**1. INTRODUCTION**

1.1 BACKGROUND

From 2004 to 2013, there were 18,289 persons above 50 years of age who underwent knee replacement surgeries respectively at public hospitals[1]. Over the same period, 426 persons aged 30 to 49 years underwent knee replacement surgeries respectively at public hospitals. Along with an aging population comes an increase in health concerns, and subsequently, an increase in medical healthcare costs, posing a concern to Singapore’s rapidly aging society and potentially putting a strain on the medical system.

One of the main reasons why patients undergo knee replacement is due to the pain from severe knee damage that limits their everyday activities. Most patients who undergo knee replacement are not able to fully straighten the leg all the way after surgery. For the complete knee motion to be fully restored the knee joint, bone and muscle must undergo recovery exercises. Repetitive physiotherapy exercises are able to improve the range of motion[2] by increasing blood circulation to your legs and feet[3], which is important for preventing blood clots and allowing their specific damaged ligament to heal. In this project, we will be focusing specifically on one physiotherapy exercise, consisting of a combination of kneading the knee and pushing the kneecap which helps to improve Knee Osteoarthritis[4].

Typically, the patients undergo physical therapy with a therapist, and are instructed to continue the exercises at home constantly. However, therapists are unable to track the effectiveness that the physical therapy exercises have on the patient’s knee movement.

1.2.1 CURRENT APPROACH

In standard rehabilitation, patients undergo face-to-face consultations with their therapist. This is crucial for the rehabilitation process as it ensures effective communication between the therapist and the patient, allowing the therapist to monitor the patient’s progress and provide feedback if necessary.

However, many patients, particularly the elderly, do not receive appropriate rehabilitation, or a limited number of rehabilitation appointments. The main reasons for patient non-compliance in physiotherapy includes inability or inconvenience to travel to the hospital often, be it due to lack of time, the high transport costs to be borne, or physical disability[5].

Furthermore, there is no way for therapists to reliably monitor the patient’s progress as they carry out physiotherapy exercises at home. Physical therapy is one of the few areas in healthcare where patients have to be engaged themselves. Improper exercise – too little, too much or in the wrong positions – could leave the patients with stiff knees and chronic pain.

With a home-based telerehabilitation system, a large extent of these problems would be mitigated, as this system would offer convenience to the patients to perform physiotherapy exercises from their own homes while allowing therapists to keep track the patient’s progress, ensuring that the exercises are done correctly, and consistently according to the therapist's prescription. Studies have already shown that telerehabilitation is at least 81% less expensive, yet more clinically effective than the standard face-to-face rehabilitation that most patients undergo after total knee replacement[6].

Another issue surrounding standard rehabilitation is the fact that without the use of a sensor, it is hard for therapists to monitor the exercises done during standard rehabilitation as therapists cannot discern the pressure applied by the patient during the exercise. Therefore, the use of a sensor will be helpful in tracking the effectiveness of the exercises by logging data of the pressure applied by the patient. Therapists will be able to have a clearer picture of how the patient is doing, and provide feedback and correction, which would in turn, help the patients in their recovery.

1.2.2 Existing Tele-rehabilitation approaches and their limitations

There are several existing tele-rehabilitation systems targeting total knee replacement. However, there are certain limitations to them.

In 2016, Pamela Youde Nethersole Eastern Hospital in Hong Kong piloted a project[7] which allows patients to watch online motion graphics of physiotherapists demonstrating preparatory and physiotherapy exercises by scanning QR codes found on pamphlets given to them.

While the project shows patients the correct exercise movements, it does not provide feedback for patients on their performance. We feel that immediate feedback and monitoring is necessary, especially if the exercises are done outside of the supervision of a professional therapist.

The Virtual Exercise Rehabilitation Assistant (VERA)[8] utilizes a Microsoft Kinect camera to capture 3D motion of the patient’s entire body to calculate joint angles and limb velocity. The data is then used to give real-time feedback to patients on their performance and how to improve their technique.

While this system has worked well for many physiotherapy exercises, it is limited to measuring “range of motion” exercises only, as it lacks the ability to discern the pressure applied by the patient on their knees. We believe that a pressure sensor is needed to measure the pressure reliably and accurately applied by the patient during the exercises.

