

# Measurement and Visualisation of Body Midline Using Sensor Technology

Enhancing Postural Assessment Accuracy with Kinect V2: An Evaluation of Objectivity and Clinical Application

Master's thesis in Biomedical Engineering

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## **Abstract**

Poor posture has been a prevalent problem which can often lead to chronic pain, musculoskeletal disorders, and a decreased quality of life. Generally, physiotherapists rely on traditional visual inspection methods to assess posture, which can be subjective and inconsistent, making accurate diagnosis and effective treatment challenging. This thesis explores the feasibility and effectiveness of using the Microsoft Kinect V2 sensor and its motion-tracking algorithm for estimating human body posture. The study demonstrates that the Kinect V2 sensor can significantly enhance the accuracy of postural evaluations by delivering numerical measurements and real-time tracking of skeletal movements. This technology reduces observer bias and the variability associated with conventional visual assessments, allowing for detailed angle measurements that can capture subtle deviations in posture.

Despite its advantages, the Kinect V2 sensor has limitations, including challenges in tracking all body joints and potential data inaccuracies due to occlusion and effects of wearing footwear. Therefore, it is recommended that Kinect technology be utilized alongside traditional assessment methods to maximize diagnostic accuracy.

Keywords: Kinect V2 Sensor, Motion Tracking, Posture, Skeletal Tracking



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Harishankar Anilkumar, Gothenburg, September 2024



# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis:

WPF	Windows Presentation Foundation
UI	User Interface
COG	Centre of Gravity
RMSE	Root Mean Squared Error
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error



# Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

## Parameters , Variables and Indices

$R_y(\theta)$	Rotation Matrix
$\vec{v}_1$ and $\vec{v}_2$	vectors representing the joint positions
$\cdot$	the dot product of two vectors
$\arccos$	inverse cosine function
$x, y$	denotes height
$z$	denotes the depth



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# 1

## Introduction

Posture refers to the alignment of body parts concerning one another. It involves intricate interactions between bones, skeletal muscles, nerves, and connective tissues. These interactions become increasingly complex when considering the vast range of human balance, motor control, and movement in relation to gravity. Over time, the body undergoes changes due to microtrauma, injuries, and the impact of diseases on these systems, contributing to unique variations in posture with age.[1] Body posture plays a critical role in various fields, from healthcare to sports and performance arts. Proper posture is not just about standing or sitting correctly; it is integral to overall physical health and performance. Correct posture is essential for diagnosing, treating, and preventing musculoskeletal disorders in healthcare, particularly in physiotherapy and orthopaedics. In sports and athletics, maintaining the correct posture is key to optimizing performance and reducing the risk of injury.[2] Additionally, the performing arts, such as dance and music, require precise posture to enhance performance and prevent strain. [3] A key component of maintaining good posture is the body's midline, an imaginary line that divides the body symmetrically into left and right halves. As the body ages and undergoes various changes, preserving this midline becomes crucial for optimal spinal health and overall movement. Deviations from this neutral position can lead to musculoskeletal pain, decreased stability, and impaired function. Maintaining the midline helps distribute forces evenly across the body, preventing injuries and enhancing movement capabilities.[4][5].

Healthcare professionals, such as physiotherapists and chiropractors, frequently rely on assessing the body's midline to diagnose and treat musculoskeletal pain and issues. Traditionally, the evaluation of posture is primarily conducted through visual observation and postural screening. Visual inspection is a foundational method where clinicians assess the patient's alignment and symmetry by observing the body from various angles. This approach allows for a quick assessment of obvious postural deviations and is widely used in clinical practice for initial evaluations.[6] In addition to visual inspection, postural screening involves systematic evaluations using standardized tests to identify misalignments and deviations. These methods help clinicians detect postural issues like scoliosis or asymmetries, providing a structured approach to assessment.[7] Despite their vast use, these traditional methods have inherent limitations. Visual inspection, while common, is subject to observer bias and may not capture subtle or dynamic postural changes, such as slight head tilts or shifts in alignment during movement. Moreover, visual assessments often lack the precision needed to quantify deviations from the midline, making it challenging to track progress over time or compare findings objectively between patients. To gain

a more comprehensive understanding of how posture affects function, clinicians also employ manual palpation and functional movement assessments. Manual palpation involves feeling for muscle tension and joint alignment, offering insights into muscle imbalances and joint conditions. [8] Functional movement assessments evaluate how posture impacts the ability to perform various tasks, linking static posture with dynamic movement patterns.[9]

To overcome these limitations, sensor-based systems like Kinect present a better alternative. They can provide real-time data on body posture and movement, allowing for a more precise evaluation of midline alignment. In addition, sensors are non-invasive and user-friendly; a clinician can easily use them to collect valuable patient data. Sensors can provide a quantitative and accurate measure of body position compared to visual inspection, reducing subjectivity and visual errors due to observer bias.

Recent advancements in research support this approach. Roya Haratian's work on *"Motion Capture Sensing Technologies and Techniques"* (2022) addresses wearability challenges in body area sensing systems for motion capture. He discusses wearer comfort, kinematics, and sensor technologies, focusing on portability and reduced power consumption. The signal processing technique proposed in their work aims to decrease energy consumption while maintaining data accuracy. This approach shows the potential for developing compact, comfortable on-body sensing systems with extended battery life.[10] Similarly, Maximilian Gießler et al. (2024) introduced a wearable sensor and framework for accurate remote monitoring of human motion. This wearable sensor uses a spatially defined cluster of inertial measurement units (IMUs) on a rigid base to directly measure the angular acceleration vector. This approach significantly enhances the accuracy of tracking angular acceleration vectors compared to conventional wearable sensors.[11]. However, the computational complexity of both systems and reliance on a controlled environment for validation may present some disadvantages.

Among the popular sensors available on the market, this thesis explores using Microsoft Kinect v2 to measure and visualise. Kinect is an inexpensive solution that offers depth perception and skeletal tracking, providing a 3D representation of the skeleton and detailed information about joint positions and angles. By tracking the patient's skeletal structure, particularly the spine and head, the system can calculate the significant angles relative to the midline. This method can provide valuable insights into postural deviations and contribute to developing more objective and reliable methods for midline assessment. Supporting this, Rasouli and Payandeh (2018) proposed a novel method for estimating human body posture using a single Kinect sensor. They used the Fast Fourier transform (FFT) to extract features from 2D cross-sectional scans of the body. Even though the system is computationally simple, it has a restricted field of view and struggles with occlusions. [12]

Further advancing Kinect-based motion tracking, Bilesan et al. (2018) addressed the slight inaccuracies of Kinect in measuring micro-motions by developing a marker-based motion capture system using Kinect v2. They utilized depth data to calculate 3D coordinates of markers, which allowed accurate capture of joint angles during motions such as ankle flexion/extension. Kinect v2 was found to be sensitive to environmental conditions and noise which limited its reliability.[13]

Additionally, Brambilla et al. (2023) explored the performance of the Azure Kinect camera for upper limb tracking and biomechanical analysis under varying conditions like camera angle, light intensity, and occlusions. Their findings indicated that a frontal camera position provided the most reliable results, with minimal impact from lighting conditions, whether artificial or natural.[14] However, using Kinect technology is challenging. Huber et al. (2015) found that while Kinect provided reliable measurements for certain shoulder joint angles, such as abduction to 90 degrees, it struggled with accuracy in the transverse and sagittal planes due to difficulties in estimating occluded joint positions.[15] In contrast, Coias et al. (2023) evaluated low-cost alternatives to Kinect, including OpenPose and MediaPipe, which, despite lacking depth capture capabilities, showed comparable performance for upper body movement assessment in a study of stroke survivors.[16]. In addition, Wang (2022) developed a multi-Kinect fusion algorithm for full-body tracking in virtual reality, utilizing six Kinects and distributed computing to enhance efficiency in motion tracking.[17].

