

Design and Development of F1 in Schools Racetrack System: Gate Timing System

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Abstract

This study addressed the problem of improving the gate timing system for F1 in School Competition. The current available gate timing system was not flexible in terms of obtaining result data and was costly. To overcome this challenge, a novel cost-effective timing system was proposed. This system incorporated design enhancements, particularly the introduction of flexible sector gates. These modifications offered users valuable insights into their vehicles' performance. The objective was to propose an innovative design for the F1 in School gate timing system, emphasizing the significance of accurate, cost-effective technology in fostering growth and success in student competitions. This was accomplished by developing two essential components, involving the software and hardware. The software production consisted of components such as Arduino Mega, NodeMCU ESP8266, and Nextion LCD display, while the hardware components were assembled from ultrasonic sensors, LEDs, buttons, and many more. The development of the prototype resulted in a well-functioning gate timing system with the capacity to record results wirelessly through a website and the flexibility required for configuring sector gates. In addition to enhancing user comprehension of their vehicle's performance, the adaptability of the sector gates allowed for more accurate results that could be converted into a plot. This research encouraged the user, mainly a secondary student, to appreciate the impact of science, technology, engineering, arts, and mathematics (STEAM) related fields and the potential for global commercialization value.

1. Introduction

F1 In Schools is a global competition designed to alter students' perceptions of science, technology, engineering, and math (STEM) which is now had include Art and changing the abbreviation to STEAM. By 2004, F1 In Schools had been introduced to nearly every country in the world and was enthusiastically celebrated worldwide [1]. It is launched in the United Kingdom in 2000 as a Design & Technology Project to address the 'Four Key Concepts' of Design & Technology as a Subject: "Creativity, Designing, Making, and Critical Evaluation [2]. With the collaboration of Formula One and other partners, the competition's organizer intended to provide a global platform to promote STEAM education [3].

The aerodynamics behind the aesthetic design of F1 cars presents students with a thrilling challenge as well as an exposure to engineering studies [4]. In this F1 In Schools competition, the vehicles' time is measured based on the total time of student reaction and race times of their car, to determine the fastest time taken and vehicle

performance [5]. To record the time, a gate timing system was used. This is a crucial aspect of this competition where it should be accurately measuring the performance of the cars as they navigate through a series of gates. To ensure fairness and precision, it is essential to develop a reliable and efficient gate timing system.

The problem is that there are less viable gate timing system options to test F1 in Schools cars. As shown in Fig. 1, the current standard package gate timing system available in the market consists of the launcher and a set of integrated gates with electronic systems such as sensors and LED display. However, due to the cost, some of the teams are not afforded to buy, thus the team are constrained to do the testing and validation on the racetrack to evaluate the performance of their F1 In Schools cars. Furthermore, the absence of an adequate number of sector gates in the current gate timing systems available poses a significant challenge and raises questions about the need for ongoing research and development efforts. Besides that, it also presents a limitation in terms of flexibility. The current sector gates are designed to be permanently installed at specific locations, making them immovable and unable to adapt to user preferences.



Fig. 1 (a) F1 in schools gate timing system; (b) Assembly gate timing system on the racetrack [6]

This rigidity has a direct impact on the performance of time tracking, as users cannot conveniently evaluate their vehicles in certain target areas that may be out of reach due to the fixed placement of sector gates.

The current build of gate timing system also limits users who are mostly comprised of school students with limited expertise to manage the system. It should be created as user friendly as possible to ease the user check all the results and performance of the F1 in school car created by them. The current gate timing system is complex and hard for them to use, which can be seen as one of the limitations of the current gate timing system.

To compensate for this problem, a cost-efficient version of the gate timing system will be designed without compromising the current existing product. This is achievable by splitting the project into two sections which are software and hardware sections. Components involved in the project are Arduino Mega, NodeMCU ESP8266, Nextion Display and HC-SR04 Ultrasonic Sensor will be used to create the entire system. The Nextion touchscreen display device is a newer design with little market recognition, and it costs less [7], [8]. However, its main benefits include touchscreen functionality, ease of screen creation, a built-in editor, and transparent and unbiased documentation [8]. For the casing, Polylactic acid or PLA material will be used to increase the sustainable value of the project as it can be recycled and reprinted back [9].

