KINETICS AND KINEMATICS DETERMINATIONS OF MARTIAL ARTS PERFORMERS USING 3D MOTION CAPTURE CAMERA

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by

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Ahmad Afiq Sabqi Awang Soh

Pulau Pinang, Malaysia

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF EQUATION

Page

LIST OF ABBREVIATIONS

CMA	Cortex Motion Analysis Software
FF	Frame Factors
MOCAP	Motion Capture
PB	Punching Bag

PENENTUAN KINETIK DAN KINEMATIK PERSEMBAHAN SENI MEMPERTAHANKAN DIRI MENGGUNAKAN KAMERA PERAKAM GERAKAN 3D

ABSTRAK

Kamera Perakam Gerakan adalah proses merakam pergerakan kejadian sebenar melalui komputer. Banyak penyelidikan telah dilakukan untuk memperluaskan penggunaan kamera gerakan optik ini dari animasi, pengawasan, mekanik sukan dan klinikal. Melalui penyelidikan ini, sistem MOCAP terus meningkat setiap tahun dalam pengunaan media seni kepada peralatan berteknologi tinggi yang digunakan dalam pelbagai bidang. Untuk menguji ketepatan sistem ini, satu sistem teknologi perantaraan MOCAP digunakan untuk mengukur gerakan dinamik pesilat dan bukan pesilat. Prosedur operasi standard (SOP) telah dibuat untuk menyeragamkan pengukuran. Menggunakan sistem MOCAP yang dibekalkan oleh Analisis Pergerakan, perisian Analisis Cortex Motion (CMA) dan kamera optik Osprey telah digunakan. 5 pelakon yang berpengalaman dalam latihan seni mempertahankan diri (N 'profesional', Z 'pertengahan', H 'pertengahan') dan yang tiada pengalaman dalam latihan seni mempertahankan diri (S dan A). Pengukuran telah dilakukan mengikut SOP yang dibuat mengikut kajian terdahulu. Dibahagikan kepada 5 bahagian protokol itu adalah dari nombor protokol 1. Pembinaan MOCAP, 2. Pengujian ketaksempurnaan, 3. Penilaian Fizikal, 4. Kedudukan marker kepada nombor protokol 5. Rakaman Pergerakan. Pukulan silang setiap pemain telah direkodkan dan dianalisis dengan menggunakan perisian OriginPro untuk merancang grafik. Melalui penyelidikan yang dilakukan, faktor bingkai (9 FF) dan penapis ralat

(Butterworth filter '6 Hz') dianggap sebagai prioriti utama yang akan memberikan hasil yang lebih baik dan lancar. Keputusan menunjukkan bahawa sistem MOCAP mempunyai peratusan ralat yang rendah iaitu $<1\%$ (sangat tepat). Mengikut urutan menaik daya tumbukan yang dihasilkan oleh pelakon-pelakon berkenaan menunjukkan N > Z > H > A > S. Lebih-lebih lagi, dari kajian ini ianya mungkin untuk menggunakan teknologi ini untuk menetukan daya pukulan dan untuk digunakan dalam pertandingan tempur dengan bantuan mekanik klasik.

KINETICS AND KINEMATICS DETERMINATIONS OF MARTIAL ARTS PERFORMERS USING 3D MOTION CAPTURE CAMERA

ABSTRACT

A motion Capture camera is the process of recording movements of real-life through a computer. Many studies have been conducted to broaden the use of this optical motion camera such as in animation, surveillance, sports mechanics, and clinical applications. MOCAP system is constantly being upgraded throughout the year, from media arts applications to more cutting-edge technology applications ensuring that this technology will never become obsolete. Hence this main objective was put to test in measuring the performer dynamic movement using MOCAP by introducing SOP with the help of physics classical mechanics. To test the accuracy of this system, an intermediate tech system of MOCAP is used to measure the dynamic motion of martial artists (silat) and non-martial artists. A standard operating procedure (SOP) was created to standardize the measurement. Using MOCAP system supplied by Motion Analysis, Cortex Motion Analysis (CMA) software and Osprey optical camera is used. 5 performers with experience in martial arts training (N 'professional', Z 'Intermediate', H 'intermediate') and non-experience in martial arts training (S and A). Measurement was done according to the SOP created according to another previous research. Divided into 5 parts the protocol was followed from the first protocol which is a construction of MOCAP, the second protocol is accuracy Testing, 3. Physical Evaluation, 4. Marker Placement to protocol number 5. Motion Recording. A cross punch of each performer was recorded and

analyzed using OriginPro software for plotting graphs. Through the research done, frame factors (9 FF) and filters (Butterworth filter '6 Hz') are considered as a high priority which will give a better and smooth result. The result shows that the MOCAP system has a very low percentage of error which is << 1% (very accurate). The position of increase in force applied by the performer shows N > Z > H > A > S. Moreover, from this research, it is possible to make use of this technology for scaling of force punch and to use it in the combat competition with the help of classical mechanics.

CHAPTER 1
INTRODUCTION

1.1 Overview

The animation starts by drawing in the paper, then a 2D animation as the computer rapidly evolved and nowadays-3D animation and graphic movies are something that become trending to this 20th century. Hence, the existence of motion capture where they use a lot in the movie animation or what they called the technique as Computer Graphic Imitation (CGI) (Kehr Dave, 2021). It is a method of using computer to make an impossible action become possible in scene. To fulfil this sensation, computer graphic and motion capture (MOCAP) is the best current tech that can make it happen. This technology keeps upgrading to follow the needs of latest generations.

Motion Capture (MOCAP) camera most known and used in animation and movie clips. It is the process of recording life or real-time movement of an object or people. The development and improvement of its application been driven by the capability and wide use of this technology. In the past decade, scientists have done various ways to expand the function of motion capture. Not limited to the area of expertise, MOCAP is use by researchers that came from the various disciplines such as biomechanics, sportsmen, anthropologies, animations, media arts, and hospital where they use MOCAP for patients to perform physiotherapy (Marýn et al., 2019).

