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Design and Analysis of A Portable Static Tilt Table Device for RC Car

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ABSTRACT

The purpose of this research study is to Design and analyse a portable static tilt table (STT) device for a remote-control car. This device could assist the understanding of basic vehicle dynamic and vehicle design for the contestant that participated in the international Land Rover 4x4 In School Challenge. The competition requires the contestant to design a good vehicle stability as it will be a main factor to complete the off-road course with the best time limit. This device is capable to measure the distribution weight of each wheel using load sensor and indicates the side angle using an accelerometer sensor for determining the impending rollover angle. The electronic component was all controlled using Arduino Uno as a microcontroller. The system is also capable of wirelessly control using the smartphone apparatus (MIT Apps Inventor) through the Bluetooth module. This project consists of several phases which is a conceptual design process for analysing the proper method to design the project, then embodiment design process which involving the detail analysis for the design and virtual 3D CAD model and generating coding and graphical user interface for output display. Based on finite element analysis, it is found that when the vertical load applied on the selected part of the device, the value of von misses stress is lower than yield strength of the PLA material used. This indicates the design is safe. However, some recommendation has been made to optimize and avoid the "over-design" of the device.

Keywords: *Vehicle Dynamic, Static Tilt Table, Rollover*

Introduction

Remote control car (RC car) can be defined as a scale down vehicle, usually in 1:10 and 1:8 scale from actual size of the vehicle. It is connected wirelessly to the remote control to control the speed and maneuverer of the vehicle. Nowadays, the RC car is not just as a toy nor as a hobby to play, but it can turn into an education module in vehicle design and engineering perspective. Look into that opportunity, the first international Land Rover 4x4 In School challenge was held in 2016 as shown in Figure 1[1]. This competition was held annually and several secondary school in has been representing Malaysia for the International level. This competition requires the contestant to design and engineered the 4x4 RC car based on the regulation provided. Through the competition, the RC car will through the scrutineering process to verify the RC car with the design requirement. There are also several off-road courses that must be completed by the contestant within the time limit [1,3]. Here, the real challenge is how to maneuver and stabilize the RC car without rollover and stuck on the obstacle. Based on collected information and observation, a poor design and lack of the knowledge of some basic vehicle dynamics among the contestants made them difficult to finish the course with the best targeted time limit. Some of RC car were also designed to have larger departure angle and ground clearance as this will avoid the RC car stuck on the obstacle. However, by doing that, the stability of the car will be sacrificed, thus rollover will tend to happen due to the higher center of gravity [12,13]. Because of that, the main objective of this research study is to design and analyse a device called portable Static Tilt Table (STT) that can assist the understanding of basic vehicle dynamic and vehicle stability.

Figure 1: Some action of the international Land Rover 4x4 In School Challenge during the course

The portable STT device offered several features to understand the basic vehicle dynamic. The device is cable to measure the vertical load from each wheel, thus the weight distribution can be identified to stabilize the RC car. Beside, the tilt table are capable to determine the value of maximum side angle that the RC car can hold before the impending rollover happen through the rotational platform (tilt table) [5,6]. From these two output generated, the design of RC car can be modified to be more stable and optimum. An understanding on basic vehicle dynamics were also achievable since the real practice and hands-on were applied during operating the device. In addition, the device also can be operated wirelessly through the bluetooth module and the output parameter can be displayed on the other device such as smartphone.

Methodology

In order to complete the research study, this project was dividing into several phases as followed the phase of the design process [2]. It consists of development of design concept, generating CAD design and analysis, and generating of coding and graphical user interface (GUI) for display.

Conceptual Design

The conceptual design is an initial step to generate the idea of the working principle and basic configuration of the product. To begin, an important input from the potential end-user and other additional information i.e standards, regulation and existing product is required to generate Product Design Specification (PDS) as well as criteria when comes to the design concept selection. The PDS is a preliminary list of specifications that will assist to generate the design concept (Table 1). In this project, a Morphological chart approach was employed to generate multiple design concepts as shown in Figure 2 and Figure 3. All the concepts will be assessed using the Weighted Decision Matrix method to select the best concept for further design analysis and development (Table 2) [2].

Table 1: Selected Product Design Specification to generate design concepts.

