Portable Motion Lab for Diagnostic and Rehabilitation Processes

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PORTABLE MOTION LAB FOR DIAGNOSTIC AND REHABILITATION PROCESSES

A thesis submitted in partial fulfillment of the requirement for the degree of
Master of Science

By

Yogesh Laxman Chavan
B.E., University of Mumbai (2011)

2017
Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Yogesh Laxman Chavan ENTITLED Portable Motion Lab for Diagnostic and Rehabilitation Processes BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

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In this thesis research, we have explored the capabilities of a household body-tracking device - Microsoft Xbox Kinect for motion analysis and assessment to assist patient’s rehabilitation after joint replacement and repair surgeries. In particular, we have combined the motion tracking capabilities of Kinect with the 3D modelling of human body for accurate and intuitive movement assessment and feedback. Our prototype system demonstrates the effective and efficient workflow of motion capturing, data processing and analyzing and augmented reality based presentation, resulting in a design which is not only accurate, reliable and robust, but also extremely cost- and space-efficient.

Furthermore, we have successfully developed a minimum viable commercial software assembling a portable motion lab that can be deployed conveniently at home, clinic office, physical therapy facilities, athlete training centers, or research institutes. We believe our system creates significant economic value for these potential customers by reducing the health care related cost, improving the rehabilitation outcome, and having the potential to prevent the excessive use of additive painkillers.
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1. Introduction

Human body motion analysis has become an integral part of recent medical study where major focus is on the big joints of the body. Recent advancements in sensor technologies have led to the development of many monitoring systems which track and map body movements. Some systems estimate the angles of various joints, which is most popularly called “Range of Motion”. These systems are used to determine any abnormalities around a particular joint or they can be used to track the progression of a patient after a surgery. The next level of “Range of Motion” is the GAIT analysis. Range of motion typically deals with calculating the angles between joints whereas GAIT analysis goes a step further and determines the speed, position and acceleration of the joints. This deduction is also very useful for the athletes who always strive to peak their abilities in their respective fields.

GAIT analysis helps in studying the biomechanics of the body which can be helpful for athletes or patients recovering from a surgery. Since this system provides such a deep study which results in impressive outcomes, it does not come cheap. Such a sophisticated system comes with a huge price tag and it requires large logistics and maintenance to function. Due to these reasons there are very few motion analysis labs which offer human body motion analysis. Thus, there is often a long wait for a patient to undergo recovery analysis, and this delay in turn delays the process where a physician/therapist prescribes certain routines to a patient based on the analysis report.
It eventually lead to the unnecessarily long recovery process which will result in wastage of time and money and could have a lasting physical effect on the patient in terms of recovery, and often cause an extended period of painkiller usage.

The motivation behind this research is to develop an affordable system which will be easy to install, easy to use and produce near accurate results as produced by these costly motion analysis labs. This system will require less hardware logistic and can be used by any physician/therapist in their clinic or patient at home. This will certainly be beneficial for the patients as there will be less or no delays in their rehabilitation process. This system will enable the physicians to handle their patients more efficiently as they can determine the progress and pattern of the recovery process of a particular patient in both a time-effective and cost-effective way. In conclusion, by developing this system we aim at reducing the cost as well as the time of the rehabilitation phase of a patient. This system will also provide an affordable way to improve athlete performance by working on their body mechanics and identifying the areas where improvement can be done. This system may motivate others to follow the same approach and develop such kind of systems which will immensely contribute to the mankind.
1.1. Introduction to GAIT analysis

What is GAIT? GAIT is a manner of walking, stepping or running, most commonly like teaching specific gait(s) to a horse [1]. In recent times, the most known or popular version of GAIT analysis is where a person’s walk or run is analyzed to determine the perfect pair of shoes which will help them run or walk properly. This is just a part of GAIT analysis whereas, GAIT analysis deal with study of human body motion, biomechanics of the body joints and activity of muscle. GAIT analysis is a study that quantifies body movements and then interprets the quantification by drawing conclusions based on the GAIT pattern observed [2]. In recent times, GAIT analysis has become a favorite among the sports community where a particular sportsperson goes through GAIT analysis and the actual potential of that particular individual can be estimated using GAIT. Once, this potential is realized, GAIT can also be used in working towards achieving that potential.