For a clinical MOCAP, they used for patient diagnostic in rehabilitation centre who has a development disabilities or movement disorders such as, Parkinson’s disease, autism, or brain spinal cord injuries. MOCAP can help the physician to understand more the motion of the patient during the treatment progress (Marýn et al., 2019). So, it can give more accessible a throughout the treatment and can reduce the treatment cost and time. Same goes to the sports and performance of an athlete’s where MOCAP can improve their training. Also, coaches can monitor athlete performance from the reproducible 3D data recorded by the MOCAP technology (Martin et al., 2014).

Silat is a Malay Archipelago-based fighting art of self-defence and survival (Kamus Dewan Bahasa dan Pustaka Edisi Keempat, 2017). Silat has evolved into a great practise of physical and spiritual training that includes traditional Malay dress, Silat musical instruments, and ceremonies dating back to the early days of the Langkasuka Kingdom. Silat comes in a variety of styles, each influenced by human anatomy, nature, and animals. Silat Harimau, for example, incorporates an attractive rhythmic motion that imitates the technique of tiger self-defense and attack. There are around 150 Silat styles in Malaysia alone, with names derived from natural elements such as animals and plants (UNESCO, 2018)

1.2 Research Problem

In Malay world martial arts Silat is not a foreign thing to the present generation, but nowadays a question is often being asked whether this martial artist has more power in his or her punch compared to other martial artist. Recent discussion has led to many ideas and conclusion, but they cannot proof. A debate always occurs when someone post or declare that a lightweight MMA fighter can throw a punch same as heavyweight MMA fighter. As a result, the aim of this study is not to prove whether the strike from the Silat performer is the strongest or not, but to demonstrate MOCAP's ability to provide such data.

MOCAP is a powerful technology with a wide range of applications. To add to the issue, by wondering if MOCAP can be used in fighting martial arts sports. Begin with the research by testing the limitless of this technology in measuring the simple kinetics of martial arts movement. MOCAP can give various view simultaneously such as real-time virtual movement and kinetics and kinematics movement analysis. Depend on the software which is in this research CORTEX compatible with the MOCAP, it is built specifically for biomechanics also MOCAP raw data can be read by other software such as 3ds MAX by Autodesk.

Physics classical mechanics is used to calculate the kinetics of a martial artist without the help of other machine such as force plate and accelerometer. Moreover, to proof whether the kinetics of a martial artist can be determined by using only MOCAP system. Since optical data needs a lot of post-processing time, the contribution of classical mechanics in physics helps to speed up the whole process. Optical data represent the position of a marker detect by the camera. From the position acquired, kinetics of an object detected can be determined using classical mechanics as the position of that object change according to newton’s law (Halliday et al., 2014).

Meanwhile, previous studies have shown the output power of human body, not limited to hand punch only but the whole-body parts. Although they have shown the result, but most of them 100% rely on the mechanical and tools of measuring. Most of them also failed to show the standardization or validation of their measurement. How much reliable are their tools and method also each study shows a different range of force punch by group of athletes.

1.3 Thesis Objective

The main objective in this research is to study the movement kinetics and kinematics of a martial artist using 3D motion capture. Specifically, this study aims to:

a) Use a new protocol (SOP) for standardizing the measurement of dynamic motion using MOCAP and introduce accuracy testing method.

b) Determine the force punch of performer using MOCAP tools.

c) To validate the protocol conducted and kinetics determination using the classical mechanics theory.

1.4 Scope of Study

Scope of study involve in this research is the computer–human Interaction and Physics Biomechanics. Computer – Human interactions means that the uses of computer intelligence (MOCAP) to study or understand the human motion. Example of the human movement in this research is movement of a martial arts performer where they will perform a dynamic motion (punching and kicking). MOCAP will provide data that can be used to measure and determined the dynamic motion. Physics biomechanics will take part when calculating the force generated by using classical mechanics theory and formula.

1.5 Thesis Outiline

Including physics in this project will play a significant role in the research as well as serve as a link between Mocap and researchers. The recording from the MOCAP will be analyse and explain by using physics classical mechanics. A previous study and application of MOCAP, classical mechanics known as the best theory at explaining a kinetics and kinematics of a rigid body will be discussed in Literature Review - chapter 2. Methodology which consists of new protocol on how to effectively use the MOCAP system for human movement motion will be discuss in Methodology - Chapter 3. This protocol is made to standardize the MOCAP application in research area. For the animation sector, this kind of protocol is not needed since they are not giving or measure a certain data. In research area such as biomechanics, the precision and reliable data is important where the protocol is needed. Chapter 4–Data Analysis and Discussion is the most important section, in which data accuracy and measurement results for all performers will be presented and discussed. Also, the factors that related to the change in measurement were discussed in this chapter. Conclusion - Chapter 5 will provide the compilation of the flows for this research and its outcome. Also, in this chapter the possible future work will be describe briefly.

CHAPTER 2
THEORETICAL BACKGROUND AND REVIEW

2.1 Theoretical Physics

This chapter will be discussed about the theory of classical mechanics related to the application in this research. Classical mechanics never disappointed in explaining a rigid body movement. Scientists can describe the velocity of a ball flying through the air and the pull of a magnet using only a few equations, as well as predict lunar eclipses. Classical mechanics is the mathematical study of the motion of common things and the forces that impact them (Coolman, 2014). Classical mechanics is sometimes known as Newtonian mechanics because it is based almost entirely on Isaac Newton's work. The following are some of the mathematical laws and principles at the heart of classical mechanics. In this chapter, a literature review of other research work reported in the journal which related to this project also will be discussed.