Sector gates insufficiency limits the ability for users to study their F1 in Schools car performance better. By designing a flexible sector gate which can be relocated depending on user preference give user freedom to observe their car performance at certain distance they might want. To increase the user-friendliness of the system, a Nextion Display will be used as it has the feature of touchscreen to interact with the start button, switch modes and can be designed well and easily from its editor. It also has features to show QR code for the system website which stores the result so that user can use to track their performance and compare them. This solves the issue where other gate timing systems are complicated to use for the user.

To sum up, the F1 in Schools competition has been effective in involving youngsters all around the world and promoting STEAM education through its global platform. However, due to the cost, insufficiency of sector gates, and the complexity of the current gate timing, limit the potential to be used by user to evaluate and validate their F1 In Schools car. The system can be enhanced to give a simpler and more accessible tool for students to assess the performance of their F1 in Schools cars by adding user-friendly elements like the Nextion Display and creating a cost-effective version with flexible sector gates.

2. Methodology

The methodology used to perform this project can be divided into two sections which are the method to fabricate the gate timing system prototype and the method to operate the gate timing system. In fabricating the gate timing system, design process of engineering will be used to ensure the capability to complete the prototype within the objective stated to eliminate the problems [10].

2.1 Project Methodology

The process to develop the prototype can be explained by providing a process flow chart of the design process as show in Fig. 2.

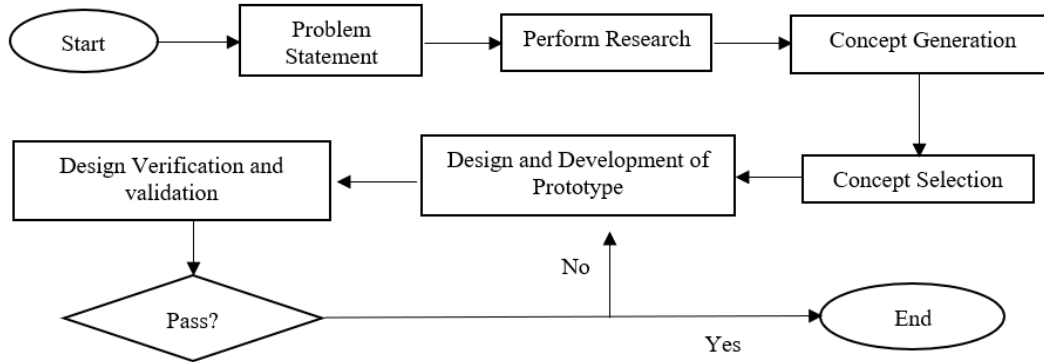


Fig. 2 Process flow chart of product fabrication

Based on the Fig. 2, the process starts with problem statement which is to list the existing problems with current available gate timing system. Then research is performed in terms of analysing the capability and limitation on current gate timing system. In the next process, concept generation is performed based on the research to propose the best solution before final concept selection will be performed [11]. The main aspects that the prototype should be accurate, lightweight, user-friendly, and cost-efficient.

Table 1 shows the list of components that will be used for the project. The selection of this existing component is based on the function, suitability, and benchmarking from various electronic project to succeed this research project. Since this project involved a coding language, it is advised to understand how to code each respective component and how the loop works. To code, software such as Arduino IDE and Nextion Editor is needed. The Arduino IDE is used to create a sketch (a small computer program) that will be uploaded to the Arduino board to provide instruction to the components [12].

Table 1 List of components related with Arduino and pins involved

No.	Component Name	Function	Quantity	No. of pins
1	HC-SR04 Ultrasonic Sensor	To function as a trigger for stopwatch once a car passed through it.	10	4
2	LED	To indicates and signal ready for race and for user to start pressing the trigger.	5	2
3	Toggle Switch	To start the launcher to launch the car.	2	2
4	Nextion LCD Display 3.5" Basic	To display result and to be used to interact with user. Will be used to change mode and start race.	1	4
5	NodeMCU ESP8266	To receive and send result to a webserver for user to check past performance and the graph of the car.	1	3

