Self-Drving Car Project Report

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***Abstract*—The project focuses on constructing a self-driving car which can follow a motorway and avoid head-on collisions. This is achieved by using object reflectance sensors and an ultrasonic distance sensor. The microprocessor used for the prototype is PIC18F87J50 which is programmed in Assembly language. The communication between a ”driver” and the vehicle is performed by a speech recognition device. The car starts operating in a Standby mode until a voice command is detected.**

I. Introduction

THE technological advancements in the car industry allowed the self-driving cars to be a tangible reality leading to a 160% increase in demand for autonomous vehicles over the past two years [1]. One of the biggest market shares is held by Tesla [2] which is the first car company to introduce the most autonomous cars to the public [3].

Self-driving cars not only grant the drivers a lower cognitive load, but also significantly increase the safety. Based on the National Highway Traffic Administration (NHTSA) and Federal Highway Administration (FHWA) statistics Tesla investigated the miles driven before an accident in Tesla automated vehicles. The results show that automated cars have driven 12 times more miles than the United States average (see Appendix A) [4]. Safety and comfort are the reasons why autonomous vehicles are the future of the transportation [5], therefore we have decided to construct a self-driving car as our Microprocessors Project.

Tesla's Model Y has several Autopilot features such as *Traffic-Aware Cruise Control* and *Autosteer* [6]. Traffic-Aware Cruise Control adjusts the speed of the vehicle according to the maximum speed set by the driver and the detected time-based distance to a car in the front. Autosteer allows the car to stay in its lane by sensing the lane markings. These features are enabled with the use of six cameras, ultrasonic sensors, and a radar [6]. We mimic these features in our self-driving car by using two object reflectance sensors and an ultrasonic sensor. They allow the car to self-drive under required conditions which makes the automation - Level 3 (see Appendix B) according to the SAE Levels of Automation [7].

The prototype can follow a black road with white edges and detect any obstacles in the front. There are certain conditions needed for the car to operate including the reflectance values of the road and edges, and a threshold distance to the nearest front object. If the threshold distance is reached, the car stops moving and goes into a Standby mode until the path is cleared. The communication between the ”driver” and the car is enabled by a speech recognition device. Once the driver says ”Autopilot” the vehicle starts self-driving. The analysis of the data from the sensors and the voice detecting device, as well as the control of the motors are performed by the PIC18F87J50 microprocessor which is programmed in Assembly language.

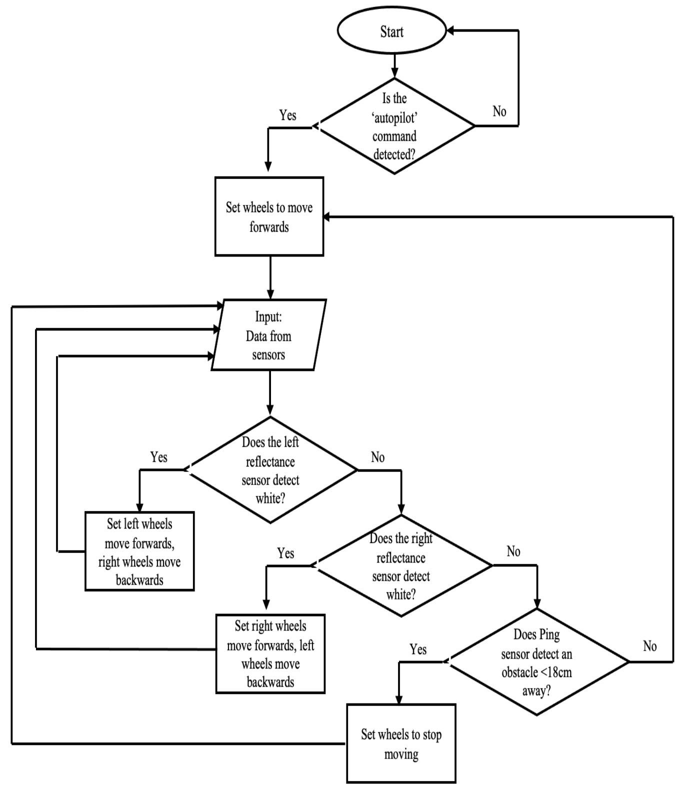

Fig. 1. A software flowchart demonstrating the operation of the microprocessor mounted onto the prototype. The software loops indefinitely which enables the car to self-drive continuously. The software also requires values for conditions which have to determined prior to operation of the car.

