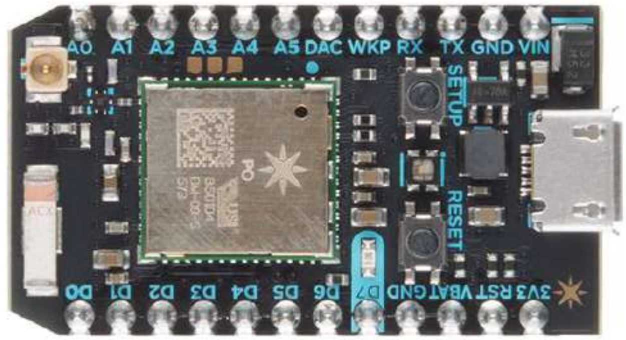


*Figure 6. Particle Photon [44].*

Features

- Particle PØ Wi-Fi module:
    - Broadcom BCM43362 Wi-Fi chip.
    - 802.11b/g/n Wi-Fi.
    - STM32F205RGY6 120Mhz ARM Cortex M3.
    - 1MB flash, 128KB RAM.
- On-board RGB status LED (ext. drive provided).
- 18 Mixed-signal GPIO and advanced peripherals.
- Open source design.
- Real-time operating system (FreeRTOS).
- Soft AP setup.

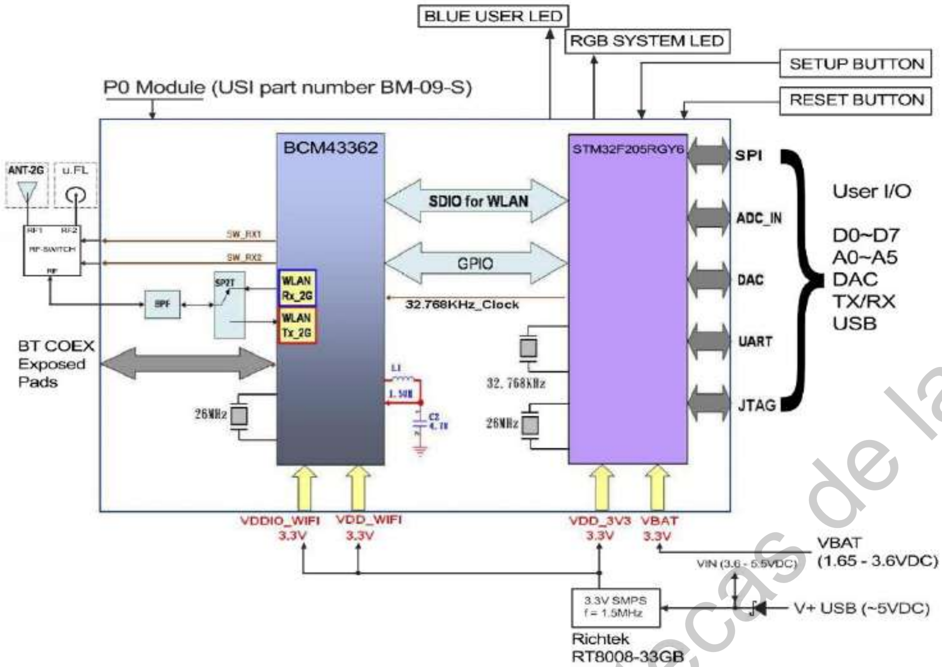


*Figure 7. Particle Photon Block Diagram [44].*

### 2.1.3. Particle Relay Shield

The shield comes with four relays that are rated at a max of 220V @10Amp allowing to control any electric appliance rated at under 2000 Watts [57]. It is not just limited to an appliance, though; any gadget that requires high voltage and high currents can be controlled with this shield. The shield (Figure 8) has four relays that are controlled by pins D3, D4, D5 and D6 on the Particle device. Each relay is triggered via an NPN transistor that takes a control signal from the Particle device and switches the relay coil ON and OFF, which in turn makes or breaks the electrical contact on the output. There is also a flyback diode connected across the coil to help protect the transistor from high voltage transients caused during switching.


*Figure 8. Relay Shield by Particle [57].*

Features

- Operating voltage: 7 to 20V DC.
- Current consumption: 150mA min to 290mA max (at 9V DC).
- Relay Max Voltage: 220V AC.
- Relay Max Current: 10Amp at 125V AC.
- Relay Part Number: JS1-5V-F
- Dimensions: 6.0" x 1.7".
- Weight: 80 grams.

### 2.1.4. Amazon Tap

The Amazon Tap (Figure 9) is a portable Bluetooth and Wi-Fi enabled speaker that offers a rich, full-range sound. With just tapping the microphone button or enabling hands-free mode we can ask for music, hear the news, search for information, order a pizza, and more with the Alexa Voice Service [48][49].

The Amazon Tap offers all of the conveniences of Amazon's assistant Alexa in a battery powered Bluetooth speaker [50].


*Figure 9. Amazon Tap [49].*

Features

- Size: 6.3" x 2.6" x 2.6" (159 mm x 66 mm x 66 mm)
- Weight: 16.6 oz. (470 grams).
- Battery Life: Up to 9 hours of continuous playback. Battery life will vary based on device settings, usage, and environmental factors.
- Supports public and private Wi-Fi networks or mobile hotspots that use the 802.11b, 802.11g, or 802.11n standard with support for WEP, WPA, and WPA2 security using password authentication. Supports 2.4 GHz wireless band only.
- Bluetooth Connectivity
- Audio: Dual 1.5-inch drivers and dual passive radiators for bass extension.

- The Alexa App is compatible with Fire OS, Android, and iOS devices and also accessible via web browser.

### 2.1.5. Motors and Speed Controllers

For the project, two DC High Speed/Torque Motors and two different DC motor speed controllers will be required [55][56]. Two 24V 250W brushed electric motors (Figure 10) were chosen, each motor can operate in forward or reverse direction, and they have an 8mm 3/4 moon drive shaft for an 11 tooth 6mm sprocket [51], so it will be easier to mount them and attach them to the back wheels.

*Figure 10. DC High Speed/Torque Motor [51].*

Features

- Voltage: 24 V.
- Wattage: 250 W.
- Rated Current: 13.5 A.
- Rated Speed: 2750 rpm.
- Chain Size: 6mm (#25).

- Number of Teeth: 11.
- Drive type: Sprocket.
- Number of Bullet Connectors: 2.
- Motor type: Brushed.

*Figure 11. Uxcell DC Motor Speed Controller [56].*

Features

- Output Current: 0-20A.
- Continuous power: 1200W.
- Input supply voltage: 9V-60VDC.
- Speed mode: potentiometer (linear).
- Speed range: 0--100%.
- Control frequency: 25 KHz.

*Figure 12. Uniquegoods DC Motor Speed Controller [55].*

Features

- Input supply voltage: 12V-40VDC.
- PWM frequency: 21 KHz; Duty Cycle adjustable: 5%-100%.
- Item size: 2.36x2.17x1.1 inches; Net Weight: 2.4 ounces.
- Maximum output power: 400W.
- Maximum continuous output current: 8A; Peak current is 10A.

### 2.1.6. Wheels

For the front part of the vehicle, two 4'' omnidirectional wheels by VEX Robotics will be mounted (Figure 14) and on the back two scooter wheels (Figure 13).

The Razor Rear Scooter Wheels use a #25 chain and have a tire size of 200x50 55 tooth sprocket [53]. The VEX Robotics are omnidirectional wheels; they are great for quick, lateral movements [54].

*Figure 13. Razor Rear Scooter Wheel [53].*

*Figure 14. VEX Robotics Omnidirectional Wheel [54].*

### 2.1.7. Ultrasonic Module Sensor

The type of sensor that will be used is the Ultrasonic Ranging Module HC-SR04 (Figure 15). This economical sensor provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can reach up to 3mm [59]. Each HC-SR04 module includes an ultrasonic transmitter, a receiver and a control circuit. The principle of work of this sensor is as follows:

1. Using IO trigger for at least 10us high-level signal,
2. The module automatically sends eight 40 kHz and detect whether there is a pulse signal back.
3. If the signal back, through high level, time of high output IO duration is the time from sending ultrasonic to returning.

The modules need two digital ports of the Particle Photon each, one for the Trigger Pulse Input and the other one for the Echo Pulse Output; the two left pins are for ground and 5V respectively.

The HC-SR04 consists of an ultrasonic transmitter, receiver, and control circuit. When triggered it sends out a series of 40 KHz ultrasonic pulses and receives an echo from an object. The distance between the unit and the object is calculated by measuring the traveling time of sound and output it as the width of a TTL pulse.


*Figure 15. Ultrasonic Module Sensor [59].*

Features

- Power supply: 5V DC.
- Quiescent current: <2mA.
- Effectual angle: <15°.
- Ranging distance: 2cm – 500 cm.
- Resolution: 0.3 cm.

# CHAPTER 3.

## 3. Methodology

### 3.1. Start-off elements

The overall design of the project will depend mostly on the type of lawn mower used as a base that is why it is such an important component. The one that will be used in this project is the Black & Decker's electric lawn mower model CM1836 shown in chapter 2. I was provided with a used one that I could modify as needed, which can be seen in Figure 16.

*Figure 16. Electric Lawn Mower.*

Although it wasn't in the perfect shape it had almost all its original pieces like the blade motor, top cover and most importantly the battery.

It's advertised by the manufacturer that the lawn mower has a 36 V battery when it's actually a set of three 12 V batteries set up together (Figure 17), this is, in fact, a good thing since they could be used separately and run the blade motor at 36 V and the direction motors as 24 V without any problem.

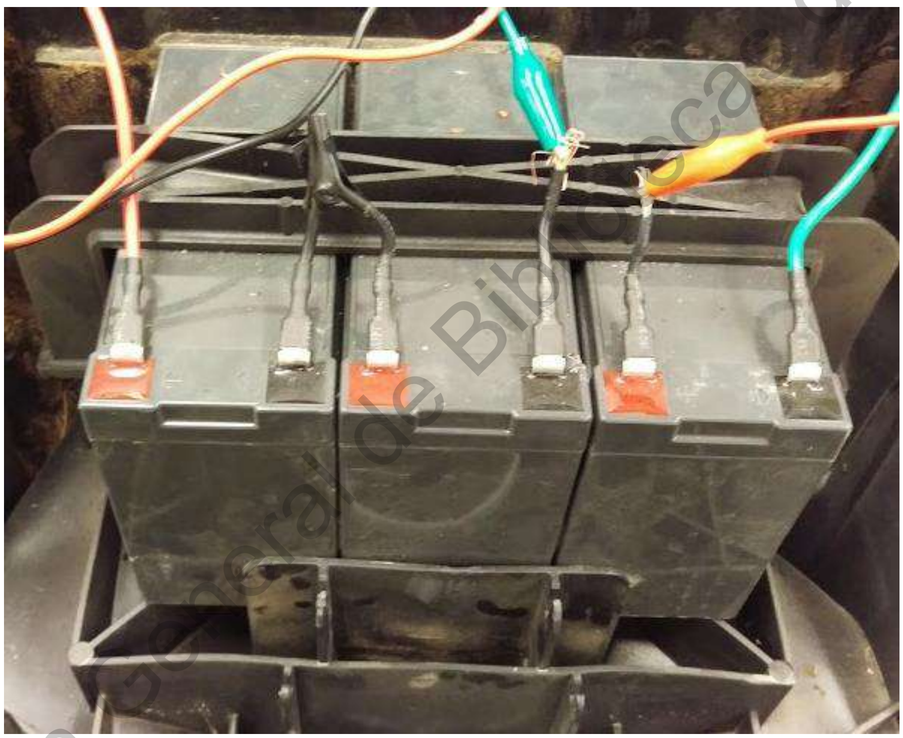

*Figure 17. Batteries.*

As is mentioned in the first chapter, Alexa is one of the most powerful personal assistants today. Any user can access to this voice service through any Alexa's enabled device, for this project, the Amazon Tap (Figure 18) which is one of the best sellers in the market will be used [79][60].