The Nextion Editor was used to design Human Machine Interface (HMI) GUIs for Nextion HMI devices quickly [13]. Another software that will be used is Visual Studio Code which will provide us with a platform to code the website in the languages of HTML, CSS, and JavaScript. Visual Studio Code is not merely an advanced Notepad with syntax coloring and auto-indentation. Instead, it is a highly effective code-focused development environment designed to facilitate the creation of web, mobile, and cloud applications [14]. Two software

programs will be used for gate fabrication which are CATIA V5 for designing the 3D CAD model and Ultimaker Cura Software V5.3.0 for reading the CATIA STL files and 3D printing the design. CATIA V5 is a three-dimensional CAD/CAM/CAE software developed by Dassault Systems for basic modelling [15]. Cura, a free software developed by Ultimaker, prepares CAD models for printing, and slices them into G-Code from STL or OBJ files as shown in Fig. 3 [16]. To convert a 3D model into a machine-friendly format for 3D printing, any CAM software requires an STL file. Cura converts STL files to the G-Code format [17].

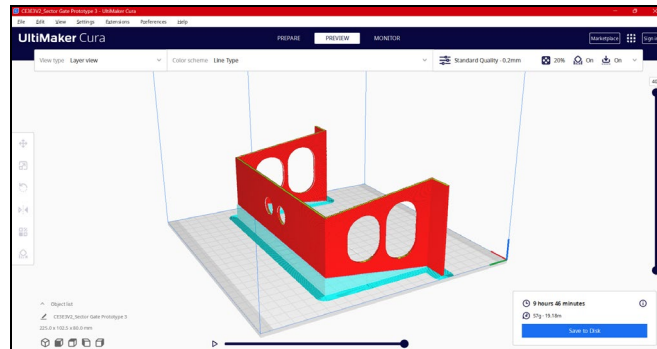


Fig. 3 Sector gate STL file in Cura Ultimaker V5.3.0

To assemble the component wiring, a schematic diagram is planned to ensure the components are assigned to the correct pins. This is important to synchronize with the coding in Arduino, Nextion and NodeMCU ESP8266 so that pin can be assigned in the code [18]. Fig. 4 shows the schematic diagram for the prototype with the connection of all the components.

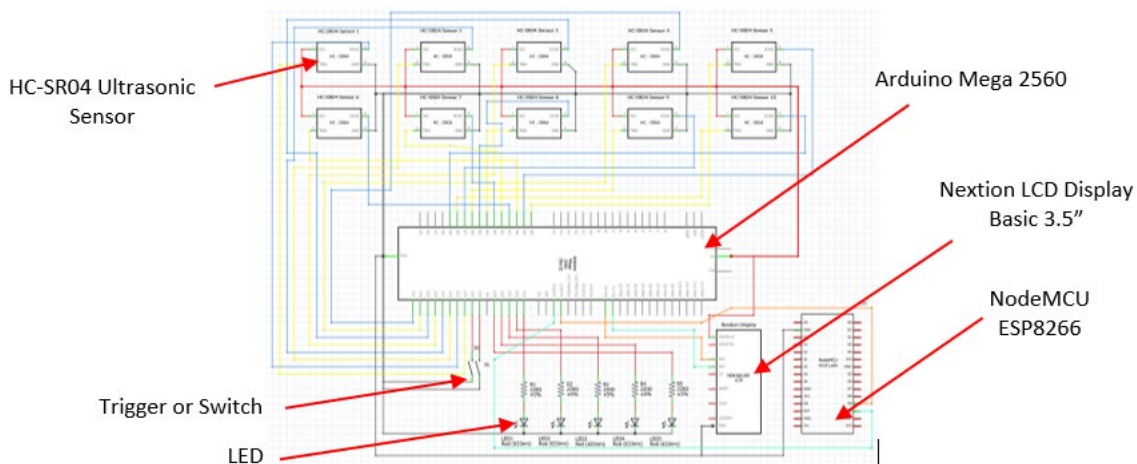


Fig. 4 Schematic diagram of prototype

2.2 System Operation Working Principle

Fig. 5 shows the flowchart to operate the gate timing system. It shows the process flow of the system, the data collection process, and the working principle of the overall gate timing system. Based on the flowchart, once the button is switched on giving the power to the entire system, the Nextion Display will start displaying interface and mode. There are few buttons on the screen that can be interacted with. First by clicking Auto Mode or Reaction Mode button it will switch to another mode. Result Check button allows user to scan a QR Code to the website. While the Start Race button will take user to another page to fill in data of racer for updating the result in the database before starting the countdown and race. Fig. 6 shows the Graphical User Interface (GUI) and the necessary info translated through the Nextion display.