II. High Level Design

The car initially starts in the Standby mode which disables the self-driving features and motors. The ”driver” can enable them by saying ”Autopilot” into the microphone of the voice-detecting device.

We imitate the motorway and the lane markings by using a black paper glued onto a white cardboard. The reflectance of the surface depends on the colour, hence the output voltage of the object reflectance sensors changes. The car inputs the signal from these sensors and compares them to the predetermined values stored in the microprocessor. If one of the sensors detects a white surface, the vehicle turns until it is back on the motorway.

The ultrasonic distance sensor is used to determine the distance to the nearest front object. The threshold distance value has to be predetermined too and stored in the microprocessor. The car stops moving forward if the threshold is crossed. A software flowchart of the car operations is shown in Figure 1.

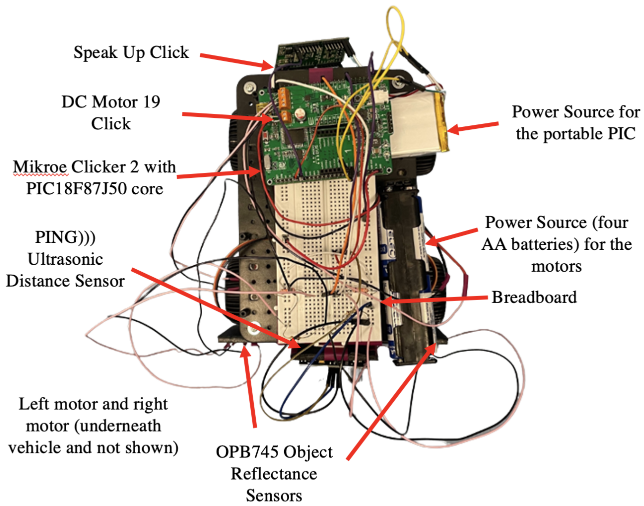

Fig. 2. The final prototype. The red arrows indicate devices used for the project.

III. Hardware Design

The prototype's operation is controlled by a PIC18F87J50 microprocessor which is mounted onto Clicker 2 for PIC18FJ. It is powered by a Li-Polymer battery 2000mAh. The microprocessor also provides a voltage of 3.3 V which is used to power the sensors. The devices connected to PIC18 are the following: SpeakUp2 Click, DC Motor 19 Click, two OPB745 object reflectance sensors, and an ultrasonic distance sensor PING))).

The motorway track has the total length of around 200 cm and the width of the lane is 19.5 cm. The shape of the track is elliptical thus allowing the prototype to be tested for a forward motion and turns.

The basis of the prototype is a 4tronix Initio 4WD kit consisting of a built chassis, speed sensors, 4 moulded wheels connected to two motors, and a top plate. We attached a breadboard to the top plate which is used to connect all sensors to the microprocessor. The finished car is shown in Figure 2.

The complete electric circuit is shown in Figure 3. All device pins in use which are connected to the microprocessor are shown in Appendix C.

TABLE I
Modes of Motors and the Corresponding Input Values

Mode	STBY	IN1	IN2	IN3	IN4
Forward	H	H	L	L	H
Reverse	H	L	H	H	L
Turn Left	H	L	H	L	H
Turn Right	H	H	L	H	L
Stop	H	L	L	L	L
Standby	L	-	-	-	-

A. SpeakUp 2 Click

The voice detecting device is SpeakUp 2 Click which is powered by 3.3 V output from the microprocessor. The click consists of a FTDI FT900 chip, a microphone, signal LEDs, and push buttons. The voice command is inputted via an on-board microphone. The analysis of the data is performed by the FTDI FT900 chip. It has 12 output pins in total. In this project, 7 are used. Each output pin corresponds to a specific voice command. Once the command is detected, the respective output pin is set high. It has two on-board indicator LEDs. The amber LED lights up when the click is ready to record or listen. The red LED lights up when the board is operating after detecting a voice command or the board is rebooting. Prior to use the click board has to be programmed in SpeakUp 2 Click Configuration software.

