Kinect-Based Knee Osteoarthritis Gait Analysis System

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***Abstract*— Measurement of the gait parameter typically requires a combination of force plate and motion tracking system, which restricts the calculated value to the laboratory environment. The possibility of a portable tracking system has been investigated in some recent studies, such as Microsoft Kinect sensors. The present research collaborated with Sibu Hospital and KPJ Sibu Specialist Hospital to collect the data from subjects. Concurrently, the law of cosine and dot cross product was used as primary measures to determine the scalar value of vector knee, ankle, and hip and the angle that formed by knee, ankle, and hip. The result generated by the proposed knee osteoarthritis severity diagnostics system is presented, specifically, demonstrate the analysis algorithm of various gait parameters system. In summary, Microsoft Kinect v2 sensor can be utilised in the present research to capture subject movement, and a knee osteoarthritis severity diagnostics system is proposed as clinically feasible options for gait analysis.**

Keywords*— *Gait Analysis System, Kinect, Knee Osteoarthritis

I. INTRODUCTION

Osteoarthritis is a degenerative disease in which the articular cartilage material around the joint slowly wears off [1]. The common symptoms of pain, swelling, and stiffness in the affected cause more difficulty movement in older people more so than any other condition [2]. According to the World Health Organisation, 20-28% of the world's population over the age of 60 is affected by some form of osteoarthritis [3]. Additionally, patients with osteoarthritis will experience pain and stiffness that will eventually limit their daily activities, depending on the diseased joints [4]. According to Global Burden of Disease (GBD) 2010 Study, the prevalence of osteoarthritis was 3.64 % (251 million people), which had increased by 64 % compared to GBD 1990 study [5].

In 2010, 9.3% of the Malaysia adults had complaints about knee pain, and more than half of the cases developed clinical symptoms of osteoarthritis [6, 7]. However, the figure was thought to be an underestimate due to its limited sample size [6] and a high drop-off rate (36.5%) of the subjects in the subsequent medical examination [7]. According to American Society of Rheumatology, the combination of clinical and radiological criteria for diagnosis has similar sensitivity (91%) but higher specificity (86%) when compared to either only clinical assessment (95% of sensitivity and 69% of specificity) or the combination of clinical and laboratory tests (92% of sensitivity and 75% of specificity [8].

Gait problems prevail in numerous clinical populations especially the elderly. In this populations, clinically feasible measurements such as gait speed predict long-term outcomes, consisting of quality of lifestyle, hospitalisation, mood, and cognition [9]. Tools that can consistently analyse gait variables in clinical practice can help accurately determine and subsequently deal with individuals at risk of negative consequences, such as limited mobility and falls [10]. Nevertheless, there are challenges in getting these gait variables as they may not be readily available to clinicians. The existing devices efficient in properly measuring gait variables are expensive, time-consuming, and lack of mobility [11]. Therefore, the objective of this study was to propose a knee osteoarthritis severity diagnostics system using a more cost-effective and user-friendly device as clinically feasible options for gait analysis.

II. LITERATURE REVIEW

A. *Radiography Assessment of Knee Osteoarthritis: Kellgren and Lawrence Grading*

In clinical practice, the severity of knee osteoarthritis is mostly assessed by conventional radiography to evaluate the Joint Space Narrowing using Kellgren and Lawrence Grading [12]. Radiography uses x-ray to visualise the internal structure of the patient [13]. In the present research, the x-ray is signifying a two-dimensional concept for joint structures [14]. The truth produces requirements for image changes based on the position of joint in space. Hence, based on the x-ray measuring the thickness of joint space is presented to assess the cartilage loss [15]. Furthermore, the Kellgren and Lawrence Grading are taking place to classify the severity level of knee osteoarthritis.

Presently, the Kellgren and Lawrence Grading are commonly utilised as a clinical tool in the diagnosis of osteoarthritis radiologically [16]. The Kellgren and Lawrence Grading are typically dedicated to knee osteoarthritis. This grading classification was accepted by the World Health Organisation (WHO) in 1961 [8]. This was originally described using the posteroanterior view of knee x-ray. The grade of each x-ray is 0 to 4, which are related to increasing severity of osteoarthritis. Grade 0 shows that there is no osteoarthritis and grade 4 shows

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severe osteoarthritis [12]. Kellgren and Lawrence Grading provide an in-depth radiographic guideline for osteoarthritis, which the clinicians can use to guide them in the diagnosis and grade the severity of the disease.