1.3 Objective

The project intends to develop a solution for therapists to monitor and track their progress and compliance of patients undergoing physical therapy via telecommunication technology. By automating the process of physiotherapy exercises, the frequency and amount of pressure applied by the patients during the exercises can be monitored from a remote location, thus feedback and corrections can be provided immediately to the patient. Developing an all-in-one device that does not require to be tethered to any other technology except for a wearable sensor and a tablet makes the system highly portable, allowing the patient to undergo physical therapy without having to travel to the hospital or clinic.

## METHODOLOGY

2.1 OVERVIEW

The ability to fully straighten the leg after knee replacement surgery can be improved through a telerehabilitation process, which involves the monitoring of a patient's repetitive physiotherapy exercises (consisting of kneading the knee and pushing the kneecap[4]). The telerehabilitation process involves 3 major phases: data collection, data processing, and data analysis. **The main focus of this project is on the Patient-end** - developing a system that facilitates the data collection and end-user-experience aspect of telerehabilitation

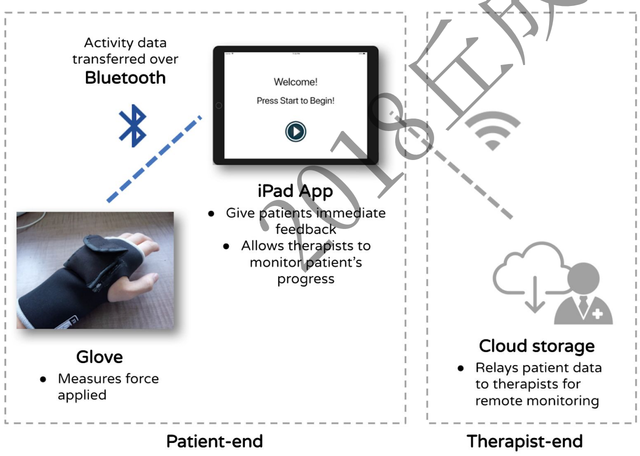


**Figure 1**: The major phases in the telerehabilitation process and their functions

In the data collection aspect of the program, the patient will carry out the prescribed physiotherapy exercises with a pressure sensor which will be able to detect the pressure applied by the patient. The pressure sensor will be connected to a Beetle BLE which will relay the data collected to the iPad, where it is presented in a clear and easy to understand application to the patient.

2.2 Hardware

The project aims to develop an Arduino-based system that can show the patient the frequency and amount of pressure applied by the patient during the exercise, with the use of a pressure sensor (FSR 406[10]). The pressure sensor has a force sensitivity of 0.2-20.0[2] Newtons[9], making it suited for use for detecting the amount of force to be applied for knee replacement exercises. The pressure sensor is connected to the 5V pin of the Arduino as opposed to the 3.3V pin in order to obtain a finer resolution of readings. A 10kΩ resistor is connected to the pressure sensor as shown in the schematic, acting as a pull-down resistor.