B. DC Motor 19 Click

The motors are controlled by the DC Motor 19 Click. It takes five inputs from the microprocessor and has four outputs which are connected to two motors. It requires an external power source to operate the motors which is delivered by the four AA batteries supplying 6 V. The DC Motor 19 Click uses a dual H bridge driver (TC78H653FTG) powered by the microprocessor. It also has two on board switches for Large-Current Drive Mode Selection and Motor Mode Selection. The DC Motor 19 Click is mounted onto Mikro Bus 2. The two on-board switches are connected to pins MODE and LARGE. Both switches are pushed low. There are 5 input pins: STBY, IN1, IN2, IN3, and IN4 which are connected to RD1, RA1, RD0, RG0, and RB2 pins on the microprocessor, respectively. It has four output pins which are connected to two DC motors. Depending on the inputs, the output pins are either set high or low thus turning the motors on/off and switching the direction of rotation. Table I shows input values which correspond to different modes of motion. ”H” stands for set high and ”L” stands for set low.

C. OPB745

Two object reflectance sensors (OPB745) are attached to the sides of the car and are powered by PIC18. They require 1 kΩ and 10 kΩ resistors. The object reflectance sensors operate by measuring the reflectance of the surface. The reflectance value is determined by measuring the outputted voltage magnitude. The sensor has four connection pins as shown in Figure 3. The minimum distance for measurements is 2.04 mm [8] and the sensors are placed 2.5 mm above the surface.

D. PING)))

An ultrasonic distance sensor PING))) is used for obstacle detection and is powered by the microprocessor. It has three pins in total and the SIG pin is used for measurements. The microprocessor's RE3 pin sends a 5 µs signal. The signal triggers the sensor and it sends a short ultrasonic burst which is then reflected off an object it faces. The PING))) detects the reflected pulse and its width corresponds to the distance to the object.

