DEVELOPMENT OF A ROBOTIC TOOTH SYSTEM FOR TRAINING DENTAL SURGEONS

PROJECT REPORT

Submitted in Partial Fulfillment of the Requirements for

the Degree of

MASTER OF SCIENCE (Mechatronics and Robotics Engineering)

at the

NEW YORK UNIVERSITY
TANDON SCHOOL OF ENGINEERING

by

Tanaya Bhave

September 20*17*

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September 2*017*

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Advisor Signature

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VITA

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MS in Mechatronics and Robotics Engineering from NYU Tandon School of Engineering

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ABSTRACT

DEVELOPMENT OF A ROBOTIC TOOTH SYSTEM FOR TRAINING DENTAL SURGEONS

by

Tanaya Bhave

Advisor: Prof. Vikram Kapila, Ph.D.

Co-Advisor: Mizanoor Rahman, Ph.D.

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A simple module proposed for dental surgery training. We suggested the dental module for training by recording the feedback obtained during the process of molar tooth extraction. A prototype was developed, that monitors the force between the tooth and the gums on the side and the bottom and is mimicked on a graph real time. Also, the prototype monitors the movement of the forceps used for extraction through an accelerometer attached to it which also generates a real-time graph.

Keywords: robot, dental therapy training, force sensors, tooth extraction, accelerometer, patient robot

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1.INTRODUCTION

Presently, a lot of human simulators are being developed for the benefit of students in medical training. The dental patient robot [1], is a robot with 14 DOF, including Jaw movement (open and close), tongue movements (protrusion, expansion and up and down movement), movement of the neck, movement of the elbow/arm to show physical reaction of the patient such as sweeping motions, eye movements, breathing movement etc.

The current dental patient[1] robot can thoroughly mimic the reactions of a human along with human like skin and structure. The sensor used on the tooth is a strain gauge placed under the tooth, which induces vomit in the patient robot as a human reaction to pain. The prospects of this dental robot, include easier replacement of consumptions of dentition or oral tissue, maintenance and improving its durability.

Addressing the above issue, the idea was to develop a tooth extraction system which could closely mimic the actual movements of the process of extraction while providing a kinematic measurements of the movements and forces acting along with a user interface which could provide a real-time data of the forces and accelerations being applied on the tooth and the tool used for extraction enabling a person to understand and modify the kinematics of their movements. The tooth extraction module is a copy of the molars present in humans and records the forces and accelerations of the process. The tooth can be successfully extracted and then fit back to use again hence preserving the oral tissue being used in the module.

The tooth module was developed and then evaluated subjectively and objectively to develop a mean data set of the reactions obtained by different subjects while using the module. The module was tested over a hundred times without damage or the need of any part replacement.

In the current scenario, dental training given to the students is only theoretical. They can only practice on actual patients to gain any sort of hands-on experience. A dental training device like this could help and enable students to bridge their gap between the theoretical and practical knowledge. This device could help them learn tooth extraction procedure without needing them to practice on a real patient. Some data that was collected from dental students is shown below:

Figure 1: Response to use of training modules

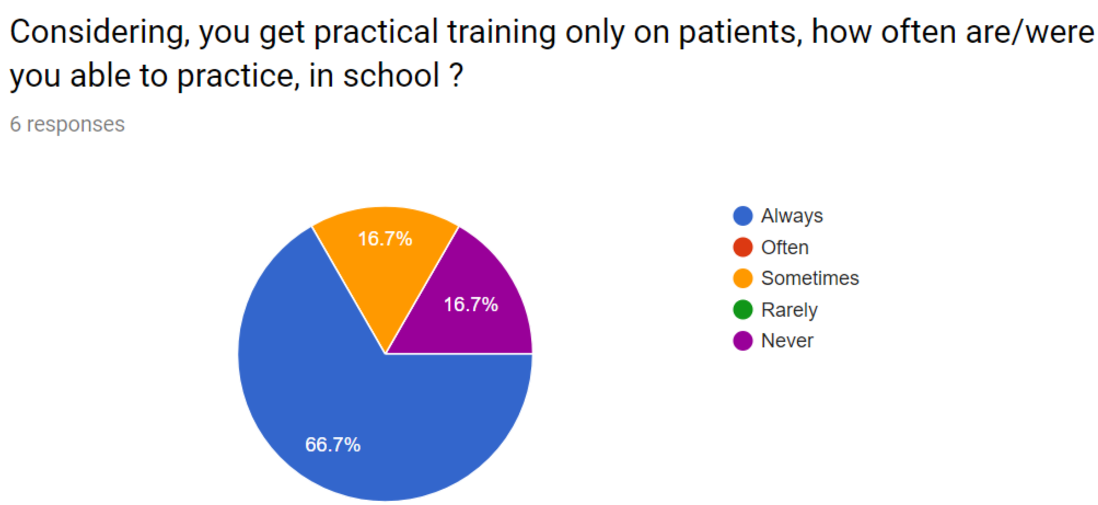


Figure 2: Response to training sessions in dental schools

2. **DEVELOPMENT OF THE MODULE**

2.1 THE OVERALL SYSTEM:

The goal of the project is to design a system that mimics the extraction of tooth in humans. This device should ease the training for not just the dental students but also for the patients. The dental patient robot or the tooth extraction module, in this case, uses, an Arduino microcontroller, two force sensors, two dc solenoids and an accelerometer. The module shows three molars, in which the molars on the corners are fixed. The tooth in the center is a removable tooth. It is tightly held together by a pair of solenoids on each side. The force sensors are positioned under the tooth and between the tooth and solenoid plunger to measure the forces exerted on the bottom and the side wall of the gums respectively. The accelerometer is fixed on the forceps to record the movements of the forceps as conducted by the human hand that holds the forceps, by measuring accelerations on it at all times. This data is read by the Arduino microcontroller and then plotted on a graph through Processing 3.3.5 software. This data can be used to understand the forces and the forceps and hand movements while extracting a tooth by studying the typical features of the graphs. The system is as shown in Fig 4.