2.1.1 Classical Mechanics

Classical mechanics also known as the Newtonian mechanics started by the well-known physicist and mathematician **Sir Isaac Newton** in (1642-1726). His book *'Mathematical Principles of Natural Philosophy'* first published in 1687 which is the foundation of classical mechanics (*Force | Definition & Formula | Britannica*, 2020.). It concerns to the physical laws which describe the motion of a bodies under the influence of other forces. Although it is the oldest study of motion studies, its application never gets old since it is the largest area in science and technology. Kinetics and kinematics are a branch of classical mechanics which will be described below.

Kinetics explained the relationship of an object motion and it causes for example momentum, forces, and torques. Forces will give change to the motion of an object with mass, m. In biomechanics, kinetics is one of main component in analysing the ‘centre of pressure’ which are the application of ground reaction force vector. It is a common study on human postural and gait analysis. A change in motor control may change the posture and gait of a human.

According to Newton’s second law of motion (equation 1 below), the magnitude of the force (F) must be directly proportional to both mass (m) of the body and its acceleration (a). Acceleration is measure by meters per seconds squared, a=ms^{-2}. An explanation is important concerning why the acceleration is measured as ms^{-2}. Taking the following mathematical expressions for average acceleration, which is states $\boldsymbol{a}$=dv/dt. Acceleration can be positive or negative. An increase is considered positive, and a decreased in speed is considered negative. The negative acceleration or slowing down also called deceleration.

$$Force\ (\boldsymbol{F}) = mass\ (\boldsymbol{m}) \times acceleration\ (\boldsymbol{a}) \tag{1}$$

Kinematics describes the motion of a bodies without the consideration of the cause of their motion. It is sometimes referred as the geometry of motion in a system. Most used in astrophysics to describe the motion of celestial bodies or in mechanical engineering for a robotics and biomechanics application.

Distance and displacement are quantities measure in meters and kilometres and Different in measurements. For example, from point A to point B, distance covered is by following the path of the distance covered. The length of displacement is measured from point A to point B using a straight line. If an athlete covers a distance from A to B and B point is the same with point A at the return, then the displacement is equal to “0” meters. Figure 2.1 below demonstrates the difference between distance and displacement. [In martial arts, distances and displacements have less importance but the time of the execution of the attacking arm which obviously covers a very short distance (Arus, 2012).

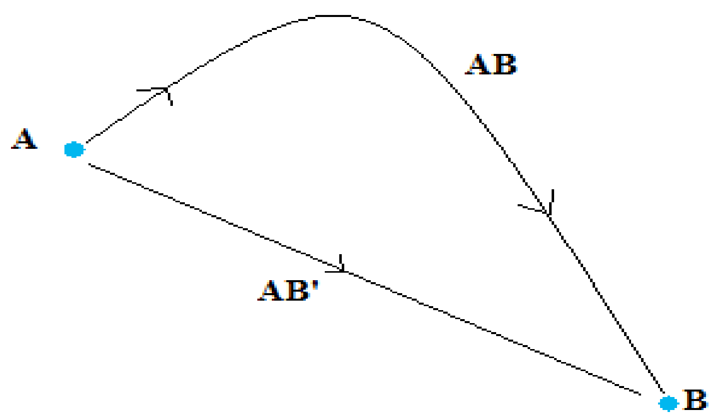

Figure 2.1. The differences between distance and displacement.

Speed and Velocity are often spoke or used in sports terminology. Speed is related to the distance covered in each time, while velocity includes the magnitude and the direction of this movement. Speed and velocity are common concepts or terms in martial arts that are measured in units of length per time, such as meters/second (m/s). Velocity is a vector quantity, which is the rate change of displacement with respect to time.

Imagined and object with mass, m moves from point A to point B (figure 2.1) where AB' = 20 m with time taken Δt

The velocity is expressed by the following formula:

$$\boldsymbol{v} = \frac{\Delta \mathrm{d}}{\Delta \mathrm{t}} \tag{2}$$

v = velocity, d = displacement, and t = time

For example, an athlete who runs at 1000 m, their speed varies during the time of running. The shorter time taken for the runner to cover the distance, then the speed run is higher. In martial arts, the speed has the most importance factor in any technical execution. However, the factor of speed is negligible if the athlete has less force to sustain the speed and ultimately the acceleration. In martial arts, the result of the speed and the force are the key factors for achieving victory.

Acceleration is rate change of the velocity, which means that acceleration tells us how fast the velocity is changing. An object can have a large velocity and zero acceleration and vice versa. Whenever a body is acted upon by an unbalanced force it will undergo acceleration. If a body is moving in a constant straight direction, the force which is acting upon it will produce shortly a change in speed. The acting force may produce a change of speed and change of direction. In general, to produce acceleration, a force must be applied to the body.

Acceleration is expressed as the differentiate value of velocity:

$$\boldsymbol{a} = \frac{\Delta \boldsymbol{v}}{\Delta t} \tag{3}$$

Where a = acceleration, Δv = change in velocity, and t = time

2.1.2 Energy of a System

Concept of energy is one of most important courses in science and engineering. Most people think that energy is in term of electricity, heating, or fuel. The food that was eaten generally will give us the energy, but it does not truly define energy. Energy present in many forms and every physical process in the universe involves energy. Energy cannot be created or destroyed, and it can only be transformed from one to another. The example of energy transfer is combustion (oil, gas, or coal) involve a heat energy transfer and organisms consume nutrient which involved chemical energy.

When an organism consumes a nutrient, will transfer to chemical energy, and transfer again to mechanical energy. Transformation of energy can be related to anything even sound is recognizing as the energy change from the source of energy. For example, a ball bouncing on the floor will have the potential energy to be converted to energy of a momentum and sound.