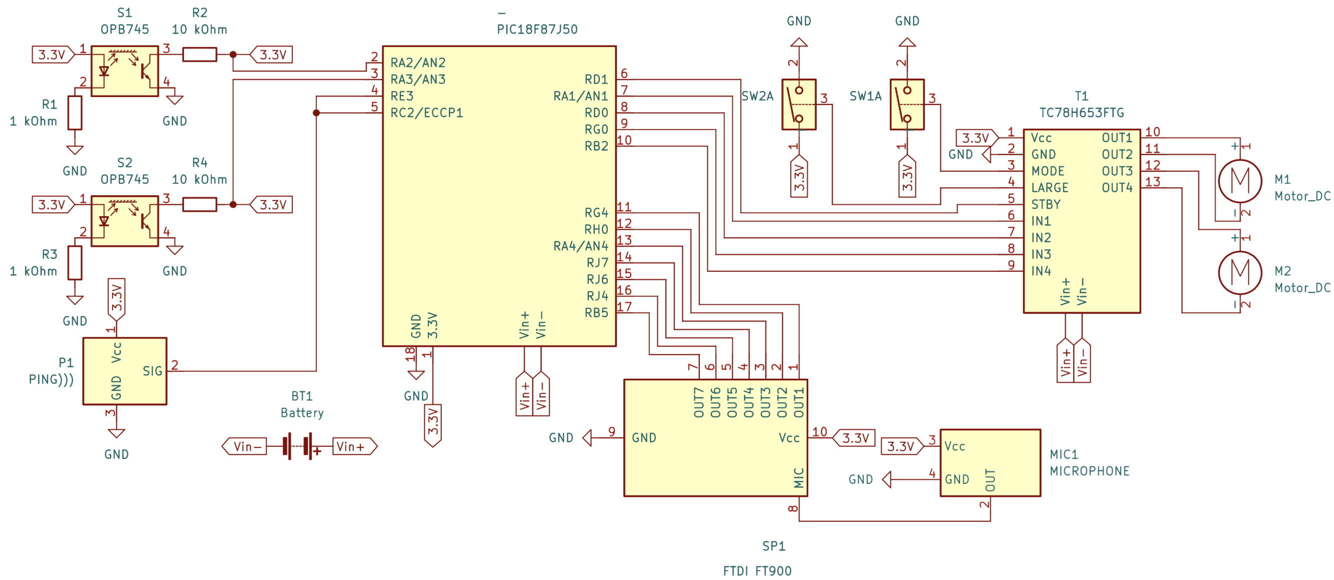

Fig. 3. The electric circuit schematic done in KiCAD application. Only the device pins in use are showed. The microprocessor PIC18F87J50 is used to analyse the data from the sensors and control the outputs. It is connected to the following devices: two OPB745 object reflectance sensors, an ultrasonic distance sensor PING))), a dual H bridge driver TC78H653FTG for motor control, FTDI FT900 chip for voice commands detection, and a battery. OPB745 has four connection pins, two of which are also connected to 1 kΩ and 10 kΩ resistors. The output is taken from pin 3 which is connected to RA2 pin of the microprocessor. PING))) has three connection pins. The output is taken from the SIG pin which is connected to RE3 and RC2 pins of the microprocessor. TC78H653FTG has 13 connection pins. The output is taken from OUT1, OUT2, OUT3, and OUT4 pins. These pins are also connected to two DC motors. FTDI FT900 has 9 connection pins seven of which are output pins. Pin MIC is connected to a microphone for the voice input.

IV. Software Design

The microprocessor is programmed in Assembly language. The project utilises the internal Analogue to Digital Converter (ADC) and a Capture, Compare and Pulse-Width Modulation mode (CCP). The different components of the self-driving car are programmed in different modules. The top-down modular design is shown in Figure 4. The Main module consists of: the setup of the motors and sensors, the speech recognition routine, the interrupt routine, and routine calls from the other modules which enable the sensors. The complete code can be accessed at https://github.com/eyesulu/Self-driving-car-.

A. Speech Recognition

The SpeakUp 2 Click is programmed in SpeakUp 2 Click Configuration software. The software allows several voice commands to be recorded. Each command is configured to set the related IO pin high. We have recorded 7 commands in total. One of them is the ”Autopilot” which enables the self-driving features of the car. The other six commands are related to the manual control of the car by setting the motors to move forwards, backwards, turn, stop, and standby. These commands are not used in the prototype (see Results and Performance).

The FTDI FT900 chip inputs the data from the microphone and compares it to the prerecorded commands. Once the comparison is done and the ”Autopilot” command is recognised the RG4 bit is set. This allows the code to branch to the self-driving routine. The Standby mode is switched off and the car starts following the road.

B. Motors Module

This module consists of 8 subroutines. The setup includes clearing specific TRIS bits thus making pins RD1, RA1, RD0, RG0, and RB2 output pins. The next subroutines include making these pins high or low depending on the mode of the desired motion. Table I show which pins need to be set or cleared in order to achieve that. The car can move forwards, backwards, turn left and right, and stop. The right (left) turns are performed by setting left (right) wheels to move forwards and right (left) wheels to move backwards.

C. Object Reflectance Sensors Module

The Reflective Sensors module consists of two ADC Setups, the ADC Read, and the Compare routines. The prototype uses two OPB745 sensors which output analogue signals. They are converted to digital by the internal ADC.

The left sensor is connected to RA2 pin which is also the AN2 pin. In the first ADC setup this pin is configured as the analogue channel. The ADC module is enabled, the voltage references are AVss and AVdd. The converter uses 16 Tad acquisition time, the internal conversion clock and gives a right justified result. The ADC Read routine enables the conversion and checks whether it is finished. When it finishes, the results stored in ADRESL and ADRESH registers are copied into the designated addresses in the access memory. The same method is used for the right sensor, however the analogue channel is changed to RA3 or AN3.

The Compare routine compares the result with the conditions, and if needed call the Turn Right or Turn Left subroutines. The measured voltage amplitudes for the black and white surfaces are 2.75 ± 0.1 V and 0.77 ± 0.05 V, respectively. When converted to digital, these voltages correspond to 02h and 01h. These values are the conditions that are compared with the ADRESH registers for both sensors.

