Optical fiber system for analyzing pétanque athletic movements

Author : Anuwat Kaewcharoon
Supervisor : Asst. Prof. Dr. Ratchapak Chitaree

A thesis submitted in fulfillment of the requirements for the degree of
Bachelor of Science, Mahidol University in the
Applied Optic Research Group Department of Physics

Abstract

In a sport activities, the practising of the athletes play an important role to improve and maintain their performance. To do that, the movement analyzer which used to record a body movement compared to the suitable movement are required.

In this study, the movement analyzer is designed and developed for the pétanque athlete. The movement of pétanque player is focused in this study, because the player is movable in a few body compared to other sport activities.

The movement analyzer is implemented based on the optical fiber system which consists of the optical fiber, light source and light detector. The plastic optical fiber (POF) is used to send the light from LED light source into photodetector. By bending the POF, the transmitted light is sense to the arm's swing movement. The result shows that the bending radius used to analyze the arm's swing movement must be less than 1.5 cm. Moreover, the movement pattern can be compared to the suitable movement on screen display of a smart phone. The optical fiber system is install on the athlete's body to trace the body movement of a subject.

Acknowledgment

First of all, I would like to thank Asst. Prof. Dr. Ratchapak Chitaree, my supervisor, for guidance, assistance and knowledge about Optic Physics or everything. Secondly, I would like to thank all of graduate students in Applied Optics Laboratory for their welcome, kindness and help. Then, I would like to thank Mr. Chaiwat Laowattanakul also for his equipment supports. And finally, I would like to thank my friends and family for their encouragement and assistance.

Contents

List of Figures

1 Introduction

1.1 Motivation

Currently, plastic optical fiber is widely used in various fields such as communication [**1**], physical therapy [**2**], and medication [**3**], [**4**]. Optical fiber system is usually used as a bending sensor because the amount of light that propagate in the fiber core can be leaked out due to breaking of the total internal reflection (TIR). In this study, the optical fiber system is used to be a sensor in movement analyzer for pétanque athlete. The pétanque athlete is focused, because it is easy to analyze compare to other sport, and it is my favourite sport.

1.2 Optical fiber sensor

A sensor based on Optical fiber system can be providing an advantages such as high sensitivity and light-weight. Generally, the optical fiber system consists of three parts; light source, optical fiber, and detector. In this study, The LED was used as a light source while a plastic fiber was used to send the light from light source to detector. The light emitted from the end of the plastic fiber was detected by photodiode. The Arduino Uno is microcontroller used to convert the analog signal, from the photodiode, to digital signal [**4**]. By using the bending of a plastic fiber, the optical fiber system can detected the slightly movement of the athlete

1.3 Aims and Objectives

According to the athlete pétanque, The movement of athletes are required in order to improve performance and proficient skill. Hence, this study, the suitable movement of the pétanque athletes arm will be investigated by the optical fiber sensor and the sensor can be used to support the amateurs for the suitable practicing. The angular displacement of the athlete's arm will be shown as a graph (between angular displacement as a function of time). The athletes can analyze their arm's motion by considering the graph pattern.

1.4 Overview of the report

This report is divided in to five sections. The first section describes about the introduction and motivation. The second section will describe background knowledge used in this study. Next, the third section, the methodology of this research will be presented. Next one is the discussion section. Finally, the conclusion section.

2 Background Knowledge

An optical fiber is a cylindrical waveguide that allowed electromagnetic wave propagate along the fiber. The conventional fibers are made from plastic or glass material, as shown in **Figure 2.1**. These fiber are composed of core and cladding region with different refractive index. The different indices of refraction between core and cladding obey the total internal reflection of light propagated in the fiber.

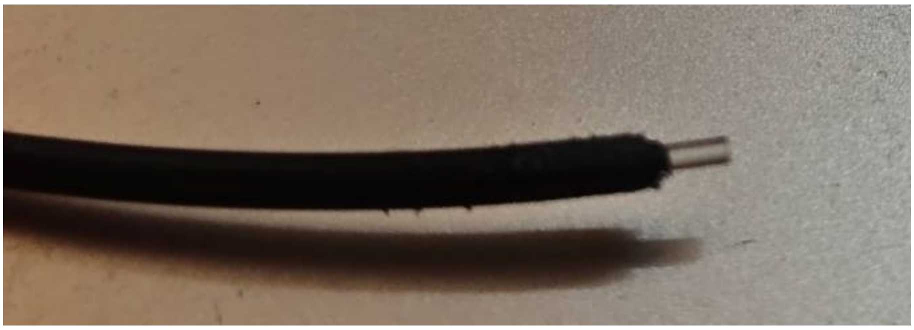

Figure 2.1: Plastic optical fiber

2.1 Snell's law

When the light propagated through the different medium, The propagation direction is changed due to refraction occurred at the boundary between them. The relation of incident angle and refraction angle is known as Snell's law, expressed as.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{1}$$

where n_1 and n_2 are refractive index of the first and second medium, respectively. θ_1 and θ_2 represent the incident and refraction angle , respectively.