No	Criteria	Remarks
1	Main function	To determine weight distribution, CoG and static rollover threshold
2	Load	Capable to hold load up to 2.5kg
3	Weight	Maximum 6kg including the electronics parts
4	Overall dimension (*l x w x h*) mm	400 x 250 x 150
6	Infill	20% to 80%
7	Mechanism	Load cell to measure weight and stepper motor to rotate the main table (80^{o})
8	Joint method	Bolt and nut
9	Tolerance	+- 2mm
10	Features	Foldable, wireless control

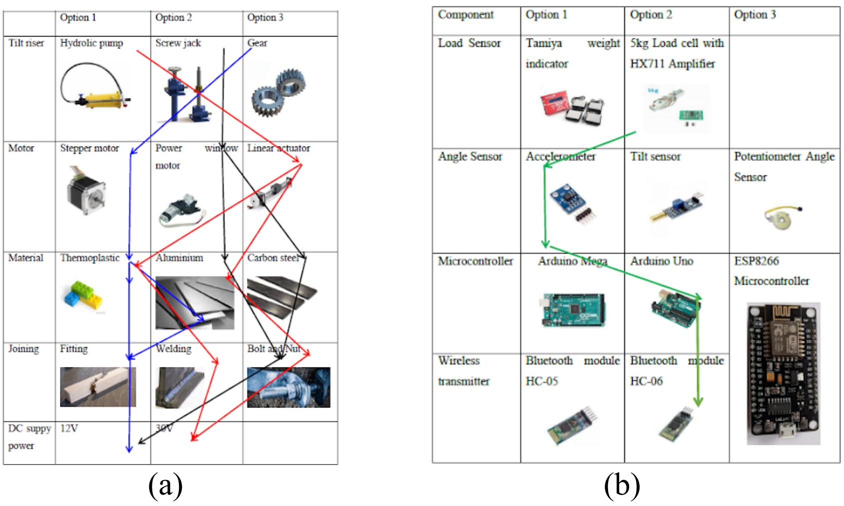
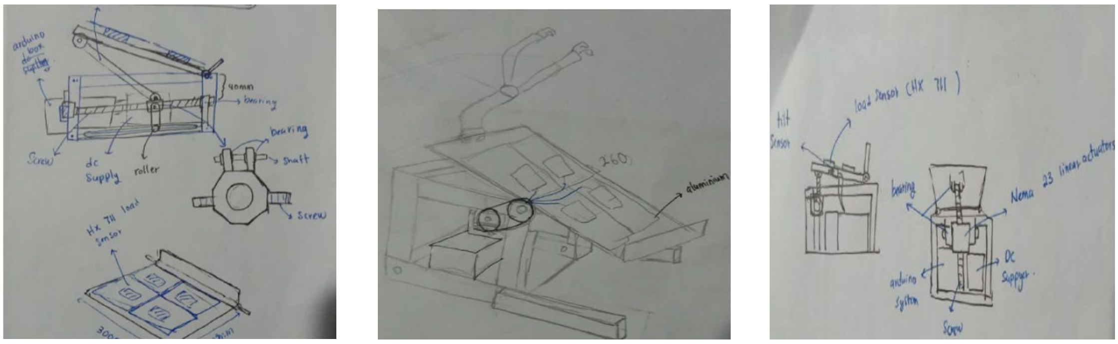


Figure 2: Morphological chart use to generate multiple design concepts. (a) mechanical part, (b) electronic part.



(a) (b) (c)

Figure 3: Three design concepts generated based on Morphological chart.
(a) Concept 1, (b) Concept 3 and (c) Concept 3.

Table 2: Weighted Decision Matrix

		Concept 1			**Concept 2**			**Concept 3**		
Criteria	*Weightage (%)*	*Assessment*	*Score*	*Weighted score*	*Assessment*	*Score*	*Weighted score*	*Assessment*	*Score*	*Weighted score*
Weight	20	Heavy	2	0.4	Lightweight	5	1.0	Lightweight	5	1.0
Joint method	20	Multiple size of bolt and nut	3	0.6	Standard size of bolt and nut	4	0.8	Multiple size of bolt and nut	3	0.6
Complexity	40	High	1	0.4	Easy	4	1.6	Medium	2	0.8
Estimated Cost	10	High	2	0.2	Medium	4	0.4	Medium	4	0.4
Total Weitghted score				**1.6**			**3.8**			**2.8**

Material selection

As the development and manufacturing of most parts of the portable STT device will be used desktop 3D printing machine, thus the suitable material should be studied. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are the most common materials used and typically similar in cost. ABS has superior mechanical properties but is harder to print with compared to PLA [9]. Table 3 below shows the mechanical properties comparison between ABS and PLA.