*Figure 18. Amazon Tap with cradle charger.*

### 3.2. Control of motors and blade

To start and stop the motors relays were used. The blade motor is only turned on or off and it doesn't require to control its speed, so a single relay is sufficient to control this function. The blade is activated with an external relay, the principle of operation is the same as with the relays on the shield, the relay is connected to a digital pin on the Particle Photon and there is a function that when it's triggered turns on this pin and then switch the relay closing the circuit and allowing the voltage to flow.

Operating the motors that will be changing the speed and direction of the vehicle it's different. Since these motors will be moving the lawn mower, it's required that they are controlled both in direction and speed. The easy way to do this is with a DC motor speed controller for each motor, but this solution is expensive and adds elements to the system. More elements add complexity to the operation and this is not what it's wanted.

With the relays array shown in Figure 19, both motors can be controlled with one single DC motor speed controller that is connected to the main supply. This controller is regulated through one of the analog pins of the Photon, the relays are activated and deactivated by the Photon as well. On Figure 20 and Figure 21 we can see how the relays on the shield are on some of the directions.

The possible combinations are shown in Table 1.

*Table 1. Possible states of relays in the shield.*

| RELAY/DIRECTION | FORWARD | BACKWARD | LEFT | RIGHT | STOP |
|---|---|---|---|---|---|
| RELAY 1 (SHIELD) | ON | OFF | OFF | ON | OFF |
| RELAY 2 (SHIELD) | OFF | ON | ON | OFF | OFF |
| RELAY 3 (SHIELD) | OFF | ON | OFF | ON | OFF |
| RELAY 4 (SHIELD) | ON | OFF | ON | OFF | OFF |

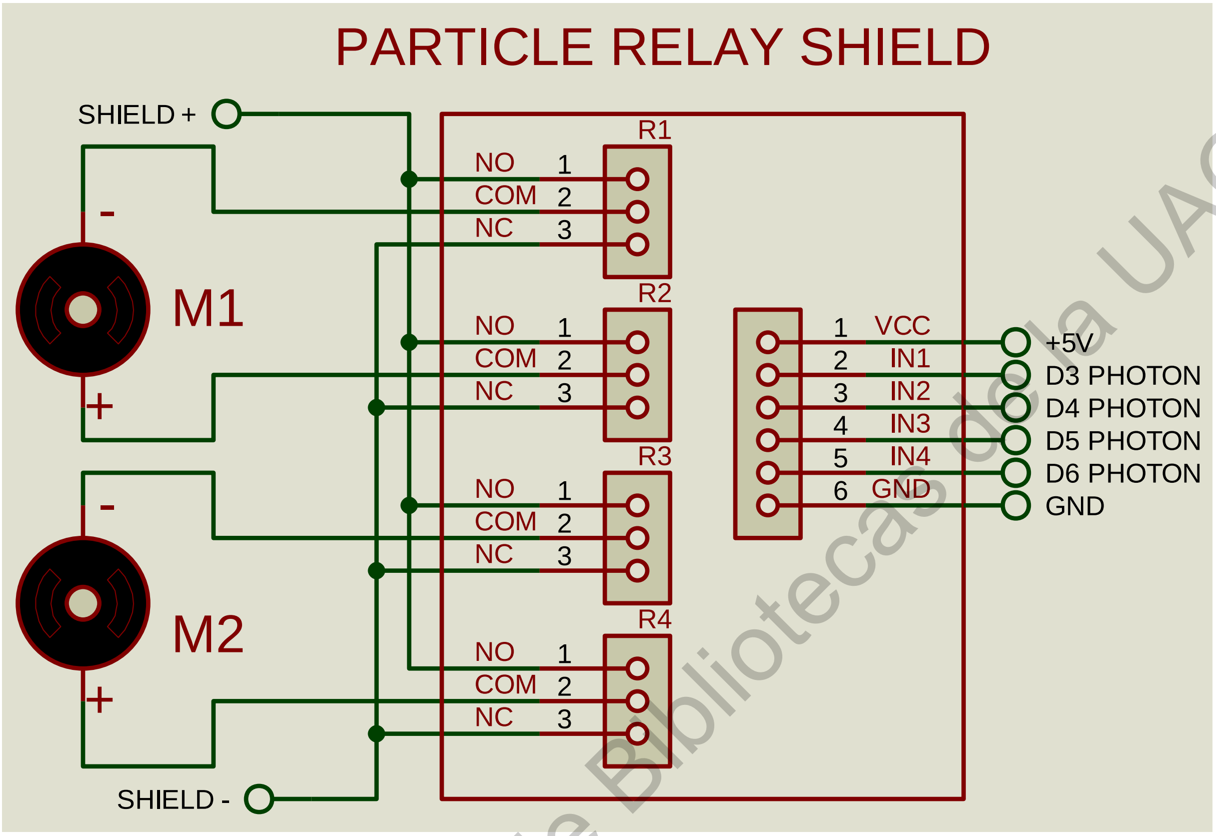


*Figure 19. Relays connection to change motors direction.*

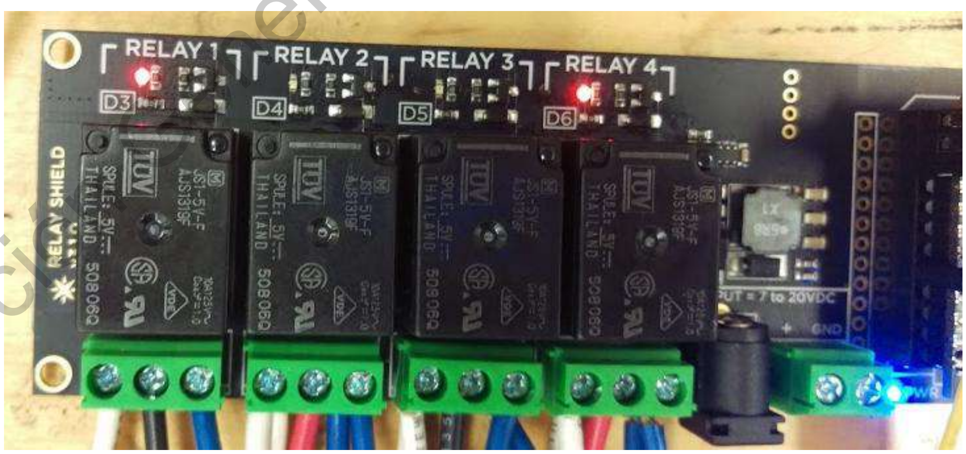


*Figure 20. State of relays to move forward.*

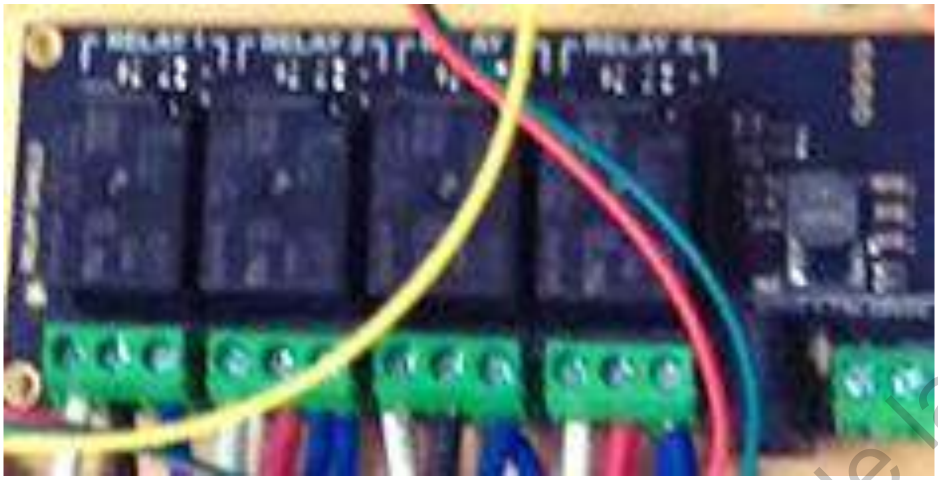

*Figure 21. State of relays to stop.*

### 3.3. Programming and connecting to the cloud

As explained in section 1.3 of this document, IFTTT (If This Then That) is a free web-based service that allows users to create chains of simple conditional statements, called "applets", which are triggered based on changes to other web services such as Gmail, Facebook or Instagram.

This is a convenient service that will help to host and manage the instructions on the cloud. The applets that will be called through Alexa were created in IFTTT. To trigger them (Figure 22) The Amazon Tap will be used, trough it, the instructions to IFTTT will be sent. Once the applet is triggered it sends a command to the Particle Photon, this command has specific instructions to activate a particular function of the code.

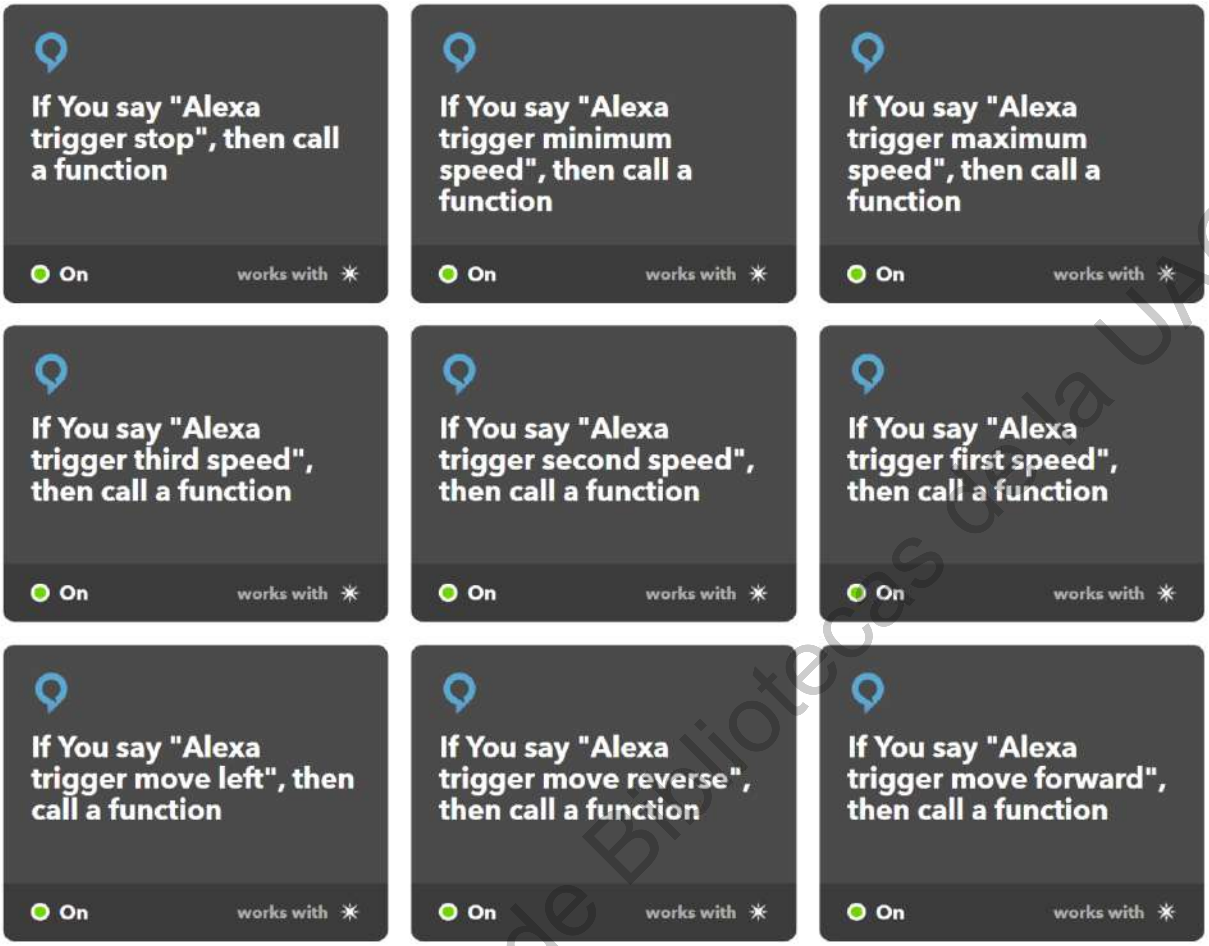


*Figure 22. Some of the applets created to the project.*

While working with motors it's important to know their power and peak current requirements. To avoid burning some component or damage the batteries a way to make the change of direction of the motors smoothly was programmed. To do this before turning on or off the relays an analog signal that gradually increases or decreases the speed through the DC motor speed controller is sent, and then, after this decrease in the speed the relays are activated or deactivated.