D. CCP Ping Module

This module includes: CCP setup, CCP reset, and the interrupt routine. In this project CCP1 module is used to operate the PING))). The associated pin for CCP1 is RC2 which is set as an input pin. CCP1 is configured to operate in Capture mode and cause an interrupt every falling edge. It uses Timer 1 to capture the count when the interrupt occurrs. For the purposes of this project the interrupt priority (IPEN) is disabled. The reflected signal from PING))) is sent to RC2. When the signal goes to low, the CCP module causes an interrupt and the program counter jumps to 0008h address. At this address the code goes to the interrupt routine. First, it checks whether the interrupt is caused by the CCP1 module by checking the associated interrupt flag bit (CCP1IF). If the interrupt occurred because of CCP1, the module's count (CCPR1L and CCPR1H registers) are copied into the designated addresses in the access memory. After the interrupt, the CCP1 and Timer 1 modules are completely disabled and all interrupt flags are cleared.

E. Ping Module

The Ping module focuses on operating the ultrasonic distance sensor. The module has following subroutines: sending a pulse to PING))), receiving the reflected pulse from PING))) and comparing the width of the reflected pulse with the threshold distance value.

The pulse is sent by setting the RE3 pin's TRIS bit low. Then the pin is set high and after 5 µs it is cleared. The CCP1 module is used to determine the reflected pulse's width. The reflected pulse is received by setting RE3 pin's TRIS bit high and immediately after the CCP1 module is enabled. There is a 30 ms delay to wait for the reflected pulse to be detected. After the CCP1 interrupt, the timer count is compared to the threshold distance value. In this project the value is 06h corresponding to 18 ± 1 cm distance and it is compared with the CCPR1H register. If the threshold is reached, the module calls the Standby routine from the Motors module.

F. Delay Module

This module has a 10 ms delay routine which is called from the Main module when waiting for the reflected pulse to be detected.

V. Results and Performance

In the Project Proposal we outlined several assessment criteria to determine the quality of the prototype including the accuracy of the autosteer and the obstacle detection features. Several additional tests were performed to determine the speed of the vehicle and the accuracy of the speech recognition device.

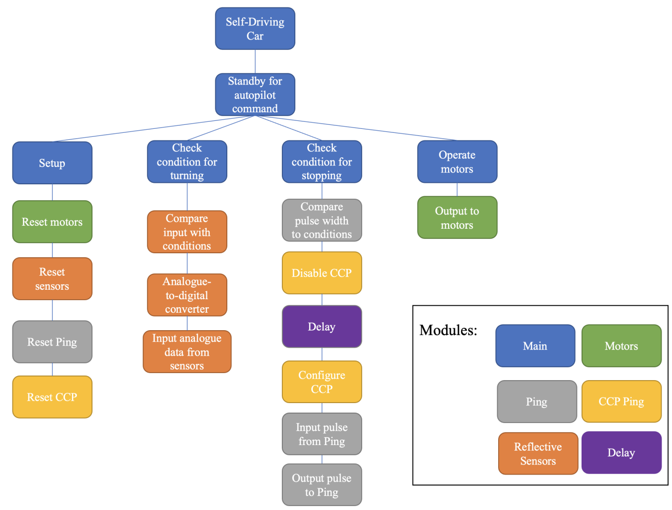

Fig. 4. The top-down modular design of the self-driving car. Each colour corresponds to a separate module. Each module is related to an external component. The complete code can be found at https://github.com/eyesulu/Self-driving-car-.

A. Accuracy of Autosteer

This was tested by letting the prototype self-drive on the track multiple times and counting the successfully completed loops. The track is elliptical hence we had to alternate the car to drive clockwise and anticlockwise. The success rate was measured to be 87%. After investigating the failed runs it was concluded that the main two causes are the speed of the car and the variations in the lane width along the track.

In the majority of the failed runs the car was observed to drive faster than the time needed for the microprocessor to analyse the data from the sensors. In these cases the car did not turn sufficiently thus causing the vehicle to drive off the track and get stuck on the white cardboard. This issue can be resolved by lowering the speed of the car. The prototype uses four AA batteries supplying 6 V. During tests, the number of batteries was reduced to three supplying 4.5 V. The success rate increased to 100%.