Energy present in various forms in this universe and every physical process occurs involves energy and energy transfers. There are two types of systems, which are non-isolated and isolated system. In this research, the non-isolated systems are considered where the investigation shows the ways that energy can cross the boundary of the system which lead to change in total energy of the systems. Energy cannot be created or destroyed, but it can transform from one form to another. For example, a stick of dynamite chemical energy converted to kinetic energy which produce a huge blast.

Conservation of momentum is very important in explaining the collision of two object. Since this project will show the impact of two object which is hand and a punching bag, hence this conservation is crucial to applied in the data analysis. Figure 2.2 below shows the example of conservation of momentum.

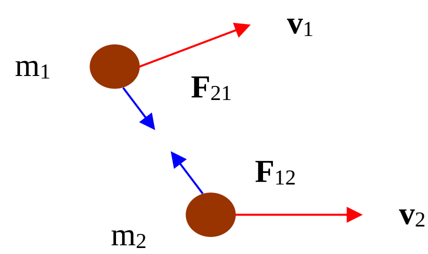

Figure 2.2. Two particles with mass, m and velocity, v

Consider two particles in the isolated system, with masses m_1 and m_2 with velocities $\mathbf{v}_1$ and $\mathbf{v}_2$, the first particle acts on second particle create second force that is equal in magnitude but opposite in direction.

According to Newton's third law,

$$\mathbf{F}_{12} = - \mathbf{F}_{21} \quad \text{or} \quad \mathbf{F}_{21} + \mathbf{F}_{12} = \mathbf{0}$$

By replacing the force on each particle with m**a** using Newton second law from equation (1), it gives:

$$m_1\mathbf{a}_1 + m_2\mathbf{a}_2 = 0 \qquad (4)$$

$$m_1(\frac{dv_1}{dt}) + m_2(\frac{dv_1}{dt}) = 0$$

With the constant masses m_1 and m_2, the derivatives operation gives,

$$(\frac{dm_1v_1}{dt}) + (\frac{dm_2v_2}{dt}) = 0$$

$$\frac{d(m_1 v_1 + m_2 v_2)}{dt} = 0$$

The sum of the quantity m**v** for an isolated of particles is conserved. Hence, this quantity called linear momentum.

The linear momentum of a particle or an object can describe as the product of the moving mass, m with a velocity, **v** of the particle.

$$\mathbf{p} = m\mathbf{v} \qquad (5)$$

Linear momentum is a vector quantity with dimensions ML/T and SI unit kgm/s.

If a particle is moving in an arbitrary direction, p has three components known as:

$$\mathbf{p}_{(x,y,z)} = m\mathbf{v}_{(x,\, y,\, z)}$$

From the momentum definitions, equation (i) can be written as:

$$d/dt\,(\mathbf{p}_1 + \mathbf{p}_2) = 0$$

The total momentum of the isolated system of the two particles must be constant because the time derivative of the total momentum $\mathbf{p}_{tot} = \mathbf{p}_1 + \mathbf{p}_2$ is zero.

$$\mathbf{p}_{tot} = \text{constant}$$

Or

$$\mathbf{p}_{1i} + \mathbf{p}_{21} = \mathbf{p}_{1f} + \mathbf{p}_{2f}$$

where $\mathbf{p}_{1i}$ and $\mathbf{p}_{2i}$ are the initial values and $\mathbf{p}_{1f}$ and $\mathbf{p}_{2f}$ are the final values of the momentum for the two particles.

The total momentum in the x, y and z directions are all independently conserved known as the law of the conservation of linear momentum.

$$\mathbf{p}_{1i(x,y,z)} + \mathbf{p}_{21(x,y,z)} = \mathbf{p}_{if(x,y,z)} + \mathbf{p}_{2f\,(x,y,z)}$$

The conservation of momentum can be stated as when the total momentum of the system remains constant whenever two or more particles in an isolated system interact.

In the other hand, the total momentum of an isolated system equals to its initial momentum. The momentum of a particle changes if only there is a net force acts on the particles.

According to Newton's second law, $\Sigma\, \mathbf{F} = d\mathbf{p}/dt$ or

$$d\mathbf{p} = \sum \mathbf{F} dt$$

The change in the momentum from $\mathbf{p}_i$ to $\mathbf{p}_f$ of a particle when the force applied over time t_i to t_f need to integrate as:

$$\Delta\mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = \sum \mathbf{F}\, dt$$

The right side of this equation called the impulse of a force.

$$\mathbf{I} = \int \sum \mathbf{F}\, dt$$

The impulse, I is a vector unit. The force varies in time and nonzero in the time interval $\Delta t = t_f - t_i$. The impulse vector is the same direction of the change in momentum.
The impulse-momentum theorem known as the change in the momentum of a particle that is equal to the impulse of the net force acting on the particle.

$$\Delta \mathbf{p} = \mathbf{I} \tag{6}$$

In Physics, SHM is very common in understanding the conservation of energy where the restoring force is directly proportional to the displacement. It can assist as mathematical model for variety of motions such as the oscillation of spring, a simple pendulum and molecular vibration. Motion of a particle or a rigid body with mass, m that moving along a straight line toward a fixed point with an acceleration and a magnitude that is proportional to the distance from fixed point is called the simple harmonic motion or simple harmonic oscillator. The red line represents the applied force, F versus the elongation, x of a helical spring according to Hooke's Law and the actual plot might look like the dashed line. At the bottom of the picture is a spring states corresponding to the force applied and the one in the middle is in relaxed state.