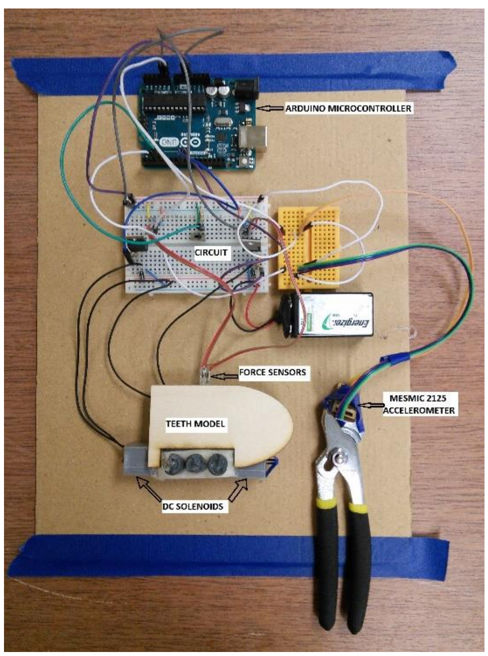


Figure 4: The tooth extraction module

2.2 COMPONENTS

1. Arduino Microcontroller:

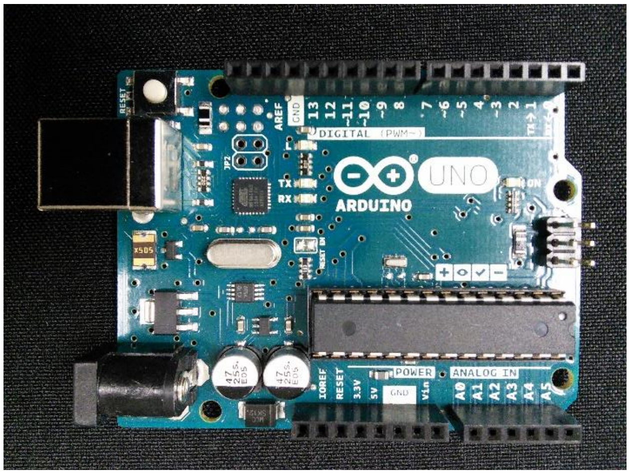


Figure 5: Arduino microcontroller

Arduino Uno is a microcontroller board based on ATmega328P as shown in Fig 5. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It is an open source platform for prototyping.

2. DC Solenoids:

Figure 6: DC Solenoid

Two DC Solenoids were used to hold down the tooth to be extracted as shown in Fig 6. The solenoids used are the Uxcell a14092600ux0438 Open Frame Actuator Linear Mini Push Pull Solenoid Electromagnets, which operate at DC 4.5V, 40 g/2 mm.

Solenoid Details:

- Body Size: 20 x 12 x 11 mm / 0. 8" x 0. 47" x 0. 43"(L*w*t)
- Plunger bar Size: 3 x 40 mm / 0. 12" x 1. 6"(D*l); cable Length: 10cm/3. 9"
- Material: metal, electronic parts; main color: as picture Shown

3. Force Sensors:

Figure 7: Force Sensor

Two force sensors as shown in Fig 7 are used in the setup to measure the contact forces and the forces created in case of extraction acting on the side wall and the bottom of the tooth. The force sensor used is from Chipworld, 500gm-10kg RFP602 thin film pressure sensor force sensor. It has a sensitive area of 10mm diameter circle.

4. Accelerometer:

Figure 8: Accelerometer

We also use an accelerometer as shown in Fig 8 to measure the accelerations on the extraction forceps by Parallax MESMIC 2125 dual axis accelerometer. The MEMSIC 2125 is a low cost, dual-axis thermal accelerometer capable of measuring tilt, acceleration, rotation, and vibration with a range of ±3 g. For integration into existing applications, the MEMSIC 2125 is electrically compatible with other popular accelerometers.

5. 9V battery:

A 9V battery is used to power the solenoids.

6. NPN- Transistor:

Figure 9: Npn transistor

An NPN transistor as shown in Fig 9 is used. NPN is one of the two types of bipolar transistors, consisting of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base is amplified to produce a large collector and emitter current. Hence, it is used in a circuit to isolate large currents from burning the microcontroller. The NPN transistor is used in the circuit to isolate the external power supply from the Arduino so as to not burn it.

7. Diode:

Figure 10: Diode

Two IN14007 diodes as shown in Fig 10 are used. A diode is a two-terminal electronic component that conducts current primarily in only one direction (asymmetric conductance). It has very low (ideally zero) resistance to the current in one direction, and high (ideally infinite) resistance in the other. It is used to restrict the flow of current only in one direction and acts like a one-way valve.

2.3 ARCHITECTURE OF THE SYSTEM:

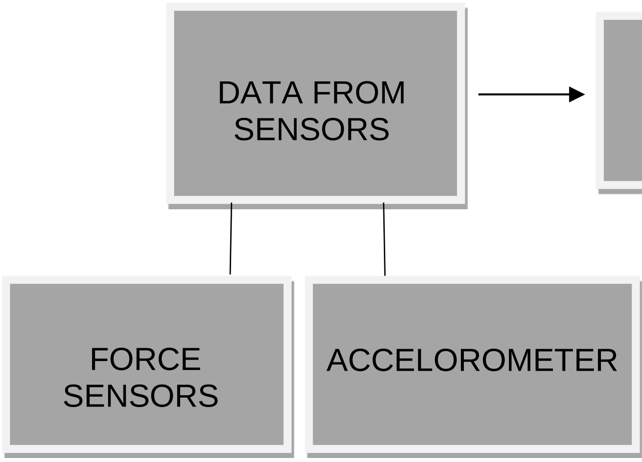


Figure 11: Architecture of the system

The architecture of the system is as shown in Fig 11. It shows the flow of data from input to output. The force sesnor and accelerometer send force data and accelerations in two directions (Z and X) to the arduino and then plotted on the graph on the processing user interface.

2.4 DESIGN AND DEVELOPMENT OF THE SYTEM

The case to hold the solenoids, molar teeth and gums were 3D printed.