B. *Device: Microsoft Kinect*

In the current developments of video game technology may provide clinically feasible options for gait analysis. Microsoft Kinect is an affordable gaming device that has shown promise as a clinical assessment analysis device [17]. The Microsoft Kinect has two generations; the first generation of Kinect (Kinect Xbox 360) was released in 2010, and currently, it is an active camera unlike human-based control tools from other brands, such as Sony or Nintendo. It enables the individual to play and completely control the console without having to carry any type of devices for the use of gesture and voice only. Microsoft Kinect Xbox 360 is an inexpensive sensor that measures information in real-time by triangulation, record images at the structure rates approximately 30 fps. It includes a red, green, and blue (RGB) camera, an infrared-based projector, an infrared camera, a tilt, a microphone, and a 3-axis accelerometer [18].

The sensor makes use of structured light technology to measure the distance [19]. The observation quantity is parallax which represents the balances out to match the pattern recorded by the IR camera to the referral model. The main negative aspect of the sensor is the low geometric quality of the transmitted data, noise, and low repeatability [18]. Besides, the depth data registered by the sensor has low quality because the structured light technique is not effective enough to provide high stability of structure scene. Meanwhile, the information extracted from normal step is always with missing section and noise [20].

The second generation of Kinect (Kinect v2) was launched in 2013 to provide high-resolution images and depth data. It provides better depth measurements for more precise skeletal monitoring and motion recognition. Microsoft Kinect v2 has the same number of the sensor as Kinect 1.0, but the depth is determined using an entirely different measurement concept [20]. Its depth and image camera equipment have been significantly enhanced. These changes can improve the automatic tracking of physical spots, potentially enhance the clinical and research utility of the device for analysing gait [11]. Hence, Microsoft Kinect is employed in the present research to capture subject movement.

The use of Microsoft Kinect in human health has been widely tested to ensure its validity and reliability. For example, Dolatabadi, Taati, and Mihailidis (2016) [21] measured the validity of Microsoft Kinect V2 for spatiotemporal gait parameters. The outcomes indicate that the 95% of the Bland-Altman Limit is narrow enough and achieved an excellent ICC2,1 in 0.9 to 0.98 and ICC3,1 in 0.73 which concluded that the Kinect v2 can be a reliable instrument to measure gait time and space parameters reported in Dolatabadi study for healthy adults. Moreover, Eltoukhy, Oh, Kuenze, and Signorile (2017) [22] determined the validity of Kinect v2 in kinematic and spatiotemporal parameters of gait analysis in treadmill. It is statistically significant in correlation coefficients for hip and knee ($0.73 < r < 0.77$) which concluded that the Kinect can be a reliable scientific instrument for analysing hip and knee kinematics and spatiotemporal variables in walking gait. Besides, Vilas-Boas, Choupina, Rocha, Fernandes, and Chunha (2019) [23] assessed the validity of Kinect for full-body motion assessment and the authors concluded that the Kinect could be an alternative tool for intrusive reference system. These studies show that Microsoft Kinect is able to achieve better resolution with sufficient accuracy and precision to identify the body's posture and movement.

III. METHOD

A. *System*

In the present research, Microsoft Visual Studio was performed as an integrated development environment to develop the knee osteoarthritis severity diagnostics system. Besides, C# is the programming language that was used to interpret the process of the data and information in knee osteoarthritis severity diagnostics system. The laptop used to develop the system was completed with Intel Core i7-7700HQ processor, Windows 10 Home as the operating system, HM175 Chipset, and nVidia GeForce GTX 1050Ti graphics card which displayed with 15.6” Full HD. This laptop specs may provide a good software performance to run knee osteoarthritis severity diagnostics system.

B. *Study Description*

One hundred and twenty subjects who are above 50 years of age were divided into training (60 subjects) and testing (60 subjects) to perform three meters walk test examination. The data from the training group were sent to the clinical research team for validation, and data from the testing group were used to test the system. This research was conducted at Sibu Hospital and KPJ Sibu Specialist Hospital, where all the participants signed written informed consent. The gait trial was performed along a walkway, and Kinect was placed in front of the participants. Kinect V2 was used to record subjects' walking data. The testing area included a footpath that each subject walk though, swing leg forward to complete the data collection procedure. The 3 meters distance allowed steady-state gait to be examined. The data recorded from Kinect V2 were used to described walking tracking algorithm. The acquired data were modelled using clustering analysis. The variables derived for this study were peak knee flexion (swing), peak knee flexion (contact), peak knee adduction (contact), knee extension, knee flexion, ankle flexion range, and hip flexion range.

