Development of Cost-effective Endurance Test Rig with Integrated Algorithm for Safety

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Abstract. This paper presents a novel algorithm for controlling a new endurance test rig for the validation of a safety switch of the Cortech HealthCare Ltd shower and commode chair.
The paper outlines the design of the algorithm as well as the main concept and criteria together with the validation and testing methods.
In order to validate the algorithm, a set of preliminary trials is also presented.

Keywords: safety, biomedical devices, smart devices, human-device interaction.

1 Introduction

Over the past century, industrial automation in a form of machines and robotics have been developed in different sizes and shapes for variety of reasons such as to increase efficiency, collect accurate data and to save money. Automated systems allows for improvements that benefits from consistent execution.

One of the aims of this scientific research is to develop an efficient rig which serves the purpose of testing safety switches in a daily life tool for elderly people, namely a toilet chair. This research seeks to overcome the difficulties experienced in previous research, with this being achieved through the repetition and critical analysis of all research on the field of study that the project is based within.

From an historical perspective, the 3rd industrial revolution, which began in 1969, allowed for the automation of the product line, due to developments in the mechanical devices, and more largely in mechatronics and robotics, and the invention of Programmable Logic Controls (PLCs). Today, the 4th revolution is building upon the previous industrial revolution, is also referred to as ‘Industrial 4.0’ [1, 2]. According to Professor Klaus Schwab [3], Founder and Executive Chairman of the World Economic Forum, this 4th industrial revolution is seen to differ to previous industrialization, it is concerned with the fusion of the physical, digital and biological worlds, to the extent which impacts all disciplines, economies and industries. The fourth revolution has also allowed for the questioning of what it means to be human [1]. Industrial

4.0 is characterized as ‘the development of AI, genome editing, 3D printing and autonomous automobiles’ [4].

Out of Industrial 4.0, the development and the emergence of mechatronics and robotics have become apparent in contemporary society. Over the five decades, research has been extensive into the study of intelligent systems; typically, research serves a purpose to overcome specific technological issues in certain area, leading to advances in ‘systems and solutions that will profoundly impact society’ [5]. The justification of the robotic processes is based upon the premise that the process allows for ‘safer operation, savings of materials, and significant savings in terms of man-hour and production line costs’ [6-10].

In this context, we are proposing a novel integrated design which combines mechatronics elements with an intelligent algorithm in order to improve human daily life and specifically, the life of elderly people. Currently Cortech HealthCare Ltd does not have a testing facility that can be used to test the safety mechanism of the shower and commode chair [11]. The aim of this paper is to present the development of a cost-effective method that shall be used to test the safety mechanism on the shower and commode chair.

2 Materials & Methods

This section is used to discuss, present and give a clear understanding of the methods and procedures used into developing the project. The section is divided into multiple parts that are going to be used throughout the project with subsections for each part; hardware, software and implementation section etc. Each section shall have a brief explanation on how every element function and how it shall be used within the project.

The hardware section is divided into controllers, sensors, actuators and any other additional equipment used through out to support the project.

The software section shall have a brief explanation of some of software used to develop the project, software such as Solid works 2018, Visual Studio 2018, Arduino IDE and simple 3D shall have a description and there purpose throughout the project

The last part is the implementation part where some of the above described elements were implemented into the project. Some of the hardware parts such as mechanical parts shall have a description with diagrams on how they were constructed into the final product and other electronics parts shall pin connection table and layout diagram. However, for brevity we have not included them.

2.1 Hardware

2.1.1 Controller

For this project an Arduino Mega 2560 shall be used as a controller. Arduino Mega is a microcontroller board that is constructed on ATMEGA 2560 chip which has a clock speed of 16 MHz. The board operates at 5 V and has 2 power sources, it embeds a USB and a DC power supply which can take an input Voltage between 7 to 12 V recommended but it can run between 6 and 20 V absolute limits. Arduino Mega 2560 has 54 digital I/O pins, 12 of which supports Pulse Width Modulation (PWM). They have internal pull up resistance of between 20 and 50 KOhms that are turn on and off by the software. The board also has 16 Analog pins and 6 interactive pins (Figure 1).