Table 3: Comparison material between ABS vs PLA

Properties	**ABS**	**PLA**
Tensile Strength	27 MPa	37 MPa
Elongation	3.5 - 50%	6%
Flexural Modulus	2.1 - 7.6 GPa	4 GPa
Density	1.0 - 1.4 g/cm3	1.3 g/cm3
Biodegradable	No	Yes, under the correct conditions

From the table 3, PLA is ideal for 3D prints for the manufacturing process. Due to its lower printing temperature, it is easier to print with and therefore better suited for parts fabrication with fine details while ABS is best suited for applications where strength, ductility, machinability, and thermal stability are required.

Generating CAD and Design Analysis

The CAD software was used to visualize the design shape and configuration of the device into a virtual 3D model. For this study, A design software tool, CATIA V5 was used to generate the 3D model. The same software also was used to study FEA by generating a static load analysis on the selected and crucial part. The load value was defined by the total vertical weight on z-axis of RC Car with an assumption that each wheel of the RC Car carried equal value of the total load through the contact patch area on the portable STT device, in this case is 25N [7]. While, the mounting of the tilt table will be selected as a “clamp” for the analysis. Figure 4 shows an overall design of the STT device generated using CATIA.

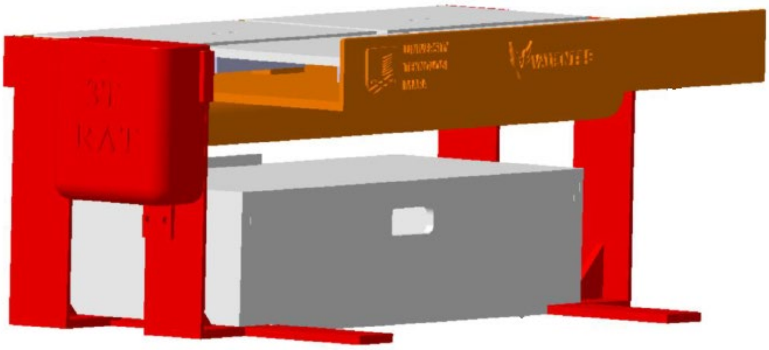


Figure 4: The portable Static Titl Table Device.

Result and discussion

Product Architecture

The product architecture of the device can be separated into two main components, which are; mechanical part and electronic part (as mentioned in the Morphological chart). The mechanical part consists of support structure, tilt table platform, electronic component box cover and base. While the electronic part consists of the circuit board, sensors, capacitors and power supply [8]. Most of the mechanical parts were designed using a design software tool, CATIA to visualize the 3D model and to conduct the strength analysis on the selected component to ensure the design is strong enough to hold the load limit which has been set. Figure 5 shows the exploded view of the portable STT device and its part list.

No	Part Name
1 2	Rear support Leg (left back)
3	Leg (left front)
4	Leg (right back)
5	Leg (left front)
6	Right supporter
7	Left supporter
8	Electronic Box
9	Electronic box lid
10	Tire Platform (left back)
11	Tire Platform (right back)
12	Tire Platform (left front)
13	Tire Platform (right back)
14	Main platform
15	Shaft
16	Gear Cover
17	Servo spur gear
18	Shaft spur gear