To summarise, traditional visual inspection of body posture comes with a wide range of limitations. The limitations highlight the need for more objective and quantitative approaches to midline evaluation. Microsoft Kinect v2 offers a promising solution, providing real-time, objective data on body posture and movement. This thesis investigates the potential of utilizing Kinect's skeletal tracking capabilities to measure and visualize the midline. Additionally, it explores the application of 3D skeleton rotation to analyze the skeleton from different perspectives, thereby reducing the need for an additional Kinect v2 sensor. Furthermore, the use of a Kalman filter to mitigate noise from the Kinect sensor is explored. This approach aims to yield valuable insights into postural deviations and contribute to the development of more objective and reliable methods for midline evaluation, ultimately enhancing patient care.

## 1.1 Aim and Research Question

This thesis explores the feasibility and effectiveness of using the Microsoft Kinect sensor and its motion-tracking algorithm for estimating human body posture. The primary goal is to develop a Kinect-based system capable of detecting a human body, calibrating its position, tracking 25 body joints, and calculating the head and spinal angles. The system aims to provide real-time feedback on posture to ensure proper alignment and prevent musculoskeletal issues. Specifically, the focus is on measuring and visualizing midline alignment by calculating the key angles of the spine and head.

### **Research Questions:**

- How does Kinect-based midline assessment enhance the understanding and management of postural abnormalities?
- What are the strengths and limitations of using Kinect-based measurements for midline alignment, particularly in the context of assessing and monitoring postural dysfunction?
- Can the application of 3D skeleton rotation in Kinect v2 improve the analysis of postural deviations, and what reliability of midline evaluation in clinical settings?

# 2

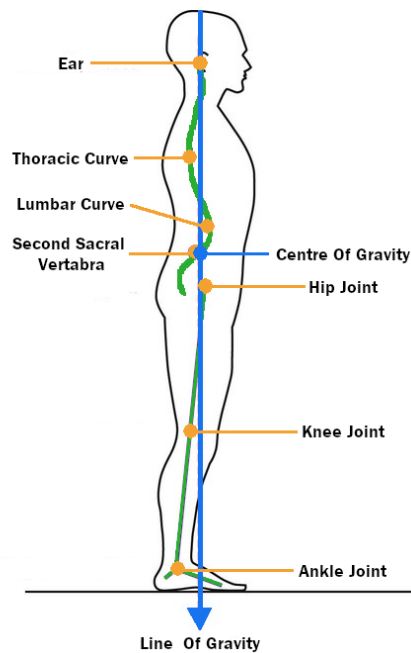
## Theory

### 2.1 Body Posture

Posture can be defined as the arrangement of body segments relative to each other. [18] As our body is a connected system, understanding any specific posture requires examining the kinematics and forces acting on all segments. Many animals can take on various positions, but standing upright on two legs is unique to humans. This erect posture frees our upper limbs for all sorts of tasks, from delicate movements to powerful actions.[18] An ideal posture is characterised by the arrangement of body segments to minimise the torque and forces acting on them due to gravity.[21][22] In a good posture, the vertebrae are aligned in a neutral position with slight natural curves in the cervical and lumbar regions. This alignment allows efficient weight distribution, thereby minimizing strain on muscles and ligaments. Conversely, poor posture, such as slouching or hunching, disrupts this balance and creates unnecessary stress on supporting structures, which can lead to chronic pain in the neck, back, and shoulders, ultimately affecting daily life.[18][21][23] The benefits of maintaining good posture are beyond pain relief. An optimal posture allows for full expansion of the chest cavity, improving both inhalation and exhalation. Research has also indicated a correlation between good posture and an enhanced mood, suggesting a positive feedback loop between physical well-being and emotional state.[18][23] In practical terms, posture describes how the human body adapts to various situations in relation to the force of gravity. Posture can vary from person to person; what constitutes good posture for one individual may not be suitable for another. Posture can be categorised as inactive when the body is at rest or sleeping, and as active when multiple muscles are engaged to maintain it.[18][23].

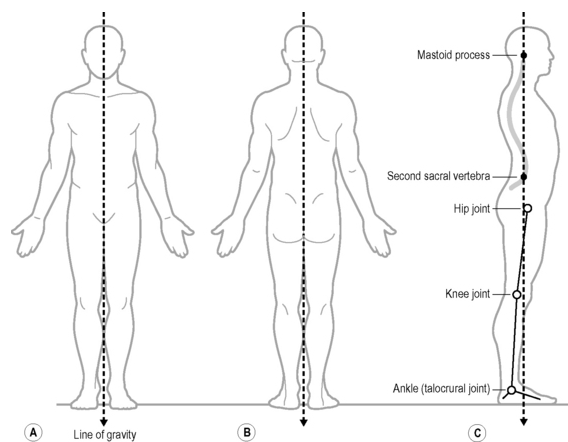
Understanding the relation between the body's movements and the constant force of gravity is complicated. The gravity line serves as a crucial reference point in analyzing posture and movement. The gravity line is a fictional line drawn through the body's centre of gravity. This is the line of action for the total gravitational force acting on the body and serves as a key reference point when analysing significant movements in the body segments caused by gravity. By examining how the gravity line interacts with the midline and intersects with our joints, we gain valuable insights into how our body maintains balance, stability, and efficient movement. [24] When the gravity line passes through a joint axis, no gravitational force acts on the joint, placing it in a state of balance. In this position, the gravitational pull is distributed evenly across the joint, and only minimal muscular effort is required to maintain stability. For instance, in an ideal standing posture, the gravity line

should ideally pass through the lateral axis of the ankle joint and the centre of the hip joint.[24] A gravitational torque is created when the gravity line deviates from a



**Figure 2.1:** Optimal Posture [19]

joint axis. This torque acts as a rotational force, causing the body segments to move around the joint axis. The direction and magnitude of the torque will depend on the distance between the gravity line and the joint axis. The farther the deviation, the greater the torque and the more muscular effort required to maintain or act against the movement. When a person is walking or running, the gravity line shifts with each step. This creates a torque at each joint and propels the body to move. A limitation of the gravity line is that it assumes that a human body is symmetrical with equal weight distribution on both sides, which is not always true. There may be inherent asymmetries in a person, which can affect the path of the gravity line.[24]



**Figure 2.2:** Gravity Line [20]

### 2.1.1 Posture and Health

Posture and health are very closely linked. Good posture is crucial for maintaining a healthy musculoskeletal system and overall well-being. Research generally demonstrates a strong link between good posture and a lot of health benefits. Studies have shown that a proper posture can reduce pain, increase circulation, enable better digestion, improve breathing, and even boost moods.[25][26]

When our body is aligned correctly, the weight is distributed evenly across the joints and muscles. This minimises stress on these structures, reducing the risk of aches and pains, particularly in the neck, back, and shoulders. Studies have shown that maintaining good posture can effectively manage chronic low back pain, a prevalent issue in modern society [27][28].