All 54 digital pins on the board operates at 5 V and can send or receive maximum of 40 mA. These pins can be utilized as input or output using commands/functions such as *pinMode()*, *digitalRead()* or *digitalWrite()*, on top of that few pins consists of specialized functions such as serial communication (e.g. I2C, SPI).

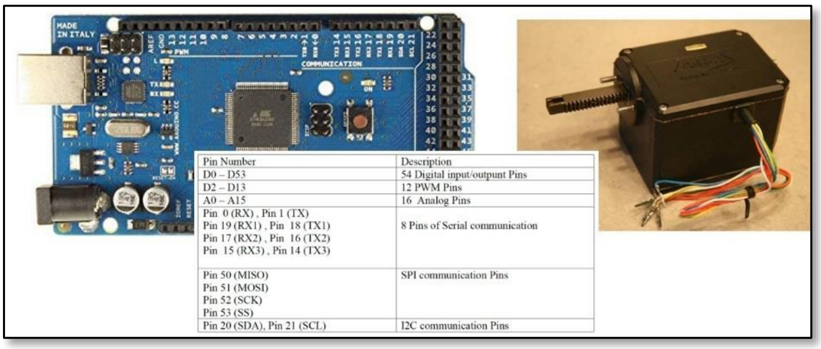
Arduino Mega 2560 has 256 Kilobytes of flash memory and 8 kilobytes of programmed memory as well as 4 kilobytes of EEPROM which can used to read and write with EEPROM library.

2.1.2 Actuator

A.R.A linear actuators are going to be used in this project. This type of actuators weere initially designed to be used as cruise control in agriculture vehicles, these are very inexpensive actuators that have an electrical operated clutch that allows its mechanical arm to be disconnected from the system. These actuators associated with Arduino and L298N boards are ideal for home projects and automotive. This type of actuator also contains a potentiometer that allows the position of the linear arm to be sensed (Figure 1).

The actuator is rated at 12 V, the clutch consumes around 120 mA when engaged while the motor draws around 500 mA while engaged under reasonable heavy load. These actuators are 95 x 72 x 75 mm and have a stroke of 50 mm; the time travel of the arm from one end to the other is around 3 s. they consists of solid aluminum die casting case with high quality gear grain.

Three of these actuators shall be used with the system to measure 3 different points of sensitivity on the proposed test rig.



Pin Number	Description
D0 – D53	54 Digital input/outpunt Pins
D2 – D13	12 PWM Pins
A0 – A15	16 Analog Pins
Pin 0 (RX) , Pin 1 (TX) Pin 19 (RX1) , Pin 18 (TX1) Pin 17 (RX2) , Pin 16 (TX2) Pin 15 (RX3) , Pin 14 (TX3)	8 Pins of Serial communication
Pin 50 (MISO) Pin 51 (MOSI) Pin 52 (SCK) Pin 53 (SS)	SPI communication Pins
Pin 20 (SDA), Pin 21 (SCL)	I2C communication Pins

Figure 1 - The Arduino Mega 2560 set-up and pin configuration (left panel) and the A.R.A. linear actuator (right panel).

2.1.3 Servo Motor Controller

L298N is a dual full bridge rectifier module that can be used to drive speed and direction of a servo or motor, it can also drive any other inductive load relays. L298N board can be driven manually using switches or much more efficiently using micro-controllers such as Arduino. This board has an input voltage value of between 5 to 35 V. This board was selected because it consists of two terminal blocks label as output A and output B as shown on Figure 2 (part 1). One terminal shall be used to drive the actuator while other terminal shall be used to drive to engage or disengage the clutch in the actuator.