2.2 Numerical aperture

In **Figure 2.2**. The orange ray represents the incident light with the incident angle α. The largest incident angle that can propagate into the fiber without refraction out, known as an acceptance angle; α. For the green-colored ray with incident angle larger than α. It will refract out of the fiber. To propagate the light along the fiber, the incident angle must be less than acceptance angle (α)

Numerical aperture (NA) is a dimension less number that indicate how easy the incident light can launch into the fiber's core. NA can be expressed as

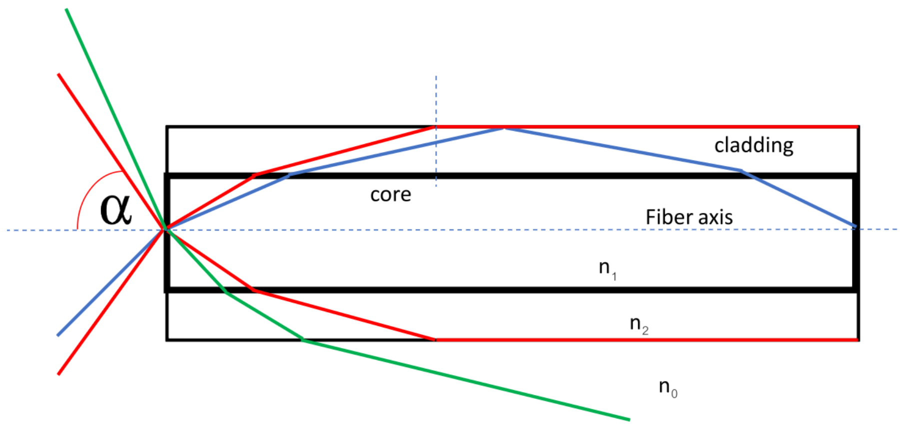

Figure 2.2: Light with incident light is less than acceptance angle (α) can propagate along the straight fiber.

$$\mathrm{NA} = n_0 \sin \alpha \tag{2}$$

where n_0 is refractive index of air (outside the fiber), and α represent the acceptance angle.

2.3 Total internal reflection

Generally, the conventional fiber consists of core and cladding parts as shown in **Figure 2.3**. The inner part of the fiber is a core. The other part is a cladding which surrounds the core.

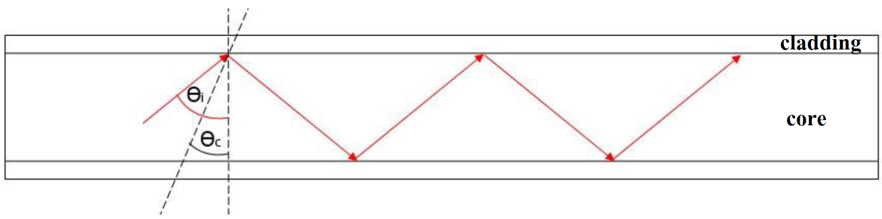

Figure 2.3: Total internal reflection

According to Snell's law, an incident angle that effect to the refracted light propagate along the boundary known as the critical angle. The phenomenon is called internal reflection. To obey the total internal reflection, the incident angle of the light within a fiber must be greater than the critical angle, To propagate light along a fiber, index of refraction of the core must be greater than the cladding also.

2.4 Attenuation loss

In the ideal optical fiber, the light that launched into the end fiber, must be equal to the other end. However, in practically the output light intensity is always less than the input intensity because loss exists between two ends of fiber. The attenuation loss, A , is defined as [**5**]

$$A = \frac{10}{z} \log \frac{I(z)}{I(0)} \tag{3}$$

where z is the length of fiber. $I(0)$ and $I(z)$ are light intensity at the origin and position z, respectively. The attenuation loss come from various causes, those are the absorption band of material, impurity of fiber core, and evanescent loss. Moreover, the attenuation loss can be increased up by increased bending radius of the optical fiber.

The attenuation of a optical fiber based on silicon dioxide (SiO_2) is shown in the **Figure 2.4**.