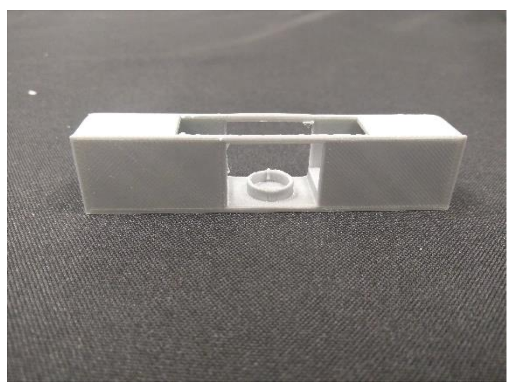


Figure 12: a)3D printed teeth(left) b) Solenoid case(right)

The system was then fixed together as shown below:

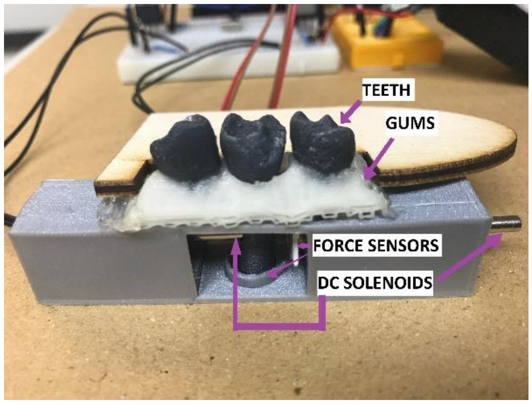


Figure 13: Assembled system

The assembled system shows all the parts of the system. The different components such as the teeth, gums, tongue, solenoid case were modelled using Solidworks software and then 3D printed. The teeth and the case were printed using polylactic acid (PLA) in different colored filaments. The gums are printed in thermplastic elastomer (TPE) which is a soft and flexible 3D printing material. The tongue is lasercut from Balsa wood.

2.6. USER INTERFACE

The user interface was developed in Processing 3.3.5. It allows the user to see and track the different forces and calculations caused by the hand movement during the pulling out of tooth allowing them to adjust their moves by looking at the graph.

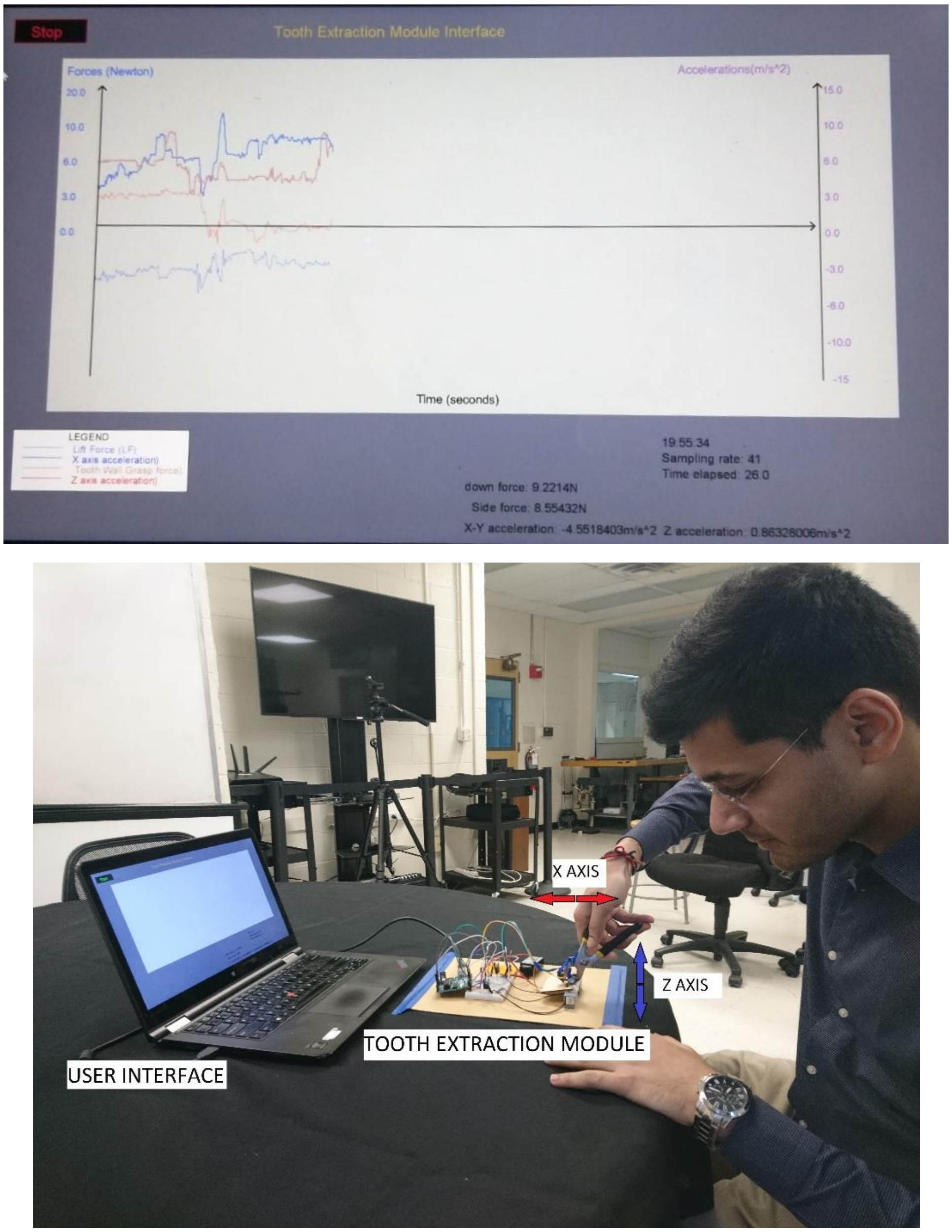


Figure 14: a) User Interface b) Subject using the system

3. EXPERIMENTAL EVALUATION OF THE SYSTEM

We designed some tests to conduct an experimental evaluation of the system based on the opinions of the users of this system and developed a mean data set of the results obtained from each trial.