The L298N board has three logic inputs for each terminal labelled as enable A, input 1 and input 2 for terminal 1 and the second terminal has the same logic where there is an enable B, input 3 and input 4.

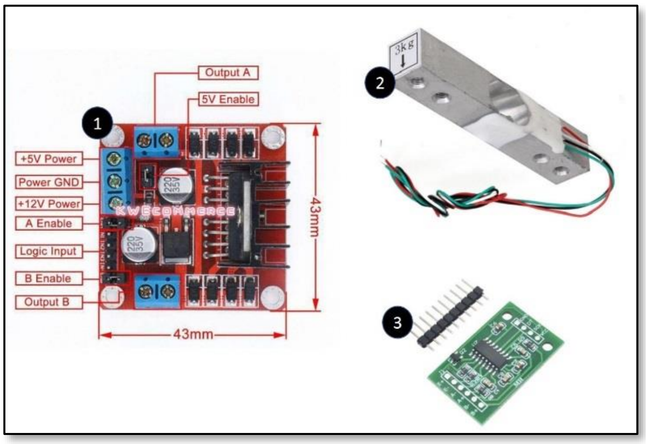


Figure 2 - The L298N motor driver (p[art 1), the XYZ-133 Mini Scale Sensor (part 2) and the HX711 module (part 3)

2.1.4 Load Cell Strain Sensor

Strain gauge sensor are devices that measure a load/strain of an object by measuring its resistance. This is due to its electrical conductance on conductors geometry. Strain gauges are used for many applications such as stress analysis, measuring forces such as pressure, acceleration or displacements etc. when force is applied to a gauge the area around the gauge narrows and its resistance increases, the variation in resistance of the gauge is reasonable linear function of its formation, it transforms mechanical strain to electrical signal.

Load cells usually follows a Wheatstone bridge configuration layout where one quarter bridge load cell is used or two half bridge load cell are used. The electrical signal from these cells are usually within few mV and need to be amplified before being used. The output of the transducer can be scaled to calculate the force applied to the transducer. Sometimes a high resolution ADC, typically 24-bit, can be used directly.

For this project, YZC-133 Mini Scale sensor are going to be used in cooperated with HX711 AD module (Figure 2). These components were selected because they are cheap and easy to buy. YZC-133 Mini Scale sensor is also a full bridge load cell sensor and therefor can be used as a standalone unit.

2.1.5 HX711 Module

HX711 module is 24 high precision Analog to Digital converter. This module has two analog input channels and a programmable gain value of 128 integrated amplifier (Figure 2). The input can be calibrated to provide a bridge voltage of pressure. Here are the main features:

- Two selectable differential input channels
- On-chip
  - active low noise PGA with selectable gain of 32, 64 and 128
  - power supply regulator for load-cell and ADC analog power supply
  - oscillator requiring no external component with optional external crystal
  - power-on-reset
- Simple digital control and serial interface: pin-driven controls, no programming needed
- Selectable 10 or 80 SPS output data rate
- Simultaneous 50 and 60 Hz supply rejection

This module shall be in cooperated with the YZC-133 Mini Scale sensor and it was selected because it has high precision, low cost sampling.

A power supply is also integrated within the hardware system architecture, together with some mechanical components such as a 20x20 series aluminum extrusion bars and a set of corner bracket gussets.

2.2 Software

2.2.1 3D design software

A 3D design software *SolidWorks®* (by Dassault Systèmes) was chosen. SolidWorks is a Computer Aided Design (CAD) modelling software that allows designers to design products and components in 3 dimensions. The procedure behind the software is generally to draft a 2D sketch and use lofting and extrusion to form a solid form. There are multiple advantages in using Solidworks some being, 3D modelling, test collaboration an so on.

The SolidWorks 2018 version was chosen for this product because the operator can build and test majority of the features within the product to ensure that it meets the design and set criteria. This process could be used to save money and time on purchasing and fitting components that would not have been compatible with the design.