To trigger the applets the commands are shown in Table 2.

*Table 2. Commands supported.*

| Instruction to Alexa | Function Triggered |
|---|---|
| Alexa trigger move forward. | The vehicle moves forward. |
| Alexa trigger move reverse. | The vehicle moves backward. |
| Alexa trigger move right. | The vehicle turns to the right. |
| Alexa trigger move left. | The vehicle turns to the left. |
| Alexa trigger stop. | Everything is stopped (including blade if it's turned on). |
| Alexa trigger minimum speed. | Set speed at the minimum programmed. |
| Alexa trigger first speed. | Set speed at the first speed programmed. |
| Alexa trigger second speed. | Set speed at the second speed programmed. |
| Alexa trigger third speed. | Set speed at the third speed programmed. |
| Alexa trigger maximum speed. | Set speed at the maximum programmed. |
| Alexa trigger blade. | The blade is turned on. |
| Alexa trigger stop blade. | The blade is turned off. |
| Alexa trigger battery fully charged | Compensate the variables of speed to work with the batteries at a 100% of charge. |
| Alexa trigger battery seventy-five percent | Compensate the variables of speed to work with the batteries at a 75% of charge. |
| Alexa trigger battery fifty percent | Compensate the variables of speed to work with the batteries at a 50% of charge. |
| Alexa trigger battery twenty-five percent | Compensate the variables of speed to work with the batteries at a 25% of charge. |

The word "trigger" must be said while working with Alexa and IFTTT, this is because Amazon protects their system with this custom phrase avoiding that other one could overlap with an existing Alexa command. Also, they assigned this phrase so Alexa knows you want that command sent to IFTTT.

## 3.4. Assembly and structural modifications

### 3.4.1. Wheels and chains

As said in Chapter two, the four wheels that the original lawn mower had were going to be changed for better performance purposes. At the front, omnidirectional wheels will be used, this because with this type of wheels the movement while making a change of direction is made smoothly. At the back of the lawn mower, the selected wheels were scooter wheels that have preinstalled the toothed sprocket to use a #25 chain (Figure 23).

*Figure 23. Omnidirectional and scooter wheels.*

*Figure 24. Lawn mower with original back and front wheels.*

First of all, the front wheels were took out to expose the axis for the wheels, they were bigger than the one that the omnidirectional wheels had. With a Dremel Tool, the inner shaft holes of the wheels were cut out to increase their diameter, this so they could fit in the original lawn mower shaft. On Figure 24, we can see the lawn mower with its original front wheels and in Figure 25 the comparison between the newly mounted wheels and the original ones.

*Figure 25. Comparison between omnidirectional mounted and original wheel.*

To install the back wheels was a more complex task. First the original wheels were took out to expose the shaft, the difference while placing the front wheels was that in this case it was required to install an extra coupling because the shaft was too small to only mount the wheels on them. A 1 1/2" long bolt as a rigid shaft coupling was selected to this application (Figure 26).

With this element, the original shaft from the lawn mower and the shaft of the wheels were joined. Because both shaft diameters were different, a special inner shim to adjust the interference in between the wheel and the shaft was installed so both sides could be the same diameter. Also the shaft length from the original lawn mower wheels was cut so they could fit properly into the shaft couplings, this was made for the purpose of making the vehicle more stable.

*Figure 26. Rigid shaft coupling.*

To mount the motors a stainless steel 90° angle bar was cut and the holes needed to attach the motor on the top were drilled. To hold them in place the screws that the lawn mower already had were used to connect the push bar (Figure 27). By doing this the motors could be kept in place and they are firm in their position.

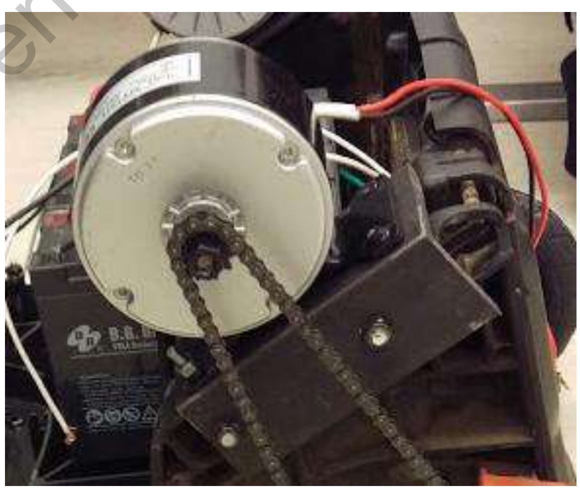

*Figure 27. Motor installed.*

The chain used is a #25 chain, this size was selected because both the wheels and the motors had the toothed sprocket of this size.

On the Figures debajo de we can see the final placement of the back wheels and the motors with the chains.

*Figure 28. Side view of the lawn mower.*

*Figure 29. Back view of the lawn mower.*

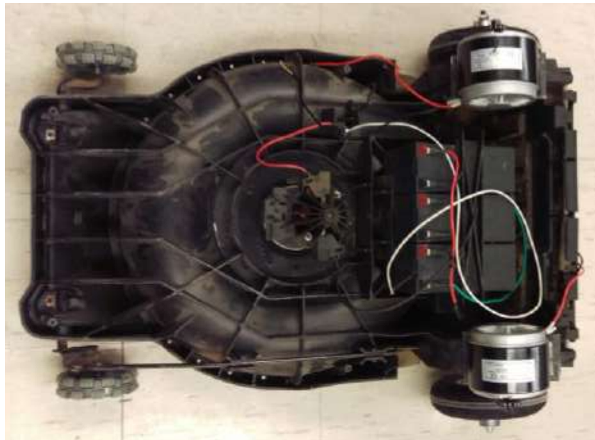

*Figure 30. Top view of the lawn mower.*

### 3.4.2. Wi-Fi Module and Electronics

To embed and protect the electronics in the vehicle all the components were placed in a plastic box that will keep them safe and clean inside (Figure 31). This box is water and dust resistant and the fact that it has a transparent top helps to identify possible failures in case something happens (Figure 32).

*Figure 31. Mounting the electronics in the lawn mower.*

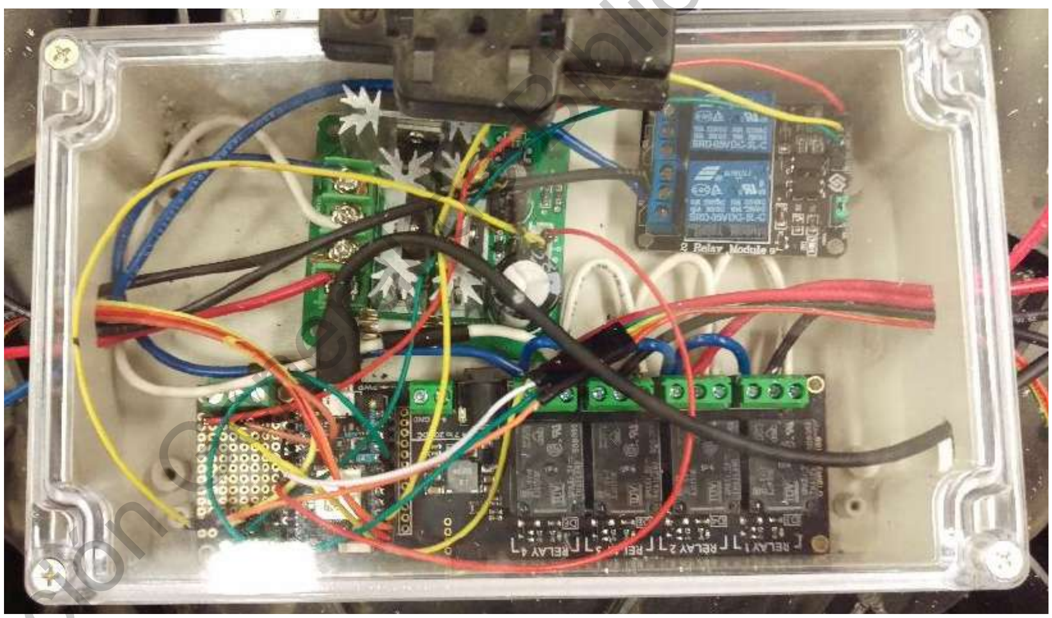


*Figure 32. Box with Photon and electronics.*

Once the components were mounted in the box, the electric connections were made starting with the motors and the batteries, then the emergency stop button and finally the ultrasonic sensors.

To mount the ultrasonic sensors in the front, 4 holes were cut (Figure 33). Also, a square to install the emergency stop button was cut at the top right part of the lawn mower case and the cable to connect the external battery that will supply energy to the electronics. On Figure 34 we can see the final look of the vehicle, with all the components assembled, this is including the ultrasonic sensors, emergency stop button, motors, and wheels.


*Figure 33. Ultrasonic sensors mounted.*


*Figure 34. Final look of the lawn mower.*

# CHAPTER 4.

## 4. Results and conclusions

### 4.1. Results

At end of this work, we have a functional vehicle that can be controlled through voice commands, capable of moving in four directions at five different speeds. This vehicle also has a blade to cut grass which also can be controlled over the cloud, two ultrasonic sensors, and a physical switch button to add safety to the system. The top cover was adapted to fit even with the components in the electronics box inside.

We can see in Figure 35 the vehicle in a front view with labels on the main components. The same applies to Figure 36 but with a side view to have a better look on the wheels.