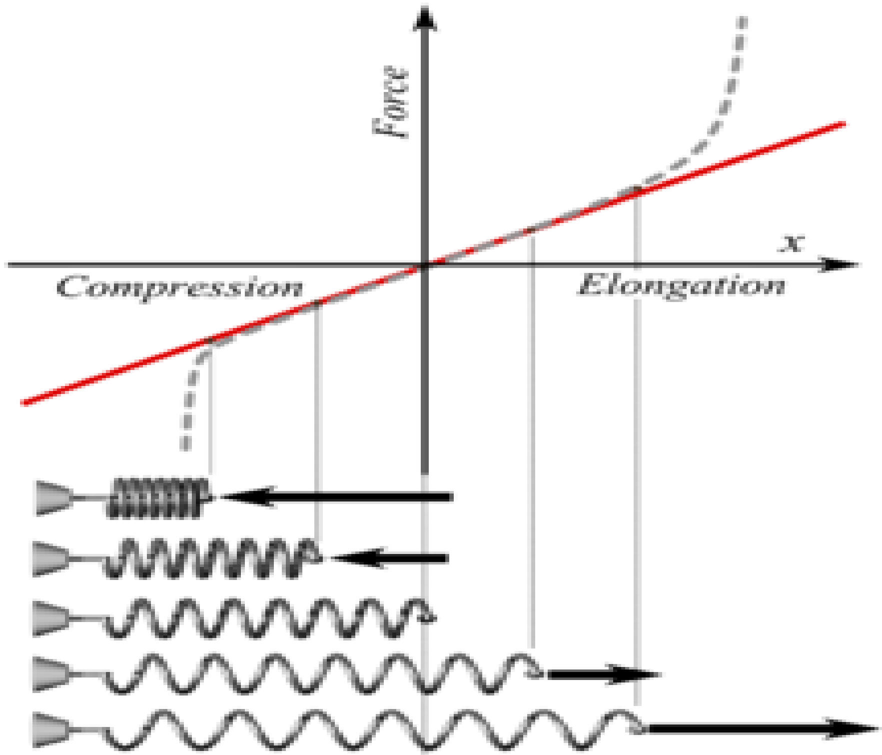

Figure 2.3. Plot of applied force F vs elongation x for a helical spring (*Hooke's Law | Boundless Physics*, 2021)

For this research, SHO model was considered as a pendulum. Hooke's Law stated that:

$$F = -kx \quad (7)$$

F = is the force applied

K = Hooke's constant

X = displacement

Figure 2.3 shows that acceleration of the bob pendulum is always maximum at the end of oscillation. In Newtonian mechanics, a 1-dimensional SHM and its equation of motion can be obtained.

$$\mathbf{F} = \frac{\mathrm{md^2x}}{\mathrm{dt^2}}$$

Where m is mass of oscillating body.

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

And oscillation of a mass, m will create a sinusoidal function of displacement through time,t. Hence by solving the differential equation will gives

$$\mathrm{x(t) = Acos(\omega t - \varphi)}$$

Where,

$$\omega = \sqrt{\frac{\mathrm{k}}{\mathrm{m}}} \qquad \text{(i)}$$

Since $\omega = 2\pi f$ and using equation (i)

$$\mathrm{f} = \frac{1}{2\pi}\sqrt{\frac{\mathrm{k}}{\mathrm{m}}}$$

And $\mathrm{T} = \frac{1}{\mathrm{f}}$

$$\mathrm{T} = 2\pi\sqrt{\frac{\mathrm{m}}{\mathrm{k}}} \qquad \text{(ii)}$$

These equations demonstrate that SHM is isochronous (period and frequency are independent of amplitude and initial phase of motion). When a pendulum swing, it accelerate centripetally and the centripetal force is equal the tensional force,**T** created from the rope. The force of motion, **F** is tangential to the tensional force, T as shown in Figure 2.4 below:

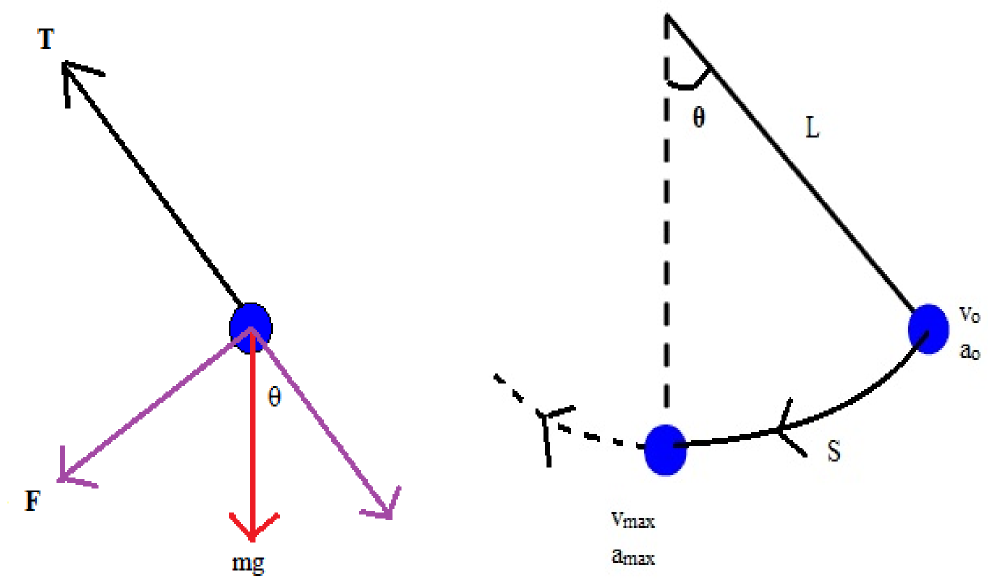

Figure 2.4. Diagram of a pendulum

Force, **F** is a vector component of bob weight, hence:

$$\mathbf{F} = mg\sin\theta$$

Compared to the Hooke's Law

$$\mathbf{F} = -kx$$

$$mg\sin\theta = kx$$

Neglect the negative sign since it only shows the opposite direction of force and movement and displacement, x is equal to the arc length or distance travel by the pendulum, S. Geometrically, the arc length is directly proportional to the angle, θ.

$$S = L\theta$$

$$mg\sin\theta = k(L\theta)$$

$$k = \frac{mg}{L} \qquad \text{(iii)}$$

Sinθ ≈ θ, for a small angular displacement. Comparing the equation (ii) and (iii)

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad (8)$$

Where T is period of oscillation

According to the angular displacement explanation, it is the angle in radians through which a point resolves around a centre or line has been rotated in a specified sensed about a specified axis. When a body rotates about its axis, the motion cannot simply be analysed as a particle, as in circular motion it undergoes a changing velocity and acceleration at any time, t. When dealing with the rotation of a body, it becomes simpler to consider the body itself rigid.