Poor posture can have bad effects, leading to pain, decreased function, and even chronic conditions. Over time, poor posture can contribute to joint degeneration and arthritis.[29][30] Additionally, poor posture can contribute to spinal curvatures like kyphosis or lordosis, further impacting mobility and causing pain.[31]

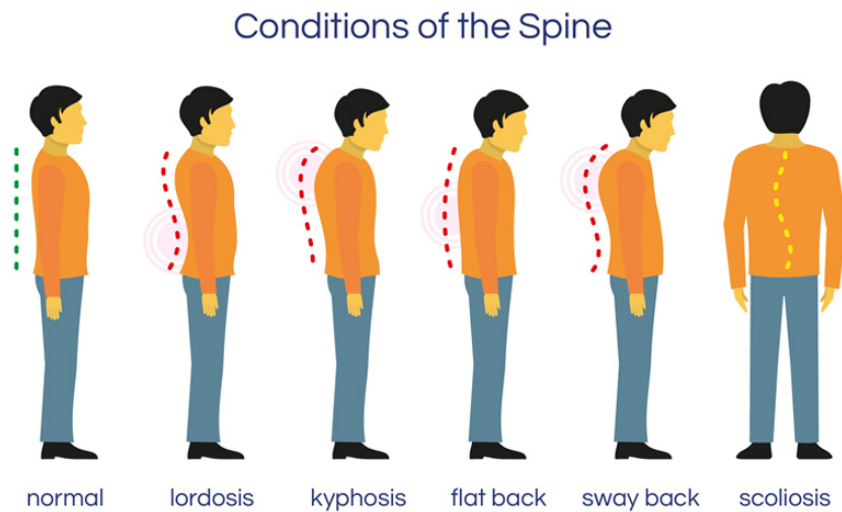
### 2.1.2 Posture and Ageing

Ageing is a process that brings about major structural and functional changes in the human body. Age has a strong effect on the musculoskeletal system. Declining bone density, reduced flexibility of tendons, decreased strength of muscles, and stiff cartilage are all common problems that can occur due to ageing. [32]

An important consequence of age-related decline is developing a condition called kyphosis. The vertebral column consists of vertebrae, intervertebral discs, and muscles. These components work together to provide structural support and allow for movement. Over time, however, age-related degeneration can occur. The intervertebral discs can dehydrate and lose height, while osteoporosis can weaken and compress the vertebrae. In simpler terms, the discs act as shock absorbers. These discs tend to dehydrate and lose cushioning, coupled with the osteoporosis-induced weakening of the vertebrae, which reduces their ability to maintain proper alignment.[33]. Kyphosis causes an excessive rounding of the thoracic spine, which compresses the chest cavity. This compression restricts the diaphragm's downward movement and limits the rib cage's upward and outward expansion. As a result, the lungs have less space to inflate, leading to a decrease in lung capacity, the maximum amount of air the lungs can hold. [34][35] With advancing age, a condition known as sarcopenia occurs, leading to a gradual loss of muscle mass, strength, and functional capacity. This weakening, particularly of the spinal muscles, also contributes to the development of a curved spine.[36]

## 2.2 Kinect

Kinect, made for the gaming platform Xbox 360, was born out as a response to Nintendo's Wii, which could track hand gestures. Initially titled Project Natal, Kinect was an upgrade from the Wii. When Wii could only track hand motion, Kinect served as a motion and voice-sensing system, enabling users to interact with



**Figure 2.3:** Conditions of Spine [37]

their console or PC without the necessity of a traditional game controller. It utilised depth and infrared camera technology, sensors, and a voice recognition microphone to track the player's movements and voice commands. This allowed for intuitive control of games and media solely through gestures and spoken instructions. While



**Figure 2.4:** Kinect V2 Sensor

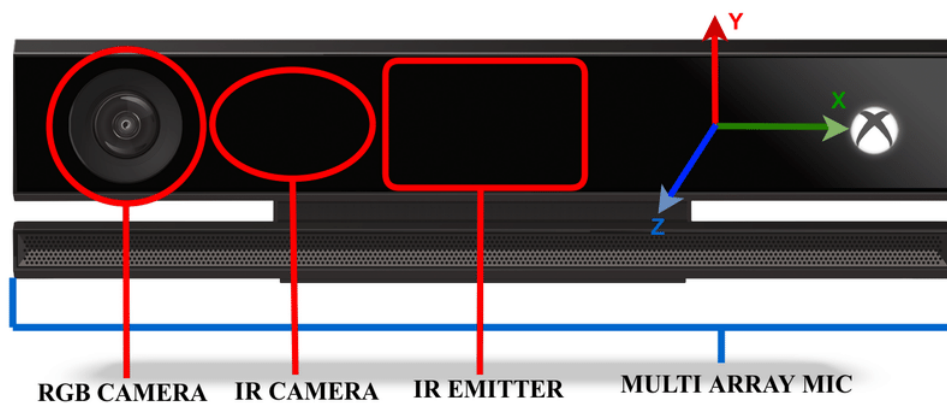
initially designed for gaming, Kinect quickly expanded its reach into research and commercial development arenas. Its notable attributes, including high precision, user-friendly interface, AI-driven body and facial tracking, and multi-microphone sound capture, catalysed innovative applications in various fields. These include but are not limited to rehabilitation, telemedicine, surveillance, 3D scanning, and numerous other domains.

### 2.2.1 Kinect in Healthcare and Rehabilitation

The affordability and non-invasiveness of the Kinect sensor make it a valuable tool for diverse clinical applications, particularly in patient monitoring and rehabilitation. In addition to being cost-effective, Kinect offers unique features that revolutionise the approach to rehabilitation.[38][39]

Its advanced skeletal tracking capabilities provide quantitative motor skill assessments. This allows for identifying minute impairments, enabling therapists to tailor rehabilitation programs more effectively. Secondly, Kinect helps with real-time feedback during exercises. The Kinect provides visual or auditory cues on speed, accuracy, and symmetry by comparing a patient's movements to pre-defined ideal ranges of motion. This helps patients to participate actively in their rehabilitation. The versatility of Kinect extends across various rehabilitation settings. In post-stroke rehabilitation, Kinect tracks arm and leg movements, aiding patients in regaining control and coordination. Similarly, it can monitor gait patterns for patients with Parkinson's disease, providing feedback on posture. Physiotherapists can also utilise Kinect for sports injuries, where patients regain strength and flexibility through exercises with real-time feedback on movement quality. The applications extend beyond physical therapy, with the potential for cognitive rehabilitation and pain management.