Figure 3 - The Cortech HealthCare Shower/Commode Chair

Figure 3 shows the Cortech HealthCare Shower/Commode Chair; a similar design with in cooperated with an endurance test rig shall be used to test the safety mechanism of this product.

Simplify3D is a 3D printing slicer software that is capable of converting 3D drawings into set of printing instruction for a 3D printer. Simpify3D consists of multiple useful feature for 3D printing, feature such as realistic simulation that allows the operator to pre-print simulation of a product and see the exact pattern the 3D printer takes. This a process shows the exact animation that the extruder takes as it lays down the plastic. This simulation features other important information such as sequence, speed that can help identify any errors before wasting time into printing a failed part
Simplify3D was selected for this project because it supports our printer and its simulation feature can be used to identify errors before printing any parts.

2.2.2 IDE Tool

Visual Studio® (by Microsoft Corporation) is an Integrated Development Environment (IDE) tool developed by Microsoft. This tool consists of code editor supporting intelligence as well as code refactoring. It also consists of debugging tools that works as a machine level debugger or source level debugger. Other included features into the tool are the code profiler where it allows form designers for building GUI application, web designers and son on. This IDE tool supports code editing and debugging for multiple programming language such as C/C++, C#, .net, and also supports other script languages such as ruby.NODE.js.

For this project Visual Studio 2018 shall be used to develop a form and Graphical User Interface (GUI) that shall be used to send and receive signal from a controller via serial and also will be used to monitor the progress of the test. The GUI shall be written and edited in C#.

2.2.3 Arduino IDE

Arduino IDE software is an open source Integrated Development Environment (IDE) that allows users to write a piece of code that is known as sketch and it give them access to upload the code into a microcontroller board such as Arduino in form of HEX file. Arduino IDE is separated into two main parts, the editor and the compiler where former is used to write both C and C++ languages and later is used to compile and upload the sketch into a given Microcontroller.

The text editor on the Arduino IDE consists of three section, library section, setup section and loop section. The library function is at the top of the editor where any component used within the sketch that requires external files need to be added, modules such as HX77 requires an external library to be added before use otherwise the sketch will not compile.

The sketch starts from the top of the first bit of code (generally marked with a curly bracket), namely of the loop function and runs until it reaches the closing bracket and return back to the opening bracket. This process repeats itself until the board is reset, turned off or stated otherwise.

Arduino IDE was selected to program the Arduino board because of its ease of use to write a program and to ultimately upload the written program to the Arduino board. Other software out there such as ATMEL Studio 7 can be used to write and program Arduino boards.

2.2.4 Proteus

Proteus is an electronic software that features schematic capture, Printed Circuit Board (PCB) layout and simulation. Proteus simulation is capable of simulating any circuit that has a microcontroller such as the Arduino in real time, this is done by uploading a hex sketch that can be obtained from software such as Arduino IDE. This feature can be used to check for any errors on the sketch that has been written for the micro-controller.

Proteus shall be used in this project to test the C# GUI software that was written in Visual Studio 2018. This software minimize the need of a physical Arduino and it can therefore be used before building up the rig.

Proteus consists of vast list of build in components and many libraries and sometimes other libraries can be downloaded and added into a component list: for example component such as Arduinos are not pre-loaded into the library and therefore it needs to be downloaded.

2.3 Design, Fabrication and Integration

2.3.1 Design

After some preliminary work, it was decided that it will be a best fit to design a frame/rig that is portable and does not need to be fixed at a specific position and by doing so the test can be set up at any location within the office.

The first step into designing the rig was to decide the configuration of the test and this was decided by inspect the location of the safety switches of the chair and weight in on the advantages and difficulties that might occur throughout the test. Accordingly, it was decided that it would be best fit to design a portable test rig that will fit around the bottom half of the tested chair.