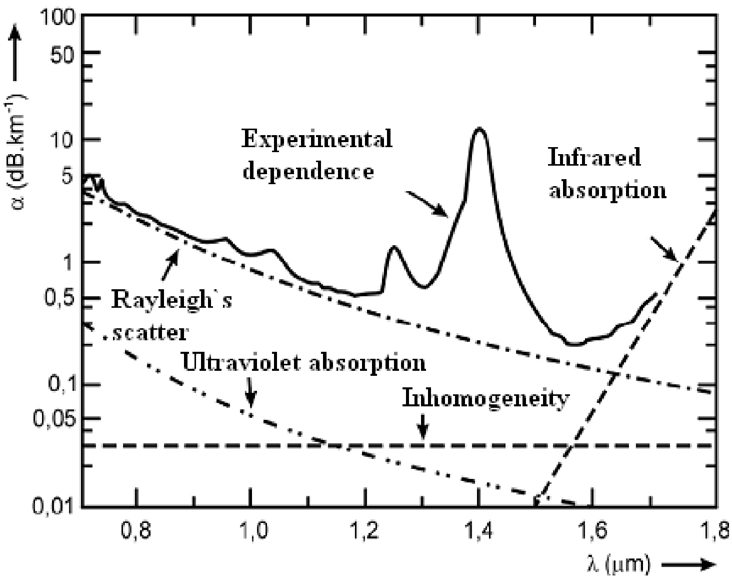

Figure 2.4: Attenuation loss of SiO_2

2.5 Macrobanding and Microbending

Bending of the optical fiber are divided into two categories. These are macrobend and microbend [**6**]. The microbend is come from very small bending radius, less than 1 mm, as shown in **Figure 2.5**. The bending usually happen by external pressing force.

The second one is macrobend. The macrobend of optical fiber is a large bend that can see by human's eye. The macrobend associated with a large

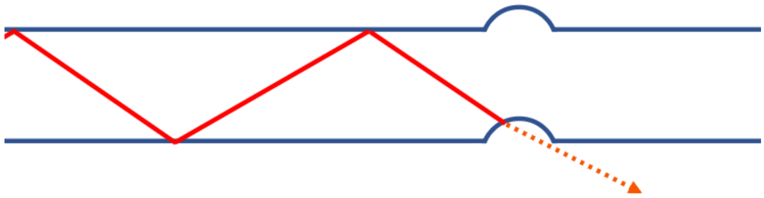

Figure 2.5: Micro bending

radius of bending, and the amount of light that leaked out depend on the bending radius, as shown in **Figure 2.6**.

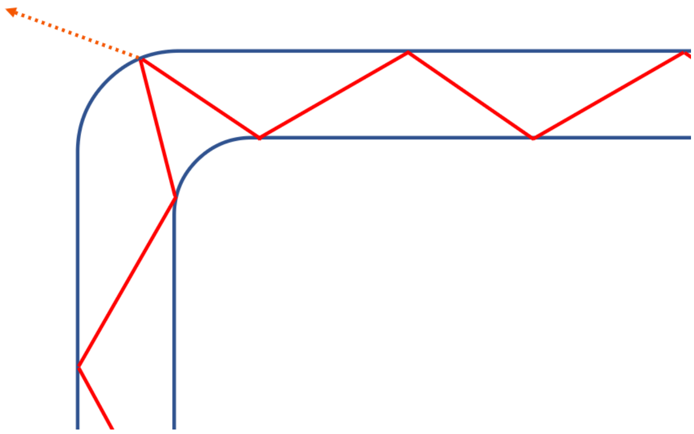

Figure 2.6: Macro bending

3 Methodology

3.1 Equipment

3.1.1 Plastic optical fiber

In this study, the plastic optical fiber (POF) as shown in **Figure 3.1** was used in the optical fiber system because of the advantages of POF such as immunity to electromagnetic wave, light-weight, flexible, low-cost, and high NA value. The NA value of POF is very high compare to the other types of optical fiber. Therefore, the light is easily copling into the plastic optical fiber (POF).

Figure 3.1: Plastic optical fiber

According to the absorption band, the absorption band of an optical fiber is different depended on the materials. In general, the plastic optical fiber absorbed light in the short wavelength.

3.1.2 Super-bright LED

Super-bright LED is a light source which has blue light peak [**Figure 3.2**]. According to the high NA value of the optical fiber, The amount of light can couple into the fiber is ample. The laser can be used as a light source instead of the LED but it is very expensive.

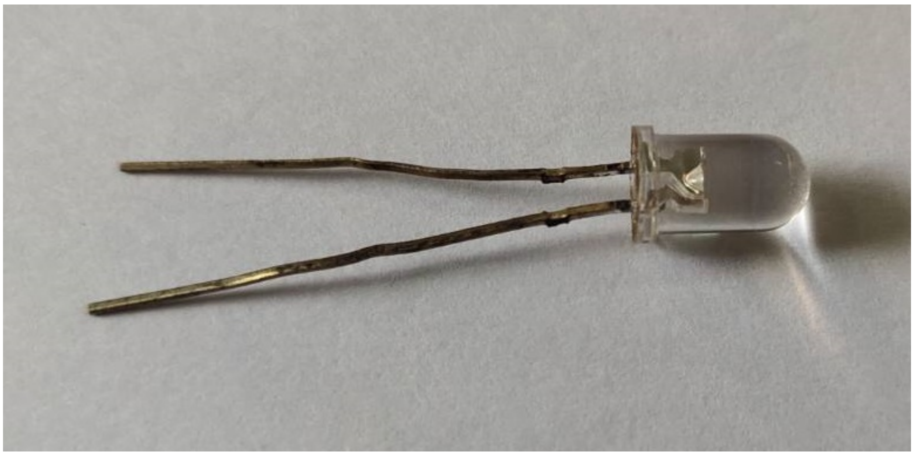

Figure 3.2: Super-bright LED

3.1.3 Photodiode

The photodiode [**Figure 3.3**] and LED are similarly but they play a different important roles. For photodiodes or photoresistor, they are a resistor that their resistance depend on the light fall upon them inversely.