2.3 Resolving Conflicts Between Hardware and Software

During prototype development, challenges often arise, such as difficulties in uploading code due to improper disconnection of RX and TX pins between Microcontrollers. This issue can be resolved by temporarily disconnecting pins for code upload and reconnecting afterward. Additionally, system sluggishness may occur due to incorrect wire connections or coding errors. To address this, prioritize checking wiring connections before analyzing the code, ensuring a systematic resolution of these challenges.

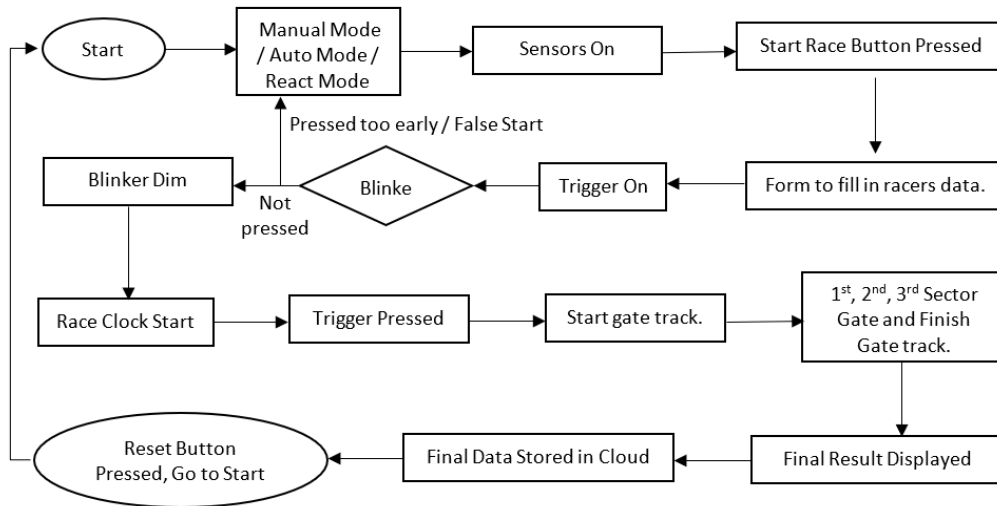


Fig. 5 Process flow chart of operating gate timing system

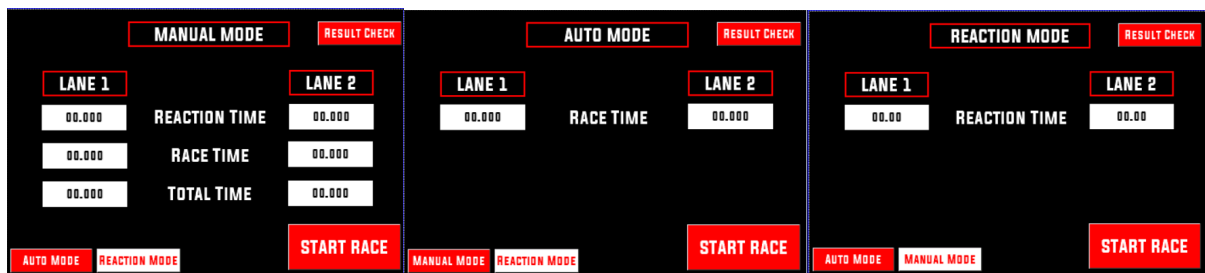


Fig. 6 Auto, manual and reaction mode interface

2.4 Serial Communication Between Arduino, Nextion LCD Display and NodeMCU ESP8266

The serial communication between Arduino, Nextion LCD and NodeMCU ESP8266 is one of the most important aspects in the project [19]. Without having serial communication therefore, many things cannot be achieved such as displaying value and updating the results at website. The result to be achieved here is the ability for these components to communicate with each other. A communication test code is also performed here to check if they can communicate between themselves. Fig. 7 explains how they are expected to work. Blue line indicates serial out or send while red line indicates serial in or receive for Arduino. The flow after NodeMCU ESP8266 receive the Race Data is that the data will be stored and uploaded inside the website. The website should update all the result and classify the data based on the race type and store user own result in My Result section.