Exampled illustrated in figure 2.4 where bob pendulum is at distance, L from the origin rotating counterclockwise. The position of the bob pendulum in terms of its polar coordinates (L,θ) which the value θ is changing while the value of radius L remain the same. As it moves along the circle, it travels in arc length s, and related each other:

$$s = L\theta \qquad (9)$$

2.1.3 Signal Processing

Signal processing is the branch of mathematics, information technologies and electrical engineering which concerns the modification and analysis of signal. It is defined as the function to supply the information of a behaviour or some phenomenon. MOCAP also parts of the computer vision which deals with acquiring, processing, analysing, and understanding digital images extract of high-dimensional data from the real world in order to generate numerical or symbolic information. Signal processing filter is a process that removes unwanted features from signals. It is often used in improving the signal received or noise cancelling. One of the signal processing filters use in MOCAP is Butterworth Filter.

The Butterworth filter is a low band-pass filter with excellent mathematical characteristics for biomechanical motion. The purpose is to remove high frequency motions (motions that are too fast for a person to perform) while leaving intact the frequencies of motion normal to human movement. The user has the choice of selecting how aggressively the filter will smooth the motion by choosing a frequency value. Lower values will cause a very smooth result while higher values will remain truer to the original data. Figure 2.5(a) shows an unfiltered data with some unwanted error.

Figure 2.5(a). An Example of Original, Unfiltered Data with Some Unwanted Error

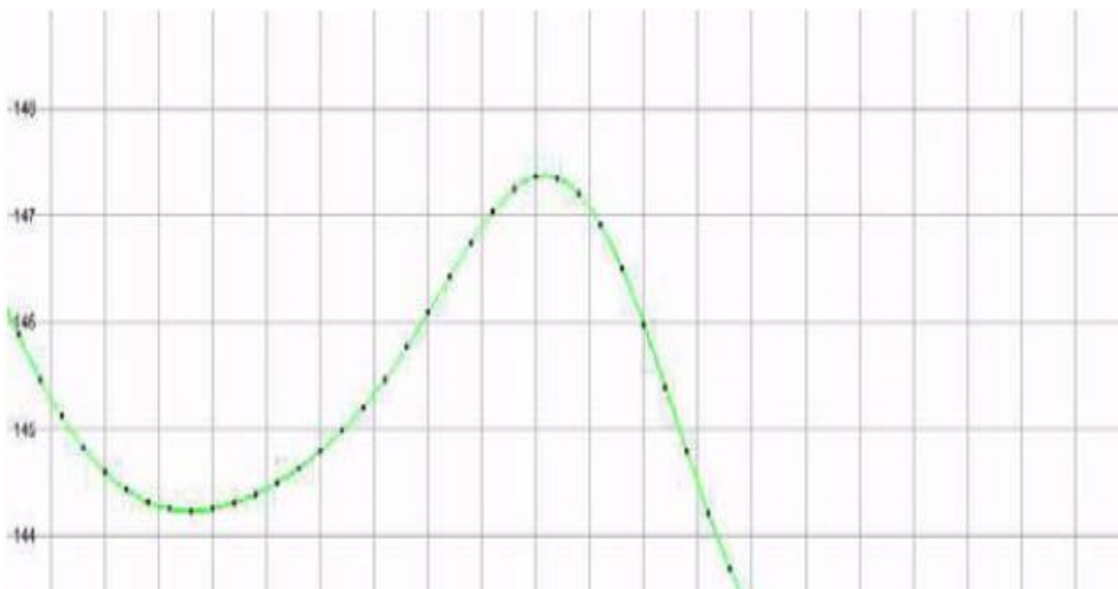

Figure 2.5(b). The Curve after an Application of the Butterworth Filter, with an Input Freq. of 3