The output intensity at the end of fiber was received by photoresistor. The resistance of photodiode was controlling the voltage in the electric circuit. The different voltage between photodiode and ground obtained using a micro-controller.

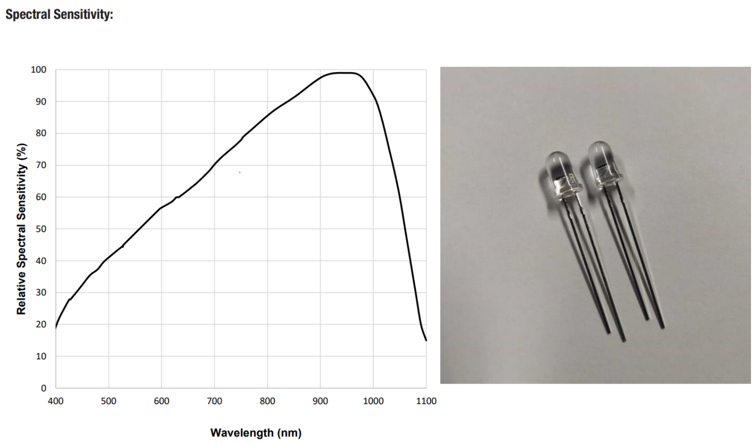

Figure 3.3: Photodiode: the left figure represent the sensity profile of the photo-resister. The photo-resistor is sensitive to the wide range of wavelength, and has a maximum peak at about 940 nm. The right figure is the photodiodes, used in this work.

3.1.4 Arduino Uno board

Arduino Uno [**Figure 3.4**] is a micro-controller with 6 analog pins and 14 digital pins. The Arduino Uno can be powered by connect to computer or AC-to-DC adapter with a USB. The Arduino Uno can be programmed by Arduino Software IDE, Matlab, etc. In this study, a digital pin is used to turn on the LED light source, while the analog pin is used to record the voltage value.

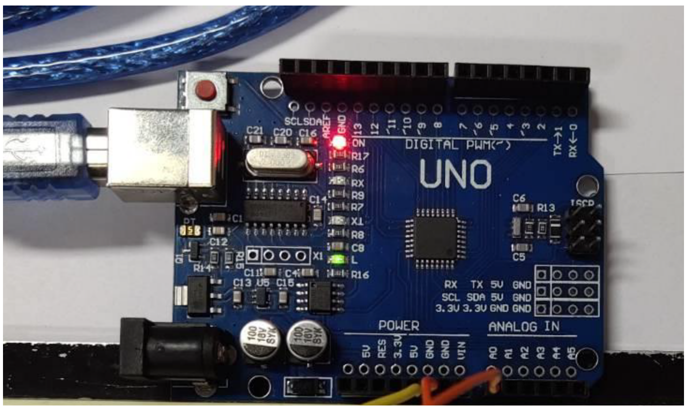

Figure 3.4: Arduino Uno board

3.1.5 Power bank

The Arduino Uno can be powered by the general power bank with 5 Volt output (the Arduino Uno can be operated by driving a few amperes current to it. In this case, the power bank with 5 volt and 1 ampere is used as power supply.)

3.1.6 Resistor

2 Mega ohms resistance was used in the photodiode circuit. According to Ohm's law, the different voltage value at analog pin A0 is directly proportion to the resistance value. Hence the high resistance corresponds to the high resolution of the movement analyzer, which used to determine the angular displacement. Therefore, the magnitude of resistance that make the high different voltage is nearly 5 volt was used in this work.

3.1.7 Bluetooth module HC06

In practical, the movement of a bulk devices in the optical fiber system including computer may not be comfortable to the pétanque player or in the pétanque court for programming the Arduino Uno board and receiving the data. A smart phone or tablet are a good choice for using instead of computer. Hence, the Bluetooth module, as shown in **Figure 3.5** was used to receive the data from Arduino Uno and send it to the smart phone.