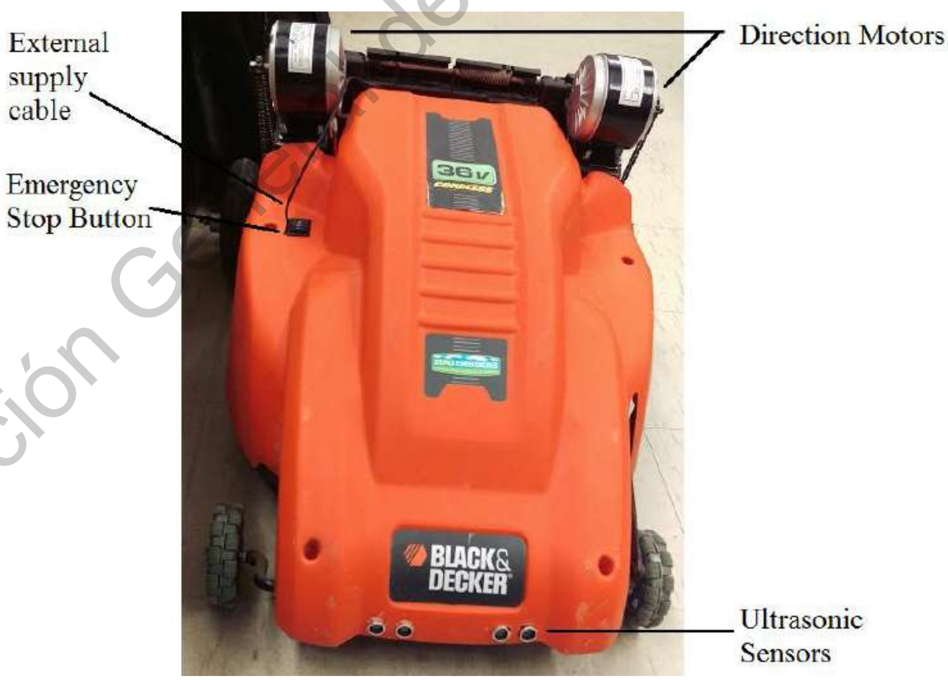


*Figure 35. Lawn mower (front view) with main components.*


*Figure 36. Lawn mower (side view) with main components.*

For an explanation of further changes to the architecture, identify failures, and implement new hardware, the reader can go to Appendix 1 and consult the pin out of the Particle Photon.

Once all the connections and hardware assembly were checked it was possible to start running tests to see the response of the vehicle in different types of situations.

#### 4.1.1. Safety considerations

The vehicle has dangerous components that could represent a danger to unqualified users or to elements near, the following considerations should be accounted for before performing maintenance operations or using the lawn mower:

- Before using the vehicle the user should check that the ultrasonic sensors at the front are visible and clean. If there is dirt or some object obstructing them the lawn mower won't start because the sensors will be triggering the stop function.

- To remove the blade the safety button must be in the off position before performing any operation with it. It's highly recommendable that also the user disconnects the batteries before working on the blade.
- The user must clear the area as much as possible where the lawn mower will be used. If there are any big or small elements that could stick the blades or damage the lawn mower they must be removed.
- If the lawn mower will perform the activity of cutting grass kids and pets must be retired of the area.
- Before performing any operation of maintenance with the chains the safety button must be in the off position.
- If the user wants to charge the batteries he must check that the polarity of the batteries and the charger are the correct.
- If the vehicle will perform demonstration actions the area must be cleared, this means that any object that blocks the path in which the lawn mower will move must be removed. This is to avoid collisions or damage both to the vehicle and the surroundings.

#### 4.1.2. Operating the vehicle

To operate the vehicle and perform any activity with it the user must follow the next basic procedure to turn it on and get it going.

1. Clear the area where the lawn mower will be performing the commanded activities.
2. Check that the ultrasonic sensor are visible and no object it's blocking their visibility (Figure 37).


*Figure 37. Free of obstruction ultrasonic sensors.*

3. Check the motors and four wheels, make sure that there isn't any object between the chains (Figure 38).

*Figure 38. Clear chain.*

4. Make sure that there is a Wi-Fi network available.
5. Connect the cable to the external supply (Figure 39) and wait until the Wi-Fi module is connected. To check that the Particle Photon is connected you can do it on the router or

hotspot to which it is connected or taking out the top cover of the lawn mower and checking that the light in the module is blue.

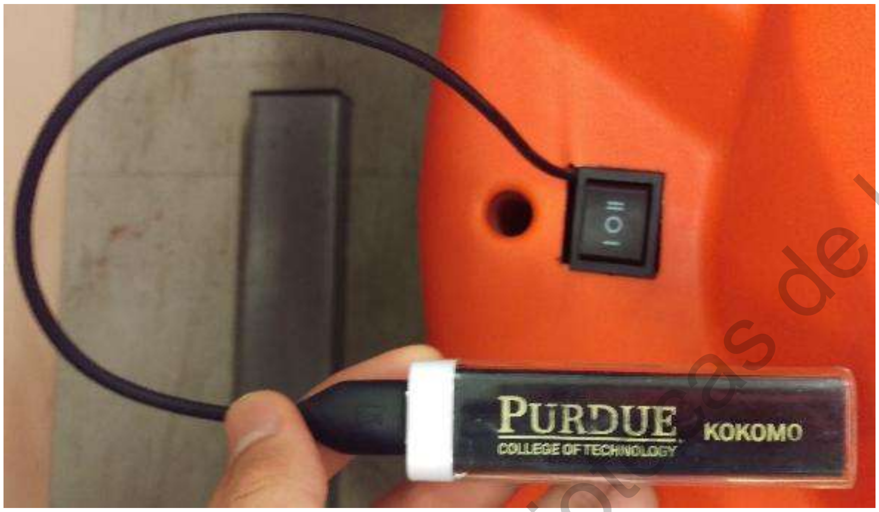


*Figure 39. External battery connected.*

6. Make sure that Alexa's enabled device it's connected to the Internet. You can check it by pushing the speaker button on the front. If the lights turn on blue (Figure 40) it means that the speaker has a connection to the Internet, if they are red it means that our device doesn't have a connection. Also, the status of the device can be checked on the Amazon Alexa App in any Android or iOS smartphone (Figure 41).


*Figure 40. Amazon Tap with blue lights.*

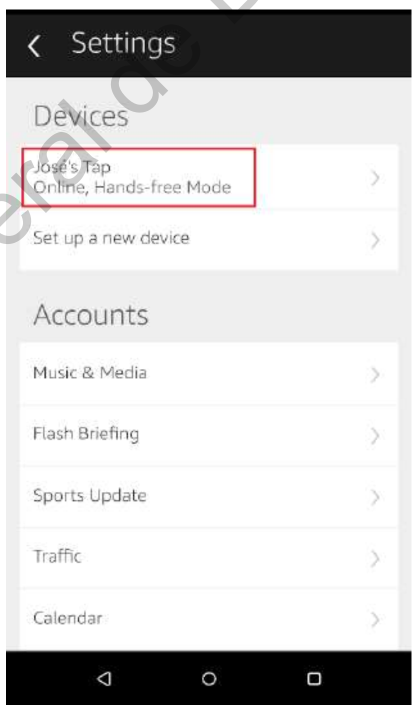


*Figure 41. Checking online status on Amazon Alexa's App (Android version).*

7. Once the module is connected to the network switch the emergency button to the on position (Figure 42). The placement of the button is shown on Figure 35

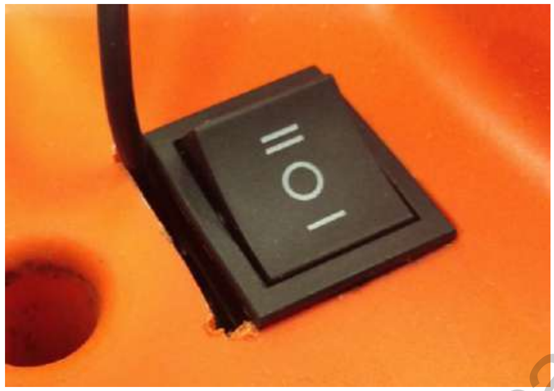

*Figure 42. Switch emergency button in "ON" position.*

8. Now the user can send commands through Alexa to the vehicle.
9. When the user finishes using the vehicle he must send the stop command and waits until the lawn mower stops. Then the emergency button must be switched to the off position (Figure 43).

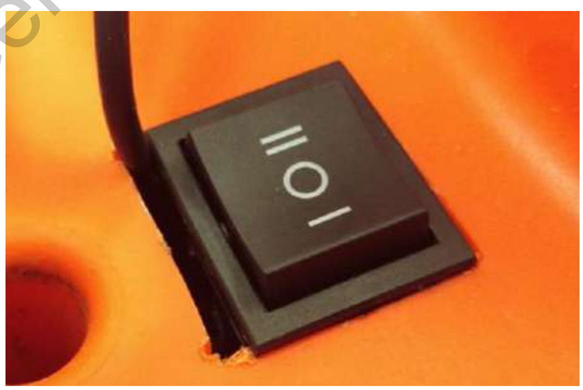

*Figure 43. Switch emergency button in "OFF" position.*

### 4.1.3. Web App

The MIT App Inventor is an innovative beginner's introduction to programming and app creation that transforms the complex language of text-based coding into visual, drag-and-drop building blocks. The simple graphical interface grants even to an inexperienced user the ability to create a basic, fully functional app within an hour or less.

The App Inventor is a platform from Google Labs to create applications for the operating system Android. The interface of this software allow the user to create an app visually and from a set of basic tools, the user can program by linking a series of blocks to create the application. The system is free and can be easily downloaded from the web. The apps made with App Inventor are limited by its simplicity but can cover a number of basic needs in a mobile device.

With the block editor of the platform, App Inventor uses the Open Blocks Java library to create a visual language from blocks. These libraries are distributed by the Massachusetts Institute of Technology (MIT) under a free license (MIT License). The compiler translates the visual blocks language for implementation on Android uses Kawa programming language, distributed as part of the GNU operating system of the Free Software Foundation App Inventor can have their first application running in an hour or less, and more complex applications can be programmed in much less time than with traditional languages, text-based.

Using this tool a web app was designed, that, like with Alexa, will allow the user to control the vehicle over the cloud.

The web app has several buttons that will give the commands to the lawn mower as if they were given trough Alexa, the difference is that instead of using IFTTT as the web service operator the commands are being sent directly to the Particle Photon with the APIs.

An Application Programming Interface (API) is a collection of protocols, tools, and subroutines that are built for application software. In this case for the project, the API is a set of clearly defined methods of communication stacked in building blocks for each button that connect the Android device with the Particle Photon.

There are four buttons, one for each direction, and below these the stop button that trigger the stop function on the code. There are also five buttons for the five different directions and a bar that shows graphically the current speed. There are two buttons to control the blade and also finally one button that allows the user to select the battery level to compensate the speeds. When the user press this button a list will appear (Figure 47), the user can select among the different options and this is going to compensate the constants that will be sent to the speed controller and therefore the voltage sent to the motors. We can see some screenshots of the web app on the following figures:


*Figure 44. Lawn Mower IoT Web App (screenshot 1).*

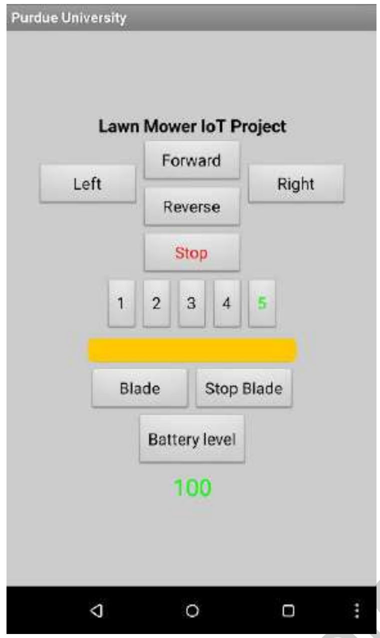


*Figure 45. Lawn Mower IoT Web App (screenshot 2).*

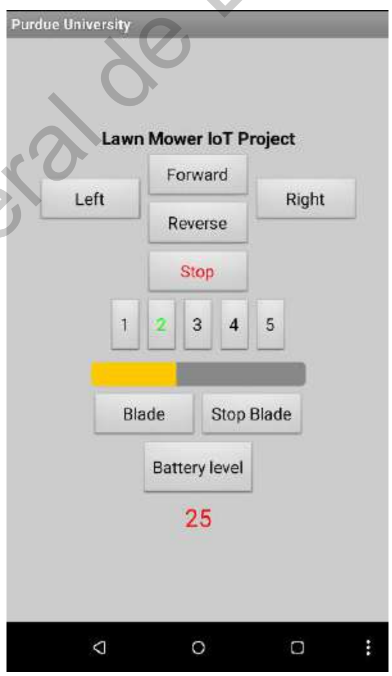


*Figure 46. Lawn Mower IoT Web App (screenshot 3).*

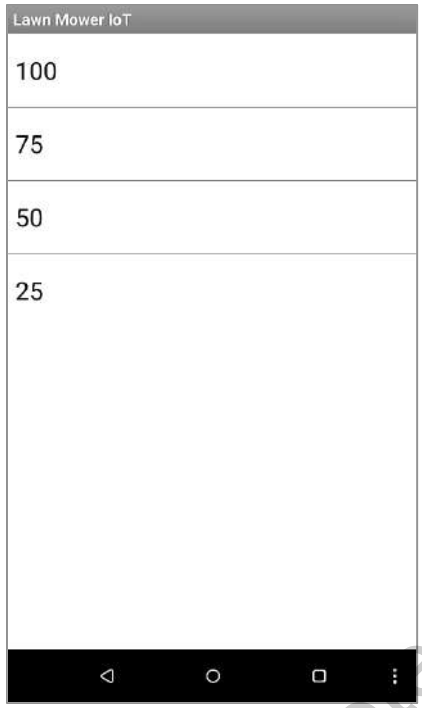


*Figure 47. The list showed to select the option that will compensate the speeds.*

#### 4.1.4. Tests

After completing the assembly of the vehicle some tests were executed. Since the lawn mower will not only be working on grass to test its performance in different scenarios was required. The tests included controlling it in floor, concrete, and grass in each case working at different speeds and with several different obstacles. Another purpose of the tests is to record the average operational time of the batteries before exhausting their charge.

The earlier trials were performed in a simple floor, this because this type of surface offers less friction, also when the vehicle is used for demonstration purposes this kind of floor is most likely to be available.

The following tests were made in concrete, this surface has more friction and the tests on it were mostly made with the purpose of checking the performance of the Particle Photon, and the signal range within which it can work.

The last tests took place in grass, this is the hardest surface in which the vehicle will move. The blade was finally tested on this surface. The grass represents a completely uneven surface and the movements were made slowly, also with the blade working it's required that only careful operators work with the lawn mower.

In order to be able to compare the results obtained in each type of surface, the same tests were performed in each one of them. The tests consist of four parts; linear movements, sideways movements, velocity and obstacle detection.

The linear movements consist in commanding the lawn mower to move forward and backward at the five different speeds possible. The sideways movements consist in commanding the vehicle to make some turns to the right and the left at the five different speeds possible. The obstacle detection is to check the reliability of the ultrasonic sensors placed in the front, these tests will tell how much distance the lawn mower requires to stop at the different speeds. Also, the tests will be made with different types of obstacles in shape and size.

#### 4.1.4.1. Floor

The performance of the lawn mower on this surface was good, all the movements were smoothly performed and the vehicle didn't have any problem. In this type of surface, the lawn mower doesn't require a lot of work to accelerate and start to move, the motors move easily the vehicle and the changes between speeds were easily noticed.

The obstacle tests were made with different elements and in different angles, the sensors had a great response to all of them and the lawn mower always stopped before hitting the obstacle. The only detail observed during the tests on a simple floor was that the lawn mower requires a little more distance before completely stopping, this is because the surface offers less friction and the vehicle has still some inertia after the command stop has been given or after the sensors have detected an obstacle in the path.

*Table 3. Velocities recorded during the tests on the floor (velocities in m/min).*

| **Distance 5 m** | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 23.08 | 32.43 | 35.89 | 41.27 | 44.44 |
| 19.67 | 34.72 | 34.64 | 52.54 | 38.61 |
| 20.55 | 39.32 | 35.09 | 30.43 | 57.80 |
| 21.19 | 31.58 | 44.71 | 30.52 | 41.49 |
| 24.69 | 33.71 | 32.05 | 33.48 | 54.05 |
| 22.40 | 34.05 | 33.63 | 35.13 | 41.10 |
| 20.09 | 26.39 | 31.68 | 56.93 | 30.74 |
| 19.62 | 28.79 | 38.41 | 43.48 | 44.64 |
| 18.90 | 32.36 | 49.92 | 57.92 | 54.45 |
| 24.75 | 42.55 | 33.15 | 40.32 | 40.98 |

With the results we can determine the average speeds:

- 1st speed: 21.50 m/min.
- 2nd speed: 33.5 m/min.
- 3rd speed: 36.92 m/min.
- 4th speed: 42.20 m/min.
- 5th speed: 44.83 m/min.

On Figure 48 we can see a boxplot that helps to interpret the results, it can be seen that the minimum velocity recorded was 18.9 m/min and the maximum was 57.92 m/min but this maximum was on the 4th speed not in the 5th. This might lead to think that the 4th speed is faster than the 5th but analyzing the other velocities recorded we can see that this only happened once and that the median velocity in the 4th speed is 40.79 m/min while in the 5th speed is 42.97 m/min.

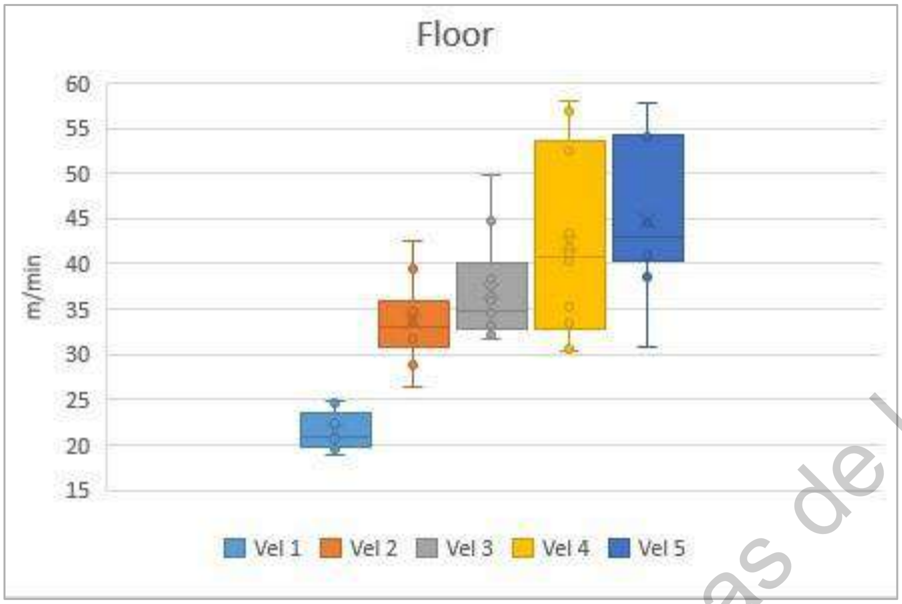


*Figure 48. Performance on the floor.*

The following pictures were taken during these tests.

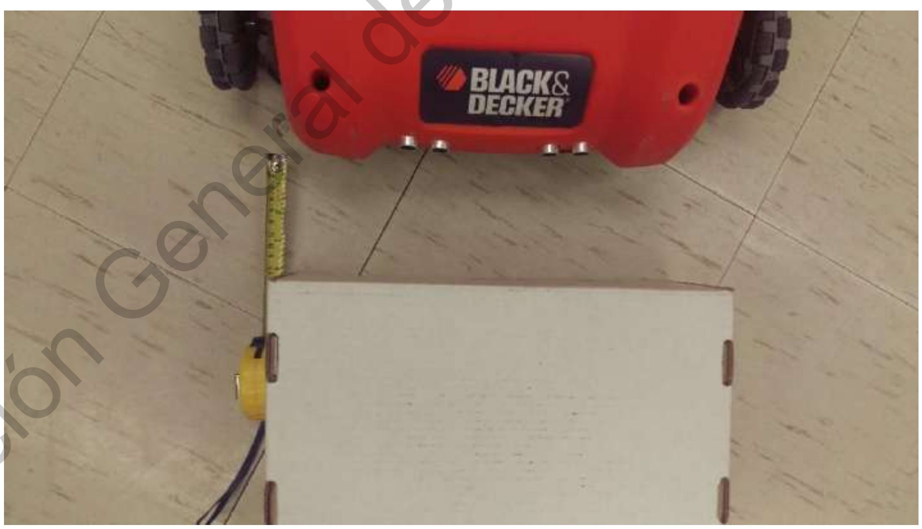


*Figure 49. The vehicle stopped when an obstacle was detected (example of obstacle 1).*


*Figure 50. The vehicle stopped when an obstacle was detected (example of obstacle 2).*


*Figure 51. Testing the vehicle on surface 1 (floor).*

#### 4.1.4.2. Concrete

Comparing the results obtained on concrete with the ones of the floor we can see that they are very similar, but the lawn mower performed faster on the floor. Although the concrete is rougher and offers more friction than the floor, the vehicle didn't have any problem or difficulty to move in all four directions and the same happens with the changes of speed.

The obstacle tests performed on this surface showed that the lawn mower is able to stop on time when an obstacle is detected on the path.

*Table 4. Velocities recorded during the tests on concrete (velocities in m/min).*

| Distance 5 m | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 10.00 | 13.93 | 18.11 | 27.99 | 34.72 |
| 9.12 | 14.46 | 17.03 | 23.66 | 27.37 |
| 10.15 | 13.41 | 17.93 | 29.18 | 27.96 |
| 10.35 | 14.22 | 17.97 | 30.80 | 41.96 |
| 9.94 | 13.46 | 15.81 | 28.93 | 36.63 |
| 10.35 | 13.74 | 18.07 | 26.02 | 27.40 |
| 9.52 | 13.36 | 16.46 | 33.19 | 36.19 |
| 10.36 | 13.09 | 17.92 | 25.42 | 38.51 |
| 9.78 | 12.61 | 17.14 | 24.69 | 39.89 |
| 10.33 | 13.26 | 17.91 | 31.06 | 39.11 |

With the results we can determine the average speeds:

- 1st speed: 9.99 m/min.
- 2nd speed: 13.55 m/min
- 3rd speed: 17.44 m/min.
- 4th speed: 28.09 m/min.
- 5th speed: 34.97 m/min.

The boxplot on Figure 52 gives us a better interpretation of the results in the concrete, in this type of surface it is possible to see that the lawn mower is indeed moving slower than on the floor. The minimum velocity recorded was 9.12 m/min on the 1st speed and the maximum was 41.96 m/min on the 5th speed.

The results have shown that in concrete the lawn mower moves with repeatability, there isn't almost any dispersion of the data while working with the first three speeds and with the 4th and 5th the dispersion is not that big as the one presented in the results on the floor. Also, the differences in the velocity can be seen easily because the medians are not close to each other.


*Figure 52. Performance on concrete.*


*Figure 53. The vehicle stopped in concrete when an obstacle was detected (example of obstacle 1).*


*Figure 54. The vehicle stopped in concrete when an obstacle was detected (example of obstacle 2).*

*Figure 55. Testing the vehicle on surface 2 (concrete).*

#### 4.1.4.3. Grass

The tests on grass were one of the most important, in them, the blade was going to be turned on and therefore more caution must be taken.

It was noticeable to see that movement was being made with more difficulty, the lawn mower required more acceleration to start moving and the movements weren't smooth, especially while moving sideways the vehicle required full power, and according to the results in this surface the lawn mower performed slower.