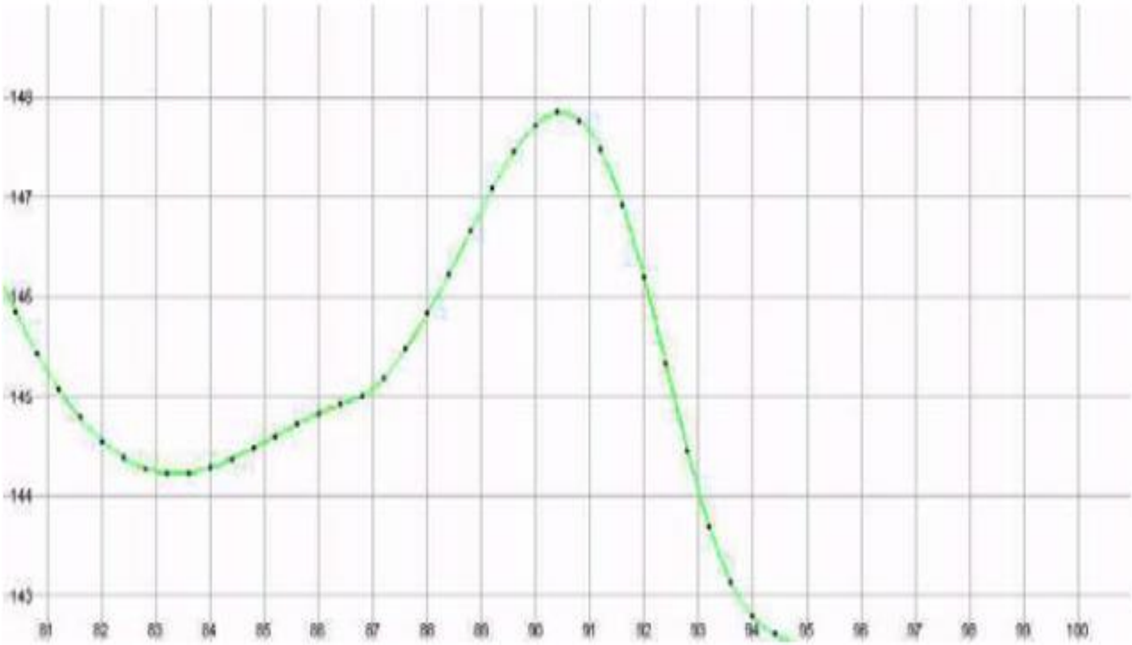

Figure 2.5(c). The Curve after an Application of the Butterworth Filter, with an Input Freq. of 6

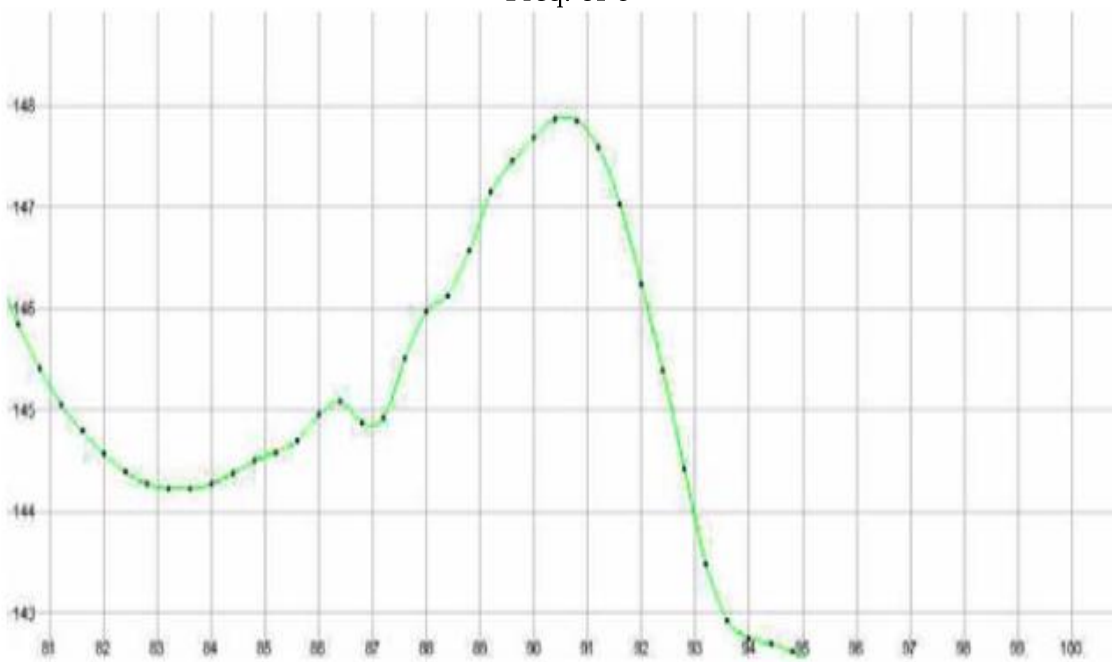

Figure 2.5(d). The Curve after an Application of the Butterworth Filter, with an Input Freq. of 12

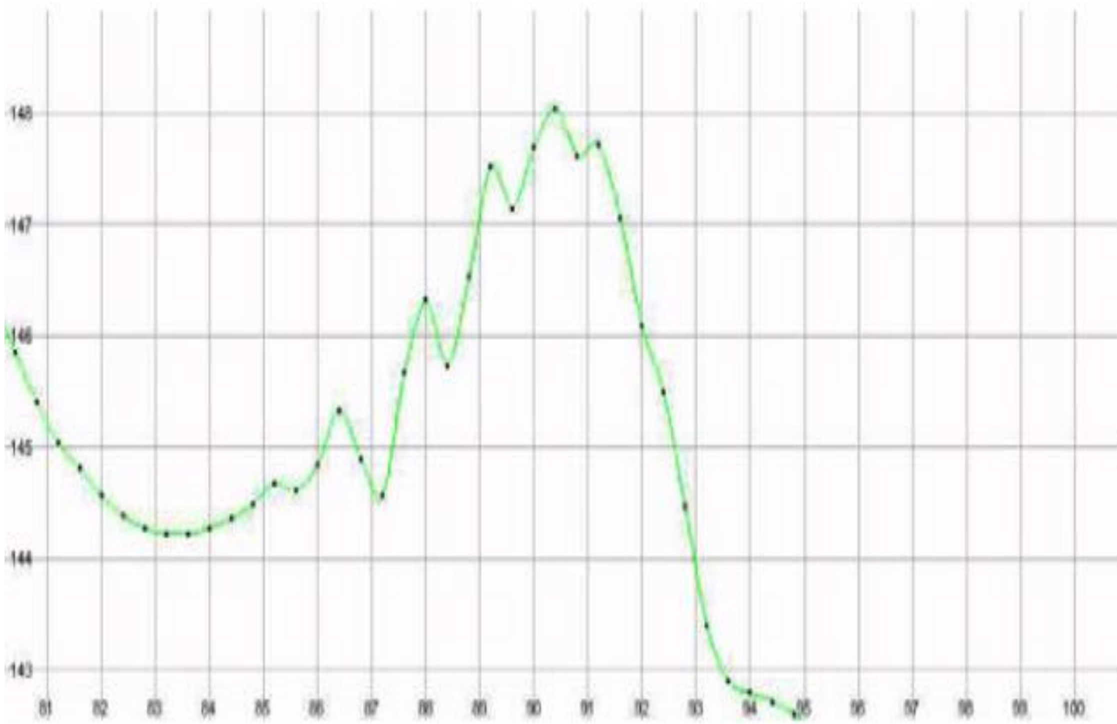

Figure 2.5(e). The Curve after an Application of the Butterworth Filter, with an Input Freq. of 18