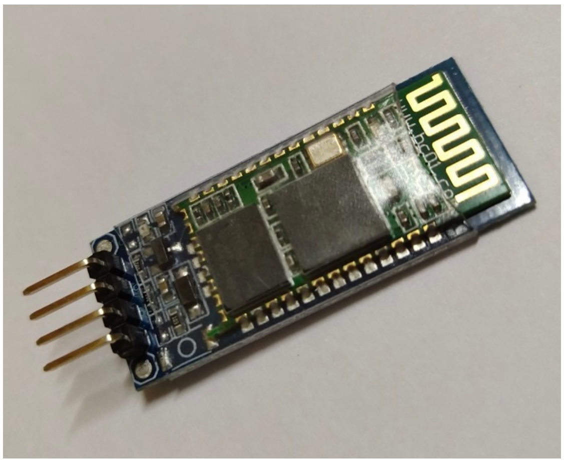

Figure 3.5: Bluetooth module HC06

3.2 Electronic circuit

There are 2 parts of electronic circuit. There are circuits for light source and light detector. For the light source, the circuit is composed of super-bright LED and a resistor connected to a digital pin and ground pin on Arduino Uno board, as shown in **Figure 3.6**.

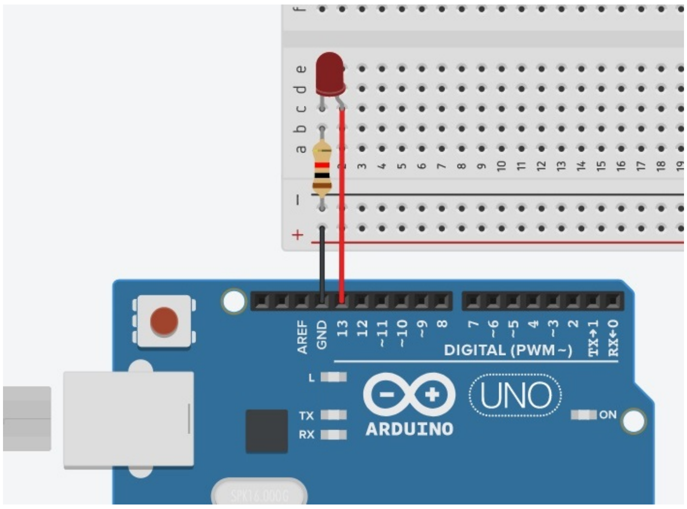

Figure 3.6: Light-source circuit

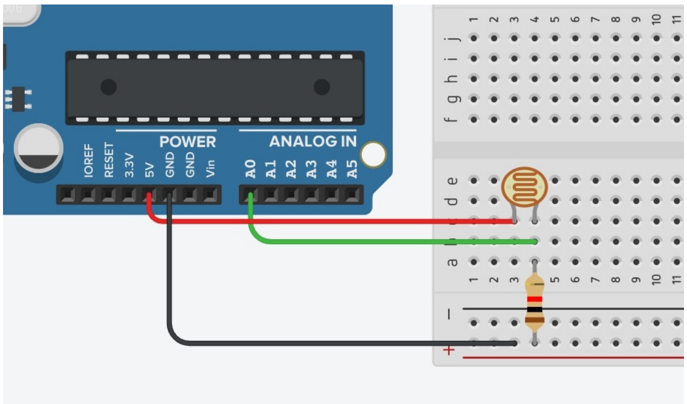

Figure 3.7: Photodiode circuit

In part of light detector or photodiode. It is composed of resistor with resistance 2 MΩ and photodiode which connecting to 5 Volt and ground pin. For read the different voltage, an analog pin was connected to the circuit at location between resistor and photodiode [**Figure 3.7**]. Indeed, both of the circuits was connected to the same Arduino Uno board, as shown in **Figure 3.8**.

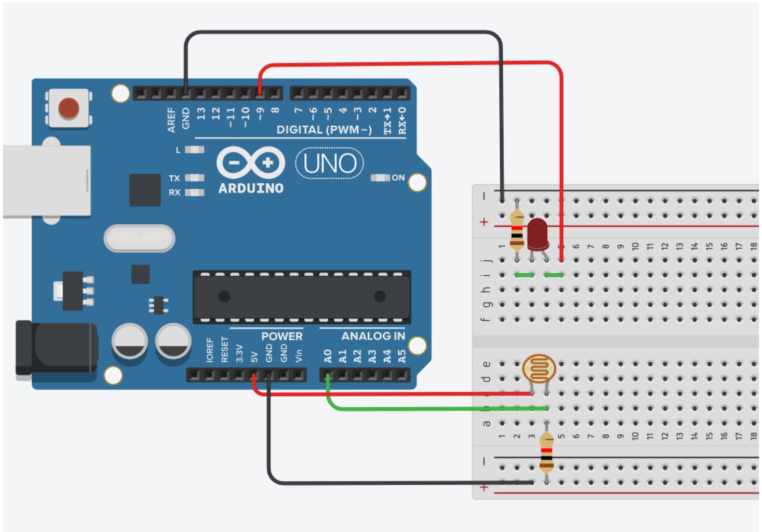

Figure 3.8: Two parts of electronic circuit are connected to the same Arduino Uno

3.3 Programming Arduino Uno

In this work, the Arduino Software IDE was used for programming the Arduino Uno [**Figure 3.9**]. The code of Arduino program was usually divided into two parts. First part was void setup which ran just one time, while the another part was void loop which ran and rerun again. In void setup, some components of Arduino (digital pin and analog pin) was given. In void loop, the analog pin was read and monitor, and the components was set to high or low.