Figure 4 (left panel) shows a mock up design of the rig that was performed with SolidWorks 2: the rig configuration consists of three main A.R.A linear actuators that shall move up and down directly on top of the tested chair according to an optimized intelligent algorithm.

Bellow the actuator there a case that shall hold a sensor that is used to measure the sensitivity of the safety mechanism before being triggered. The sensor case itself contains its own mechanism that was designed *to mimic a functionality of a finger* (Figure 4, right panel).

The mechanism consists of two ram. One at the top and bottom connected together using a spring that is placed in the center between two rams, the main aim to this type of mechanism is to give a sensor and the tested part of the seat a smooth force transaction other than just being hit or push with a solid component.

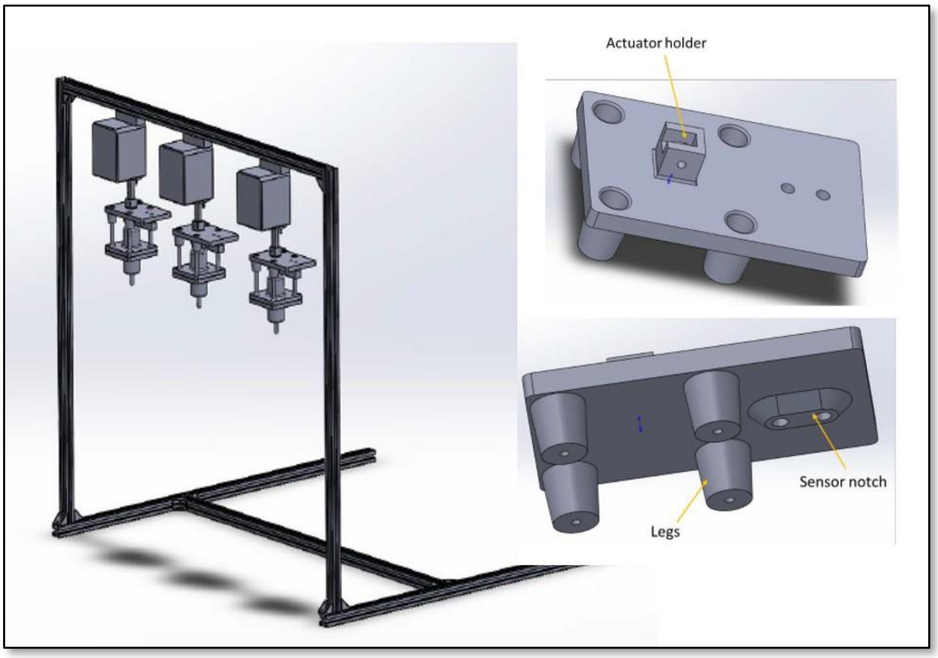


Figure 4 - The Endurance Test Rig Design (left panel) and the details of the Strain Gauge Holder parts (right panel)

2.3.2 Fabrication and Components Integration

To reduce the cost and to keep the rig light weight, the sensor case and some of the connector blocks were manufactured using Raised pro2 plus 3D printer using Acrylonitrile Butadiene Styrene (ABS) filament. There are multiple advantages in using ABS filaments some being that it has a great mechanical properties, it is well known to be tough, strong and durable, this allows it to be tolerant to heat, scratches and chemicals. Another major advantage to using ABS filaments is that the surface of the final product can be processed with acetone or glue parts together, lastly some material can be filed off if needed.

Following the assembly of the frame, 20 x 20 series Aluminium extrusion were linked together using 2028 Corner Bracket for 2020 Aluminium Extrusion at every joint on the designed frame as shown on Figure 5 (left panel). These joints allows the frame to be held together and stop it from falling apart.

The electronic components were also integrated within the rig frame and connected to all the hardware elements (Figure 5, right panel).