The identification of these variables was the difference as which, peak knee flexion (swing) is specified as the peak knee flexion of the left knee while swinging left leg. Peak knee flexion (contact) is described peak knee flexion of the left knee is shifted during the early contact phase of the ground contact. Besides, peak knee adduction (contact) is elucidated peak knee adduction of the left knee during entire ground contact of the left ground contact. Knee extension is defined as the walking heel-strike when the knee is usually near full extension. Moreover, knee flexion is referred to the knee flexion during swing phase while walking. Ankle flexion range has described the flexion of the ankle during the entire phase of the stride, and hip flexion range is defined as the flexion of the hip during the entire phase of the stride. This was performed for the full gait cycle which is often useful in the gait analysis of clinical populations, specifically knee osteoarthritis [24].

C. Data Analysis

Law of cosine is a set of basic equations that relate the side length of the triangle to the cosine of the angle. This law was found in Euclid's Element many years ago, and the first explicit form was in fifteenth-century provided by Jamshid al-Kashi [25]. The current form of cosine law was established based on the development of algebra in the nineteen centuries [26]. Furthermore, the law of cosine and the dot cross products were used as primary measures to determine the scalar value of vector knee, ankle, and hip and the angle that was formed by knee, ankle, and hip. In the present research, the dot product of vector knee, ankle, and hip was written as K, A, and H, respectively. Let the vectors $K = <K_1, K_2, K_3>$, $A = <A_1, A_2, A_3>$, $H = <H_1, H_2, H_3>$, and $F = < F_1, F_2, F_3>$ be given.

For each variable, the following examines the angle formed by K, A, and H. θ is usually referred to as the angle of specific joint. Specifically,

$$PKFS\theta = cos^{-1}(\frac{KH \cdot KA}{|KH||KA|}) \tag{1}$$

where $PKFS\theta$ is peak knee flexion swing angle.

$$PKAC\theta = 180° - cos^{-1}(\frac{K_{1,2}H_{1,2} \cdot K_{1,2}A_{1,2}}{|K_{1,2}H_{1,2}||K_{1,2}A_{1,2}|}) \tag{2}$$

where $PKAC\theta$ is peak knee adduction contact angle.

$$PKFC\theta, KE\theta, KF\theta = 180° - cos^{-1}(\frac{KH \cdot KA}{|KH||KA|}) \tag{3}$$

where $PKFC\theta$, $KE\theta$, and $KF\theta$ are peak knee flexion contact angle, knee extension angle, and knee flexion angle respectively.

$$HRF\theta = 180° - cos^{-1}(\frac{HK0 \cdot HK1}{|HK0||HK1|}) \tag{4}$$

where HFRθ is hip flexion range angle.

$$AFR\theta = 180° - cos^{-1}(\frac{AK \cdot AF}{|AK||AF|}) \tag{5}$$

where AFRθ is ankle flexion range angle.

IV. PRESENTATION OF DATA AND RESULT

A knee osteoarthritis severity diagnostics system was proposed, and the data analysis is presented as follows. The total step for both legs of the normal subject is shown in Fig. 1. Generally, the subject was walking toward the camera from 3.3 meters (refer to Fig. 2).

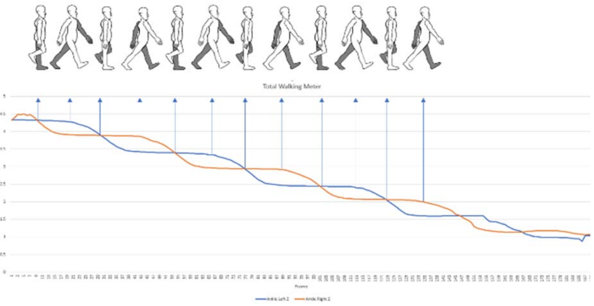


Fig. 1: Gait cycle of subject generated by developed knee osteoarthritis severity diagnostics system.

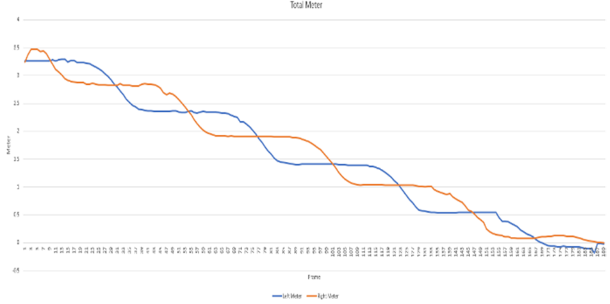


Fig. 2: Total gait cycle analysis.