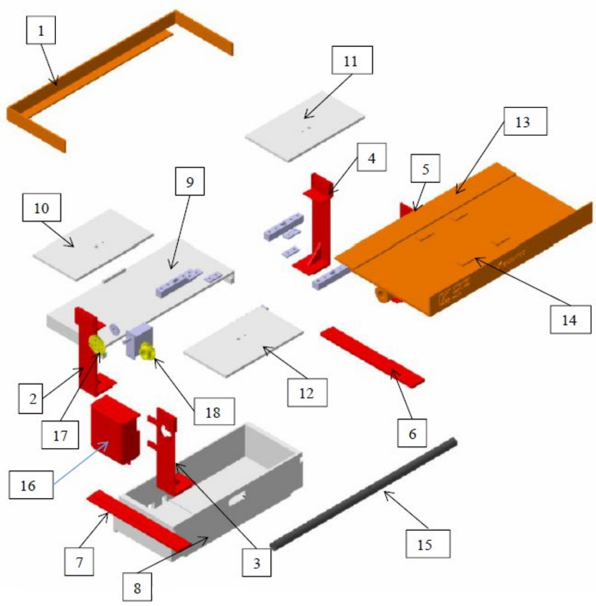


Figure 5: The exploded view of portable Static Tilt Table Device

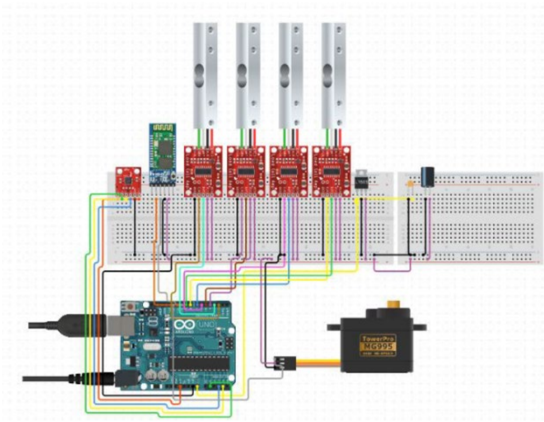


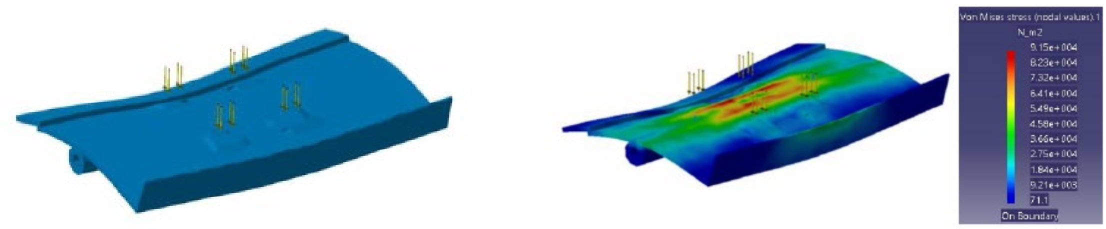
Figure 6: The schematic design of electronic component connection

Table 4: List of the electronic components used.

Component	Quantity	Working Voltage
Load Cell Straight Bar 0 - 5kg Weight Sensor for Arduino IoT	4	2.6V - 5.5V
ADXL335 Accelerometer GY61 Sensor Module	1	2.3V-5V
HX711 Weighing Sensor Dual-Channel 24 Bit Precision Module Arduino	4	2.6-5.5V
HC-06 Bluetooth Module	1	3.6-6V
Arduino Tower Pro 38g SG5010 High Torque Servo Motor	1	4.8-7.2V
12V 2A AC to DC Power Supply Adapter	1	12V
Voltage regulator LM7805	1	5V
Capacitor Ceramic	1	100 microF
Electrolytic Capacitor	1	1microF/50V

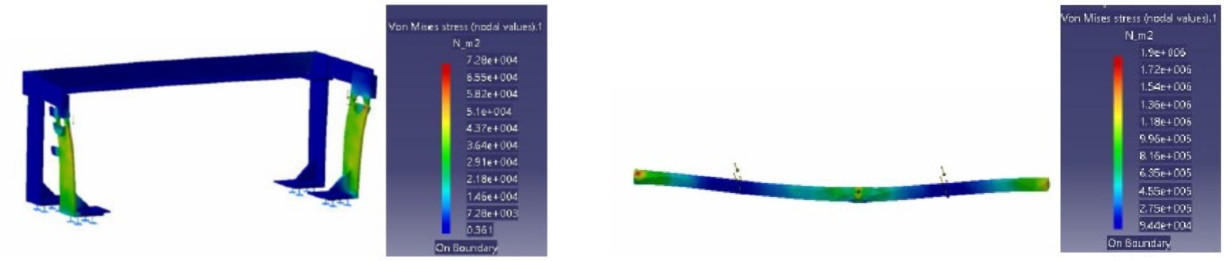
Strength Analysis

FEA of the product is generated on Catia V5 software using the structural generative features. Selected critical part was chosen to be analysed which received the most load. Based on Figure 7 and 8, it is found that the maximum value of Von Misses Stress generated when the 25 N load are 91.5 kPa for the main platform, while 72.8 kPa and 1.9 MPa for the leg structure and shaft respectively. These values are compared with the yield strength of the PLA material which is 26 MPa. It can be said all the part are not fail when the load is applied since the maximum Von Misses Stress is below than yield strength value [11].