The obstacle tests proved once again that if an obstacle is detected the lawn mower will stop. Due to the type of surface, the lawn mower stopped almost immediately when commanded or when it detected an object on its path.

*Table 5. Velocities recorded during the tests on grass (velocities in m/min).*

| Distance 5 m | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 7.13 | 8.50 | 13.22 | 24.00 | 25.86 |
| 7.56 | 9.23 | 12.07 | 22.27 | 23.42 |
| 6.61 | 8.25 | 15.63 | 31.51 | 27.50 |
| 7.33 | 8.89 | 12.62 | 31.38 | 24.39 |
| 7.65 | 9.35 | 12.27 | 20.96 | 26.32 |
| 6.60 | 9.35 | 13.79 | 21.35 | 30.43 |
| 6.59 | 8.33 | 14.10 | 24.43 | 29.18 |
| 7.06 | 7.90 | 15.55 | 21.72 | 26.74 |
| 7.26 | 7.81 | 12.45 | 29.38 | 30.03 |
| 7.16 | 9.33 | 14.38 | 24.04 | 26.22 |

With the results we can determine the average speeds:

- 1st speed: 7.09 m/min.
- 2nd speed: 8.69 m/min.
- 3rd speed: 13.60 m/min.
- 4th speed: 25.10 m/min.
- 5th speed: 27.00 m/min.

On Figure 56 is shown a boxplot that gives us a better insight of the results, the minimum velocity recorded was 6.59 m/min and the maximum was 29.38 m/min, but like in the results on the floor, this happened in the 4th speed, not in the 5th. Now analyzing the data on these two speeds we can see that the median velocity in 4th speed was 24.21 m/min while in the 5th it was 26.92. This velocity recorded was an outlier, but it's still within the permitted range. The changes in speed can be easily perceived among the three first speeds.

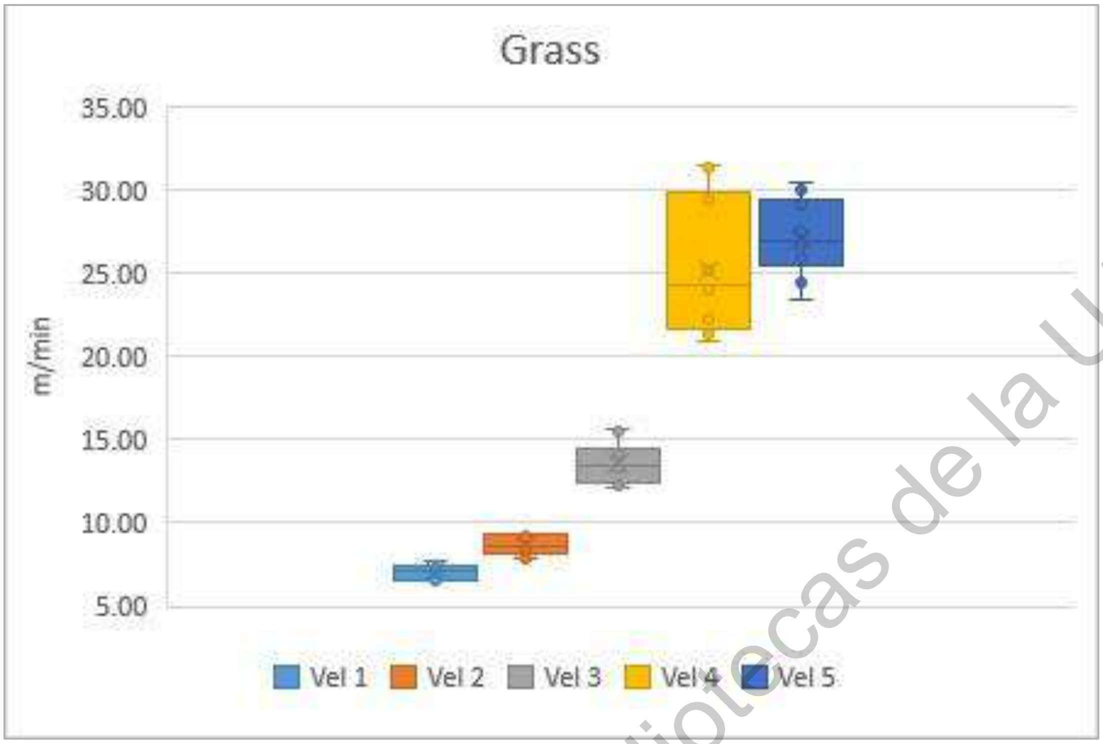


*Figure 56. Performance on grass.*

The following pictures were taken during these tests.


*Figure 57. The vehicle stopped when an obstacle was detected (example of obstacle 1).*

*Figure 58. The vehicle stopped when an obstacle was detected (example of obstacle 2).*

*Figure 59. Testing the vehicle on surface 1 (grass).*

#### 4.1.4.4. Obstacle tests

To try the reliability of the ultrasonic sensors several tests were performed with different obstacles in the three surfaces and at the five different velocities programmed.

To perform these tests the lawn mower was commanded to move forward and then wait till it stops once the sensors triggered the function of the emergency stop on the code, then the distance between the obstacle and the front of the lawn mower was measured.

On Figure 60 we can see a graphic in which it is shown the results of these tests, and it was verified that the ultrasonic sensors indeed do stop the vehicle when an obstacle it's detected within a range of 15 cm as programmed. On average the lawn mower stopped at 7.3 cm of the obstacle, and the closest that it was to the obstacle before it stops was at 1 cm, but it never collided with any of the obstacles.

These results are also in appendix 3 and 4 of this document.


*Figure 60. Obstacle detection results.*

### 4.1.5. Troubleshooting

The following are the most frequent problems detected during the experimentation, as well as their possible solutions.

#### 4.1.5.1. Amazon Tap

Sometimes the Amazon Tap has troubles while connecting to the internet or it loses its connection. If something like this happens and you notice that the indicator light in the front are red the best thing to do is set up again the Amazon Tap, to do this follow the next steps:

1. Download the Alexa app and sign in: The app it's available for smartphones and tablets with Android, Fire OS, and iOS.
2. Turn on Amazon Tap: Make sure that the Amazon Tap it's charged or plug it into a power outlet with a charger.
3. Connect Amazon Tap to a Wi-Fi network: Follow the instructions in the app to connect the Amazon Tap to a Wi-Fi network. If the setup process does not automatically start, press and hold the Wi-Fi / Bluetooth button on Amazon Tap for five seconds, the lights will turn on orange. Then, open the Alexa app, and go to Settings > Set up a new device.
4. Complete the process and after it's finished the Alexa will tell you that now the process has finished.

#### 4.1.5.2. Alexa

If Alexa does not understand the requests made you can try the following:

1. Make sure the Amazon Tap has a connection to the Internet: For Alexa to work, it's required to have an active Wi-Fi connection. An active Wi-Fi connection means that Alexa can access the servers on the cloud and answer your questions or process your requests.
2. Check for an ideal location: Devices such as microwaves and air conditioners may cause interference, place the Amazon Tap at least eight inches away from these kind of devices.
3. Be clear: Make sure there is no background noise when you speak to Alexa and speak naturally.
4. Use Voice Training: You can spend a few minutes to do a training session with Alexa, during a Voice Training session, the Alexa app shows 25 different phrases, which you need to say to your device. After the training session, Alexa will understand you better.

#### 4.1.5.3. Lawn Mower

1. The lawn mower doesn't run when activated:
   a. Check that the emergency button switch is in the "On" position.
   b. Make sure that the batteries are charged.
   c. Check that the Particle Photon is activating and deactivating the relays when commanded.
   d. Check that the chains are not obstructed.

e. Avoid overloading the vehicle.

2. The lawn mower stops while moving:
   a. Make sure that the batteries are charged.
   b. Check if there is an obstacle in the path of the lawn mower. If that is not the case, check that the ultrasonic sensors are clear.
   c. Avoid overloading the vehicle.
3. The lawn mower is running slow:
   a. Avoid overloading the vehicle.
   b. Make sure that the batteries are charged.
4. The blade does not start:
   a. Make sure that the batteries are charged.
   b. Check that there isn't any object obstructing the blade. Put the emergency stop switch in the "Off" position before performing any operation with the lawn mower.

**4.1.5.4. Particle Photon**

The Particle Photon has an RGB LED that will change to different colors according to a list of instructions preset by the manufacturer, this makes easy to identify troubles and solve them.

During initial setup of a device these are the usual LED specifications:

1. White pulse: Start-up (happens when the Photon is first powered on or when it's reset).
2. Flashing blue: Listening Mode, waiting for Wi-Fi credentials.

3. Flashing green: Connecting to the local Wi-Fi network.
4. Flashing cyan: Connecting to Particle Cloud.
5. High-speed flashing cyan: Particle Cloud handshake (connection checked).
6. Breathing cyan: Connected to Particle Cloud.
7. Flashing magenta: Receiving new firmware update over-the-air (OTA).
8. Breathing magenta Safe mode, connected to Particle Cloud but user firmware not running.
9. Flash red twice: Connection failure, no internet connection.
10. Flash red three times: Connection failure, Cloud is unreachable.
11. Orange flashing: Connection failure.

#### 4.1.5.5. Batteries

Recharging the batteries will be a common activity to be performed, and is important to make it correctly to avoid damaging them. The stack of batteries is constituted by three 12 V batteries, and to recharge them is necessary a 12 V charger.

The steps to recharge the batteries are shown below:

1. Remove the four screws that hold the top cover and carefully put it aside (Figure 61).


*Figure 61. Location of the screws on top cover (inside circles).*

2. The batteries are connected in series and since the charge must be made individually it's required that the user removes the cables that connect them, there are four small cables that can be easily removed by pushing them out. Remove all of them (Figure 62).

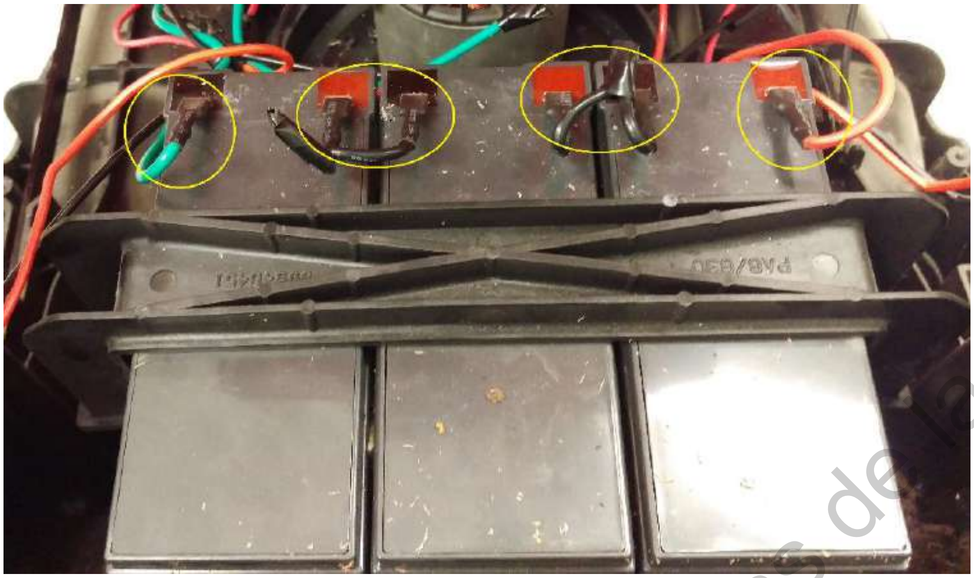

*Figure 62. Location of the cables that connect the batteries (inside circles).*

3. Attach the clamps of the charger to the terminals of the battery, paying attention of connecting them with the right polarity. The terminals of the battery have a different color, the black one is the negative and the red one is the positive terminal. The clamps have the same colors and correspond to the same polarities (Figure 63).