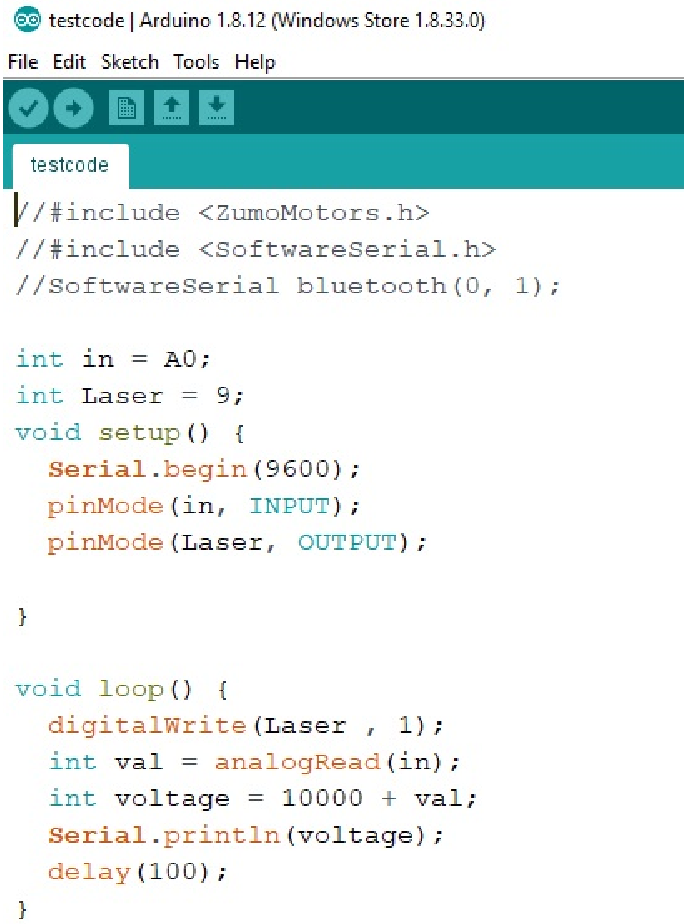

Figure 3.9: Code in Arduino IDE

In this case, analog pin A0 was set to be input, while The digital pin 9 was set to high for turn on the LED light source.

3.4 Coupling the connector created by 3D printer

According to POF bending sensor, the transmitted intensity was measure to monitor body movement. An amount of light falling upon the photodiode correspond to the resolution of the movement analyzer, to determine the angular displacement. Nevertheless, an amount of coupling loss occurs at two joints, the light source (LED and fiber) and the light receiver (fiber and photodiode). Hence, to reduce the coupling loss, the connectors was designed by Tinkercad website and printed by 3D printer shown in **Figure 3.10**.

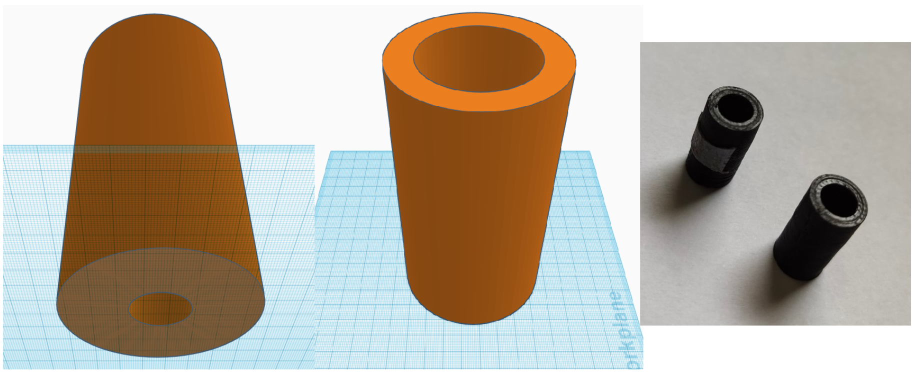

Figure 3.10: Left: Design connector with 3D printer and Right: coupling connector printed using 3D printer.

The two black connectors was connected between two each end of POF tip to support the coupling of light [**Figure 3.11**].