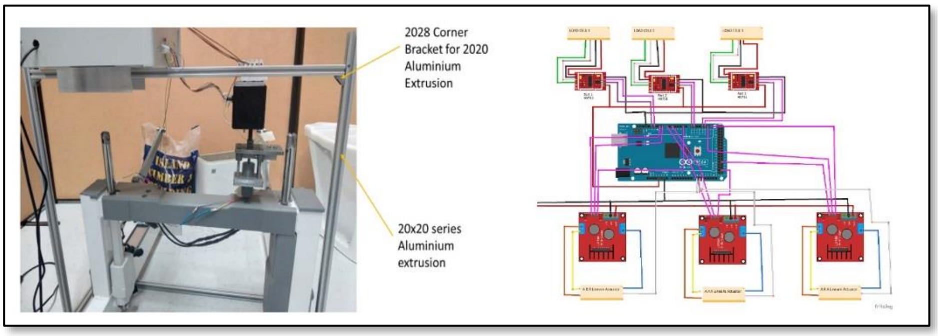


Figure 5 - The manufacturing of the Endurance Test Rig Frame (left panel) and the Integrated Electronics and Circuit Design (right panel)

3 Design of the Algorithm

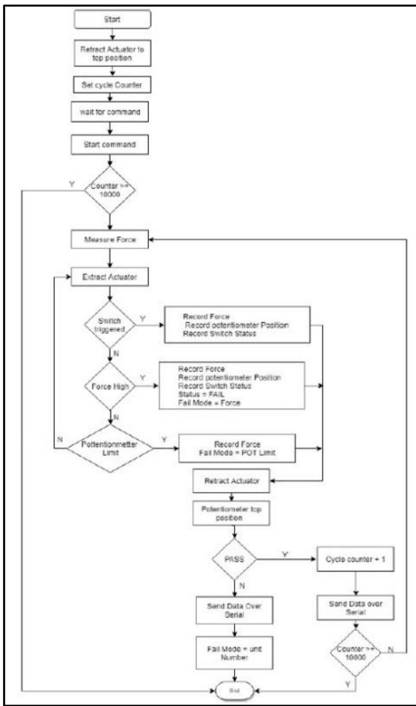
In this section, all the design of the algorithm and written code are reported. This contribution mainly refers to the aforementioned Arduino IDE software.

The overall main rational of the algorithm is based on performing the following sequence of action and check:

- Set up the test and move to start position (cycle start at 0)
- Start test by extracting actuator
- Observe switch
- Observe potentiometer position or limit
- When switch is triggered record potentiometer position and Applied force
- Retract actuator

Accordingly, a flowchart was designed to give graphical representation of the algorithm. Flow chart allows us to easily create an algorithm and also allows us to analyze different processes within an algorithms.

The schematics within the flowchart shown on Figure 6 (left panel) displays the different part of the algorithm, throughout this process we can highlight a certain element and relationship between each section of the algorithms.



Functions		
Functions	Description	Called by
Retract ()	This function retract the actuator to its home position. this is done by first engaging the clutch and turning of signal to motor_e variable and sending signal to motor_r variable with power variable of 255	This function is called when case statement is set to 1 or 2
TestCycle ()	This function was used for checking any new added variable and there function without amending the core program in case 1 or 2	This function is called when colState is set to TestCycle
measure()	Measure function consists of load cell algorithm that is used to read a signal from the load cell	This function is called when extendedState is 1
force()	This function consists of fail measure for the load cell, once a set load has been exceeded the first part of this function will execute	This function is called when extendedState is 1

Figure 6 – The Flow Chart design (left panel) and the Portfolios of the Designed Function (right panel)

In order to perform the task, the software needs to be upload with the proper libraries which link to the used different electronic components. In this context, the HX711.h library allows the Arduino board to communicate with the HX711 module which is connected to the load cell. The library also provides extra function that can be used in cooperation with the module, namely functions such as *.tare( ), .read_average( )*.