(a) (b)

Figure 7: Finite Element Analysis on the platform of portable STT device, (a) deformation (b) Von Misses Stress



(a) (b)

Figure 8: Finite Element Analysis on another selected part of portable STT device, (a) Leg structure (b) Von Shaft.

However, even though the structure is not into failure mode, it is found that the calculated safety factor value is too high from the recommended value. Thus, this overall design can be said as “over design”. A recommended modification can be made to lower the safety factor value by reducing the thickness of the overall design, adjust the percentage of infill during manufacturing process and modified or reduce some part design shape. The material changing could also reduce the safety factor value, but it is not an option as the suitable and best material for 3D printing for this project has been chosen as PLA. The modification of the design will optimize the use of material and can reduce the manufacturing cost as well as make the strength to the weight ratio of the device more reasonable.

MIT Apps Inventor Application

The coding to connect the portable STT device wirelessly has been done using Arduino sketch. This approach are easy to use and simple compared to the other coding language software [8,9]. This coding was created to control the device to operate wirelessly via Bluetooth module (to activate the servo motor to tilt the platform) and to collect the output generated from the sensors. The MIT Apps Inventor application has been widely used to generate the graphical user interface on the smartphone to display all the necessary control functions to operate the device and to display the output [10]. The MIT Apps Inventor is basically divided into 3 parts, connection part, device control, and load displayed part as shown in Figure 9 and Table 5.

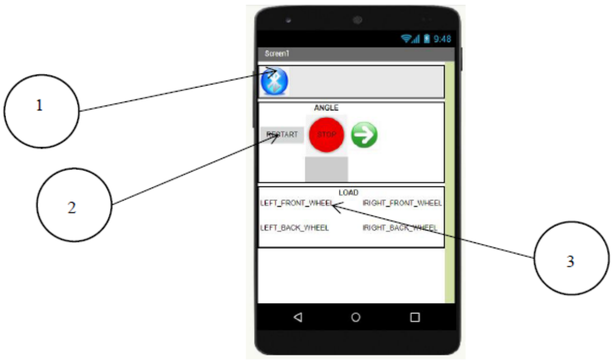


Figure 9: MIT apps inventor on smartphone display

Table 5: The manual instruction of the MIT apps investor

Part	Description
1	**Bluetooth connection:** 1. Press the Bluetooth icon to search connectivity of other devices especially HC-06 of 3T-RAT device 2. The Bluetooth will display red and print NOT CONNECTED if it fails to connect with the device and will print CONNECTED and display green color if it successfully connected with the device.
2	**Device control;** 1. To initiate the 3T-RAT device press the arrow button or continue the angle rollover. 2. To stop or restart the platform off to its initial condition press the red button. 3. The angle will be displayed below the red button based on data received from the accelerometer in the device.
3	**Load display** 1. The weight of each tires platform will be displayed in LF (left front wheel), LB(left back wheel), RF(right front wheel), and RB(right back wheel) based sign on the tires platform.

Conclusion

In conclusion, a design and analysis of the portable STT device has been successfully completed through the research study. The design process is started with generating the product design specification to assist the development of the conceptual design. Three design concepts were developed and assessed using the Weighted Decision Matrix approach to select the best concept. The final concept sketch is transferred to the virtual 3D model using design software with proper tolerance and mechanical parts. It is found that the maximum von misses stress value is below than yield strength of the material as this is a good indicator to ensure the device structure is safe. The Arduino sketch and MIT apps inventor were used to generate coding and GUI on the smartphone to control the device wirelessly through Bluetooth connection. Some recommendations were also suggested to improve the overall design and shape of the device.

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