MANCHESTER
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Embedded RFID Ignition and Power Supply System

Third Year Individual Project – Final Report

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1. Introduction

1.1. Motivations

Electric vehicles are powered by electric motors rather than conventional internal combustion engines in the modern petrol cars, and the energy supply of motors is electricity comes from rechargeable batteries.

Comparing electric vehicles with petrol vehicles and electric vehicles have the following benefits. Firstly, electric vehicles are eco-friendly. By eco-friendly, it suggests electric vehicles can improve air quality and reduce climate change. "T*ransport accounts for around a quarter of the UK's carbon emissions, a key contributor to climate change. Pure electric vehicles don't produce any greenhouse gas exhaust emissions whilst being driven and those from plug-in hybrids are significantly lower than from a traditional petrol or diesel car.*" [1] Secondly, electric vehicles are less expensive compared to petrol vehicles regarding daily use. "*Compared to petrol or diesel, electricity is cheap. On a cost per mile basis this means a pure electric car could cost a third (or less) of what a traditional petrol or diesel car might cost.*" [2]

Moreover, electric vehicles are more adaptive to all kinds of essential electricity-based components. For example, automotive lighting, sirens and smart key system. Speaking of the smart key system, nowadays, big car companies have already implemented it and they see it as a necessity for modern cars. So, the reason behind that is the smart key systems bring users not just improvements regarding accessibility because it is easier to carry with, but also the safety aspect. To illustrate that, locking systems auto-lock the car after a certain period when the user left the car unlocked and the car cannot be ignited when smart keys are not around.

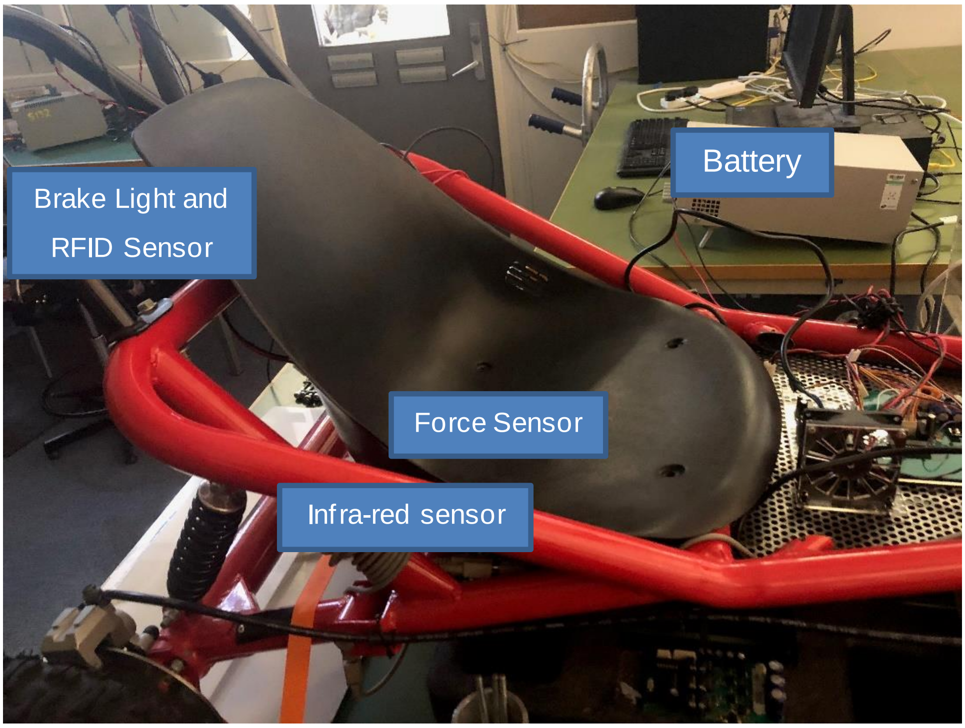


Figure1. Kart with Power supply of 48V

This project works on a 48V-supplied electric kart, and this kart is locked by a chain lock through the wheel to the table. This key locking system sometimes can be challenging to cope with regarding safety and accessibility. For example, anyone can have access to the kart if it is left unlocked by accident. On the other hand, that can hardly happen when the kart is applied with the RFID ignition system. An auto-lock system can be easily introduced by using all sorts of sensors to determine whether the kart is left unattended or not. Also, keyless is much better regarding accessibility. Speaking of pedestrian safety, this electric kart does not have a siren or brake lights, so adding these safety precautions are also part of the project. Nevertheless, most components involved in this project cannot work directly with a 48V supply. As a result, power distribution problem needs to be solved by building up voltage conversion circuits which can convert 48V into 12V/ 5V.

1.2. Aims and Objectives

This aim of this project is to enhance owner and pedestrian safety system by adding keyless locking system, siren and brake lights. Moreover, designing PCB circuits capable of converting 48V down to provide 5V for micro-controllers and 12V for brake lights.

This project has the following objectives:

- Investigate Arduino coding on how to design RFID reader system
- Try to use microcontroller on the front of the kart if there are spare pins
- Build up connection between brake and lights using microcontroller
- Test infrared sensor and Force sensitive sensor and do some comparisons
- Design circuits for power supply system of 5V/12V
- PCB design and test
- Enclosure design

1.3. Literature reviews

Nowadays, there are three common key system of cars, and they are mechanical key-lock system, remote keys system and keyless entry-system. RFID has long been a critical technique to the smart key system because it guarantees safety with unique encryption technique being applied. RFID is radio-frequency identification technology which keeps sending radio waves to identify and track tags. RFID has a wide range of application. "*RFID applications in healthcare could save important resources that can further contribute to better patient care. RFID applications could reduce the number of errors by tagging medical objects in the healthcare setting such as patients' files and medical equipment tracking in a timely manner*" [4]

As mentioned above, the smart key system has been widely implemented on board and considered a necessity for big car companies. For example, BMW has a long history of developing the smart key system. Nowadays, they even add a display screen on the key fob to display all essential information, like the status of air condoning, windows, doors and fuel levels. "*The key fob with display is therefore capable of showing the sort of status information that can be accessed on a smartphone with the BMW i Remote app. However, the data is transmitted to this premium key fob by means of the same radio signal used to lock or unlock the vehicle. The information can be updated if the vehicle is within radio range of the key.*" [5] This short report was published by BMW blog in 2015, and up until that time, RFID was still the most fundamental technology in their smart key systems. However, there will be a step from the smart key towards "keyless" in the future. "*Biometric identification identifies by using the biological features of a driver as the basis of identification, thus reducing the risks of theft or loss of property due to driver's negligence.*" [6] Drivers will no longer have to bring key fobs with them, and biometric locks provides even more safety and convenience by checking fingerprints, iris (a thin, circular structure in the eye) or other biological evidence.

1.4. Structures

In this paper, experimental test on RFID ignition system will be discussed in chapter 2, Power supply circuit design will be discussed in chapter 3, proposed solution and implementation will be discussed in chapter 4, and lastly conclusion is in chapter 5.