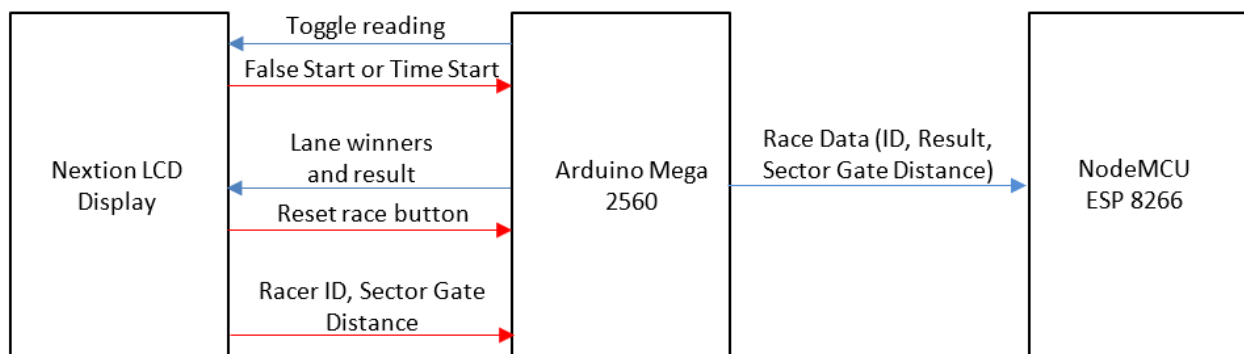


Fig. 7 Serial Communication flow between microcontrollers and display

3. Results and Discussion

3.1 Design and Prototype Build

To begin the design process, after identified the problem, the product design specification (PDS) is developed from the data provided by existing gate timing system such as dimension, overall weight, features, system capability and design architecture of gate timing. The PDS will be used as a guide to develop a conceptual design of a new gate timing system, by sketching approached [20]. Fig. 8 shows a conceptual design of the overall gate timing system. It consists of two mechanical parts which are the gate timing and the display casing. To enhance the existing gate timing system, this concept must be simplified, lightweight, compact, and easy to assemble. These conceptual designs were analyzed through design selection tools with specific criteria to select the final design that will be fabricated.

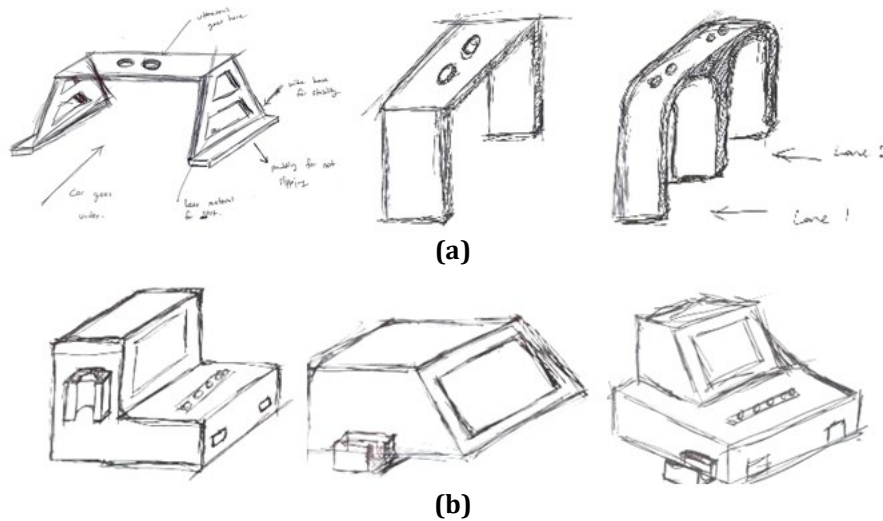


Fig. 8 Conceptual designs of the gate timing system (a) The gate timing; (b) The display casing

To reduce the material and the weight, the gate legs were created with holes. While on the top section of the gate, two circular holes are made to insert the ultrasonic sensor. It is for the purpose of ultrasonic sensor shoot ultrasonic waves before receiving it back. Fig. 9 shows the design process and prototype development of the gate timing system that consists of 3D modeling using engineering design software, 3D printing on the parts, assembly of the product and product testing and validation. As per tested, the build is strong enough to withstand the weight and had shown significant stability for the ultrasonic sensor to emit the ultrasonic wave and receive properly.