1.2. Standard GAIT process and Setup

A standard GAIT laboratory consists of multiple cameras placed at different positions and fixed at specific angles, typically at all the corners of the room. These cameras are usually video and/or infrared cameras [2]. The cameras are connected to a computer which has a specific software to read, process and display the collected data. A typical laboratory setting for GAIT analysis can be seen in the following images.
Figure 1 - A standard motion analysis laboratory for GAIT analysis [3].

Figure 2 - Infrared cameras are used to capture human body motion [4].
The patient has to walk or run on a treadmill surrounded by these cameras. The patient has to wear reflective markers at the various joints of the body depending upon which joints are to be analyzed. Once these markers are placed, the patient has to then walk on a ramp or run on the treadmill, where these strategically mounted cameras capture the motion and project these marker positions in a three-dimensional space. This mapping can be used to calculate the trajectory of each marker (joint). The trajectory calculated can then be used to calculate the movement of the underlying muscles and bones [2].

### 1.3. Cost of GAIT analysis

A typical GAIT analysis lab consists of infrared cameras, a computer software, a high configuration computer to support this high level of computation with relative speed and a room to accommodate all the equipment. The high cost is due to the overall process of motion analysis. It starts from installing high tech motion sensor infrared cameras which are not cheap, next comes the post-processing of the images captured by these cameras by the computer software which has its own level of complexity, the cost of space to run the whole process and the cost of personnel performing this analysis. An initial cost estimate to set up such a lab would be somewhere around million dollars as well as its annual maintenance cost of around $100,000. Due to these factors, the overall cost for motion analysis is very high, as the initial investment cost directly impacts the affordability of this service for the patients. This forces the doctors and the therapists to rely on the estimates made by their own eyes, which most of the
times are not accurate enough. This may lead to incorrect recovering procedures and exercises, which may cause delay in the overall recovery period and most important of all, physical pain to the patients. To overcome this physical pain, many patients are exposed to having pain killers which may lead to addiction, as per CDC.

A major focus of this research is to minimize the logistics, computation, human intervention and build a cost-effective system which will be accurate, portable and user friendly without compromising on the latest motion tracking sensory technologies. We aim to reduce the logistics by utilizing computer aided sensory data fusion and perform analysis based on it. This will help in reducing the number of cameras, which will reduce the space required and the majority of human intervention. Once these factors are reduced, the cost will automatically come down which will result in a cost-effective setup. We put forward an efficient system which consists of a Microsoft Xbox Kinect 2 connected to moderately high configured computer which has graphic processing capability. Kinect is a motion tracking system which keeps track of body movements. Kinect body tracking is fused with 3D human modelling animation, along with image capturing and processing techniques to create this low-cost gait analysis system. This system overcomes the limitations of existing gait analysis tools and produce near accurate results. This system efficiently captures all the parameters like acceleration, velocity and trajectory of a joint in a human body which is in motion. This system also focuses on the user experience aspect which ensure that the application is very user-friendly. This system successfully reduced complexity without compromising on the accuracy, which is of utmost importance. We expect that this proposed system opens
doors for further research and development using this approach which will benefit the society and contribute in the well-being of mankind and generations to come.
2. Kinect for Motion Tracking

Microsoft Xbox Kinect V2 is the motion sensing device that we have used for the system. Let’s first know what Kinect is before going into the specification details of it. Kinect is a motion sensing device developed by Microsoft for Xbox 360 games [7]. The latest version of Kinect, i.e. Kinect 2.0, was launched in 2013 with the Xbox platform [8]. Kinect consists of a camera and other sensors including infrared, depth and body sensors. The camera of Kinect is of an impressive 1080p quality fused with wide-angle time of flight capability. It has a 60% wider periphery of vision than normal camera, which enables it to track a human body standing at close proximity from the sensor. Kinect also detects heart rates, facial expressions, position of joints (25 joints to be precise), gestures etc. [7]. Kinect has the power to process 2 gigabits of data per second to analyze its environment. The accuracy of Kinect is one of its greatest advantages; it can track up to 6 skeletons at a time, pointing out the reference points (joints) with immaculate accuracy [8]. Kinect also comes with Software Development Kit 2.0 (SDK) which can be downloaded from the official Microsoft website [9]. This SDK comes with drivers for using Kinect 2.0 sensors on a computer running on Windows 8 and above operating systems. The SDK also includes various application programming interfaces (API) and device interfaces which allow fetching of sensory data and various frame data. Kinect is accurate as well as fast in processing the environment and the things in its field of vision. Kinect produces 30 frames per second
and these frames consist of color, body, depth and infrared frames. Using these frames, we can produce a 3-dimensional mapping of the environment which helps in accurately tracking a particular body which is of interest.