PROCEDURE:

1. In the experiment, each user had to perform the task of tooth extraction 10 times to attain a level of dexterity in the task.

2. The user was not informed of any motion or method to be used for the process of extraction but only about the device and the information displayed on the graphical interface.

3. The user with the help of the forceps pulled out the tooth from the module taking their own time.

4. The forces and accelerations for each trial were recorded.

5. Each user had to fill out a form for a subjective evaluation to understand the opinion of the user regarding the device over pHRI (physical human robot interaction) criteria such as safety, robustness, stability, maneuverability, likeability, cHRI (cognitive human robot interaction) criteria such as engagement, trust and the NASA Task Load Index.

3.1 OBJECTIVE EVALUATION

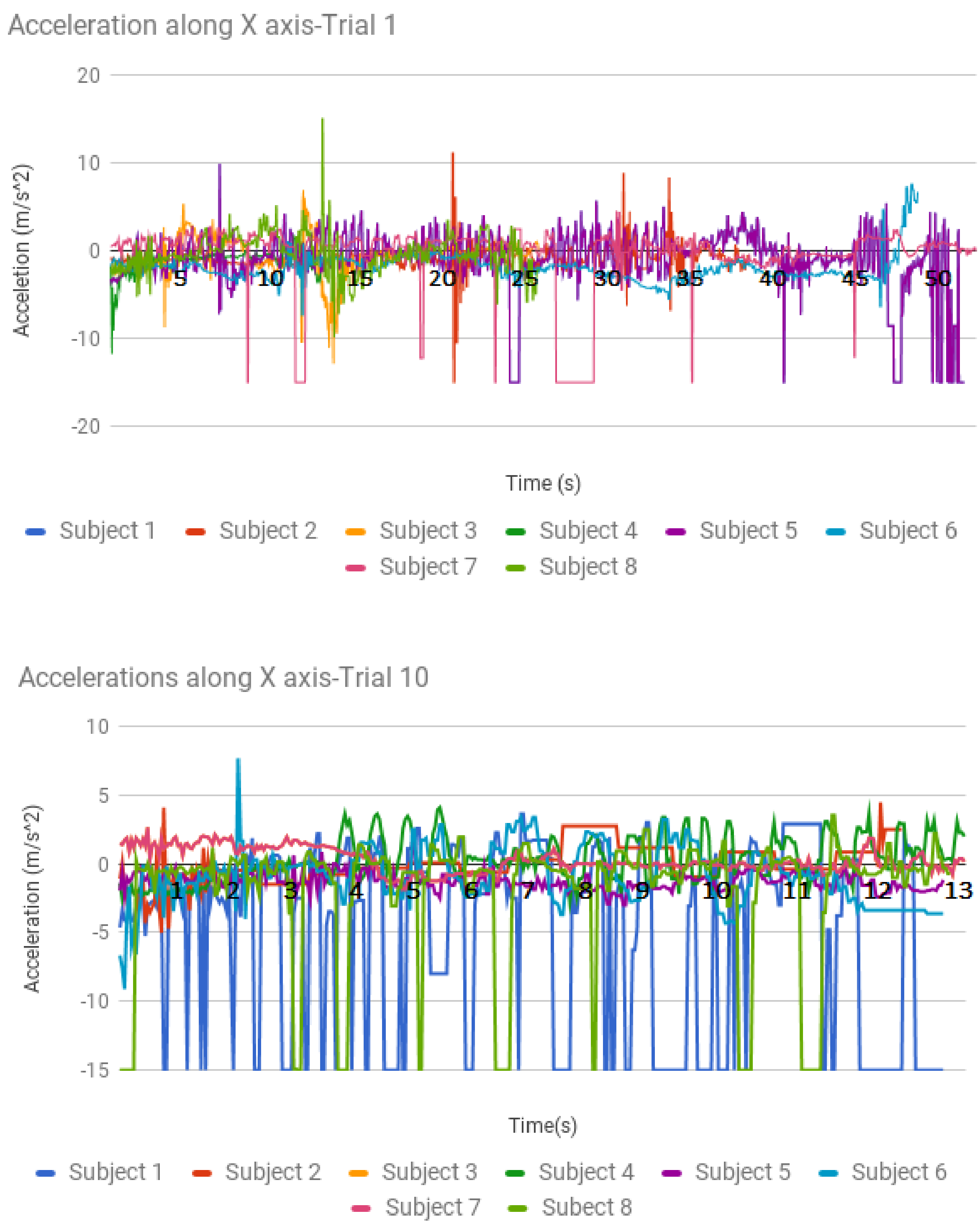


Figure 15: a)X axis acelrations in Trial 1(top), b) X axis acelrations in Trial 10(bottom)