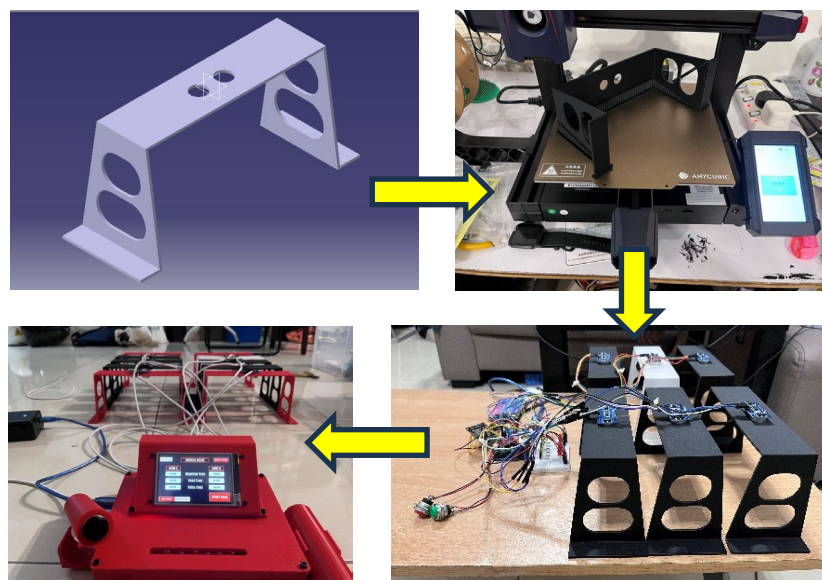


Fig. 9 3D model design and fabrication of the prototype

3.2 Functionality of Components

The functionality of components portrays the ability of the component to work well within its specified function. Basic components such as LED, toggle switch and ultrasonic sensor should perform the task as it was assigned to. To obtain and detect the functionality of each component, each component needs to have a basic code to verify whether the hardware is broken or the code in the main coding might have problems as shown in Fig. 10.

<pre>const int ledPin = 13; void setup() { pinMode(ledPin, OUTPUT); } void loop() { digitalWrite(ledPin, HIGH); Serial.println("LED turned on"); delay(1000); digitalWrite(ledPin, LOW); Serial.println("LED turned off"); delay(1000); }</pre>	<pre>void setup() { pinMode(28, INPUT_PULLUP); pinMode(29, INPUT_PULLUP); } void loop() { int state = digitalRead(28); int state2 = digitalRead(29); if (state == 0) { Serial.print("Trigger 1 Function"); } else if (state2 == 0) { Serial.print("Trigger 2 Function"); } }</pre>
(a)	(b)

Fig. 10 Snippet of test code (a) LED and (b) toggle switch test code

In the basic components the functionality often can be seen by eyes and verified if it's working or broken. If the wiring is correct and it has the right code inside the right loop, it should function well enough. Major components such as Arduino, Nextion LCD display and NodeMCU ESP8266 on the other hand are more straightforward. It is visible to see if it's working by seeing how other components work. Arduino can be checked by trying simple code such as in Fig. 9 or observing the availability of port in Device Manager. While for Nextion display, if it does not turn on or flickering, it is sign that the Nextion might be damaged. To test the NodeMCU ESP8266, the library from the library manager usually provides code for testing purposes in the example section.

Based on the component verification test, the function of the components is working well, thus, the result for the components functionality for this project is considered successful. Components functionality varies by time as it might break when prone to harsh environment or too old which require repair and change of parts to be performed.

3.3 Nextion LCD Display Responsiveness

Since the component is working well, the Nextion LCD display will display a prompt and perform its task to start the race. Nextion has two functions which are to display results and time as well as to act as button and to interact with users [21]. The Nextion is expected to provide more than just the race results; it should also be capable of displaying specific prompts to the user, including messages like the "False Start" warning. If the screen shows the correct message during the logic that it was supposed to show, then the result is successful. For example, if a button for trigger was pressed during the time when the LED is not yet turned off, it should display a message telling a false start happened at which lane. It should also be able to receive lane winners that is compared inside the Arduino.