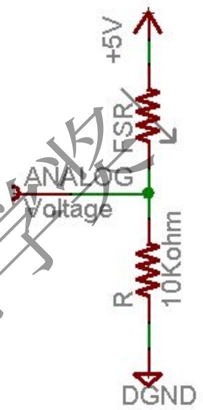


**Figure 2(a)**: Schematic of pressure sensor/arduino connection

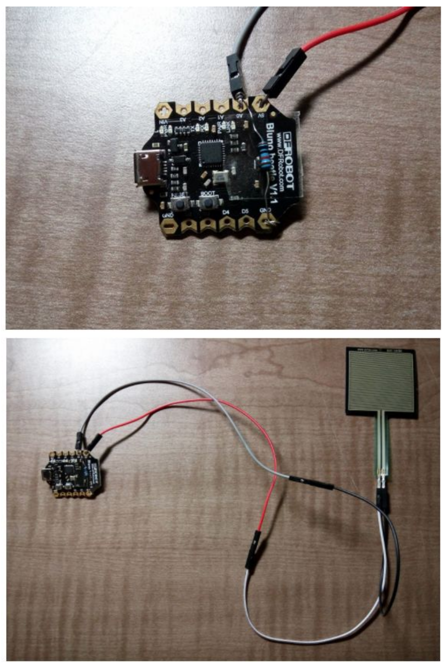

**Figure 2(b) and 2(c)**: Physical Connections of the Pressure sensor to the Beetle BLE

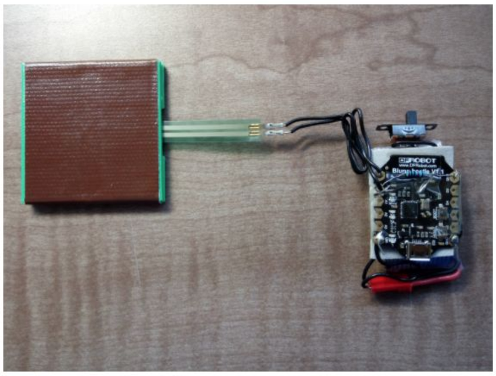

**Figure 2(d)**: Pressure sensor and Bluno Beetle with Battery and Switch; **Figure 3**: Final Glove with the electronics and Pressure Sensor

The raw data from the pressure sensor is processed by a Beetle BLE, the smallest Arduino Uno based board with Bluetooth 4.0. The Arduino code (see Figure 4 in the Appendix) collects the raw data from the pressure sensor and displays how much pressure (in units) is applied, the duration of each press, and how many times the sensor is pressed beyond the minimum threshold required. This data is then wirelessly sent to the iPad via Bluetooth 4.0 where it will be displayed in a clear manner through the iPad application.

2.2.1 Glove

The pressure sensor and the Beetle BLE will tucked into pockets sewed onto the outside of a glove which is worn by the patient during the exercise. This makes the system more compact, allowing the patient to use the product more conveniently. Since this application is mainly targeted at the elderly, the increased convenience will make the product more accessible.

We discovered that one of the problems with the pressure sensor is that they can give different readings under the same force conditions, depending upon how they are pushed. This is because the sensor averages out the pressure over the whole surface, and a poorly distributed load will apply a lot of pressure in one place, but not another. To counter this effect, pieces of stiff plastic are placed on either side of the pressure sensor, with a thin sponge between acting as a cushion, in order distribute the load evenly.

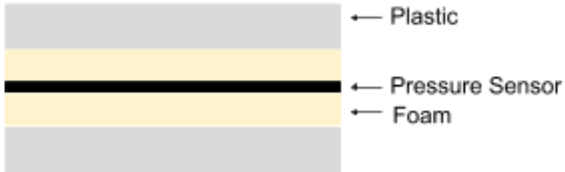


**Figure 3**: Pressure sensor is sandwiched between 2 pieces of foam and plastic from either side. An illustration is used as the actual setup is too thin to be seen from a photo.

2.3 Calibration of Pressure Sensor

As the sensor needs to be manually calibrated first, human subjects are needed get a rough sense of the force required (As our project is still in its preliminary stage, team members are used as experiment subjects.) This will be used to determine a general threshold beyond which the patient should press. Since the threshold can vary significantly from person to person, the threshold we obtained (at 800 units) merely serves as a rough estimate. Nevertheless, it is sufficient for being used as a technology demonstrator. However, the therapist will have the ability to vary the threshold for individual patients based on their needs.

2.4 Processing

Processing is an additional part of the project that allows the operators (therapists) of the system to visualize the data more conveniently. The data collected from the Arduino is saved and displayed as a pressure vs time graph, allowing the therapist to quickly analyze the data. This is helpful as the therapist is likely to receive data from multiple patients. (See Figure 5 in the Appendix)

2.5 User Interface

In order for the patient to understand the data logged from the pressure sensor easily, an accessible application has been created. This application must be easily understandable (for the elderly's usage), and the interface should not be cluttered. With this application, therapists can track the patient's progress, and provide feedback to the patient as soon as possible.