### 2.2.2 Skeletal Tracking using Kinect



**Figure 2.5:** Coordinates and Components of the Kinect V2 Sensor [40]

The RGB camera in the Kinect v2 sensor captures high-definition colour images. This enhances the depth data by providing detailed visual context. It supports facial recognition and tracking and enables more immersive augmented reality experiences and precise gesture recognition. Complementing this, the depth camera in the Kinect v2 sensor uses infrared light to capture 3D spatial data, enabling precise measurement of distances and the creation of detailed depth maps that facilitate accurate motion tracking, gesture recognition, and 3D scene reconstruction.

The skeletal tracking system works by projecting an infrared light onto the patient and capturing the reflected light with its depth camera. This enables Kinect to create a detailed 3D model of the user's body, allowing it to track the positions and

orientations of individual joints. In practice, Kinect v2 can capture up to 25 joints of the body and upto six bodies. Each joint has 11 properties: colour (x, y); depth (x, y); camera (x, y, z, w); and orientation (x, y, z, w). [41]

$x$  : Horizontal position (left or right)

$y$  : Vertical position (up or down)

$z$  : Depth position (distance from the camera)

$w$  :  $\cos\left(\frac{\theta}{2}\right)$ , where  $\theta$  is the angle of rotation around the axis defined by the unit vector  $(x, y, z)$ .

### 2.2.2.1 Colour Coordinates

The colour of each pixel is described by its RGB values, typically represented as integers ranging from 0 to 255. The Kinect returns a value between 0 and 1 for the colour coordinates (x, y). These values represent percentages of a predetermined scale of 0 to 1 based on the camera's resolution 1920 x 1080 pixels. This means that each coordinate represents a fraction of the total width and height of the camera's image.[41]

### 2.2.2.2 Depth Coordinates

Similarly, the Kinect returns depth coordinates as values between 0 and 1. These depth coordinates represent the relative distance of objects from the sensor, with 0 indicating objects very close to the sensor and 1 representing objects farthest away. The values are percentages of the sensor's depth range, typically based on the sensor's maximum detection range.[41]

### 2.2.2.3 Camera Coordinates

Unlike colour and depth coordinates, camera space coordinates are derived from the Kinect's infrared sensor, providing precise spatial information about joint positions. These coordinates are measured in meters and offer accurate location data within a three-dimensional framework.

In camera space, the coordinate system originates from the centre of the Kinect's IR sensor, denoted as the origin (0, 0, 0). The X-axis extends to the sensor's left, while the Y-axis grows upward, considering the sensor's tilt direction. Meanwhile, the Z-axis extends outward from the sensor's viewpoint, with each unit representing one meter.[41]

The range of camera space coordinates varies depending on the joint's distance from the sensor. For instance, the x-coordinate may be negative or positive, indicating the joint's left or right position relative to the sensor. Similarly, the y-coordinate is positive above the sensor and negative below it. Meanwhile, the z-coordinate is always positive, extending outward from the sensor.

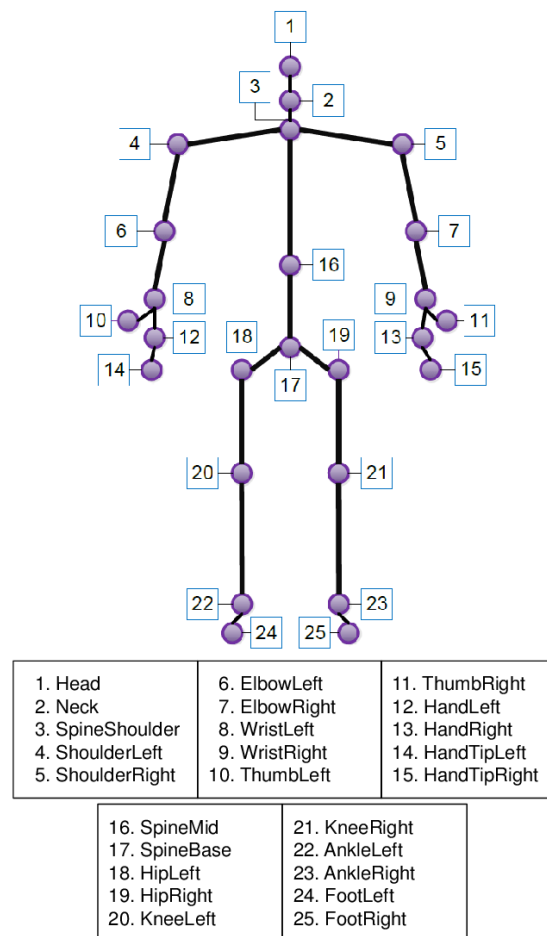
To ensure effective tracking, it's recommended to maintain a minimum distance of around 0.5 meters between the patient and the camera. Typically, the z-coordinate falls within the range of 0.5 to 4.5 meters, representing the farthest distance that the camera can accurately capture.

### 2.2.2.4 Orientation Coordinates

Kinect uses quaternions to track how joints are oriented in 3D space. Quaternions describe an orientation in 3D space using four parameters:  $(x, y, z, w)$ . [41]

### 2.2.3 Body Joints

Kinect can facilitate motion analysis of 25 joints in the patient. These joints include the head, neck, shoulders, elbows, wrists, spine, hips, knees, and ankles.



**Figure 2.6:** Body Joints Tracked by Kinect [42]



# 3

## Methods

In this study, we aim to evaluate the effectiveness of a Kinect v2 sensor system for monitoring and analyzing human posture and measuring head and spinal angles. The following sections outline the experimental setup, the approach used for data collection, and the analysis techniques employed to achieve our research objectives.

### 3.1 Approach

#### 3.1.1 Experimental Setup

A single Microsoft Kinect v2 sensor, positioned 2 metres from the participant at a fixed height of 1.5 metres, will capture skeletal tracking data from the participants assuming static postures. The system will analyze joint angles, focusing on those relevant to the body's midline, and compare them to established ideal angles.