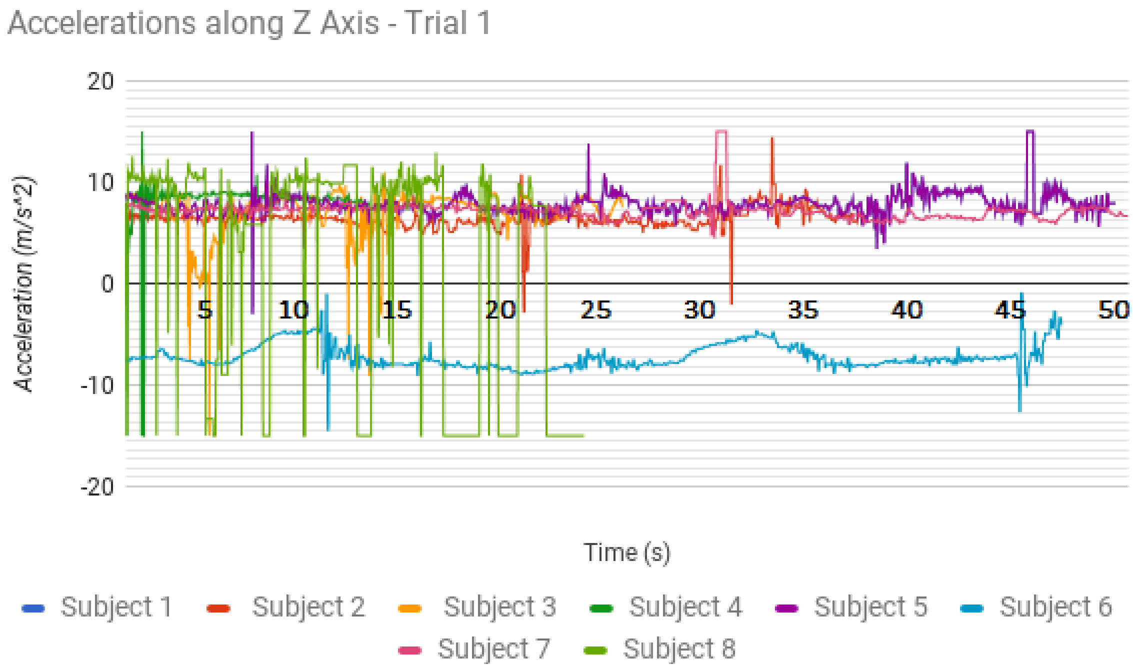


Figure 16: a) Z axis acelrations in Trial 1(top), b) Z axis acelrations in Trial 10(bottom)

RESULTS OF THE OBJECTIVE EVALUATION

The hypothesis tested in the evaulation is that if this tooth extraction module can be used for training purposes.

The approach being followed to test the hypothesis is to study the forces and accelerations generated in the whole process.

The accelerations along X axis in trial 10 show a significant difference as compared to the first trial. During the first trial, the accelerations along the X axis show are low hence depicting less movements of twisting motion which is generally followed by the dentists before uprooting a tooth. The X accelerations are quite frequent in the tenth trial depicting ample of twisting motion to loosen the tooth before pullig it out.

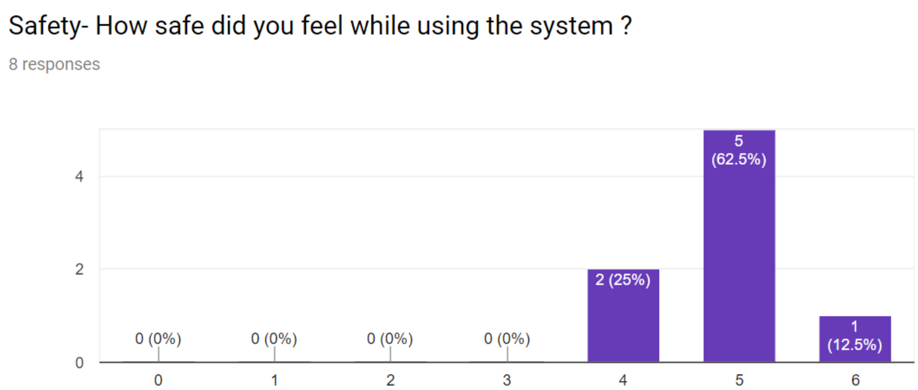
The accelerations along the Z axis were high and frequent in trial 1, as every user took to a pulling movement and jerked their wrist to pull out the tooth at once. The users did not try to loosen or twist the tooth in their first trial, but slowly graduated towards understanding the required motion from their own experience. In the last trial, the Z accelerations are smaller, with lesser peaks, hence depicting the fall in sudden and jerking movements of the hand.

The time taken in the first trial ranges from 25-50 seconds. The tenth trial shows a drastic change bringing down the extraction time to under 13 seconds.

The observations obtained from the objective evaluation results support the hypothesis that the extraction module can be used for training of dental students.

3.2 SUBJECTIVE EVALUATION

pHRI Criteria:



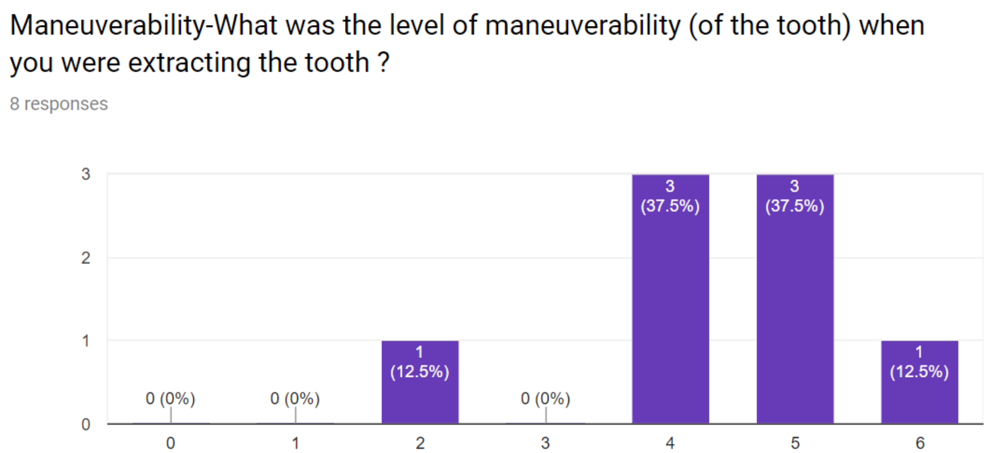
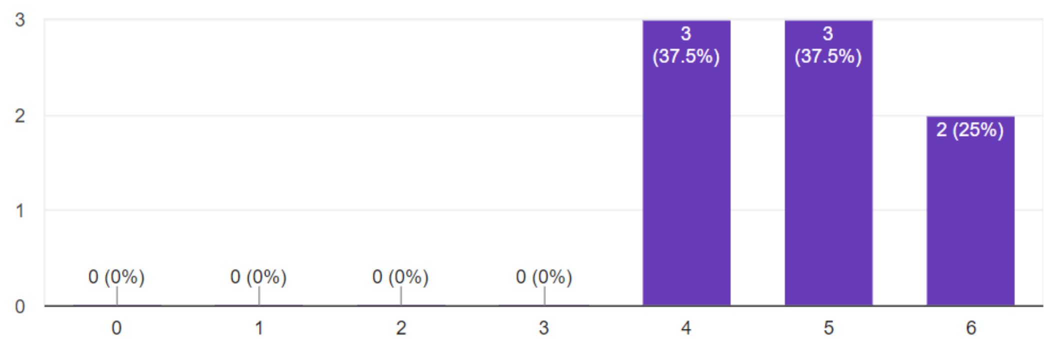


Fig. 17: pHRI: a)Safet(top)y, b)Maneuverability(center), c) Stability and Robustness(bottom)

Ease of use- How easy/convenient was it to use the system ?