2. RFID Ignition System

This project consists of two main tasks, RFID ignition system and power supply system. RFID ignition system acts like a switch to 48V battery, either supply 48V to the kart or cut the supply off。 Furthermore, the switch position ON/OFF is determined by a Leonardo CAN BUS shield micro-controller on the back of the kart.

RFID ignition system can be viewed as the following the block diagram and this diagram is made of 5 main blocks, tags, readers, sensors, micro-controllers and the ignition system.

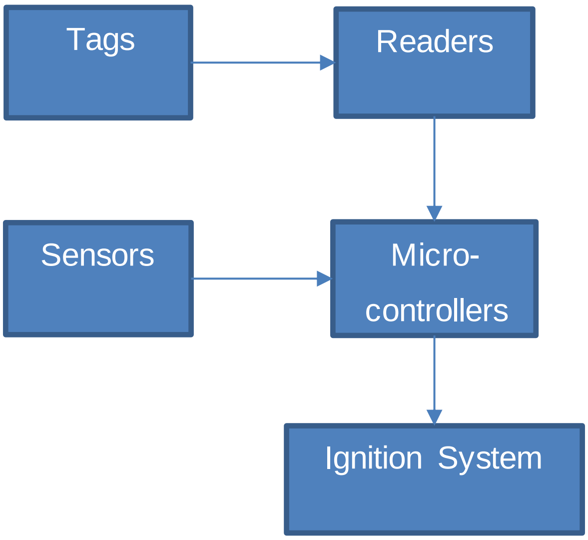


Figure 2. Overview of ignition system and sensor inputs

2.1. Tags

The Tag acts like a key to the RFID ignition system. In other words, the kart can only be ignited when the RFID reader detects the correct UID (unique identification) code of the RFID tag by comparing with its database. Moreover, tags can be differentiated into three different types by their own features; passive tags, active tags and semi-active/passive tags.

2.1.1. Comparisons between tags and selection

Table1 shows general features of all three different types of tags from both physical and commercial aspects, including power source, working range, size and price. Comparing between all three types, passive tags have the following advantages and limitations.

	Passive Tag	Active Tag	Semi-passive/active ag
Tag power	Energy transferred from reader	Internal battery	Internal battery/ energy transferred from reader
Working range	Short (up to 10m)	Long (100m or more)	Moderate (Up to 100m)
Price	Cheap (£0.1 or more)	Expensive (£15 or more)	Moderate (£8 or more)
Tag size	Small (25 x 30 x 5 mm)	Big (120 x 36 x 30 mm)	Moderate (130.4 x 23.4 x 12.7 mm)

Table1. Comparisons between tag types and typical value

Firstly, passive tags are cheap. A typical passive tag is made up of three parts, an antenna, a micro-chip and a substrate which allow components to be mounted on. Because of this simple structure, passive tags are very easy and cheap to manufacture. therefore, the typical price of a passive tag is about £0.1 or more.

Secondly, passive tags are small. The simple structure of passive tags also suggests the physical size of a passive tag can be extremely small, about 25 x 30 x 5 in mm. Passive tags can bring users portability, since they are small enough to be carried around.

Lastly, passive tags are safer in terms of data protection compared with other types of tags. A major concern of RFID tags today is security and privacy problem. To be specific, RFID tags send signals to readers without alerting their owners, therefore anyone can access to this fixed serial number signal within reading range.[8] Passive tags' limited working range can effectively prevent driving system from being hacked.

However, there are still some limitations of passive tags. The lack of on-board power supply affects passive tags' reading range and limits it up 10m. "10m reading range" sounds like a rather long distance, but the actual working range must consider the power loss in signal as distance goes further. In practice, a 13.56MHz high frequency reader can only operate when the matching passive tag within 4cm at the most. After taking the above aspects into consideration, passive tags are chosen for this RFID ignition system.

2.1.2. Tags implementation

Passive Tags can be further differentiated into LF (low frequency), HF (high frequency) and UHF (ultra-high frequency) by their working frequency range. Table 2 below gives out information regarding working frequency range and reading range of all three types of passive tags. [9]

	Low Frequency RFID Passive Tag	High Frequency RFID Passive Tag	Ultra-High Frequency RFID Passive Tag
Frequency range	125 kHz. and 134.3 kHz	13.56 MHz	860 ~ 960 MHz
Reading range	Read distance of 30 cm (1 foot) or less	Maximum read distance of 1.5 meters (4 foot 11 inches)	Minimum read distance of over 1 meter

Table2. comparisons between different frequencies-based RFID tags

Table2 show a positive relationship between working frequency and reading range. In other words, reading ranges extend as working frequency goes up. LF and HF RFID passive tags are rather cheap and easy to be bought from online store, like Amazon. In this case, designing and manufacturing one is not prioritized because that would be time-consuming and less efficient. After exploring the online store, MIFARE® 13.56MHZ TAGS have become the first option at the beginning of this project for several reasons.