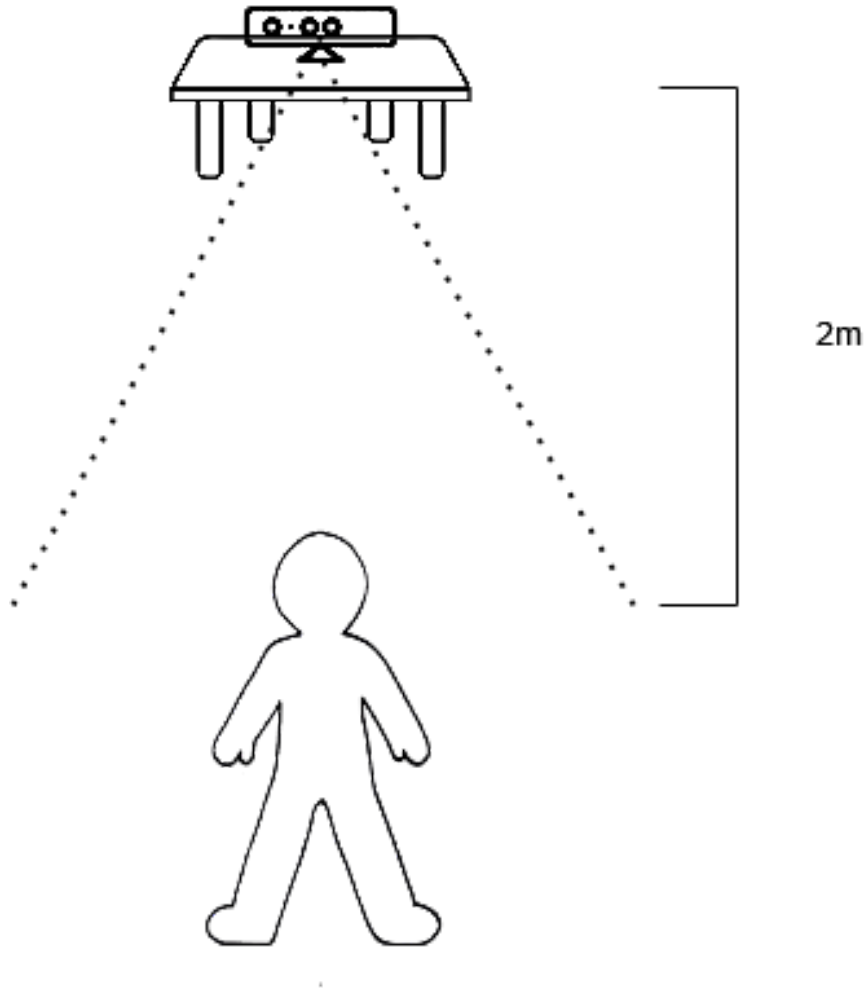
### 3.2 Requirements

The requirements for designing and developing the system are as follows.

- Microsoft Kinect v2 Sensor: Essential for capturing body movements and tracking joints with high precision.
- Windows Adapter for Kinect: Necessary for connecting the Kinect sensor to a Windows PC.
- Visual Studio 2022: Integrated development environment (IDE) for writing, testing, and debugging the software.
- Kinect SDK: Software Development Kit that provides the tools and libraries needed to interact with the Kinect sensor and process the captured data.

Specification	Details
RGB Camera	1920 x 1080 pixels resolution, 30 frames per second
Depth Camera	512 x 424 pixels resolution, time-of-flight technology
Microphones	Array of microphones for enhanced voice recognition and noise cancellation
Voice Interaction	Natural and smooth interaction through voice

**Table 3.1:** Kinect v2 Specifications



**Figure 3.1:** Experimental Setup

### 3.3 Designing an application in C#

A critical component of this Kinect-based system is its UI, as it facilitates interaction between the user and the system. I used C# and leveraged its WPF (Windows Presentation Foundation) to develop this Windows application. WPF provides a framework to build a visually soothing and easy to use application on a Windows platform.

Feature	Description
Real-Time Skeleton Visualization	<ul style="list-style-type: none"> <li>The UI includes a canvas where the skeleton is drawn in real-time, showing the positions of different joints.</li> <li>Joints are represented as ellipses, and bones are depicted using lines connecting these ellipses.</li> </ul>
Joint Angle Calculation	<ul style="list-style-type: none"> <li>The UI calculates angles between specific joints in both the XY and YZ planes.</li> <li>These angles are displayed on the screen, helping users understand their posture.</li> </ul>
User-Friendly Controls	<ul style="list-style-type: none"> <li>Checkboxes and buttons are provided for users to control various aspects of the UI, such as showing joint coordinates.</li> <li>The interface is designed to be intuitive and easy to use, even for individuals without technical expertise.</li> </ul>

**Table 3.2:** Key Features of the UI

### 3.3.0.1 Setting Up the Development Environment

- Language and Framework** Microsoft Kinect is a versatile apparatus that works with various programming languages and frameworks. In this project, the development environment is centred on the C# programming language and the Windows Presentation Foundation (WPF) framework. C# is a versatile programming language. It is integrated with the .NET framework, which provides a vast library of pre-built functionality for different tasks. Detects errors in advance, significantly reducing the chances of runtime errors. The graphical user interface (GUI) consists of two main components: a canvas to render the skeleton joints and a separate canvas to display calculated angles. The skeleton joints are represented by ellipses, with text blocks showing their corresponding 3D coordinates.
- Project Configuration** In Visual Studio, a new project targeting the WPF and .NET framework is selected.
- Data Acquisition** Once Kinect is initialized, body frames are read continuously from the Kinect sensor, and joint positions from the body frames are extracted for each tracked body
- Skeletal Points** The project utilizes WPF canvas to render the skeleton. Ellipses are drawn on the canvas to represent each joint. In addition, a checkbox is provided to display the coordinates of the joints and another checkbox is provided to draw the gravity line.



**Figure 3.2:** UI layout for the Kinect Application

#### 3.3.0.2 Kalman Filter

The skeletal point data collected from the sensor was prone to noise, causing oscillations in the skeletal points. A Kalman filter was used to reduce noise, which combined noisy measurements with sensor predictions to smooth out these fluctuations. [43]

In our implementation of the Kalman filter,

- **Initialization:** Each Kalman Filter is initialized with specific values for process noise ( $Q$ ), measurement noise ( $R$ ), estimation error ( $P$ ), and initial value ( $X$ ).
- **Update Method:** The ‘Update’ method in the Kalman Filter performs the prediction and update steps. (see Appendix A.1 for detailed derivation)

By continuously updating estimates based on both current data and previous predictions, the Kalman filter significantly improved the stability and accuracy of the skeletal tracking. This resulted in more stable and accurate tracking of skeletal points, reducing oscillations and improving overall data reliability.

#### 3.3.0.3 3D Rotation

A rotation matrix in 3D space is used to rotate the skeletal joint around a specified axis. This is done to rotate the skeleton by 90 degrees to provide a better view for analysis. By rotating, we get two views of the same skeleton. For a rotation by an angle  $\theta$  around the Y-axis, the rotation matrix  $R_y(\theta)$  is defined as:

$$R_y(\theta) = \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix}$$

- $\cos(\theta)$  and  $\sin(\theta)$  handle the rotation in the X and Z coordinates.
- The middle row  $[0 \ 1 \ 0]$  indicates that the Y coordinate remains unchanged during the rotation.