The iPad application, iTherapist 1.0, was developed with the Objective-C programming language, as well as the Xcode integrated development environment. The application provides the patient with video instruction on how to carry out the knee replacement exercise correctly. A progress bar (see Figure 8(c) in the Appendix) reflecting the pressure applied by the patient during the exercise will be displayed. If the pressure applied exceeds the set limit, the patient can proceed on to the next set of exercises. A counter will also be displayed to show the patient how many sets of exercise there is left.

The Beetle BLE is coded to connected wirelessly to the application so that it is more convenient for the patients (see figure 7(a) and 7(b)). The code is modified with reference from an existing code found online[7].

## RESULTS AND DISCUSSION

All results reflected are preliminary findings. All graphs are plotted with team members as experiment subjects.

### 3.1 Assessment of Graph

The therapist will be able to assess the patient's progress by looking at the data from the graph. Initially, as the patient begins his therapy sessions, the force applied during the physiotherapy exercises would be weaker and less frequent at the later stages of their therapy.

Hence, the graph observed will peak at lower values, with each peak taking a longer period of time. (see figure 6(a) and 6(b)).

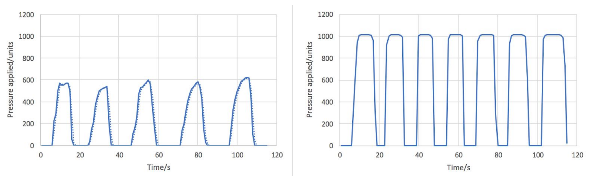

**Figure 6(a) and 6(b):** Examples of pressure vs time graph throughout the exercise as observed by the therapists. The graphs enables therapists to easily observe the patient's progress at a glance based on the force applied and frequency of each press. Hence therapists can easily monitor many patients' progress in a shorter period of time

### 3.2 Assessment of Application

As the main target audience of the application is the elderly, it is essential that the interface of the application is simplified and uncluttered (see figure 8(a) and 8(b)). The repetitive nature of the application is the defining feature. The application allows the patient to repeat his knee replacement exercise in multiple sets as prescribed by the therapist. Each push will be counted and logged only if the patient manages to hit the end of the progress bar.

## CONCLUSION

Telerehabilitation can allow patients to go through their rehabilitation in their own homes without having to travel to the hospital. The system is designed to be portable and wireless, offering convenience and ease of use for knee replacement patients. Telerehabilitation also allows therapists to determine the patient's progress remotely with increased accuracy.

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## APPENDIX

All illustrations in this report are self-generated.

```
Final_Arduino_Code

int fsrAnalogPin = 0; // FSR is connected to analog 0
int fsrReading;      // the analog reading from the FSR resistor divider
int count = 0;
bool aboveThreshold = false;
int threshold = 800;  //minimum value to register as a count

void setup(void) {
  Serial.begin(9600);   // We'll send debugging information via the Serial monitor
  pinMode(LEDpin, OUTPUT);
}

void loop(void) {
  fsrReading = analogRead(fsrAnalogPin);
  //Serial.print("Analog reading = ");
  //Serial.println(fsrReading);
  if(fsrReading>threshold&&!aboveThreshold){
    aboveThreshold = true;


  }
  if(aboveThreshold){
    if(fsrReading<threshold){
      aboveThreshold = false;
      count++;
      Serial.println(count);
    }

}
```