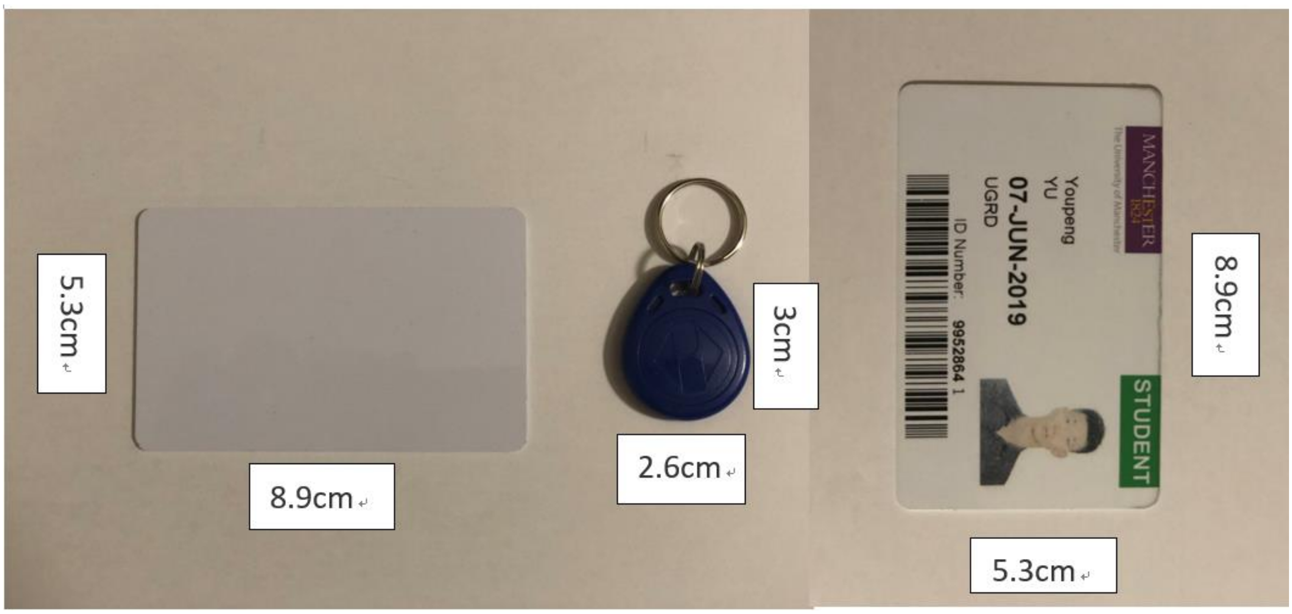


Figure3. Card type and Key fob Type Passive Tag & student card

Firstly, MIFARE tags come in many different types of design. Figure3 shows card type and key fob type of the MIFARE tags. The card type tag has a dimension of 5.3cm x 8.9cm in plane view with a rather thin layer that can easily be fitted into a wallet or a card case. The key fob tag has a dimension of 3cm x 2.6cm in plain view with a key ring on the top which can easily be chained to other key rings.

Secondly, MIFARE 13.56MHz can be rewritten and duplicated easily using Arduino RFID sensor (MFRC522). MFRC522 is a RFID reader compatible with Arduino microcontroller that operates at 13.65MHz.

However, MIFARE tags have been replaced by student cards of Manchester university as project went along. Student card is also 13.56MHz passive RFID tag, and for a better reason, students in this university must carry their student cards with them all the time. As a result, choosing student card to be the tag will not create any extra burden to the users, especially when users are the university stuff or students.

2.2. RFID Readers and Micro-controllers

Micro-controllers and RFID readers both play important roles in the RFID ignition system. RFID readers are used to detect RFID tags and transmit signals to micro-controllers, then micro-controllers identify the signal received and perform a series of tasks.

2.2.1. Comparisons between RFID readers and selection

RFID readers is used to build up connections between tags and the ignition system. In other words, the correct RFID tag cannot start the kart without the presence of a RFID reader. Most RFID readers are made up of integrated circuits to modulates and demodulates radio frequency signals and transmit the signal through the antenna of RFID readers.

	Low Frequency RFID Reader	High Frequency RFID Reader	Ultra-High Frequency RFID Reader
Band Frequency	120–150 kHz (LF)	13.56 MHz (HF)	433 MHz (UHF)
Working range	10 cm	10 cm–1 m	1–100 m
Data Speed	Low	Low to moderate	Moderate

Table3. comparisons between different frequencies-based RFID reader

RFID readers can be differentiated into three types in common based on their band frequencies, Low Frequency (LF) RFID readers, High Frequency (HF) RFID readers and Ultra High Frequency

(UHF) RFID readers. Band frequency-based RFID readers share some similar properties of RFID tags. As the band frequency goes up, the working range and data transferring speed also grows. For example, HF RFID readers have 10cm-1m working range which is larger than 10cm working range of LF RFID readers, but smaller than UHF RFID readers' working range (1-100m).

The main reason of HF RFID readers is chosen for this project is because RFID readers must operate at a band frequency which matches RFID tags' to be able to transmit and receive signals. Therefore, a 13.56 MHz operated passive RFID student card can only be detected by a 13.56 MHz (HF) operated RFID reader.

2.2.2. RFID readers implementation

As mentioned before, RFID readers are made up of integrated circuits containing antennas. Designing and building ICs for RFID readers is not a wise approach for this RFID ignition project since RFID readers satisfies the requirements in 2.2.1 section can be easily bought from online stores. Furthermore, two HF RFID readers (RS232-B1 v2 and MFRC522) with different features are considered at the start up stage of this project.

	RS232-B1 v2 RFID Reader	MFRC522 RFID Reader
Operating Frequency	13.56MHz	13.56MHz
Read range	5cm	3cm
Length x Width	75 x 50 x 3 mm	60 × 39 x 3 mm
Price	£18.11	£5.76
Input voltage	4.5V to 25V	2.5V to 3.3V

Table4. Comparisons between RS232-B1 v2 and MFRC522

Information (operating frequency, read range, size, price and input voltage) of two different HF RFID readers are shown in table4. The reason to chose two high frequency (13.56MHz) operated RFID readers is both RFID readers are compatible with university student cards, and that gives this ignition system some advantage in tags choosing.

In comparisons, MFRC522 readers are cheaper and smaller. RS232-B1 v2 readers (£18.11) are much expensive than MFRC522 readers (£5.76) because B1 readers provide extra functions beyond the requirements of this ignition system. For example, the B1 reader have voltage regulator on board and this voltage regulator allows the reader to be powered up by an input voltage between 4.5V and 25V. The B1 readers can simply be powered by micro-controller's 5V output, and this wide range of input voltage is not essential for a RFID reader. Furthermore, B1 readers are 15mm and 11mm longer in length and width respectively. The difference in size between two readers suggests that MFRC522 readers take less space, therefore can be fitted in a smaller enclosure box.

On the other hand, B1 readers are 2cm longer than MFRC522 readers in terms of reading range. However, both B1 and MFRC522 readers' reading range are less than 10cm and the limited reading range suggests that both readers are NFC readers. NFC stands for near-field communication, and NFC technology is a more finely-honed version of RFID. NFC operates at 13.56MHz as High Frequency RFID does, but it is more secure in terms of data exchange and the maximum reading range is limited (up to 10cm). The advantage of NFC readers for this RFID ignition system is the RFID tags can be prevented from being accidentally detected from a long distance and therefore lead to unwanted tasks being processed. Besides that, both RFID readers can be powered by micro-controller using 3.3V and 5V respectively. To consider the above analyses of both readers, MFRC522 RFID readers are chosen for this project because RS232-B1 v2 RFID readers cost more money than MFRC522 RFID readers and the additional functions are inessential.

2.2.3. Comparisons between Micro-controllers and selection

Micro-controllers are small computers built on integrated circuits, and they are coded to perform a series of tasks by observing the states of digital inputs, analogue inputs and other types of inputs. There are three types of microcontrollers or microchips being considered to optimize the selection of micro-controllers, which are Arduino Uno, Arduino Leonardo CAN BUS shield and ATtiny 45.