As the previous sequence of images shows, the input value to the Butterworth filter noticeably changes the result. The first example, a frequency input of 3 shown in figure 2.5(b) and figure 2.5(c), shows a lot of smoothing applied to the curve while the last example shows very little change to the curve means that data acquire will be less accurate. Depending on the needs, these might be appropriate levels of change. For most purposes, however, values of input frequency 6, 12 shown in figure 2.5(d) and figure 2.5(e) work very well as can be seen it give a balance performance which is a smooth line great for observation from graph and more accurate data. In these two examples, the noisy part of the data has been removed while the overall characteristics of motion have been retained.

Properties of the Butterworth filter are:

- Monotonic amplitude response in both passband and stopband
- Quick roll-off around the cut off frequency, which improves with increasing order.
- Considerable overshoot and ringing in steps response, which worsens with increasing order.
- Slightly non-linear phase response
- Group Delay largely frequency-dependent

Figure 2.6 is an image showing the gain of a discrete-time Butterworth filter next to other common filter types. All these filters are fifth order.

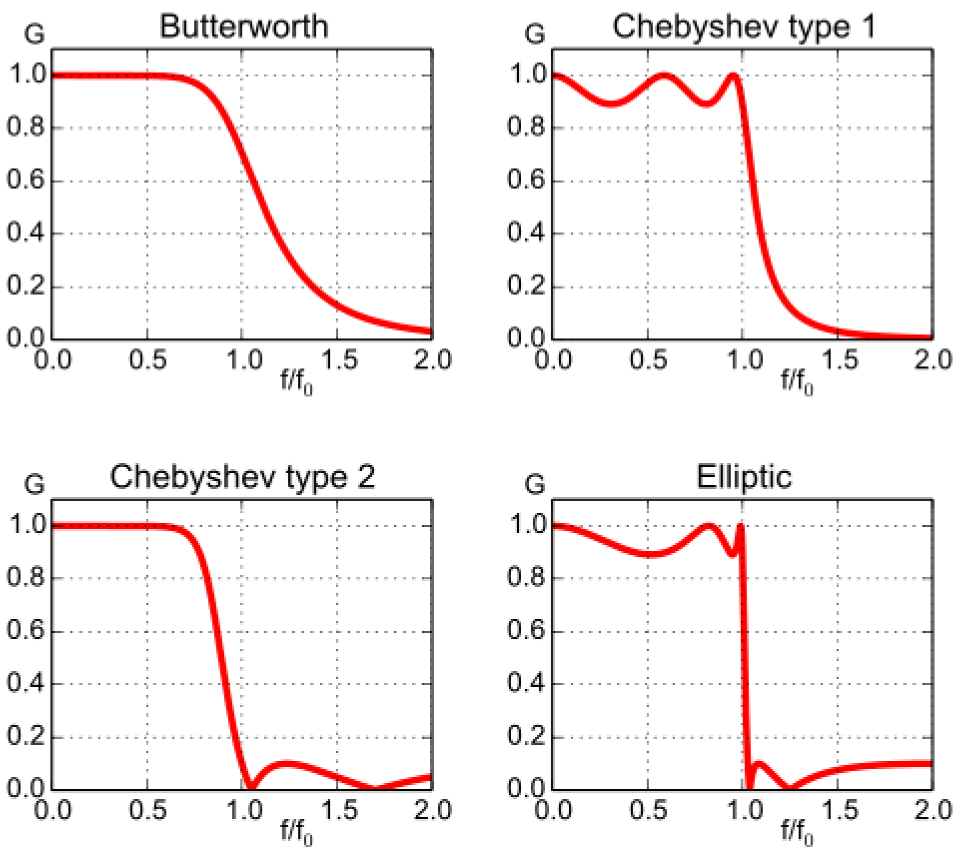

Figure 2.6. Type of filter use in signal processing.

Greyscale image processing is use in digital photography, colorimetric and computer-generated imagery which the value of each pixel is a single sample representing an amount of light. It only carries the intensity information and composed exclusively of shades of grey (variations of grey which the contrast ranges from black at the weakest and white at the strongest). It can be the result of measuring the intensity of light of each pixel according to the combination of certain frequency or wavelength which the principles of frequencies can be from anywhere of electromagnetic spectrum.

In computing, greyscale can be computed through rational numbers, but image pixels are usually used to store them as unsigned integers to reduce the required storage and computation. Early grayscale can only display up to sixteen different shades which is stored in binary using 4-bits. Today greyscale images are commonly stored with 8-bits per sample pixels. Pixel's depth allows 256 different intensities (shades of grey) to be recorded.

In its morphology, images are functions mapping a Euclidean space or grid *E* into:

$$\mathbf{R} \cup \{ \infty , -\infty \}$$

Where **R** is set of real numbers.

Greyscale structuring elements are also functions of the same format called structuring functions. Denoting an image by f(x) and the structuring function by b(x), the greyscale dilation of f by b is given by,

$$(f \oplus b)(x) = \sup [f(y) + b(x - y)] \tag{10}$$