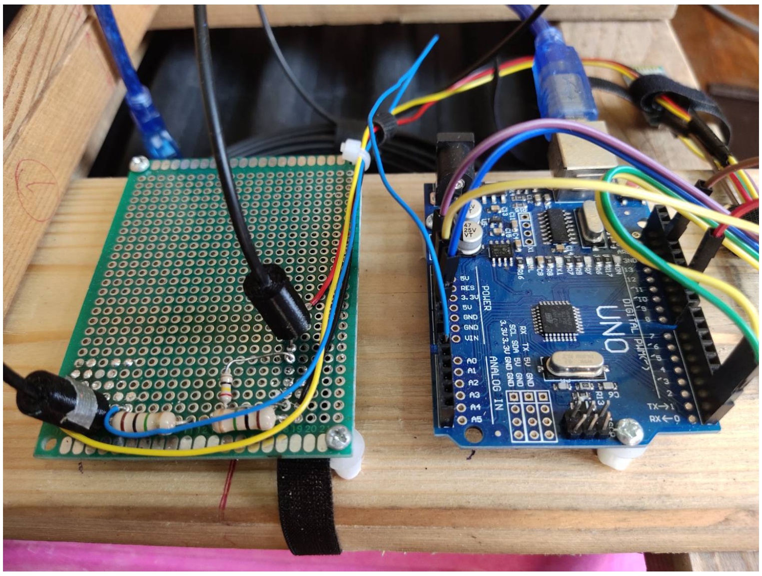

Figure 3.11: Connect the fiber to LED and photodiode by two connectors.

3.5 Prototype of hardware

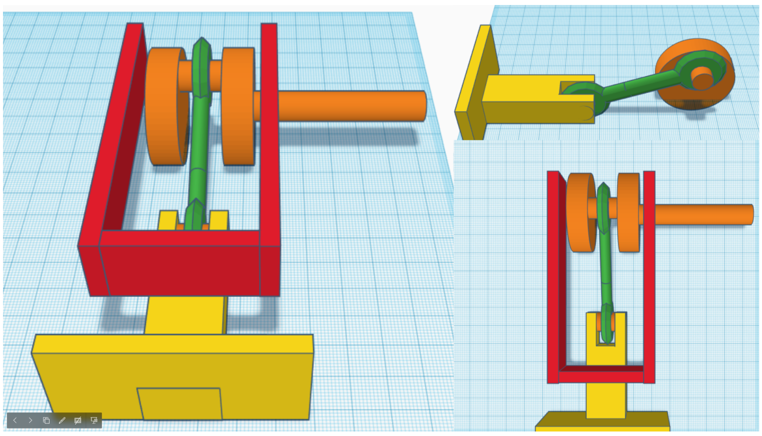

Figure 3.12: Mechanical for fiber system

In of **Figure 3.12**, left figure, the fiber placed between the red and yellow plate, which parallel to each other. The red plate was fixed while the yellow plate was movable. When the yellow plate was moving closed to the red plate the bending radius of POF was decreased. Result in the transmitted intensity was decreased also. The two plate were controlled by the orange wheel and the green rod. The orange wheel was also controlled by athlete's arm.

By using the model of two plates. The prototype of movement analyzer was created, as shown in **Figure 3.13**.

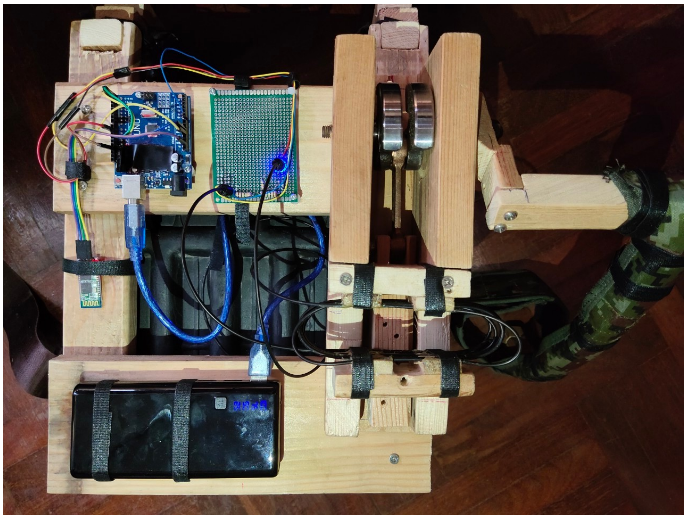

Figure 3.13: The prototype of movement analyzer

3.6 Application on a mobile phone

In this study, the smart phone was used to record and display the data from the Arduino Uno instead of the computer. The application was created on **MIT App inventor website**. This application can receive the data and plot the graph, as shown in **Figure 3.14**

The application can also show the comparison of each movement on the same screen display to compare with the reference movement (right hand of the **Figure 3.14**).

Figure 3.14: Displaying platform created by application on smart phone-The left figure is the home page of an application for showing all movement files that recorded as reference pattern. The middle figure shows how to record and display the movement between Voltage and time. : The right figure shows the comparison of a two movement..