8 responses



Quality/likeability of human machine device interface- What was the level of the quality/likeability of the physical interface(via forceps) and visual graphics(via data display screen) ?

8 responses

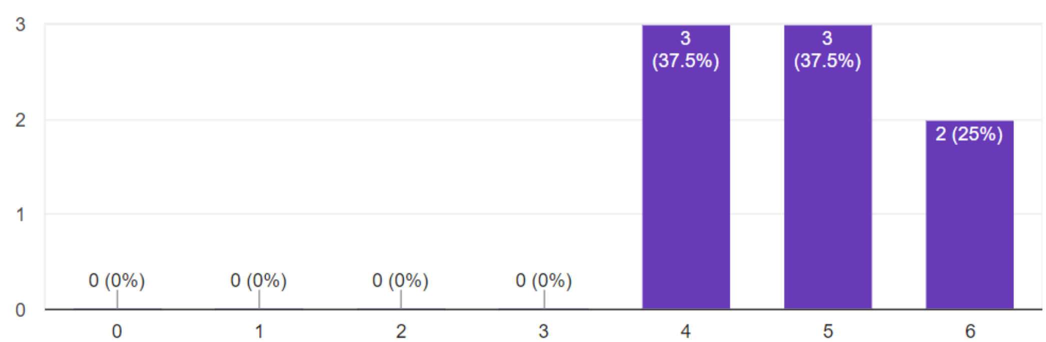
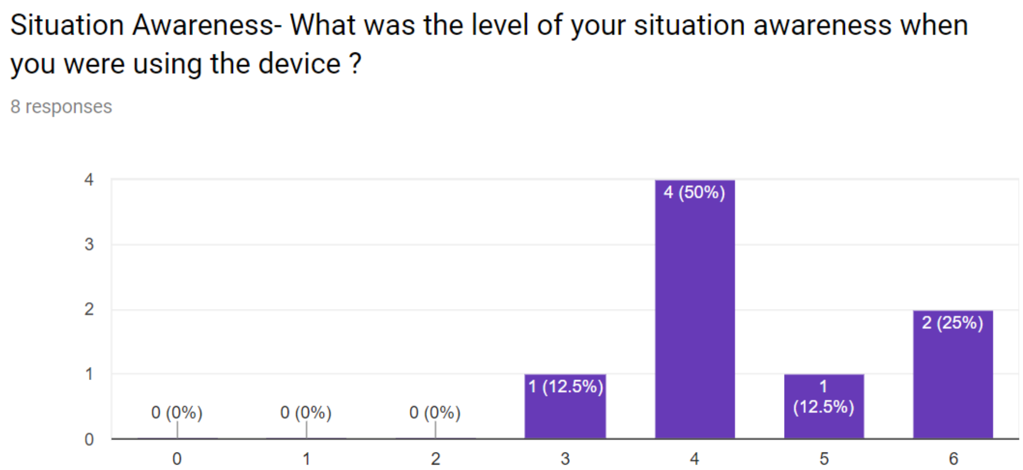
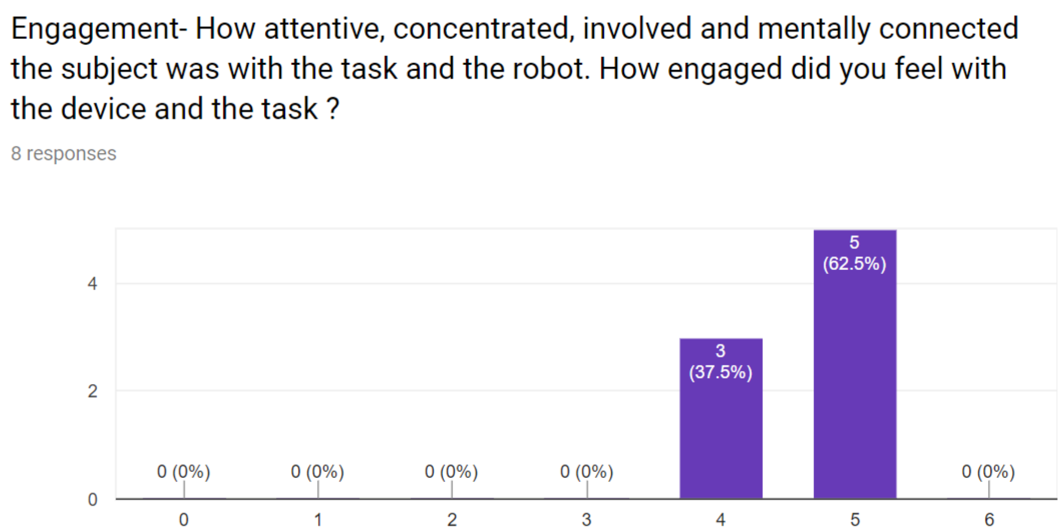


Fig. 18: pHRI: d) Ease of use(top), e)Likeability(bottom)

cHRI Criteria:





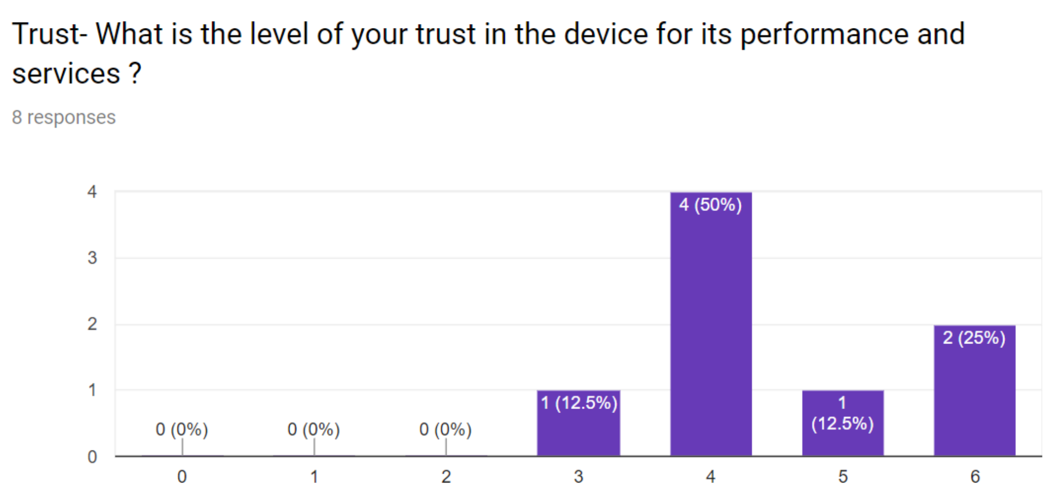
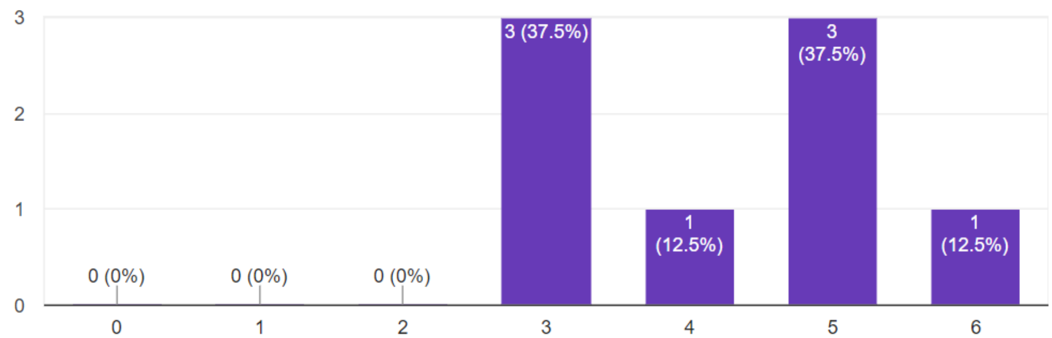


Fig. 19: cHRI: a)Situation Awareness,(top) b)Enagementy(center), c) Trust(bottom)

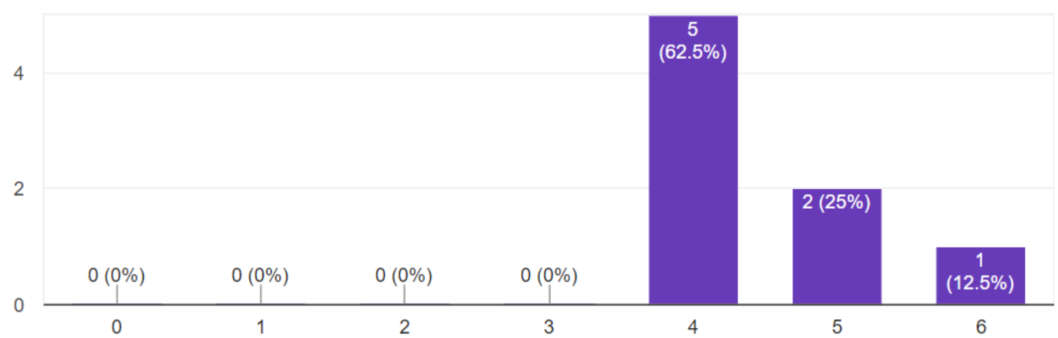
Performance/prospect as a learning tool- How similar is the working principle of the device in comparison with actual doctor patient scenario?

8 responses



How efficient is the system ?

8 responses



How much potential does the system possess as a learning tool ?

8 responses

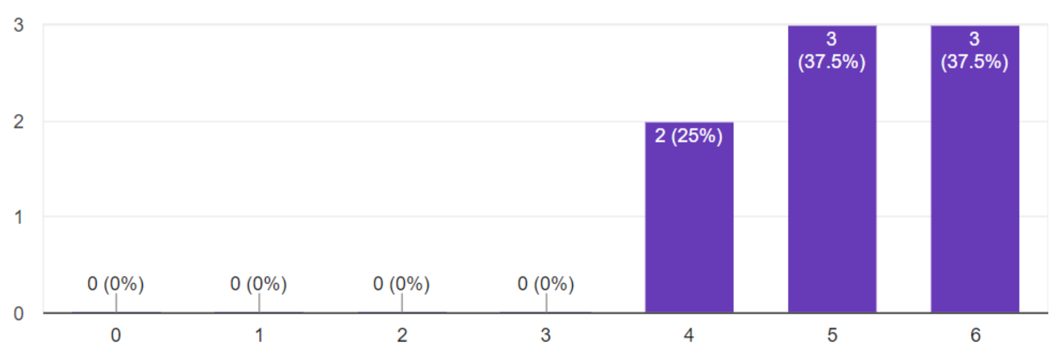


Fig. 20: cHRI: d)Performance(top),d) Efficiency(center), e) Potential(botoom)