- $-\sin(\theta)$  and  $\cos(\theta)$  handle the rotation in the Z and X coordinates, respectively.

In this case, it is a 90 degrees rotation (i.e.,  $\theta = \frac{\pi}{2}$ ). So the cosine and sine values are:

$$\begin{aligned}\cos\left(\frac{\pi}{2}\right) &= 0 \\ \sin\left(\frac{\pi}{2}\right) &= 1\end{aligned}$$

Substituting these values into the rotation matrix, we get:

$$R_y\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$

By using a rotation matrix, we effectively transform the orientation of the skeleton, which can be particularly useful for aligning the Kinect data with other visual or analytical requirements in a graphical user interface.

#### 3.3.0.4 Angle Calculation, Data Analysis and Interpretation

Once the data is filtered and rotated, the angle between the two joints is calculated by computing vectors between the two joints. Angles in the XY and YZ planes are calculated and presented with their corresponding joint and plane information. In this thesis, we are focused only on the spinal and head angles. The computed angles are then compared with ideal angles. If the angles are within the given range of ideal angles, the program returns "Good Posture". Else, it returns "Bad Posture."

For angles in the XY plane:

$$\text{Angle}_{\text{XY}} = \arccos\left(\frac{\vec{v}_1 \cdot \vec{v}_2}{\|\vec{v}_1\| \cdot \|\vec{v}_2\|}\right) \quad (3.1)$$

For angles in the YZ plane:

$$\text{Angle}_{\text{YZ}} = \arccos\left(\frac{\vec{v}_1 \cdot \vec{v}_2}{\|\vec{v}_1\| \cdot \|\vec{v}_2\|}\right) \quad (3.2)$$

Equation (3.1) gives the angle between vectors  $\vec{v}_1$  and  $\vec{v}_2$  in the XY plane, while Equation (3.2) gives the angle in the YZ plane.

Where:

- $\vec{v}_1$  and  $\vec{v}_2$  are the vectors representing the joint positions.
- $\cdot$  represents the dot product of two vectors.
- $\|\vec{v}\|$  represents the magnitude of vector  $\vec{v}$ .
- $\arccos$  is the inverse cosine function, returning the angle in radians.



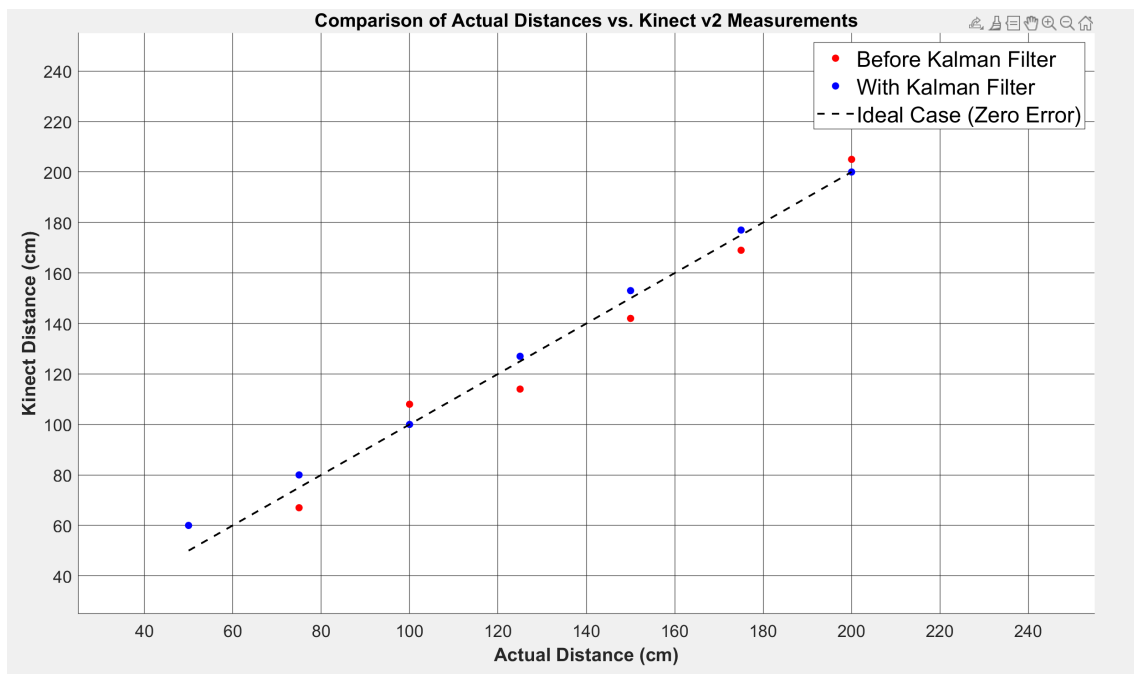
# 4

## Results

In this study, we have managed to show Kinect V2 sensor's potential in assessing body posture and accurately visualising and calculating posture deviations. Through detailed analysis of various postural scenarios, such as head tilts and different sitting and standing postures, we have shown Kinect V2's precision in capturing subtle postural changes. Our findings suggest that Kinect V2 is a promising tool for clinical applications, offering a cost-effective and accurate solution for posture assessment.

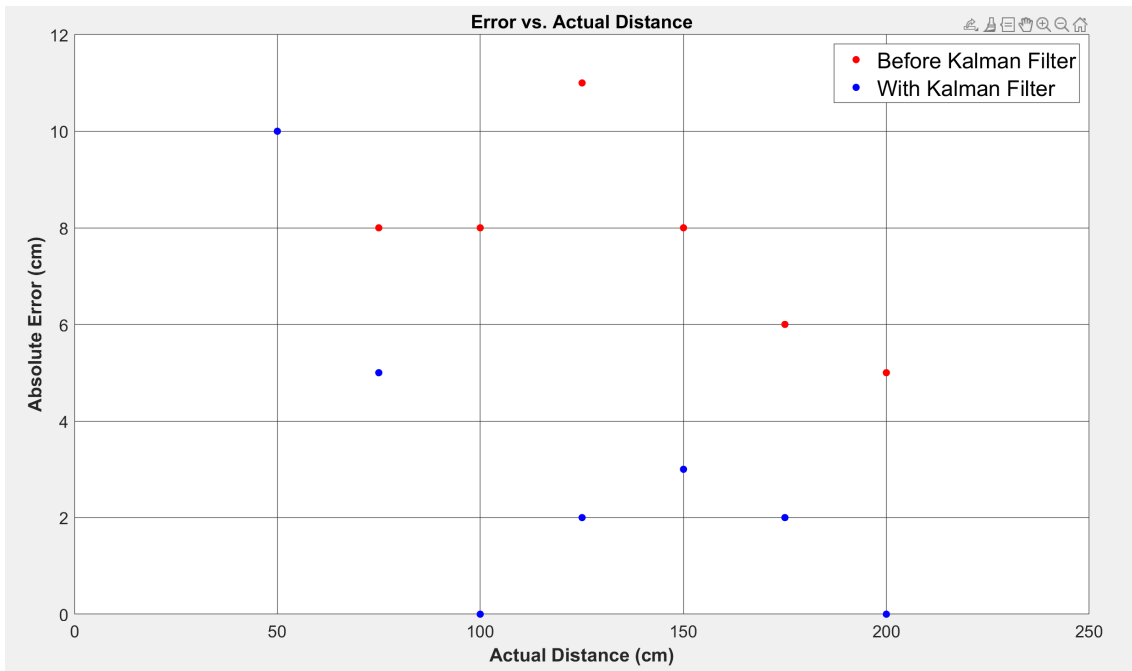
### 4.1 Filtering Errors

Kinect v2 is prone to errors due to inherent noise and calibration. To evaluate the performance of the Kinect v2, we compared its distance measurements with actual distances between the patient and Kinect.