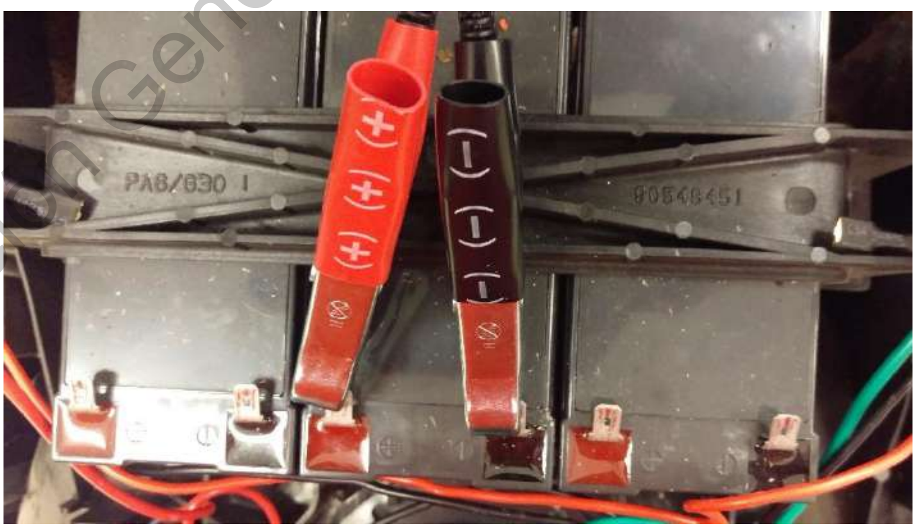

*Figure 63. Clamps attached to battery terminals.*

4. Once that the clamps are in place plug the charger to a wall output. A LED in the front will indicate that the battery is being charged (Figure 64).
5. Once the battery is fully charged a different LED will be turned on (Figure 64). This will indicate that the battery is now charged.


*Figure 64. Battery charger (indicator LEDs inside circle).*

6. Remove the clamps and repeat the process to the other two batteries.
7. When all the batteries are fully charged place back the cables that connect them.
8. Place the top cover and hold it in place by screwing it again.

## 4.2. Conclusions

The hypothesis was proven right, this work tested the proposed methodology of implementation for the development and assembly of a small semi-autonomous utility vehicle using off-the-shelf home automation components while integrating open source based electronics.

The circuitry assembled to control the system will be easy to adapt to others. Due to the versatility of the components used the vehicle can be easily upgraded as needed besides the 32-bit processor used is low power, cost-sensitive and offers a great solution for real-time embedded applications. The Particle Photon allows communicating to other microcontrollers through different protocols of communication so if the time comes and the application require more inputs or outputs it's not a difficult task to connect an external FPGA, a PLC, an Arduino or other microcontrollers.

This work contributes to existing knowledge on the Internet of Things by providing a semi-autonomous vehicle capable of being controlled over the cloud, currently, there is limited work done combining these technologies.

At the end, the vehicle successfully was controlled with the Alexa voice service, the lawn mower moved as commanded. The vehicle was tested in floor, concrete, and grass having a great performance while performing movements at different speeds and the ultrasonic sensors fulfilled their purpose by stopping the vehicle when an obstacle was detected in its path.

This work has several practical applications. Firstly, it points to the use of the vehicle as a didactic material, to observe examples and to perform experimentation and research of robotics, kinetics, electronics, control, etc. Secondly, this will serve as a base for future work based on Voice Control, Internet of Things and Autonomous Vehicles, technologies that have proved that only will grow in the years to come.

### 4.3. Possible applications

#### 4.3.1. Academic and research applications

It will be possible to use the vehicle as a didactic material, to observe examples and to perform experimentation and research of robotics, kinetics, electronics, control, etc.

Since the project, it's open source based it can be easily upgraded and modified, this means that the system could be integrated into another university or research projects that are based on the Internet of Things and autonomous vehicles technologies.

#### 4.3.2. Industrial

If the vehicle it's properly modified it could be used as a full utility vehicle, taking advantage of the power of the motors and the materials of the main structure the vehicle could be used to carry packages in a warehouse or to move manufactured products in a factory.

#### 4.3.3. Society

The vehicle could be used to make demonstrations so it can be shown in exhibitions and congresses, as a robotics project that could show the possible applications of the Internet of Things and Cloud Computing to people who are not related to these fields.

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# 6. Tables

# 7. Figures

# 8. Appendix

## 8.1. Appendix 1. Particle Photon pin out

*Table 6. Particle Photon pin out.*

| Pin | Connection |
|---|---|
| **D0** | Trigger Pin – Ultrasonic sensor 1. |
| **D1** | Echo Pin – Ultrasonic sensor 1. |
| **D2** | Relay 1 – Blade (Two relays external shield). |
| **D3** | Relay 1 – Shield. |
| **D4** | Relay 2 – Shield. |
| **D5** | Relay 3 – Shield. |
| **D6** | Relay 4 – Shield. |
| **D7** | Echo Pin – Ultrasonic sensor 2. |
| **A5** | Analog Signal Pin – Speed Controller. |
| **WKP** | Trigger Pin – Ultrasonic sensor 2. |