	Digital pins	Analogue pins	ICSP pins
Requirements	6 pins	1 pin	6-pin set

Table5. Requirements on pins of micro-controllers

	Arduino Uno	Arduino Leonardo CAN BUS shield	ATtiny45
Programming language	Arduino	Arduino	Arduino
Price	£19	£24	£2.1
MCU	ATmega328P	ATmega32U4	ATmega328P
CAN BUS	Extra CAN BUS shield	YES	NO
Digital pins	14	9	2
Analogue pins	6	3	3

ICSP pins	6	6	0
Clock speed	16MHz	16MHz	10MHz
Input voltage	7V-12V	5V-16V	2.7V-5.5V

Table6. Comparisons between different micro-controllers

Table5 shows the requirement number of pins for digital, analogue and ICSP pins. This project requires 6 digital pins. To be specific, it requires 2 digital output pins for LED presentation, 1 digital input pin for the RFID reader, 2 digital input pins for two infrared sensors and 1 digital output pin for (BJT) bipolar junction transistor. Furthermore, 1 input analogue pin is needed for force sensitive resistor. Lastly, 6-pin set ICSP are needed for RFID readers implementation including MISO, MOSI, SCK, RST, 3.3V and GND. After comparing properties shown in table6, Arduino Leonardo CAN BUS shield is the better option among these three microcontrollers or microchips for the following reasons.

To begin with, this RFID ignition project requires 6 digital pins, 1 analogue pin and 6-pin set ICSP. Arduino Uno can provide 14 digital pins, 6 pins and 6-pin set ICSP, and the provided pin numbers of Uno is more than enough. On the other hand, Leonardo CAN BUS shield can provide 9 digital pins, 3 analogue pins and 6-pin set ICSP, and the pin setting of Leonardo is just enough compared with the requirements. To shrink this RFID ignition system, ATtiny45 microchip is also considered at the start of this project, but it is soon excluded from the options because the limitation of digital pins (2 digital pins) and ICSP pins (no ICSP pins set).

Furthermore, Leonardo CAN BUS shield is a shielded Leonardo board which supports CAN bus connection. CAN bus connection is rather essential in this project because the brake light needs to be light on whenever the brake of the kart is pressed. This brake signal is monitored by another micro-controller at the front of the kart. So, it requires a 9-pin D-SUB cable to transfer the signal from the front to the back of the kart, and a 9-pin D-sub has pin2 represents CAN_L signal and pin7 represents CAN_H signal. Among these three choices, Leonardo CAN BUS shield is the better choice because Arduino Uno board needs an extra CAN BUS shield to be applicable to CAN BUS connection and ATtiny45 cannot work with CAN BUS. This Arduino Uno CAN BUS shield adds extra £25 on the original price, so the total price becomes £44 which is rather expensive compared with the price of Leonardo CAN BUS shield (£24).

2.2.4. Connections between RFID readers and Micro-controllers

Since the choice of RFID readers and micro-controllers are chosen to be MFRC522 and Leonardo

CAN BUS shield, the connections between them must be made to allow signals to travel through wires from MFRC522 to Leonardo board.

	MFRC522 Reader Pin	Arduino Leonardo CAN BUS shield
RST/Reset	RST	ICSP-5
SPI SS	SDA(SS)	Pin 10
SPI MOSI	MOSI	ICSP-4
SPI MISO	MISO	ICSP-1
SPI SCK	SCK	ICSP-3
Power	3.3V	ICSP-2
GND	GND	ICSP-6

Table7. pin layout of MFRC522 reader and Leonardo CAN BUS shield

As can be seen from table7 (pin layout table), 5 different types of signals besides the power and ground need to be transferred from reader to the micro-controller. These 5 types of signals are RST (reset), SPI SS (serial clock), SPI MOSI (Master Output Slave Input), SPI MISO (Master Input Slave Output), SPI SCK (serial clock) respectively.

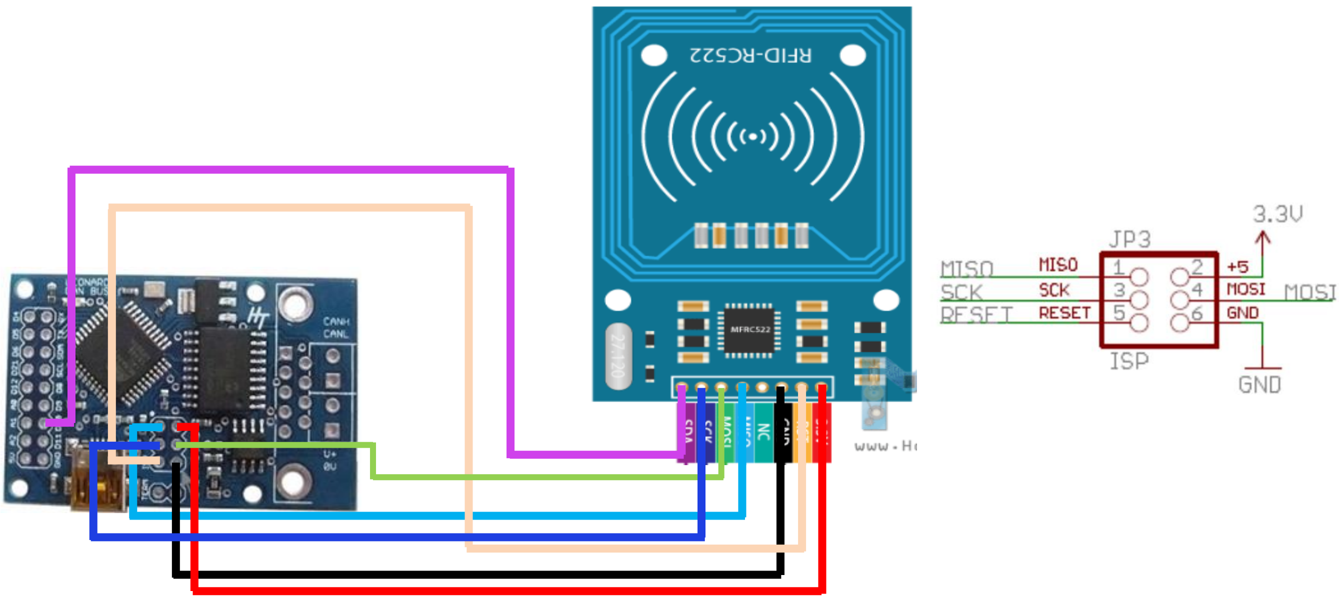
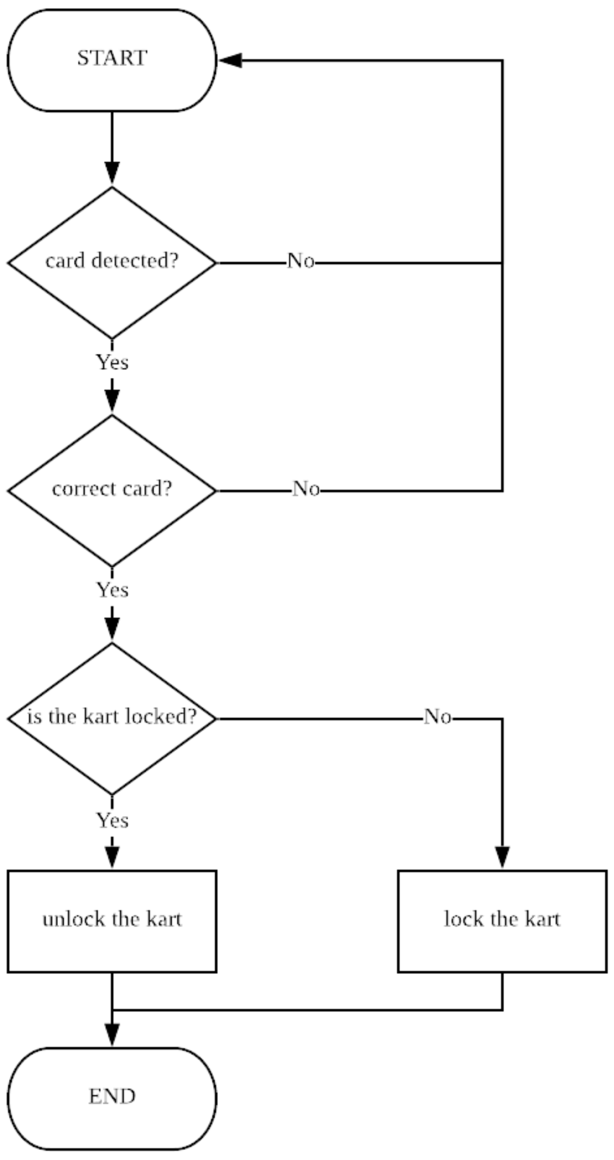