Furthermore, a set of declared variables is introduced in order to define the output and input: this allows the Arduino module to determine if to send signal out or it need shall be receiving signal from the connected component.

Finally a set of functions elaborates all the processes used in the Arduino sketch. All the names of these function used and how they are called are shown in Figure 6 (right panel)

4 Results

A set of preliminary tests was performed in order to validate the integrated hardware and software system.

4.1 Calibration

One of the main component in the design is the sensor, as this device is going to be used to measure the amount of load required to trigger the safety system on a shower commode chair and that was one of the aim reasons of designing and constructing the test rig. In this context, one of the main device used in the rig is the YZC-133 Mini Scale sensor. Before placing the sensor on the rig, the sensors had to be test to ensure that it is capable to perform at a reasonable level. For calibration and testing the sensor was placed between two aluminum plates separated using two nuts and secured together using threaded bolts. Then a sequence of loading steps was performed: this was done by loading and unloading a known weight on top of the weighting plate and reading the output shown on the Arduino IDE. From these data a weight of 0.74 kg was placed on the weighing plate. The produced output from this weight was 0.76 kg. The errors on the given output was adjusted to give a correct output by changing the sensor sensitivity using a *set_scale* function.

4.2 Hardware's outcome

From the calibration results, it was noted that the sensor gave out a stable output with error tolerance of +/-2. From these results it was concluded that YZC-133 Mini Scale sensor can be used in the testing rig as it is capable of giving out a stable results throughout the test. The output/tolerance of the sensor can be adjusted and improved by adjusting the units within the aforementioned *set_scale* function.

Following the experiments a set of observations were performed. All the 3D printed parts in this rig were manufactured using ABS filament, this type of material has its own drawbacks.

• *Temperature issues*: the ABS filaments require a good temperature management throughout the process, any errors in the process mint result in the final product to have cracks or split layers in them and will require the part to be reprinted. One of the ways to prevent this issue is to have all enclosures within the printer closed throughout the process.

• *Extruding problem*: extrusion issues can happen at any time and cause major setbacks on printing time. No extrusion and under extrusion can be caused by variety of facts some being that the filament temperatures settings are incorrect, clogged nozzle, loose extruder gears. These issues most of the time causes the part to be reprinted and could delay the part even longer if the issue occurs near the end of printing or at the beginning of and someone failed to spot the issue.

• *Printing time*: printing parts in high quality took a long time and sometime the printer had to be set on print for than 2 hours and when something goes wrong with the printing the entire process had to be stop and start printing again from the start.