**Figure 4**: Arduino code

```

- (void)didReceiveMemoryWarning
{
    [super didReceiveMemoryWarning];
}


#pragma mark- DFBlunoDelegate

-(void)bleDidUpdateState:(BOOL)bleSupported
{
    if(bleSupported)
    {
        [self.blunoManager scan];
    }
}
-(void)didDiscoverDevice:(DFBlunoDevice*)dev
{
    BOOL bRepeat = NO;
    NSLog(@"%@",dev);
    for (DFBlunoDevice* bleDevice in self.aryDevices)
    {
        if ([bleDevice isEqual:dev])
        {
            bRepeat = YES;
            break;
        }
    }
    if (!bRepeat)
    {
        [self.aryDevices addObject:dev];
        [self.blunoManager connectToDevice:dev];
    }
}
-(void)readyToCommunicate:(DFBlunoDevice*)dev
{
    self.blunoDev = dev;
    NSLog(@"ready");
    self.readyLabel.hidden = NO;
}
-(void)didDisconnectDevice:(DFBlunoDevice*)dev
{
    NSLog(@"not ready");
}
-(void)didWriteData:(DFBlunoDevice*)dev
{

}
```

```
-(void)didReceiveData:(NSData*)data Device:(DFBlunoDevice*)dev
{
    self.indicatorView.hidden = YES;
    self.nextButton.hidden = NO;
    self.counterLabel.hidden = YES;
    int reading;
    NSString *str = [[NSString alloc] initWithData:data encoding:NSUTF8StringEncoding];
    reading = [str intValue];

    if ([str rangeOfCharacterFromSet:[NSCharacterSet decimalDigitCharacterSet]].location != NSNotFound) {
        reading = [str intValue];
        self.counterLabel.hidden = NO;
        if (reading >= 300) {
            reading = 300;
            max = true;
        }
        [self smoothProgressBar:self.progressView progressValue:(reading/300.0)];

        if (reading == 0 && max == true) {
            counter++;
            max = false;
        }


        [self.counterLabel setText:[NSString stringWithFormat:@"%d/10", counter]];

        if (counter >= 10) {
            NSLog(@"END!");
            self.counterLabel.hidden = YES;
            self.endButton.hidden = NO;
            self.tenLabel.hidden = NO;
        }
    }
}
```

**Figure 7**: Code for the Beetle BLE

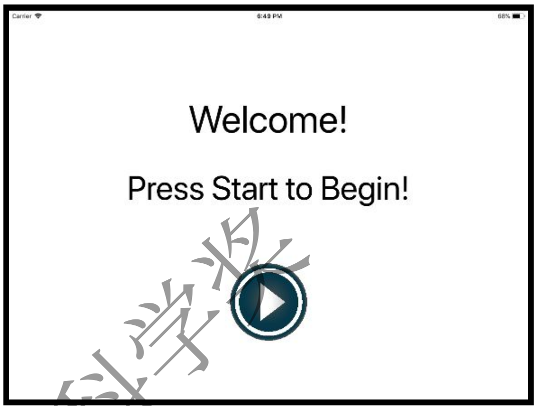


**Figure 8(a):** Start Screen. Upon clicking into the app, patients are met with a uncluttered start screen with clear instructions. The large font size and button makes it easier for the elderly to use the app

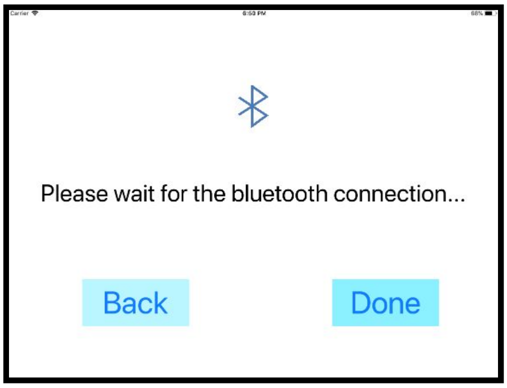


**Figure 8(b):** If the device is not connected, bluetooth will be automatically turned on and this page will appear as the iPad establishes wireless communication with the Beetle BLE

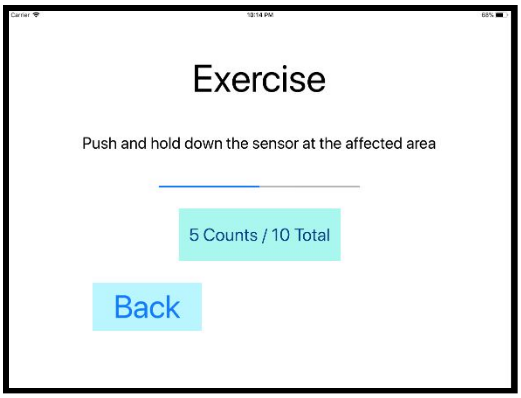


**Figure 8(c)**: The progress bar and counter shows patients their progress throughout the exercise