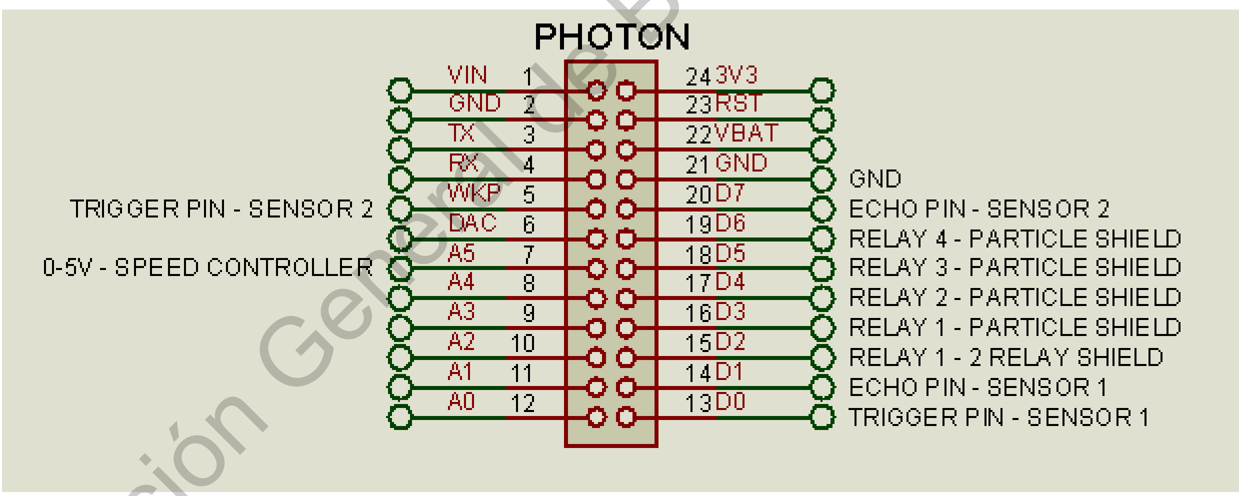


*Figure 65. Particle Photon connection.*

## 8.2. Appendix 2. Other schematics and connections

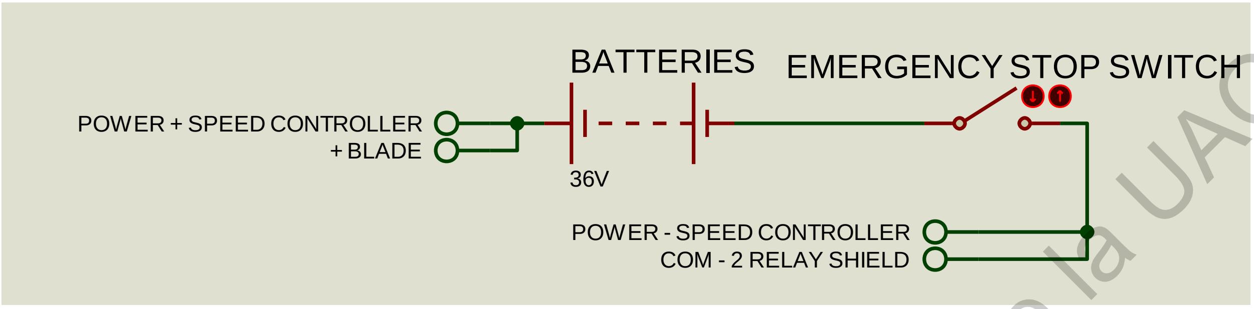


*Figure 66. Batteries connection.*

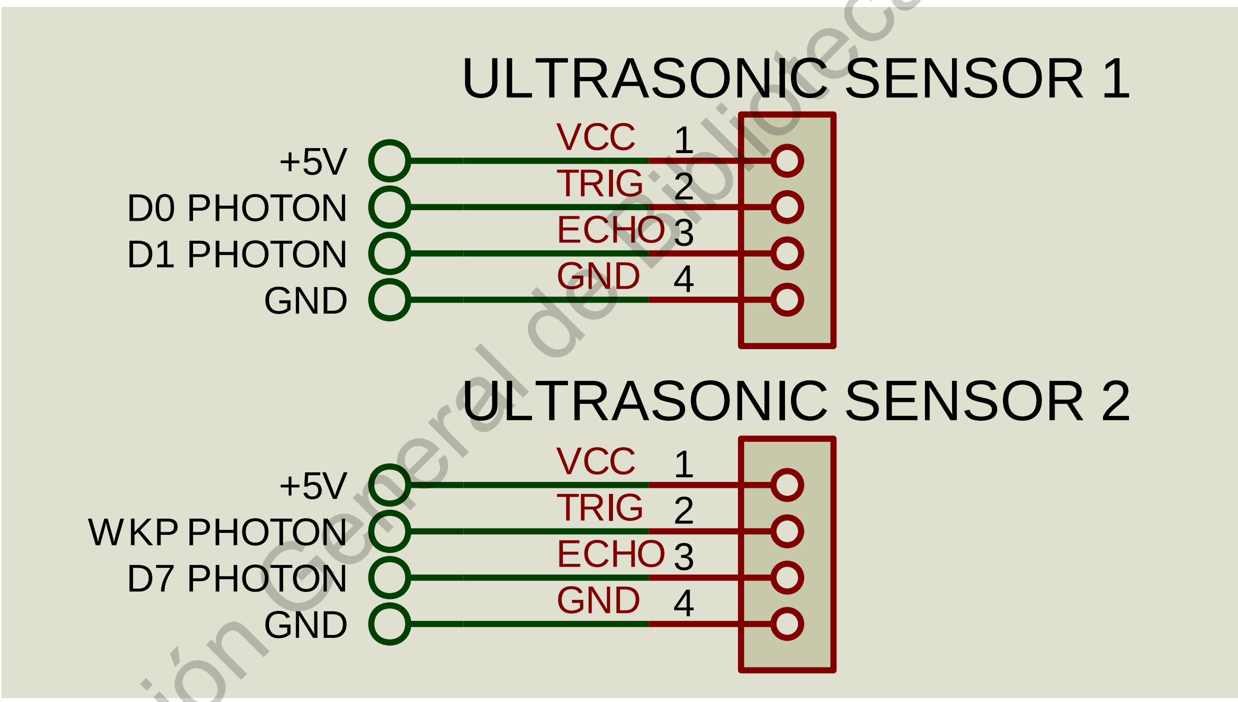


*Figure 67. Ultrasonic sensors connection.*

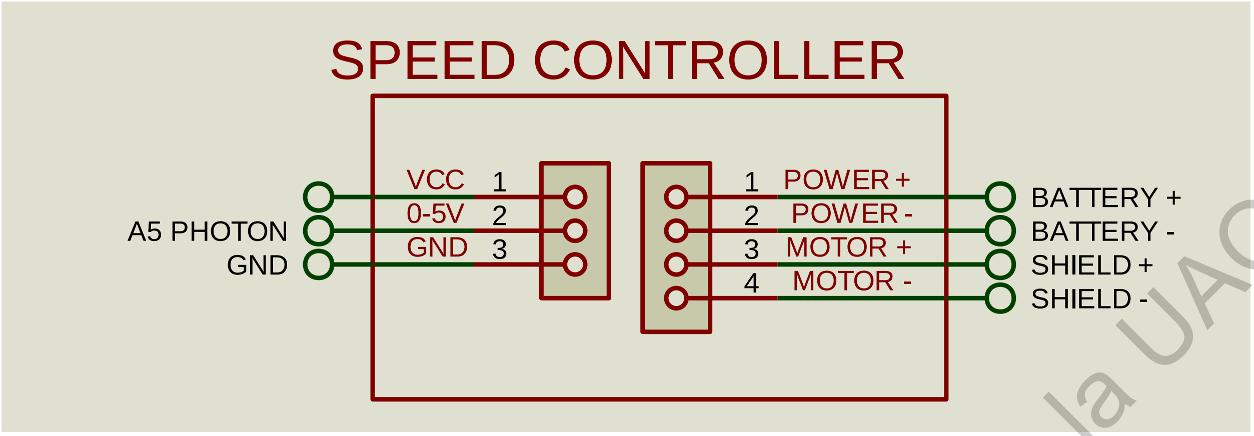


*Figure 68. Speed controller connection.*

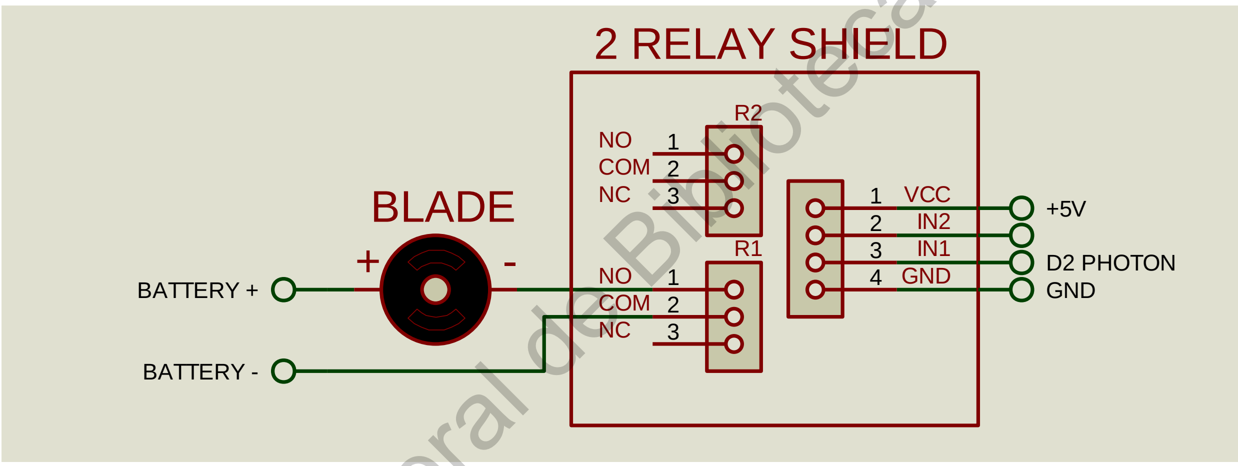


*Figure 69. Two relays and blade connection.*

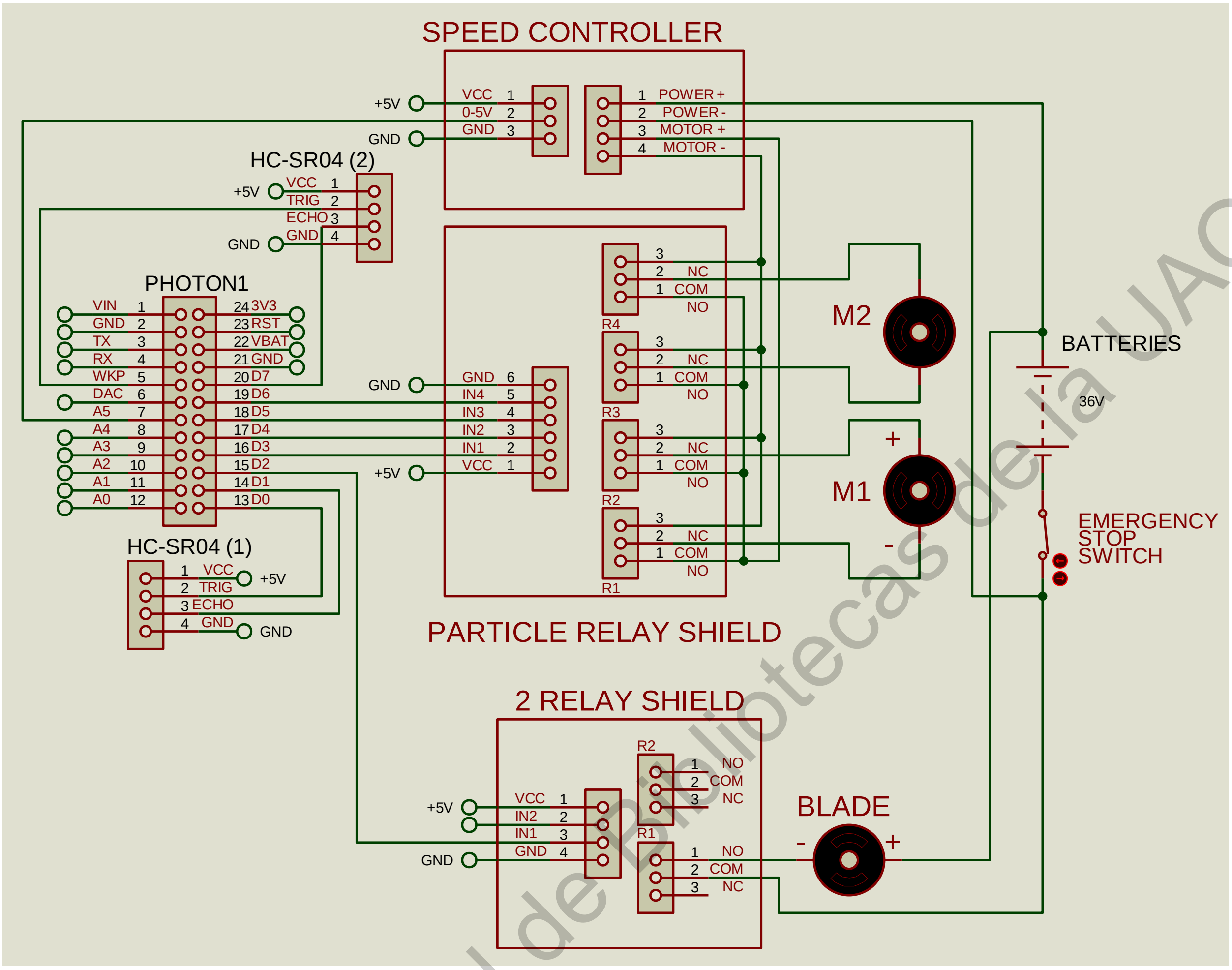


*Figure 70. Overall connection of the system.*

## 8.3. Appendix 3. Results of velocity tests

*Table 7. Times recorded (in seconds) during the tests on the floor.*

| Distance 5 m | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 13 | 9.25 | 8.36 | 7.27 | 6.75 |
| 15.25 | 8.64 | 8.66 | 5.71 | 7.77 |
| 14.6 | 7.63 | 8.55 | 9.86 | 5.19 |
| 14.16 | 9.5 | 6.71 | 9.83 | 7.23 |
| 12.15 | 8.9 | 9.36 | 8.96 | 5.55 |
| 13.39 | 8.81 | 8.92 | 8.54 | 7.3 |
| 14.93 | 11.37 | 9.47 | 5.27 | 9.76 |
| 15.29 | 10.42 | 7.81 | 6.9 | 6.72 |
| 15.87 | 9.27 | 6.01 | 5.18 | 5.51 |
| 12.12 | 7.05 | 9.05 | 7.44 | 7.32 |

*Table 8. Times recorded (in seconds) during the tests on the concrete.*

| Distance 5 m | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 30.00 | 21.53 | 16.57 | 10.72 | 8.64 |
| 32.91 | 20.74 | 17.62 | 12.68 | 10.96 |
| 29.57 | 22.37 | 16.73 | 10.28 | 10.73 |
| 28.98 | 21.09 | 16.69 | 9.74 | 7.15 |
| 30.19 | 22.28 | 18.97 | 10.37 | 8.19 |
| 28.98 | 21.84 | 16.60 | 11.53 | 10.95 |
| 31.51 | 22.46 | 18.23 | 9.04 | 8.29 |
| 28.97 | 22.92 | 16.74 | 11.80 | 7.79 |
| 30.67 | 23.79 | 17.50 | 12.15 | 7.52 |
| 29.05 | 22.63 | 16.75 | 9.66 | 7.67 |

*Table 9. Times recorded (in seconds) during the tests on the grass.*

| **Distance 5 m** | | | | |
|---|---|---|---|---|
| **1st speed** | **2nd speed** | **3rd speed** | **4th speed** | **5th speed** |
| 42.1 | 35.31 | 22.7 | 12.5 | 11.6 |
| 39.66 | 32.52 | 24.86 | 13.47 | 12.81 |
| 45.39 | 36.38 | 19.2 | 9.52 | 10.91 |
| 40.91 | 33.76 | 23.78 | 9.56 | 12.3 |
| 39.2 | 32.09 | 24.44 | 14.31 | 11.4 |
| 45.48 | 32.1 | 21.75 | 14.05 | 9.86 |
| 45.54 | 36 | 21.28 | 12.28 | 10.28 |
| 42.52 | 37.97 | 19.29 | 13.81 | 11.22 |
| 41.33 | 38.39 | 24.09 | 10.21 | 9.99 |
| 41.91 | 32.17 | 20.86 | 12.48 | 11.44 |

### 8.4. Appendix 4. Results of obstacle detection tests

*Table 10. Obstacle detection test results.*

| No. of test | Distance to the obstacle at stop (cm) |
|---|---|
| 1 | 9.5 |
| 2 | 13.0 |
| 3 | 3.8 |
| 4 | 10.2 |
| 5 | 14.7 |
| 6 | 2.8 |
| 7 | 7.9 |
| 8 | 8.0 |
| 9 | 4.5 |
| 10 | 6.3 |
| 11 | 12.7 |
| 12 | 2.0 |
| 13 | 12.1 |
| 14 | 8.9 |
| 15 | 11.1 |
| 16 | 5.8 |
| 17 | 5.0 |
| 18 | 1.0 |
| 19 | 2.1 |
| 20 | 1.2 |
| 21 | 2.0 |
| 22 | 3.3 |
| 23 | 7.1 |
| 24 | 8.8 |
| 25 | 7.9 |
| 26 | 14.0 |
| 27 | 13.7 |
| 28 | 12.4 |
| 29 | 1.5 |
| 30 | 6.1 |