Fig. 11 shows the Nextion display prompt for different modes and cases, since Nextion is displaying all the prompts correctly as what has been instructed by Arduino and Nextion, therefore it prove that the serial communication between Arduino Mega and Nextion LCD Display work well. The result expected for the Nextion display is achieved.

3.4 Gate Timing System Race Logic

The gate timing system race logic is one of the most important results that should be monitored very closely. It will prove the syntax and logic so then the system is working as per intended. This includes tests such as time display, lane winner display, lane false start, and Did Not Finish (DNF) are correct. It also will display the correct logic by calculating the time taken and compare the time taken on each lane to determine the winner or the fastest F1 In Schools car. Fig. 12 shows a total time (summation of reaction time and race time) on each lane. The QR code were generated after each race completed to enable the user to access the result and to see the F1 In Schools car performance analysis on the web based as shown in Fig. 13.

A series of test was conducted to determine the result is credible for every mode without bug. Each test is conducted with intention to find consistency in the logic and result. The result should show the correct logic where the shortest amount of time is considered as lane winner. While for false start, it should prompt false start for each lane according to button pressed. All the test was conducted by performing six times for each test where

three of them will be biased toward one of the lanes before switching the lanes. This is to ensure that the logic can be identified as correct following the biased lane. All the data from the test performed are in [Table 2](#).



Fig. 11 Multiple display prompts on the Nextion display panel during operational of gate timing system

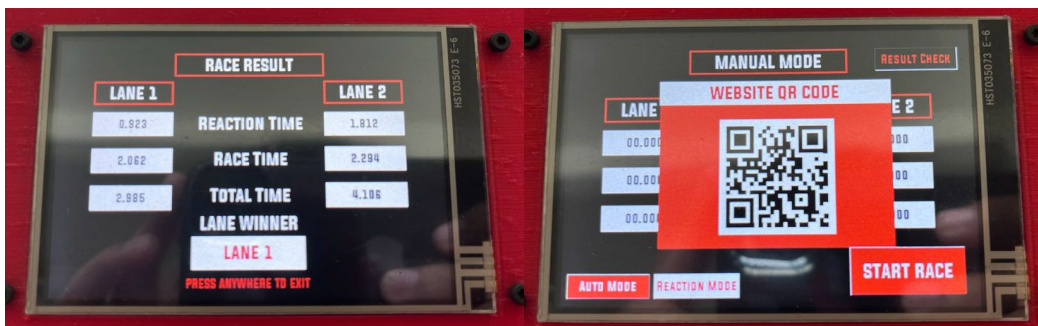


Fig. 12 Results showing total time and winner for each lane and excess to the website to display the result