**Figure 4.1:** Comparison of Actual Distance Vs Kinect Measured Distance

Without the Kalman filter, the Kinect v2 sensor displayed a wider range of errors. These errors were observed to vary both above and below the actual distance. Although the minimum recommended distance between the subject and the Kinect v2



**Figure 4.2:** Error Vs Actual Distance

sensor is 50 cm, it was observed that the sensor did not consistently capture data at this distance often resulting in no data being collected.

After applying the Kalman filter, the Kinect v2 sensor’s error patterns improved. The measurements became more consistent, with errors remaining relatively stable and mostly below the actual distance. This suggests that the Kalman filter effectively reduced the variability in measurements, providing more reliable readings. Despite the improvements, noise was still prevalent at 50 cm indicating a limitation to Kalman filter. For analysing the error, 75 cm was considered as the baseline. Kinect V2 sensor without a Kalman filter showed an RMSE of 7.9 and a standard deviation of 2.07 while with Kalman filtering, the RMSE was 2.65 cm and the standard deviation was 1.90 cm. Note that 50 cm was not considered as it did not provide a proper reading without Kalman filter. These results indicate that the Kinect V2 sensor performed significantly better when paired with a Kalman filter.

Metric	Before Kalman	After Kalman
RMSE (cm)	7.90	2.65
MAE (cm)	7.67	3.14
MAPE (%)	6.45%	4.49%
Standard Deviation of Errors	2.07	1.90
Max Error (cm)	11.00	5.00

**Table 4.1:** Error Metrics Before and After Kalman Filtering for Distances of 75 cm and Above

## 4.2 Assessing Body Posture

### 4.2.1 Standing Poses

The subject was first asked to stand in a comfortable position. Their stance displayed a deviation from good posture: the head was slightly tilted, and the spine was not straight as seen from Figure 4.3



Figure 4.3: Normal Standing Pose



Figure 4.4: Adjusted Standing Pose

Following this, the subject was instructed to maintain a straight head and spine, resembling a "military stance." The sensor accurately captured that the spine and head were aligned straight and coincided with the midline. They were then asked to bend forward, bend backward, and tilt their head left and right. The deviation from

## 4. Results

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the ideal line is visible in the measurements, indicating that the system detected these as deviations from the correct posture, thus returning a "bad posture" result.



Figure 4.5: Bend Forward

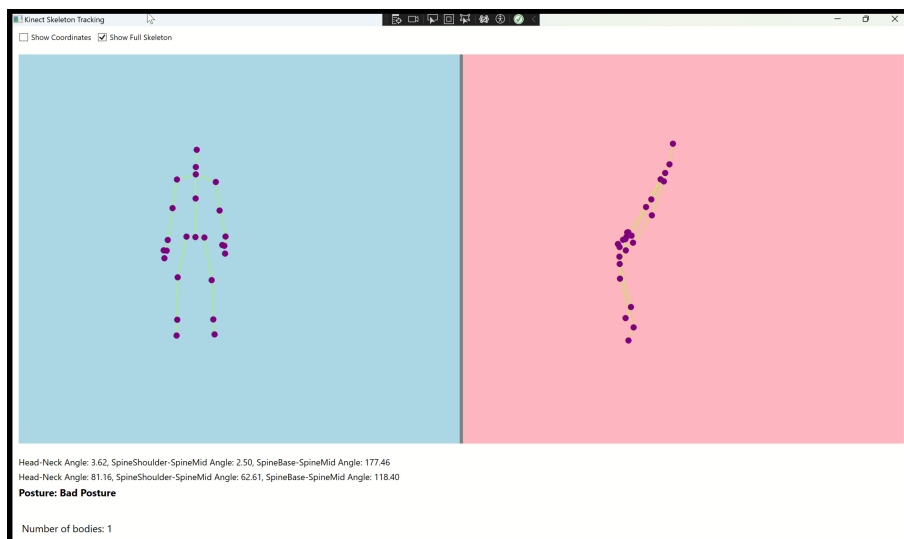


Figure 4.6: Bend Backward



Figure 4.7: Neutral Standing Pose With Head Tilted Left



Figure 4.8: Neutral Standing Pose With Head Tilted Right

## 4. Results

### 4.2.2 Sitting Poses

The subject was asked to sit in their normal sitting position. They adopted a fairly slouched posture, which indicated a noticeable deviation from the midline.



**Figure 4.9:** Normal Sitting Position of The Subject

Afterwards, they were asked to sit with their back aligned with the chair and their head aligned with the spine.



**Figure 4.10:** Adjusted Sitting Position of The Subject

Another important finding is the issue of occlusion or partial tracking of the skeleton. After the subject was seated, an opaque board was kept in front of them, covering the lower limbs. This obstructed the Kinect's field of view, resulting in occlusion and improper tracking of the subject's skeleton as seen in figure 4.11. This suggests that the experiment should be conducted with a clear field of view between the subject and the Kinect V2 sensor.



**Figure 4.11:** Improper Tracking due to Occlusion

In summary, the Kinect v2 sensor demonstrated high precision in skeletal tracking, effectively capturing and displaying postural deviations. This capability makes the Kinect v2 a valuable tool for assessing and correcting posture. The findings support the use of Kinect in clinical settings for physiotherapy and other posture-related applications, offering a cost-effective method to monitor and improve patient outcomes. However, the Kinect v2 sensor is prone to noise, which may impact tracking accuracy. The Kalman filter was able to reduce the errors across various distances, especially improving accuracy at longer ranges but its effectiveness is limited at very short distances. Additionally, occlusion occurs when a foreign object blocks the field of view of the sensor, potentially affecting its performance.



# 5

## Discussions

Our study evaluated the Kinect V2 sensor's skeletal tracking capabilities to measure and visualize deviations from the body's midline, focusing on head and spinal angles. We investigated whether the Kinect V2 could provide a more objective and precise alternative for postural assessment.