Figure4. Connections between MFRC522 and Leonardo CAN BUS shield and 6-pin ICSP set

Figure 4 shows the wiring diagram between MFRC522 and Leonardo CAN BUS shield and the pin layout of the ICSP port. To be specific, the ICSP port are connected to the matching signal output of the MFRC522 readers, and the SDA(SS) pin on the MFRC522 is connected to pin D10 by default setting in the Arduino library.

2.3. Coding and Logics of locking system

The RFID ignition system of this project can be split into two different parts (self-locking system and RFID tag locking system) and described by flowchart in Figure5. Furthermore, this code is written using Arduino language because the micro-controller (Leonardo CAN BUS shield) is an Arduino board.



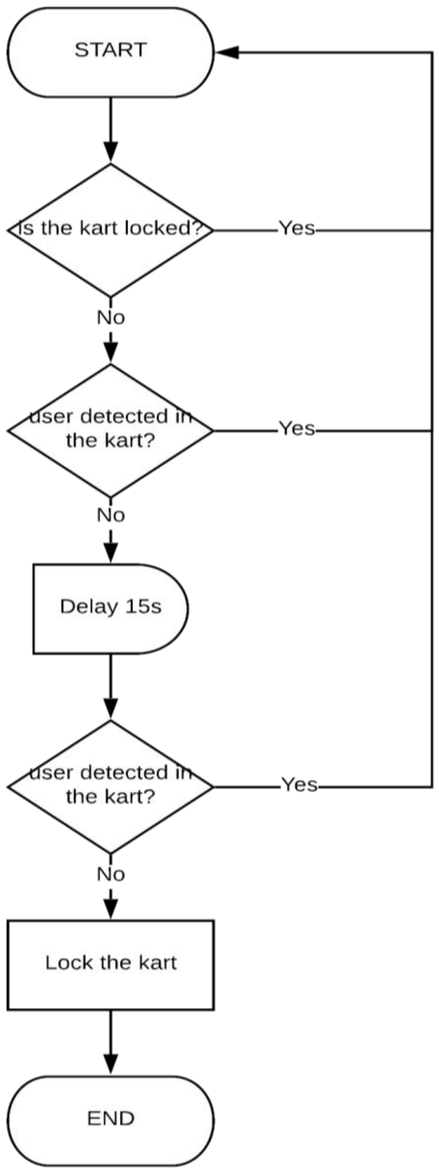


Figure5. Flowchart of RFID tag locking system (left) and self-locking system (right)

The locking system is designed to perform following tasks:

- Lock the kart 15s after users' leaving
- Tap the card to unlock the kart when kart is locked
- Tap the card to lock the kart when the kart is unlocked

There are a few things are not shown explicitly from programming perspective in figure5.

- Card detected?
- Correct card?
- Unlock/Lock the kart
- Is the kart locked?
- Users detected in the kart

2.3.1. Card detected implementation

```
if ( ! rfid.PICC_IsNewCardPresent())

return;
```

As the above code shows, **rfid.PICC_IsNewCardPresent()** as a function inside the Arduino library by communicating with the MFRC522 readers to know if there is a card present. Furthermore, using an "if" statement including a "!" to say if there is not a card shown, then the execution of the function is stopped. In other words, if no card is shown, then start over the main loop.

2.3.2. Correct card implementation

```
String content= "";

for (byte i = 0; i < rfid.uid.size; i++)

{content.concat(String(rfid.uid.uidByte[i] < 0x10 ? " 0" : " "));

content.concat(String(rfid.uid.uidByte[i], HEX));}

content.toUpperCase();

if (content.substring(1) == "04 5D 53 6A 5E 43 80")
```

Firstly, define a string "content" to be empty, and use a for loop to log the value of RFID UID. When the byte number is smaller than the UID size, then keep logging. After a logging process, value in the "content" string is successfully converter to HEX form, then capitalize "content" string. The last step is using a "if" statement to compare the value in the "content" with a predefined UID number. If they match, that means the correct card is shown.

2.3.3. Unlock/Lock the kart implementation

#define LED_G 4

digitalWrite(LED_G, HIGH);

Unlock and lock the kart is simply illustrated by turn on/turn off a green LED, “LED_G” is defined to be D4 pin on the micro-controller. So, putting D4 pin high is saying give green LED a power supply.

2.3.4. Is the kart locked implementation

int r=0;

digitalWrite(LED_G, HIGH);

r=1;

The current locking system can be identified by define a character, for example, “r”. r is initialised to “0”, and “0” means the car is locked. On the contrary, “1” means the car is unlocked. Furthermore, value of r is changed respective to the locking state every time after car is being locked or unlocked.

2.3.5. Users detected in the kart implementation

int force = 0; int isObstacle = HIGH; int isObstaclePin = 5; int pressurePin = A0;

force=analogRead(pressurePin); isObstacle = digitalRead(isObstaclePin);

if (force < 500 && isObstacle == HIGH)

The user detection system is constituted of two infrared sensor and one force sensitive sensor, but the code shown above just used one infrared sensor and one force sensitive sensor for illustration purpose. So, the first line defines the pin setting and initialise the value of D5 and A0. D5 is the input from infrared sensor, and A0 is the input from force sensitive resistor. Next step is use “digitalRead” and “AnalogueRead” functions to read the value of D5 and A0, then equate the value to predefined variables “force” and “isObstacle”.

Variable “force” is an analogue input between 0 and 1024, and the value of “force” increases as the forces applied to FSR increases. So, 500 is set to be the boundary value. When “force” is smaller than 500, it means no one is sitting on the seat. On the other hand, Variable “isObstable” is a digital input either be “LOW” or “HIGH”, and value “HIGH” means no body is in front of the infrared sensor in a measurable range. Lastly, using a “if” functions to determine the user being detected or not. The last line of the above code can be interpreted as both detectors cannot detect users.