The step width and walking style for the subject is illustrated in Fig. 3, indicating the right and left feet. There were 0.4 for left feet and -0.4 for right feet. Meanwhile, the average of a walking pattern of the left or right foot was 0.4. The gait parameters of all sequences were recorded by the Kinect and compared for each participant on both the left and right. The subject had no obvious walking asymmetry. However, the subject with knee osteoarthritis showed an obvious walking asymmetry. Additionally, Fig. 4 illustrates the raw data of subject walking movement before analysis.

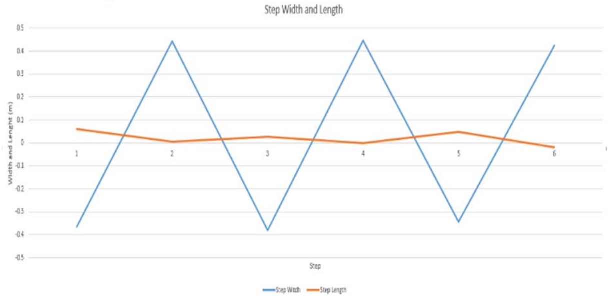


Fig. 3: Analysis of step width and length in metre.

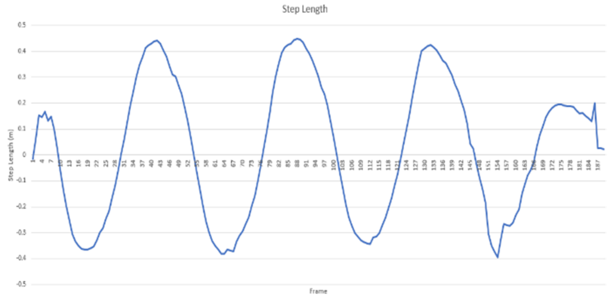


Fig. 4: The raw data before analysis for step length of both legs in metre

The ground contact analysis is presented in Fig. 5 with the orange line defined as the right leg and blue light defined as the left leg.

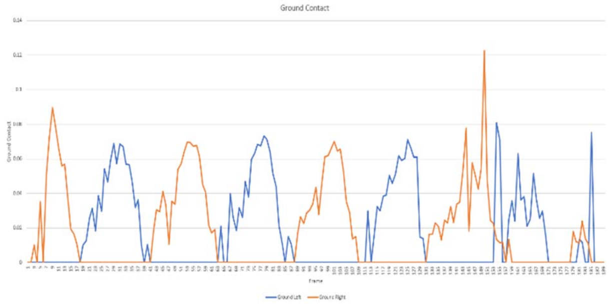
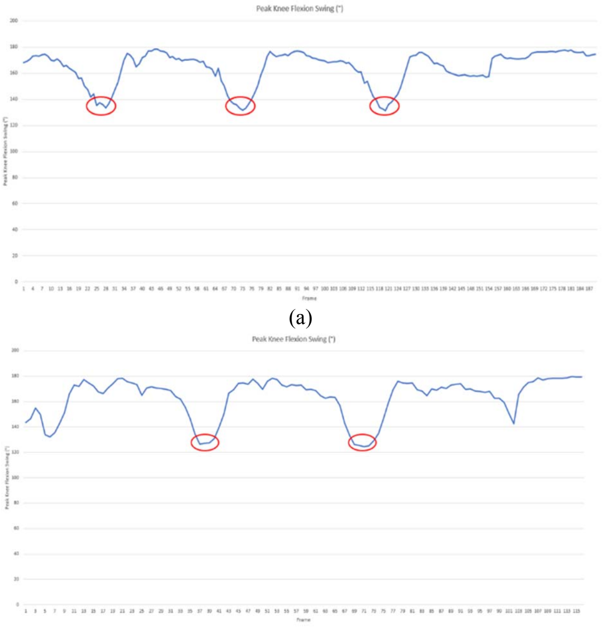


Fig. 5: Ground contact analysis.

The result of peak knee flexion in swing context is generated by the system and shown in Fig. 6(a) Line in the red circle was the result, and the result indicated the peak knee flexion of the subject with knee osteoarthritis symptom has 130° to 140° while swinging. Conversely, Fig. 6(b) presented the result of the normal subject has 122° to 130° while swinging in the evaluation of peak knee flexion.