The proposed Kinect V2 sensor's capacity to measure and visualize deviations from the body's midline offers a significant enhancement in understanding and managing postural variations. The Kinect V2 sensor was able to track skeletal movements and calculate head and spinal angles in real-time, which are crucial indicators of posture alignment. The quantitative data collected allowed for a more objective assessment of posture. The ability to track and record changes in angle and other deviations over time facilitates better monitoring of postural changes and interventions, which can enhance the management of postural abnormalities.

Key Strengths of the proposed Kinect V2 system include

1. **Detailed Angle Measurements:** The sensor offers detailed numerical data of head and spine angles, which is collected in real-time. This is crucial for monitoring and tracking posture changes and deviations over time.
2. **Repeatability of Data:** Traditional methods, such as visual inspection, are often subject to observer errors and biases, which can complicate the long-term tracking of a patient's progress. The Kinect V2 sensor enhances data repeatability by offering objective and consistent measurements of body angles, reducing variability, biases and other inaccuracies associated with human observation.
3. **3D Rotation:** The 3D rotation capability of the Kinect sensor provides a detailed and precise depiction of body alignment. This feature allows both the operator's and the patient's to clearly understand and assess posture and deviations.
4. **Kalman Filtering:** Kalman filter was able to reduce the noise captured by kinect sensor leading to more consistent and stable error patterns.

Despite the promising findings, several limitations should be considered. One significant limitation is the Kinect V2 sensor's potential difficulty in accurately tracking all body joints, particularly those related to the foot and ankle, which could affect the analysis of lower limb posture where precise alignment is crucial. Additionally, since the Kinect captures data from a single viewpoint, certain body parts may block the sensor's view, leading to missing or inaccurate data for specific joints. This occlusion can result in incomplete or less reliable posture data, especially during dynamic

movements or complex poses. In physiotherapy, it is important to assess muscle tone, joint stability, and the condition of soft tissues. The Kinect does not offer a solution to evaluate these critical factors, as it primarily focuses on tracking skeletal movements and measuring angular deviations. Therefore, even though Kinect provides valuable data, supervision by a qualified professional is necessary to ensure a comprehensive evaluation. Another limitation involves the variability introduced by allowing participants to wear their own shoes during the assessment instead of standing barefoot. Footwear can significantly influence posture, particularly in the alignment of the feet, ankles, and lower extremities, leading to variations in the data collected by the Kinect sensor.

An important consideration while using the Kinect V2 sensor for measurements is to perform the measurement in a room with good lighting. While the Kinect sensor is designed to operate in a dimly lit environment, it is always preferred to conduct the experiment in a well-lit environment for better performance. Additionally, it is crucial to avoid rooms with reflective surfaces, such as mirrors or glossy walls, as this can affect the reliability of Kinect measurements.

Moving forward, further research should focus on improving the accuracy of the Kinect V2 sensor in tracking body joints, possibly through software enhancements or the integration of additional sensors and cameras. This would give the system the ability to capture data from another field of view, which can reduce occlusions and remove the need for 3D skeletal rotation. Incorporating multiple views of the skeleton would facilitate a more comprehensive assessment of body alignment.

Exploring the potential of using ordinary cameras instead of Kinect sensors is also promising. With advancements in computer vision and machine learning, ordinary cameras offer a possible solution to postural tracking. Cameras are cost-effective and easily available. However, an ordinary camera has limited depth perception. While ordinary cameras can still be used with advanced algorithms for depth estimation using frameworks like Mediapipe, they might not achieve the same level of accuracy as dedicated depth sensors. This might make it hard to conduct postural analysis in a dynamic environment. Additionally, sophisticated algorithms increase computational complexity, as estimating and analyzing multiple frames in real-time requires substantial processing power from both the GPU and CPU.

Research should also look into filters that can be used to reduce the inherent inconsistencies and related errors of the sensor. Standardized footwear or developing algorithms that automatically calibrate the system to account for different types of footwear can ensure consistent data collection. Investigating the combination of Kinect-based assessments with other diagnostic tools could provide a more comprehensive assessment of posture. In addition, long-term studies are needed to evaluate the long-term reliability of Kinect-based evaluations and their effectiveness in guiding treatment decisions in diverse patient populations. Addressing these limitations will be crucial for optimizing the use of Kinect technology in clinical settings and ensuring its effectiveness as a tool for postural assessment and rehabilitation.

# 6

## Conclusion

To conclude, this thesis investigated the potential of using the Kinect V2 sensor as a diagnostic tool for assessing postural alignment. By accurately calculating spinal and head angles, we measured and visualised deviations from the body's midline, evaluating the sensor's effectiveness in postural assessment. Our findings demonstrated that the Kinect V2 sensor performs well in real-time skeletal tracking, particularly in measuring head and spinal angles and detecting midline deviations. This capability allowed for a better understanding of posture, revealing subtle misalignments that might be challenging to observe with traditional methods. The 3D rotation feature introduced in this thesis further enhances this by providing a clear depiction of body alignment, which facilitates a better understanding of posture deviations for both clinicians and patients. The sensor's consistent and objective data make it a reliable tool in physiotherapy.

Looking ahead, future research should focus on improving the accuracy of the Kinect V2 through technological advancements and integrating it with additional diagnostic tools for a more comprehensive evaluation. Addressing the limitations identified in this study will be crucial for optimising the application of Kinect technology in clinical settings. By doing so, we can enhance its effectiveness as a tool for postural assessment and rehabilitation, ultimately benefiting patient care and clinical practice.



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# A

## Appendix 1

### A.1 Kalman Filter

The Kalman Filter operates in two main phases: the **prediction phase** and the **update phase**.<sup>[43]</sup>

**Mathematical Formulation:**

- **State Prediction:**

$$\hat{x}_{k|k-1} = A\hat{x}_{k-1|k-1} + Bu_k$$

where:

- $\hat{x}_{k|k-1}$  is the predicted state estimate.
  - $A$  is the state transition matrix.
  - $\hat{x}_{k-1|k-1}$  is the previous state estimate.
  - $B$  is the control input matrix.
  - $u_k$  is the control vector.
- **Covariance Prediction:**

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q$$

where:

- $P_{k|k-1}$  is the predicted estimate covariance.
- $P_{k-1|k-1}$  is the previous estimate covariance.
- $Q$  is the process noise covariance matrix.

In the update phase, the filter corrects the predicted state estimate based on the new measurement.

- **Kalman Gain Calculation:**

$$K_k = P_{k|k-1}H^T(HP_{k|k-1}H^T + R)^{-1}$$

where:

- $K_k$  is the Kalman Gain.
  - $H$  is the measurement matrix.
  - $R$  is the measurement noise covariance matrix.
- **State Update:**

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k(z_k - H\hat{x}_{k|k-1})$$

where:

- $\hat{x}_{k|k}$  is the updated state estimate.
- $z_k$  is the measurement vector.

- **Covariance Update:**

$$P_{k|k} = (I - K_k H) P_{k|k-1}$$

where:

- $P_{k|k}$  is the updated estimate covariance.
- $I$  is the identity matrix.

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