4 Discussion

In the previous property, the properties of plastic optical fiber was discussed. The important is the absorbance band of POF. The POF can absorb visible-light in short wavelength (less than 700 nm [7]). So, the LED in UV wavelength range should be avoided. The proper wavelength range that suitable to the plastic fiber is the red light up to near infrared. In this study, the blue Super-bright LED was used as a light source. Although, the blue super-bright provides a short wavelength peak. The super-bright LED are still cover the proper wavelength for POF; red light up to near infrared. Moreover, the LED is providing the high output intensity, result in a high resolution of the movement analyzer. In the light source circuit, the resistor should be low magnitude, because the photodetector required the light brightness of the LED.

The macrobending play as an important role to measure the angular displacement of athlete. The proper range of the bending radius used to determine angular display must is about less than 1.5 centre-meters [7] [**Figure 4.1**].

The pétanque athlete must to swing the arm in both backward and froward way, with the range about 180 degrees. So, the maximum bending radius (about 1.5 cm) or maximum transmtted light was set to the most

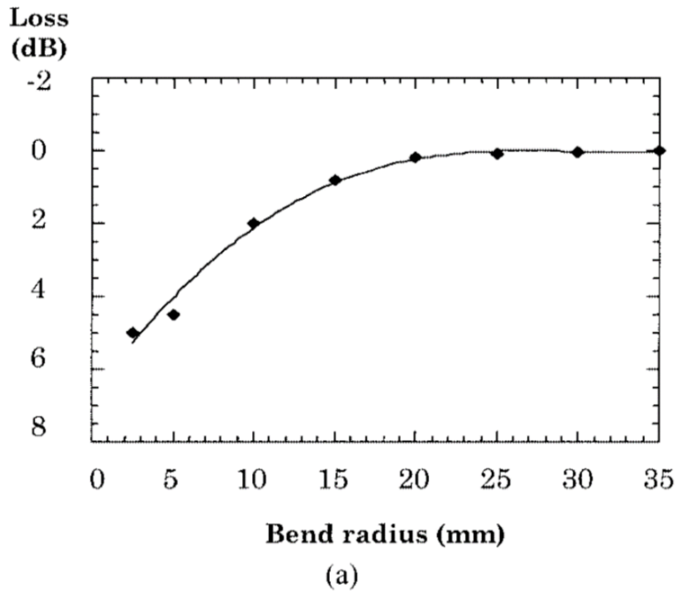

Figure 4.1: The relation between Loss and bending radius

backward swing, while the minimum bending radius or minimum transmitted light was set to the most forward swing.

This prototype is mainly made from wood and metal. Therefore, The weight is too large to install on an athlete. The alternative materials should be used instead of these such as plastic by using the 3D modeling and 3D printer. However, there are an accident about COVID-19, the process have to stop, result in the relation between transmitted intensity or voltage and angular displacement had not finished yet.

The graph on the application show the relation between voltage and time. Even though, the movement analyzer cannot describe the angular displacement in real-time now, but the movements of an athlete can be analyzable and comparable by the voltage pattern.

5 Conclusion

According to the advantages of the optical fiber such as light-weight, immunity to electromagnetic wave, and low-cost, the plastic fiber optic is used to design a movement study for athlete's pétanque.

The bending loss is main point for this study. In this study, the arm's movement of pétanque athlete is measured by the optical fiber system. The movement analyzer is very useful not only pétanque but also other sports. The movement analyzer can used to support and develop an athlete performance by recording the movement pattern. Then, compare to the suitable movement.

To design the swing arm movement analyzer, The POF must to be sense to the athlete arm's movement. The bending radius is greater than 2.0 cm is not affect to bending loss for plastic optical fiber. Hence, the range of bending radius of fiber must be set to less than 1.5 cm.

In this semester, the movement analyzer is not complete because the COVID-19. However, the movement analyzer can be improved by choosing the alternative materials which are light-weight, and reduce the size of the movement analyzer for suitable to install on a athlete.

References

[1] Nick Massa, "Fiber Optic Telecommunication" in FUNDAMENTAL OF PHOTONICS, p. 293-347, 2000

[2] G.M. Salim and M.A. Zawawi, "Knee joint Movement Monitoring Device Based on Optical Fiber Bending Sensor".

[3] A Arifin, A K Lebang, M Yunus, S Dewang, I Idris and D Tahir, "Mearsurement heart rate based on plastic optical fiber sensor", 2018.

[4] Hariyanti, Kresna Devara, Fitriyanti Nur Aisyah, Ketut Vanda Aryanthera Wisnu Nadia and Retno Wigajatri Purnamaningsih, "Design of a wearable fiber optic respiration sensor for application in NICU incubators", 2019.

[5] Kádár Ondrej, Electrotechnika, "Modern telecommunication optical fibers", 2010.

[6] John A. Jay, "An Overview of Macrobending and Microbending of Optical Fibers", December 2010

[7] Joseba Zubia and Jon Arrue, "Plastic Optical Fibers: An Introduction to their Technological Processes and Application", 2001