The variations in the width of the track were observed to cause the car to turn left and right constantly on a straight path due to both sensors detecting a white surface. The measured width of the road was 19.5 ± 1.5 cm. In the narrower parts of the lane the width was comparable to the dimensions of the car. This was resolved by widening the track thus eliminating any failed runs due to this issue.

The investigation of the autosteer feature also included measurements of the output voltages of the OPB745 sensors in different conditions. We performed the experiments in a well-lit and a dim-lit rooms. Although the magnitude of outputted voltage depended on the brightness of the room, the change in values was insignificant compared to premeasured conditions for a black and a white surfaces. Therefore the variability in brightness did not cause unsuccessful loops.

B. Accuracy of Obstacle Detection

The accuracy was measured by placing different types of obstacles in front of the car and counting the number of successful cases of obstacle detection. The experiments showed that the head-on collision avoidance depended on the dimensions and a material of the obstacles.

The success rate was 100% for obstacles with dimensions bigger than 15 x 10 cm. For smaller obstacles the success rate highly depended on the position of the obstacle relative to the ultrasonic sensor. The obstacle had to directly face the sensor for a successful run.

The threshold distance for stopping the movement was 18 cm. However, due to the time needed to execute the code and change the motors settings the stopping distance was 13.5 ± 1.0 cm.

Most tests were performed by a rectangular sheet of paper. In the latest tests we changed it to a soft "fluffy" material leading to a significant reduction in performance. After observation, we concluded that this type of material caused a diffuse scattering of the ultrasonic pulses [9] thus disallowing the reflected pulse to be detected.

C. Speed

The maximum speed of the wheels was measured to be 0.17 ± 0.02 m/s. The average speed of the car driving around the track was 0.15 ± 0.02 m/s resulting in 13 ± 1 s time needed to complete one loop. For a prototype powered by three AA batteries (4.5 V) the maximum speed was reduced to 0.11 ± 0.01 m/s and the average speed around the loop was 0.09 ± 0.01 m/s.

D. Accuracy of Speech Recognition

The speech recognition success rate highly depended on the background noise and volume of the voice command. In a quiet room the SpeakUp 2 Click turned on the Autopilot features 60% of the time. If the background noise level increased, the voice command was detected only 27% of the time. Moreover, the detection of the command was only observed if it was called by the same person who recorded it.

The device was also programmed to recognise voice commands for a manual control of the car. When testing, it did not detect any commands if the motors were running due to the noise level. Therefore we decided not to include manual control features in the prototype.

VI. Future Improvements

The prototype can be further improved by perfecting the existing and adding advanced features.

In the current version of the car, there is only one speed setting for the motors which is the maximum speed. The speed can be lowered by utilising Pulse-Width-Modulation (PWM) features. Instead of setting the motors' input pins high, we can send pulses configured by a PWM module. The duty cycle of the PWM corresponds to the speed and it can be altered to achieve a desired motion. In cases of obstacle detection the car can decelerate instead of stopping depending on the distance to the obstacle. This method can ensure a smooth movement around a loop.

The SpeakUp 2 Click is a device with the least success rate. It can be improved by creating a more controlled environment for the voice detection. This can be done by connecting a wireless microphone to the microprocessor. This will solve the problem of the noise level dependency and also make the manual commands to be available for execution.

In the Project Proposal we also mentioned adding a feature which allows the car to manoeuvre around the obstacle by itself. This is unavailable for the prototype but it can be added in the future versions. By adding ultrasonic sensors on the sides and the back of the car we can create a routine to let the car drive around an obstacle if it is present for an extended amount of time. However, there are safety issues that must be considered before attempting to create such feature.

VII. Conclusion

In this project we built a car with some Autopilot features. The level of automation is Level 3 [7].

The car is programmed in Assembly language and uses PIC18F87J50 microprocessor to control all the components. We use two object reflectance sensors for the autosteer features. The analysis of the data from the sensors is done by utilising the internal Analogue to Digital Converter. The ultrasonic distance sensor PING))) is used for obstacle detection. It outputs a signal which is analysed by the Capture, Compare, Pulse-Width-Modulation module.