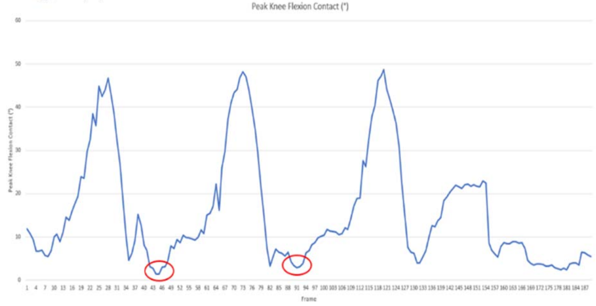


(a)

(b)

Fig.6: (a) Result of peak knee flexion for subject with knee osteoarthritis symptom – swing (°) and (b) result of peak knee flexion for normal subject – contact (°).

The finding of peak knee flexion in contact is presented as follows. Fig. 7(a) shown the findings for the subject with knee osteoarthritis symptom and line in the red circle is the result which specified as 3° to 5° during contact. Alternatively, the system interpreted that normal subject has 0° to 1° while contact of peak knee flexion evaluation in Fig, 7(b).

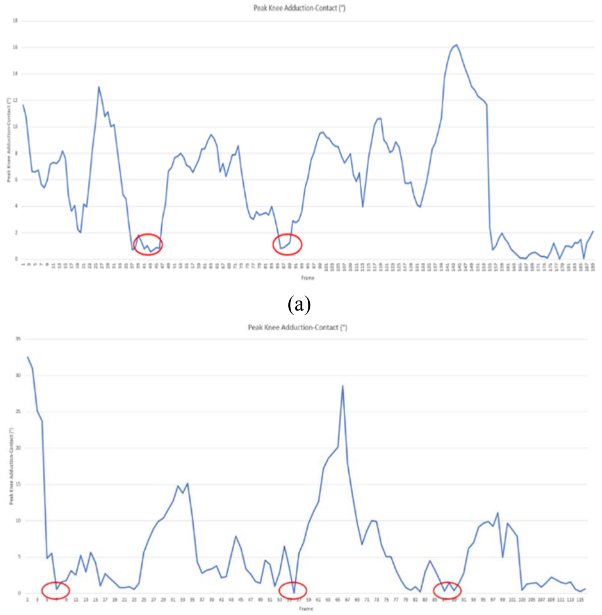


(a)

(b)

Fig. 7: (a) Result of peak knee flexion for subject with knee osteoarthritis symptom – contact (°) and (b) result of peak knee flexion for normal subject – contact (°).

The evaluation of peak knee adduction of both normal subject and subject with knee osteoarthritis symptom. As shown in Fig. 8(a), the result of peak knee adduction in contact is indicated 2° to 3° during adduction contact. On the contrary, Fig. 8(b) indicated the normal subject has 0° to 1° during adduction contact.

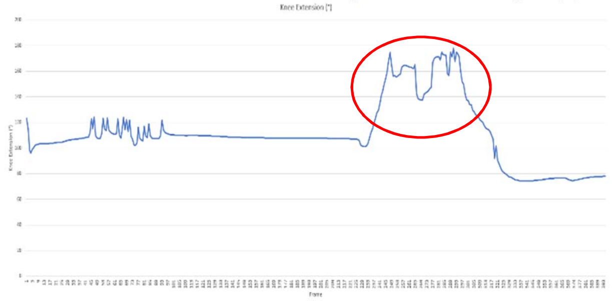


(a)

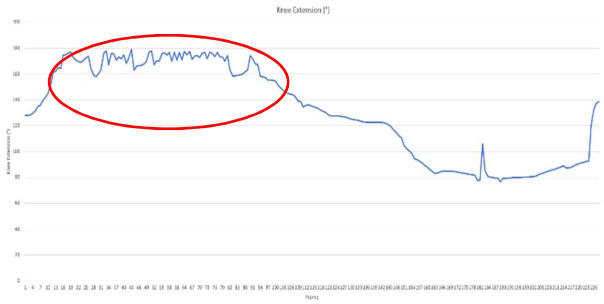
(b)

Fig. 8: (a) Result of peak knee adduction for subject with knee osteoarthritis symptom – contact (°) and (b) result of peak knee adduction for normal subject – contact (°).

Furthermore, the result of knee extension of the subject with knee osteoarthritis symptom presented in Fig. 9(a) and line in the red circle is the result demonstrated a 172° for knee extension. On the other hand, the normal subject must reach 180° for knee extension, as presented in Fig. 9(b).