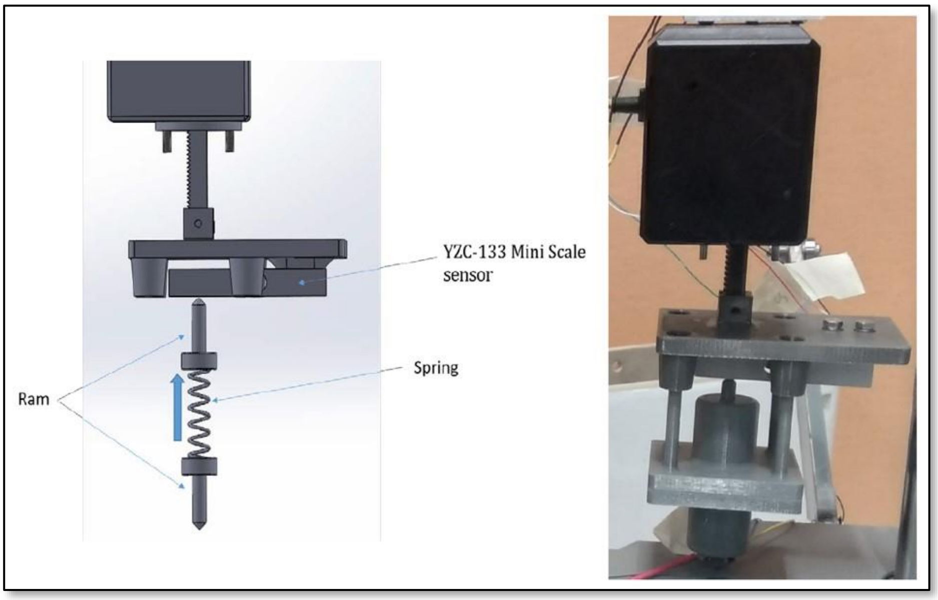


Figure 7 – The Endurance Rig Spring

Among these problems, the spring mechanism itself shows some limits: from the carried out test run of the rig, it was concluded that there were not enough load being transferred to the YZC-133 Mini Scale sensor, this is due to the chosen spring not been stiff enough to transfer the load between the two rams in the unit (Figure 7). This issue can be fixed by either replacing the spring to a stiffer string or change the design where the string is pre-loaded within the case.

4.3 Software's outcome

Concerning the Software, it was determined that 3 types of testing need to be carried out to insure that the final software is function in the manner it was intended to. There are three types of testing that need to be carried out before the rig can be used to conduct the testing:

- Unit Testing
- Integration Testing
- System Testing.

a. *Unit testing*

Throughout the first test, the program is submitted to assess specific components to determine whether each one is fully functional and can carry out a given task. The aim of this is to determine if the application and module function as designed e.g one of the first test carried out was to determine if an Arduino board can operate an A.R.A linear actuator, this was done by writing a small Arduino sketch that shall retract and extract the motor. Once each component passes its initial unit testing, it could be moved to the next phase of testing which integration is testing

b. *Integration Testing*

Integration testing gives us the opportunity to combine all supported components within a program and test them as a group. This testing level is intended to discover any defects or limitation between the modules. This is especially valuable since it decides how productively the units are running together. Bearer in mind that regardless of how proficiently every unit is running, on the off chance that they are not appropriately incorporated, it will influence the effectiveness of the software program.

In this type of testing, one of the three units was constructed to test how each unit function individual and to check if there are any limitation or defects that should be fix before carrying on (Figure 7, right panel). Once we are confident that one of the constructed units meets the requirements the rig shall be moved to the next phase of testing which is known as System testing.

c. *System Testing*

System testing is the level where a whole system is tested as one. The objective at this testing is to assess whether the system has conformed to the majority of the defined fundamentals and to see that it satisfies Quality Guidelines. System Testing is vital since it checks that the application meets the specific, practical fundamentals that were set.

5 Conclusions & Future Works

This project started out with a goal of designing and implementing a cost-effective testing rig. Throughout each process, we become closer and closer into having a complete system that shall be used to test the safety system of the chair/shower commode chair. Just like any other project, this project has overcome majority of its toughest obstacle where the first chosen load cell was deemed not fit for the purpose and therefore a new load cell had to be selected which lead to changing some of the rig original designs. All these changes added more time to the project and push the initial time even further than the estimated time that was set for completion.

After extensive discussion, it was concluded that the C# GUI program was no longer needed and therefore only the Arduino sketch need to be implemented in cooperation with PLX-DAQ software. PLX-DAQ is a Microsoft Excel add on tool that was designed by parallax to acquisition data from microcontroller via serial port and send the data directly into Excel. This tool provides easy spreadsheet analysis of data collected from the microcontroller. The final decision to this came down to eliminating the time taken to produce the GUI and spend that time into finalizing the test rig.

At the time being, the rig is on the last huddle of integration testing before moving to system testing, this is due to having no sufficient time to carry out all the tests Once these issues have been fixed therefore the two extra A.R.A linear actuator units shall be implemented into the test rig and the software shall be implemented for the extra units.

This technology may be enriched with further sensorial components [12, 13] in order to prevent injuries. Moreover this solution maybe adopted in other applications especially when the systems involve daily life use and applications for elderly people.

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