The vehicle can follow a black coloured road with white boundaries imitating a motorway. The self-driving capabilities are triggered by a voice command said by a "driver". The speech recognition requires some improvements to be made to ensure a fully operating device with both Autopilot and manual control modes.

The speed of the prototype depends on the number of batteries used to power the motors. For a four AA battery version the maximum speed reaches 0.17 m/s, while a three AA battery powered car can drive at 0.11 m/s speed. The smoothness of driving can be upgraded by using Pulse-Width-Modulation modules of the microprocessor to control the speed of the wheels.

Overall, the performance of the car proved that the prototype is a quality product with a near 100% success rate of autosteer features.

VIII. Product Specifications

Below are the physical dimensions of the prototype.

TABLE II
Product Specification of a Self-Driving Car

Product name	Self-driving car
Width	18 cm
Length	21 cm
Height	15 cm

Below is the list of all components used:

- PIC18F87J50 microprocessor mounted onto Clicker 2 for PIC18FJ
- A dual H bridge driver TC78H653FTG mounted onto DC Motor 19 Click

- An ultrasonic distance sensor PING)))
- Two object reflectance sensors OPB745
- FTDI FT900 chip mounted onto SpeakUp 2 Click with an on-board microphone
- A Li-Polymer battery 2000mAh to power the microprocessor
- Four AA batteries supplying a total of 6 V to power the motors
- 4tronix Initio 4WD kit as the chassis of the prototype with in-built motors, wheels and a top plate.
- Breadboard for connecting all sensors to the power sources and the microprocessor
- Wires for connection purposes

Below is the results of product performance testing:

TABLE III
PRODUCT TESTING RESULTS

Feature	Success rate
Autosteer	87 - 100%
Obstacle detection	100%
Speech recognition	60%
Maximum speed	0.11 - 0.17 m/s
Stopping distance	13.5 m/s

The prototype's photo from above is shown in Figure 2.

To operate the car first place the vehicle onto a black surface with white boundaries. Turn on the microprocessor and wait for 2-5 s until the amber LED on SpeakUp 2 Click lights up. To turn on the autopilot features say "Autopilot" to the microphone. The car will start driving around the loop until there is an obstacle ahead or the microprocessor is turned off.

APPENDIX A
TESLA VEHICLE SAFETY REPORT

The safety report conducted by Tesla is shown in Figure 5. The report demonstrates the miles driven before an accident of automated Tesla vehicles and the United States average. The statistics are based on NHTSA and FHWA data [4].

APPENDIX B
LEVELS OF AUTOMATION FOR SELF-DRIVING CARS

The levels of automation are shown in Table IV [7]. The SAE levels are used to assess vehicles with Autopilot features.

TABLE IV
THE SAE LEVELS OF AUTOMATION.

Level 0	No automation
Level 1	Semi-automated systems, like cruise control.
Level 2	Semi-automated systems, like steering, speed and braking.
Level 3	Primary driving functions are automated under some conditions.
Level 4	Primary driving functions are automated under most conditions.
Level 5	Primary driving functions are automated under all conditions.