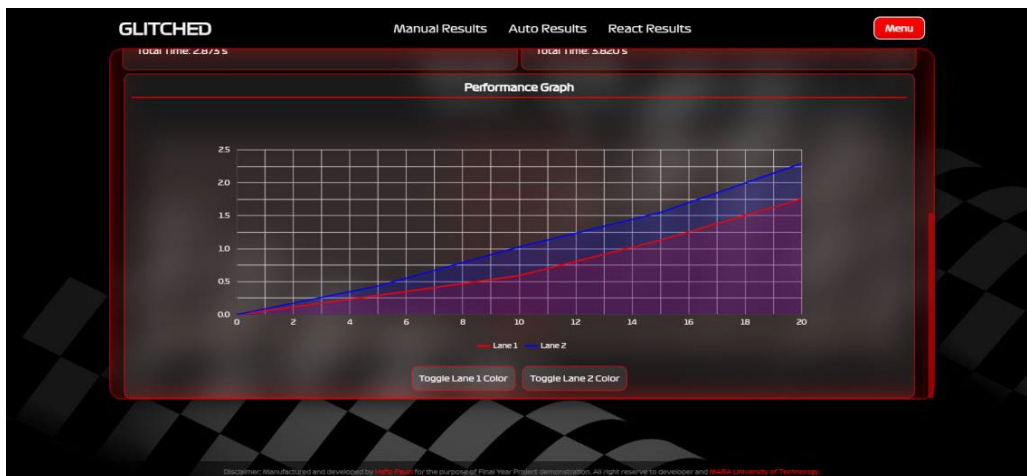


Fig. 13 Statistic performance of the F1 in schools car displayed on the website

Table 2 Manual mode logic test result

Run No.	Controlled Lane	Lane 1 Time	Lane 2 Time	Displayed Winner
1	1	2.221	3.392	Lane 1
2	1	1.675	2.132	Lane 1
3	1	1.982	2.592	Lane 1
4	2	4.022	1.542	Lane 2
5	2	3.627	1.784	Lane 2
6	2	3.299	1.892	Lane 2

Based on [Table 2](#), the controlled lane was set as lane 1 for the first three test and lane 2 for the last three test. All the logic test was listed and compared within each other, and it shows the similar lane number on the Displayed Winner, thus achieve 100% accuracy which proves that the logic is correct. The logic tests are also performed on the auto and reaction mode. Even though manual mode logic test is enough to proof that the other modes logic is correct since they contain the same code structure, there might be unnoticeable bugs that was overlooked. Therefore, the test was also conducted for other modes. The test performed also show 100% accuracy for both other modes as it shows correct logic as shown in [Table 3](#) and [Table 4](#). For the Logic Test of each mode, the test can be seen as credible due to its correct logic based on a series of conducted test. The controlled lane indicates where the lane is intentionally sided with to check whether the lane will win or not.

Table 3 Reaction mode logic test result

Run No.	Controlled Lane	Lane 1 Time	Lane 2 Time	Displayed Winner
1	1	0.266	0.668	Lane 1
2	1	0.349	0.436	Lane 1
3	1	0.291	0.381	Lane 1
4	2	0.272	0.231	Lane 2
5	2	1.438	0.373	Lane 2
6	2	1.549	1.105	Lane 2

Table 4 Auto mode logic test result

Run No.	Controlled Lane	Lane 1 Time	Lane 2 Time	Displayed Winner
1	1	1.718	4.999	Lane 1
2	1	2.188	2.813	Lane 1
3	1	2.812	3.829	Lane 1
4	2	1.787	1.016	Lane 2
5	2	2.031	1.787	Lane 2
6	2	3.282	1.640	Lane 2

As can be seen on the [Table 5](#), the result show significant accuracy on showing the logic in a correct expected result. The false start logic here is to evaluate whether the trigger is capable of prompting and recording if any of the lanes pressed the trigger button too early. Since trigger is only available on Reaction and Manual mode the test is conducted only for both modes. Here another controlled lane is used to control the outcome of the action. The result also shows credible results after six runs of the experiment.

Table 5 False start logic test result

Run No.	Mode Tested	Controlled Lane	False Start Displayed
1	Reaction	Lane 1	Lane 1
2	Reaction	Lane 2	Lane 2
3	Reaction	Lane 1	Lane 1
4	Manual	Lane 2	Lane 2
5	Manual	Lane 1	Lane 1
6	Manual	Lane 2	Lane 2

4. Conclusions

The gate timing system prototype is working successfully as the objective intended which eliminates all the problem stated. Overall, the system enhances the performance from existing gate timing system in term of design simplification, features offered, overall cost, and user experience. The specified coding developed for this system also has been assessed and proved the accuracy of the result. This gate timing system are ready to be used on the real competition for F1 In Schools in future or become an education teaching material to promote STEAM education among school students. However, there are several recommendations that can be offered for the future, which are; 1) to add more gate system to get more accurate result, 2) to use a multithread core microprocessor that can read more Ultrasonic sensors in once (depends to the number of gate systems) and to introduce another platform of website webserver for better data storage and security.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Nurzaki Ikhsan, Muhammad Hafiz Mohd Fauzi; **data collection:** Muhammad Hafiz Mohd Fauzi; **analysis and interpretation of results:** Ramlan Kasiran, Nurzaki Ikhsan; **draft manuscript preparation:** Nurzaki Ikhsan, Mohd Hanif Mat, Muhammad Hafiz Mohd Fauzi. All authors reviewed the results and approved the final version of the manuscript.*

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