2.4. Sensors

In this RFID ignition system, a self-locking system is designed for security consideration. To be specific, the kart can be locked automatically after a period provided no one is on the kart. In the meantime, the measurements of “if someone on the kart” have to be conducted by sensors which can precisely reflect the seating status of the kart.

Two types of sensors, infrared sensors and force sensitive resistors, are considered as user-detection sensors at the beginning of this project. However, these two sensors behave differently, and it is hard to choose which one fits more by comparing them without testing them. For testing purpose, FC-51 IR proximity sensors are chosen as infrared sensor and FSR406 (38 x 38mm) Square Force Sensing Resistor are chosen as force sensors.

2.4.1. Force sensitive resistor

Force sensitive resistors can be abbreviated as FSR. As the name suggests, FSR are resistors but with resistance change accordingly to force. Since FSR are the fundamental components which can hardly be designed and built in this project, the best option is to purchase from online stores. In this case, the biggest size of FSR can be bought from Rapid is 38 x 38mm.

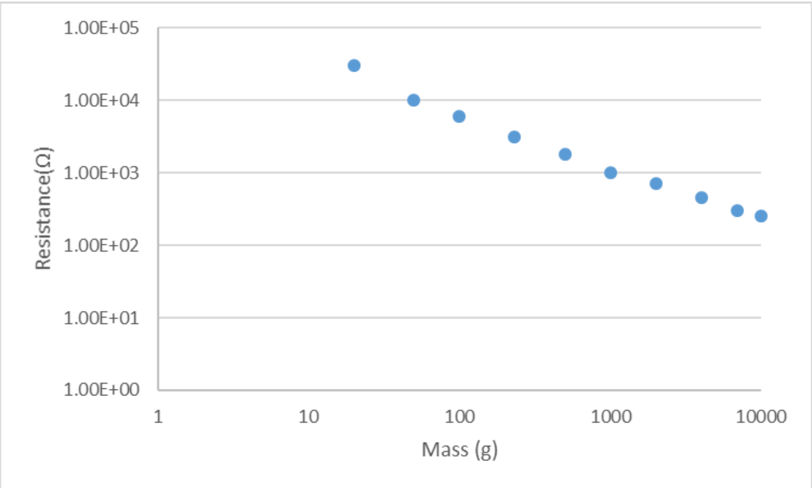


Figure6. the logarithmic scale plot of resistance against mass

Figure6 is a logarithmic plot of resistance in ohms against mass in grams, the table of data points used in the graph plotting can be found in appendix 4.2. There is a rough linear relationship between resistance and mass provided both in logarithmic scale. In other word, resistance changes dramatically at low mass end of the mass-resistance characteristic, but only changes slightly at the high mass end. For example, resistance of FSR drops 20k when the mass on the pad is increases from 20g to 50g, but only drops 50ohms when mass on the pad increases from 7kg to 10kg.

2.4.2. Force sensitive resistor implementation

The basic implementation of force sensitive resistor is building a 5V voltage divider together with a 1k-ohm resistor and measuring the voltage across the 1k-ohm resistor with analogue input pin A0 from the Leonardo CAN BUS shield.

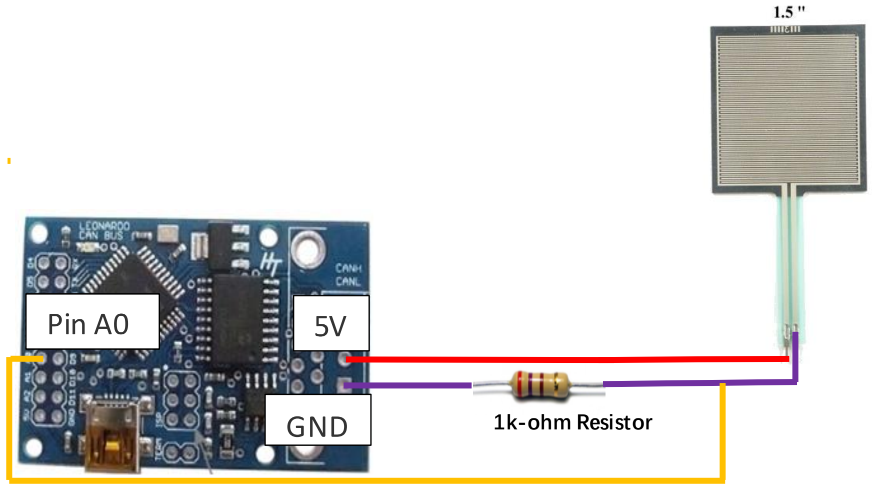


Figure7. Connections between FSR and Leonardo CAN BUS shield

In the Arduino code for FSR, 500 is selected to be the boundary value for easier calculation because 500 is about the median compared to the input range of pin A0 (0 to 1023). To elaborate on that, the input value of A0 can be calculated from equation1 by replacing the value of resistance of FSR.

$$A0 = \frac{R_{FSR}}{1000+R_{FSR}} \times 1023 \qquad \text{eq.1}$$

In section 2.3.5, the Arduino code of sensor implementation is given as "**if (force < 500 && isObstacle == HIGH)**". This line of code relates to FSR is saying when the pin A0 has a reading smaller than 500, then no one is detected on the kart through FSR. Furthermore, the voltage across 1k-ohm resistor is below 2.5V when reading of pin A0 is smaller than 500. In other words, FSR is taking over half of the voltage supply when FSR's resistance is bigger than 1k-ohm resistor. In appendix 4.2 Table 8 "mass-resistance characterises of FSR", FSR only have a resistance higher than 1k ohms when the mass on the pad of FSR is bigger than 1kg.

The resistance of fixed value resistor in series of FSR cannot be too high, so the kart cannot automatically lock itself. On the other hand, the resistance of fixed value resistor cannot be too small, therefore the kart shut the power supply even with people driving the kart. As a result, 1k-ohm resistor is chosen carefully, so the kart still can lock itself with mass on the kart smaller than 1kg.

However, FSR only has a dimension of 38.1 38.1 in mm, and this sensing area is compared to be relatively small to the area of the kart's seat. Dealing with this problem, two possible improvements can be implemented on the kart. To begin with, increasing the number of FSR, so the total sensing area of the seat is increased. Secondly, placing the FSR at the front area of the seat. This idea comes from a paper "driving posture analysis", and the experiment of "driving posture analysis" [11] suggests that 41% of people drive with their upper body slouched on the seat, which means the weight of driver will be applied to the seat towards the front.

2.4.3. Infrared sensor

Infrared sensors are rather complicated and delicate device which contain Infrared emitters, infrared receivers, potential meters, comparators and other components. E18-D80NK and FC-51 are both IR sensors which satisfy the requirements of user detection sensors. Since these two sensors can both be bought from online stores for a rather cheap price, then it is not necessary to design and build one for this RFID ignition system.