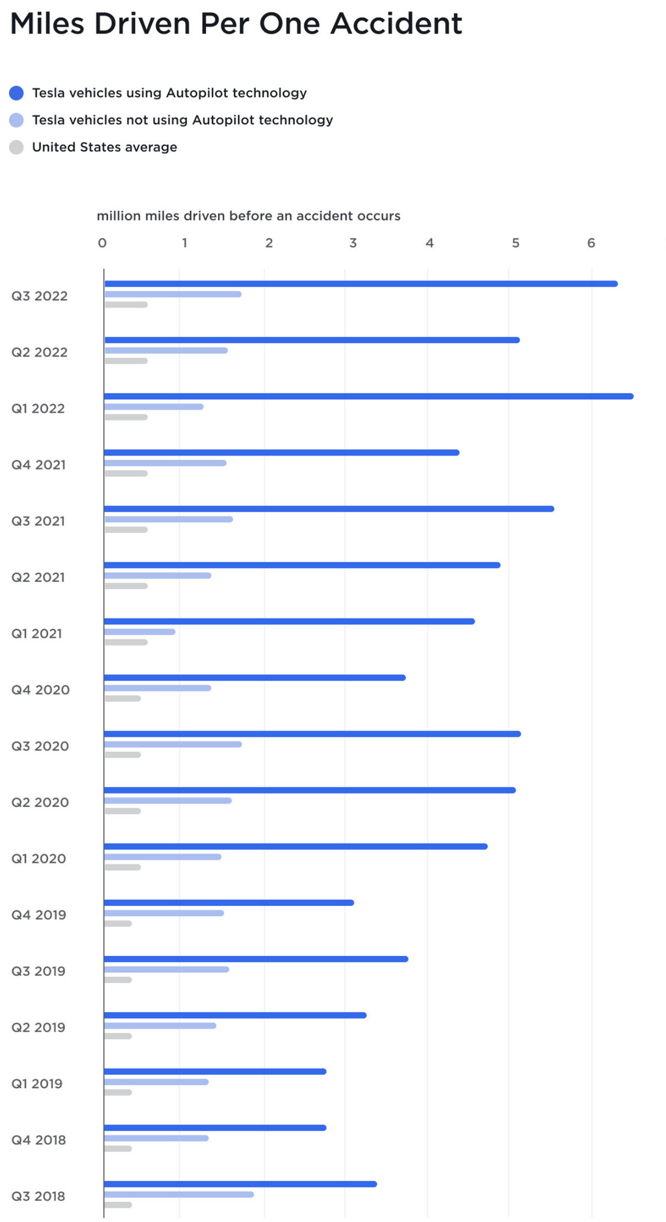

Fig. 5. The safety report conducted by Tesla. The miles driven before an accident for autopiloted Tesla vehicles and a United States average are shown with dark blue and grey labels, respectively.

APPENDIX C
PIN CONNECTIONS

The electric circuit for the prototype is shown in Figure 3. Only pins in use are showed. The components are connected to the microprocessor via pins shown in Table V.

APPENDIX D
FEEDBACK FROM PREVIOUS LAB CYCLES

The experiment done in Cycle 1 was Hall Effect. The marker's summary comments are the following: "Good description of the physics of the Hall measurement - nice graphics Nice presentation of results - looked like it could be in a publication. Good use of literature to compare results.

TABLE V
THE COMPONENTS' PINS AND THE ASSOCIATED PINS ON THE PIC18F87J50 MICROPROCESSOR.

Name of the component	Component's pin	The microprocessors pin
OPB745 (1)	Pin 3	RA2/AN2
OPB745 (2)	Pin 3	RA3/AN3
PING)))	SIG	RE3
		RC2/ECCP1
DC Motor 19 Click	STBY	RD1
	IN1	RA1/AN1
	IN2	RD0
	IN3	RG0
	IN4	RB2
SpeakUp 2 Click	OUT1	RG4

Excellent consideration of errors - exhaustive list and I agree the biggest uncertainty is in the fit function. I really liked that you plotted the residuals vs field No motivation as to why the topic is interesting Got a bit bogged down in technical details. It was fine but not very interesting and not the best use of time. You need to have confidence that the audience will believe you can do textbook physics correctly. Having a big table and leaving a pause for the audience to read it is not the mosty exciting presentation technique. Try to pick out key points."

The Project Proposal done in Cycle 2 had the following feedback: "Nice, comprehensive structure with the lengths of sections well balanced. Diagrams are clear and informative. Some more text describing the figures in the captions would be helpful. Formatting looks clear and professional. Throughout the report, try to keep using a passive and objective voice. Avoid using 'we' where possible and minimise the use of subjective adjectives and adverbs. It would help if more attention were paid to make the style consistent (e.g., if your citing follows a space, if the font size is kept similar, etc.). Proof-read the report to spot issues like the quotation marks. To assess the projected performance, try to quantify the criteria with measurables. For example, instead of asking computation to be 'precise', try to estimate the tolerance."

Later, the assessor admitted that the Imperial College policy encourages the use of active voice.

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