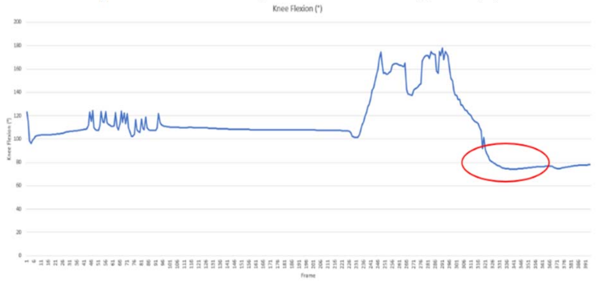
(a)



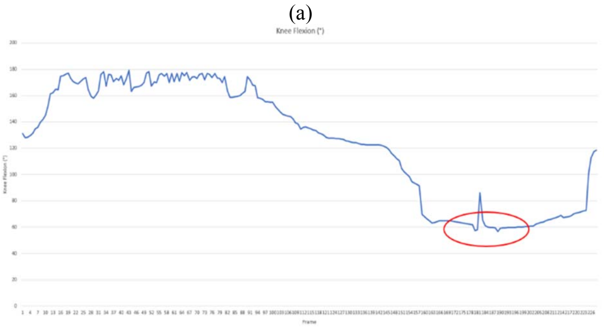
(b)

Fig. 9: (a) Result of knee extension (°) for subject with knee osteoarthritis symptom and (b) result of knee extension (°) for normal subject.

The finding of knee flexion for the subject with knee osteoarthritis symptom is presented in Fig. 10(a) and line in the red circle is the result which specified as 73° for knee flexion. Conversely, the finding of knee flexion for the normal subject is 59° and presented in Fig. 10(b).



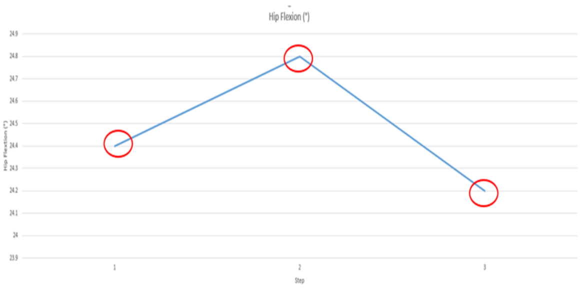
(a)



(b)

Fig.10: (a) Result of knee flexion (°) for subject with knee osteoarthritis symptom and (b) result of knee flexion (°) for normal subject.

As shown in Figure 11(a), the result of hip flexion range reading is around 24.2° to 24.8° for the whole 3 step stride and line in the red circle is the result. On the contrary, the result of hip flexion for the normal subject is around 28.4° to 29.2° and presented in Fig. 11(b).



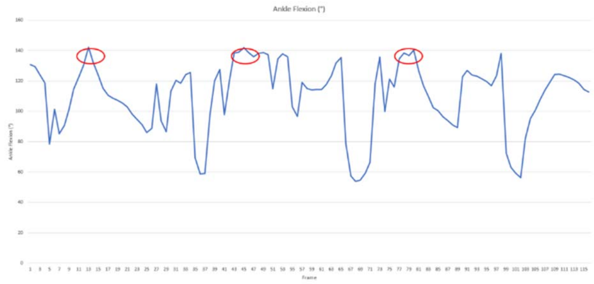
(a)

(b)

Fig.11: (a) Result of hip flexion (°) for subject with knee osteoarthritis symptom and (b) result of hip flexion (°) for normal subject.

Ankle flexion evaluation has not constant walking for the subject, yet it is still considered useful for data interpretation. While Fig. 12(a) indicated the reading for ankle flexion of the subject with knee osteoarthritis symptom is 124° to 125°, which line in the red circle is the result. However, the normal subject has 130° to 138° for the ankle flexion evaluation as exhibited in Fig. 12(b).

(a)



(b)

Fig. 12: (a) Result of ankle flexion (°) for subject with knee osteoarthritis symptom and (b) result of ankle flexion (°) for normal subject.

V. CONCLUSION

In summary, Microsoft Kinect v2 sensor can be utilised in the present research to capture subject movement, and a knee osteoarthritis severity diagnostics system is proposed as clinically feasible options for gait analysis. The result generated by the proposed knee osteoarthritis severity diagnostics system is presented, specifically, demonstrate the analysis algorithm of various gait parameters system. As for future work, the system will be enhanced in order to determine the grade of knee osteoarthritis severity with machine learning algorithm.

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