	E18-D80NK IR sensors	FC-51 IR proximity sensors
Shape	Cylinder	Cuboid
Size	Length x Width: 45 x 17 mm Diameter:18mm	Length x Width: 45 x 14 mm Thickness:7mm
Supply voltage	3.3V-5V	5V
Detection angle	35 degrees	<15 degrees
Detection distance	3-80 cm	2-30 cm
Price	1 piece for £6.99	5 pieces for £8.89

Table8. Comparisons between E18-D80NK IR sensors and FC-51 IR proximity sensors

There are three key difference between E18-D80NK sensors and FC-51 sensors, and these three are detection parameters, shape of sensors and prices.

Firstly, detection parameters, detection distance and detection angle, of two sensors are rather different. E18-D80NK sensors' detection distance (3-80 cm) is much longer compared with FC-51 sensors' (2-30 cm), and the detection distance of both IR sensors can be adjusted by potential meters on board. However, the required detection distance under normal conditions are only about 20cm, which is the distance from handles aside to the centre of the seat on the kart. Thus, both IR sensors satisfy this detection distance requirements. From detection angle perspective, FC-51 sensors have extra 20 degrees of detection range than E18-D80NK sensors, which is the main reason of choosing FC-51 as IR sensors. To be specific, FC-51 sensors can still detect users when they are leaning forward or backword with extra detection angle.

Secondly, the shape of two sensors are different. E18-D80NK sensors are cylinders with diameter of 18mm, and FC-51 sensors are cuboid with thickness of 7mm. Since the length and width of two sensors are similar, thin layer-built FC-51 is more easily to be fixed on the handle of kart.

Lastly, prices of two different sensors are rather different. E18-D80NK have a unit price of £6.99, but FC-51 only costs less than £2 for each unit. On top of that, FC-51 sensors have larger range of input voltage from 3.3V-5V compared with. E18-D80NK's 5V input voltage. After taking the above comparisons into considerations, FC-51 IR proximity sensors are chosen to do some tests as IR sensors.

2.4.4. Infrared sensor implementations

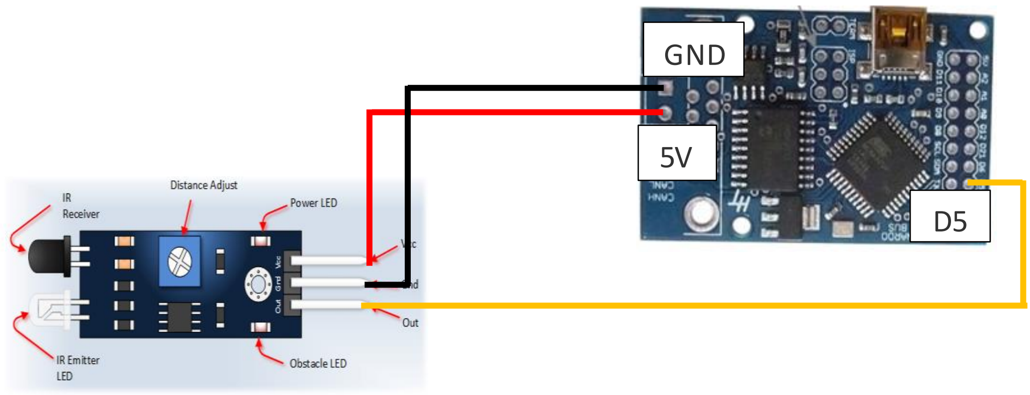


Figure8. Connections between Infrared sensor and Leonardo CAN BUS shield

For the hardware implementation, FC-51 IR proximity sensors have three pins need to be connected, including pin Vcc, pin GND and pin Out. To be specific, pin Vcc and pin GND are responsible for power supply and pin Out is responsible for signal output. Furthermore, Table in appendix5.3 and Figure8 show the pin layout and physical connection respectively for FC-51 and Leonardo.

Placing strategy

For the software implementation, pin Out is a digital output pin which means it only outputs a "HIGH" state or a "LOW" state. So, a digital pin D5 on Leonardo board is chosen and defined to be digital input. In section 2.3.5, the Arduino code of sensor implementation is given as,

if (isObstacle == HIGH) {digitalWrite(LED_G, LOW)};

This line of code relates to IR sensors is saying when the pin D5 is reading a "HIGH" signal, then no one is detected on the kart through IR sensors and turn off green LED. In this case, turn off green LED is a showing of cut off the power supply of the kart.

2.4.5. Sensors comparisons and solution

There are a few concerns need to be considered when designing sensors,

1. Can sensors still detect drivers when they are leaning backward or forward?
2. Can sensors still detect drivers when they stand up a little?
3. Can kart be automatically locked when small object left on the seat?
4. Will the kart be stopped by sensors while driving? (highly dangerous)

	Force sensitive resistor	Infrared sensor
Advantages	• Posture irrelevant (provided sit on FSR)	• Users can be detected even stand up a little
Disadvantages	• Detection area limited (38.1mm x 38.1mm) • Users need to sit on FSR to be detected	• Detection angle limited (35 degrees)

Table10. comparisons between FSR and IR sensors

Table10 shows the advantages and disadvantages for FSR and IR sensors, and this can be utilized to solve above four concerns regards sensors implementation.

The first concern can be solved by either increasing the number of FSR or IR sensors. To be specific, increasing the number of FSR make sure users can still sit on FSR when they are leaning forward and backward. Furthermore, increasing the number of IR sensors can increase the angle of detection. Therefore, one of IR sensors can still detect users when they are leaning forward and backward.

The second concern is targeted of using IR sensors rather than FSR. FSR can only detect users when they have a force towards it, but in this case, users may not create any force towards FSR. On the other hand, IR sensors can still detect users when they are standing up a little.

Moving to the third concern, small objects can be neglected if using IR sensors but not FSR. To elaborate on that, FSR's mass boundary is proposed to set to 1kg in section 2.4.2 and that means any objects over 1kg will be recognised as user detected. If a small object is weighing more than 1kg, then the self-locking system will not work. On the other hand, the small object can easily be ignored by an IR sensor which is fixed on the handle aside the seat.

Lastly, there are two possible situations when all the sensors send signals saying users not detected. The first one is all the sensors function correctly, and there is not a user on the kart. In this case, the kart can be locked by cutting off the power. Secondly, users are out of detection region or fault signal is sent out from sensors. In the worst case, the kart's power is cut off while moving because of fault detection. This can lead to a serious car crashing accident, and people get injured. A possible solution to this problem is sending a speed measurement signal of the kart or motor to Leonardo micro-controller, and only runs the self-lock function while kart is being stopped.

To overcome the above concerns of the self-locking system, 2 or more FC-51 infrared sensors can be placed at different angles on the handle aside of the seat. This is a better solution than using FSR alone or together with FSR because FSR cannot ignore small size heavy object and cannot detect user when they are above seat.