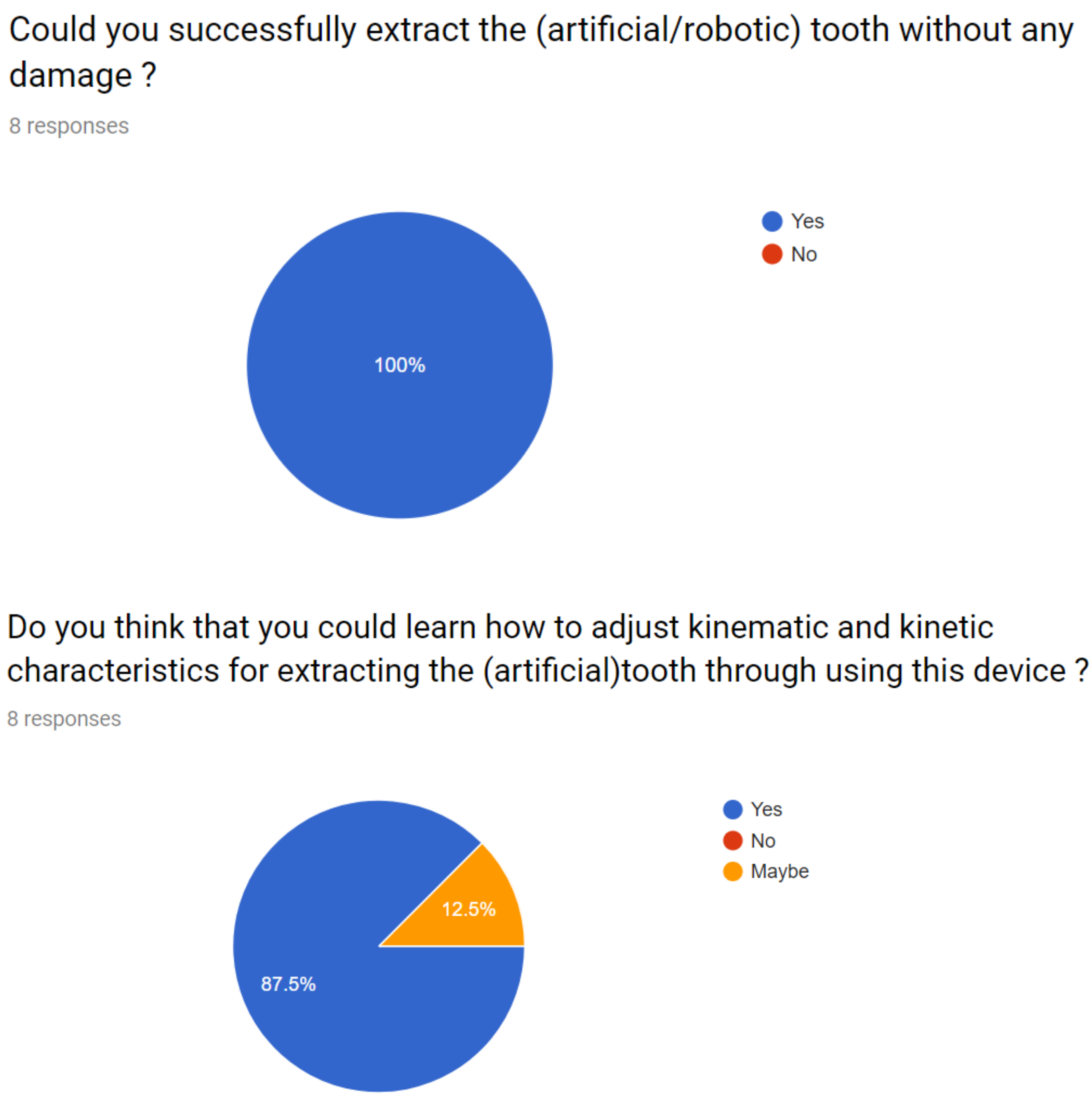


Fig. 21: cHRI: f)extraction success(top) g)learning potential(bottom)

RESULTS OF THE SUBJECTIVE EVAUATION

Majority of the users have rated the module high on pHRI (physical human robot interaction) and cHRI (cognitive human robot interaction) index. 100% of the users were able to successfully extract the tooth from the module without damaging the tooth. 87.5 % of the users believe that the module can help them to learn to adjust the kinematic and kinetic characteristics of the extraction process.

4. CONCLUSION AND FUTURE WORK

Overall the module achieves the goal of a training module that eases a user in the process of tooth extraction. The system can collect data and help to bring about smooth and easy movements of hand while tooth extraction without damaging the tooth module.

The system can be further be improved by making it more interactive and responsive by providing a skelatal structure or voice outputs similar to humans.

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4. www.arduino.com
5. www.parallax.com
6. www.wikipedia.com

INDEX- I : ARDUINO CODE

```
//Tooth Extraction module:Arduino code- Tanaya Bhave
/*    Components       Pin number
 *  force sensor 1        A0
 *  force sensor 2        A1
 *      xy axis           2
 *      z axis            4
 *      Switch            3
 *    Solenoid1           8
 *    Solenoid2           9
 */

int firstSensor = 0;    // first analog sensor
int secondSensor = 0;   // second analog sensor
int thirdSensor = 0;    // digital sensor
int fourthSensor = 0;    // digital sensor
int switchPin;   //to switch the module on and off
 int FSR_PIN1 ;
 int FSR_PIN2 ;
const int xyPin = 2;     // X or Y output of the accelerometer
const int zPin = 4;      // Z axis
int pulseXY, pulseZ;
int accelerationXY, accelerationZ;

void setup() {
  // start serial port at 9600 bps:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port only
  }
```

```
  pinMode(xyPin, INPUT);
  pinMode(zPin, INPUT);
  pinMode(3, INPUT);


}

void loop() {
  switchPin=digitalRead(3);
  if (switchPin==1){
    digitalWrite(8,HIGH);
    digitalWrite(9,HIGH);
    FSR_PIN1 = analogRead(A0);
    firstSensor= map(FSR_PIN1, 0, 220, 0, 3000);
    FSR_PIN2 = analogRead(A1);
    secondSensor= map(FSR_PIN2, 0, 220, 0, 3000);
    pulseXY = pulseIn(xyPin, HIGH);
    pulseZ = pulseIn(zPin, HIGH);
    thirdSensor = (((pulseXY / 10) - 500) * 8);
    fourthSensor = (((pulseZ / 10) - 500) * 8);
    // send sensor values:
    Serial.print(firstSensor);
    Serial.print(",");
    Serial.print(secondSensor);
    Serial.print(",");
    Serial.print(thirdSensor);
    Serial.print(",");
    Serial.println(fourthSensor);
    delay(25);
  }
}
```