3. Power Supply System and Enclosure Design

4. References

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5. Appendices

5.1. Appendix 1 Arduino Source code

```
#include <deprecated.h>
#include <MFRC522.h>
#include <MFRC522Extended.h>
#include <require_cpp11.h>

//RFID
#include <SPI.h>
#include <MFRC522.h>

#define SS_PIN 10
#define RST_PIN 9
#define LED_G 4 //define green LED pin
#define LED_R 6 //define red LED pin
int pressurePin = A0;
int isObstaclePin = 5; // This is our input pin
int force = 0;
int isObstacle = HIGH; // HIGH MEANS NO OBSTACLE
String RFID;
void ReadOn();
void ReadSensor();

MFRC522 rfid(SS_PIN, RST_PIN);   // Instance of the class



void setup()
{
  Serial.begin(9600);   // Initiate a serial communication
  while (!Serial);    // Do nothing if no serial port is opened (added for Arduinos based on
ATMEGA32U4)
  SPI.begin();     // Initiate  SPI bus
```

```
  rfid.PCD_Init();   // Initiate MFRC522
  rfid.PCD_DumpVersionToSerial(); // Show details of PCD - MFRC522 Card Reader details
  Serial.println(F("Scan PICC to see UID, SAK, type, and data blocks..."));
  Serial.println();     //space
  pinMode(LED_R, OUTPUT);
  pinMode(LED_G, OUTPUT);
  pinMode(isObstaclePin, INPUT);
  digitalWrite(LED_G, LOW);
  digitalWrite(LED_R, LOW);


}
void loop()
{
  RFID = "";           //clear RFID Read
  ReadSensor();          //Read Sensors
  if (force < 500 && isObstacle == HIGH){          //  if no one
   for(int i=0;i<100;i++){                       //enter a for loop,255 times
     if (RFID.substring(1) == "04 5D 53 6A 5E 43 80"){          //if RFID is correct
      i=0;                                                  //initiate i
      digitalWrite(LED_G, LOW);                                   //turn off green light
      break;                                           //break out from for loop
     }
     else{
     delay(50);                                               //delay 50ms
     ReadOn();                                                 //read RFID
     }
   }
   ReadSensor();                                              //read sensor
    if (force < 500 && isObstacle == HIGH){                          //if no one
    digitalWrite(LED_G, LOW);                                        //turn off green light
    }
    else{
    ReadSensor();                                              //read sensors
```

```
}
  Serial.println("Ready to Tap");
  digitalWrite(LED_R, HIGH);                    //red light on
RFID = "";                                  //clear RFID
while(RFID.substring(1)!= "04 5D 53 6A 5E 43 80"){             //while RFID
nothing
 ReadSensor();                                //read sensors
 if (force < 500 && isObstacle == HIGH){              //if no one
  for(int i=0;i<100;i++){                     //for loop
   if (RFID.substring(1) == "04 5D 53 6A 5E 43 80"){          //RFID correct
    i=0;                                 //clear i
   break;                                  //break
   }
   else{
    delay(50);                             //delay50ms
    ReadOn();                              //read RFID
   }
  }
  ReadSensor();                                //read sensors
  if (force < 500 && isObstacle == HIGH){                //if no one
  digitalWrite(LED_G, LOW);                        //turn off green light
  }
  else   ReadSensor();                             //read on
 }
 else  ReadSensor();                            //someone keep reading RFID
 }
 digitalWrite(LED_R, LOW);                       //turn off red light
if (RFID.substring(1) == "04 5D 53 6A 5E 43 80") //change here the UID of the card/cards
that you want to give access
{
 Serial.println("Authorized access");
 Serial.println();  //space
 digitalWrite(LED_G, HIGH);                       //access
```

```
        delay(2000);                     //wait 2s
        }
      }
      else{                              //some one
           Serial.println("Ready to Tap");
           digitalWrite(LED_R, HIGH);                        //red light flashes
        RFID = "";                                  //initiate RFID
        while(RFID.substring(1) != "04 5D 53 6A 5E 43
80"){                          //when not correct thing is read
          ReadSensor();                                        //check sensors
         if (force < 500 && isObstacle == HIGH){                        //if no
one
         for(int i=0;i<100;i++){                                //wait 10s
           if (RFID.substring(1) == "04 5D 53 6A 5E 43 80"){
           i=0;
           break;
           }
           else{
            delay(50);                                        //inside 10s loop
            ReadOn();                                        //read RFID
           }
         }
          ReadSensor();                                                 //read
sensors
          if (force < 500 && isObstacle ==
HIGH){                                            //if no one
          digitalWrite(LED_G, LOW);
//green light goes down
          }
          else ReadSensor();
//readsensors
         }
         else {
```

```
      ReadSensor();                                          //read RFID
     }
    }
    digitalWrite(LED_R, LOW);
//turn off red light
      if (RFID.substring(1) == "04 5D 53 6A 5E 43 80") //change here the UID of the
card/cards that you want to give access
   {
    Serial.println("Authorized access");
    Serial.println();   //space
    digitalWrite(LED_G, HIGH);
//turn on green light
    delay(2000);                                    //wait 2s
    }
   }
  }



  void ReadOn(){
   // Look for new cards
   if ( ! rfid.PICC_IsNewCardPresent())
   return;

   // Select one of the cards
   if ( ! rfid.PICC_ReadCardSerial())
   return;

   //Show UID on serial monitor
   Serial.print("UID tag :");
   String content= "";
   byte letter;
   for (byte i = 0; i < rfid.uid.size; i++)
```

```
    {
      Serial.print(rfid.uid.uidByte[i] < 0x10 ? " 0" : " ");
      Serial.print(rfid.uid.uidByte[i], HEX);
      content.concat(String(rfid.uid.uidByte[i] < 0x10 ? " 0" : " "));
      content.concat(String(rfid.uid.uidByte[i], HEX));
    }
    Serial.println();
    Serial.print("Message : ");
    content.toUpperCase();
    RFID = content;
   }

   void ReadSensor(){
       force = analogRead(pressurePin);
     isObstacle = digitalRead(isObstaclePin);
}
```

5.2. Appendix 5.2 table of FSR resistance against force

	Force in Nm	Resistance in ohms
No mass	0	Infinite
20g mass	0.2	30k
50g mass	0.5	10k
100g mass	1	6k
230g mass	2.3	3.1k
500g mass	5	1.8k
1000g mass	10	1k
2000g mass	20	700
4000g mass	40	450
7000g mass	70	300
10000g mass	100	250

5.3. Appendix 5.3 pin layout of FC-51 IR proximity sensors and Leonardo CAN BUS shield

	FC-51 IR proximity sensors	Leonardo CAN BUS shield
Power	Pin Vcc	5V
GND	Pin GND	GND
Signal output from sensor	Pin Out	D5