**Why Kinect?**

There are many motion sensing devices available in the market, hence a question arises, why Kinect? To answer this question, we must compare the available motion sensing devices. Popular motion sensing devices are SONY PlayStation Move, Wii and Leap Motion. The following is a table of comparison between these devices:

<table>
<thead>
<tr>
<th></th>
<th>Kinect</th>
<th>Infrared cameras</th>
<th>PlayStation Move</th>
<th>SONY Wii</th>
<th>Leap Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hands-free</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Markers</td>
<td>No</td>
<td>Yes</td>
<td>No (Wand)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Accuracy</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Tracking</td>
<td>Multiple</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Table 1 - Comparison between different motion sensing devices.*
The above table compares these different motion sensing devices based on various factors such as hands-free or not, are markers required to mark the joints, how accurate is the system, how many bodies can be tracked and cost effectiveness. After comparing, it can be concluded that Microsoft Kinect is the most accurate, affordable and portable device that can be used for motion tracking.

2.1. Dimensions of Kinect

Kinect is very portable as it can be kept on any table top or it can be mounted on a visual device or a tripod. Below is a picture of Microsoft Kinect 2.0:

![Figure 3- Kinect and its components.](image)

As seen in picture the dimensions of a Kinect are small, to be precise 24.9 cm x 6.6 cm x 6.7 cm and weighs only 3.1 lbs. (1.4 kg) with a cable of length 9.5 feet (2.9 m) [10].
### 2.2. Specifications of Kinect

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color stream</td>
<td>1920 x 1080 @30 fps</td>
</tr>
<tr>
<td>Depth stream</td>
<td>512 x 424</td>
</tr>
<tr>
<td>IR stream</td>
<td>512 x 424</td>
</tr>
<tr>
<td>Max depth distance</td>
<td>~4.5 m</td>
</tr>
<tr>
<td>Min depth distance</td>
<td>50 cm</td>
</tr>
<tr>
<td>Horizontal field of view</td>
<td>70 degrees</td>
</tr>
<tr>
<td>Vertical field of view</td>
<td>60 degrees</td>
</tr>
<tr>
<td>Joints tracked</td>
<td>26</td>
</tr>
<tr>
<td>Skeleton tracked</td>
<td>6</td>
</tr>
<tr>
<td>Audio capture</td>
<td>4-mic array 48K Hz audio</td>
</tr>
<tr>
<td>Latency</td>
<td>~60 ms with processing</td>
</tr>
<tr>
<td>USB standard</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*Table 2 - Kinect specifications.*
2.3. Components of Kinect

a. RGB camera – The color camera captures 1080p video which can be displayed in the same resolution in any display. With this high-quality video feed along with wider field of vision and processing speed of 2 gigabits per second, we get a smooth, reliable, accurate and sharp video stream [10].

b. Infrared stream – This capability allows the Kinect to see in minimum lighting area or in dark areas and produces lighting independent view. The capability can be combined with the high-resolution camera feed [10].

c. Depth stream – With increased depth fidelity and improved reduction in noise floor, depth stream provides an accurate 3D visualization which can detect smaller objects efficiently. This also helps in distinguishing various objects in the environment and results in better body tracking [10].

d. Multi-Array of microphones – Four microphones are present to capture the audio. They are also used to track the source of the audio and the direction of the sound wave [10].
2.4. Co-ordinate Mapping

If we refer to the Table 2, we can see that the Color stream has different resolution (1920 x 1080) compared to the Depth and Infrared stream (512 x 424). This difference in resolution means that a depth frame cannot be laid over a color frame as the coordinate mapping will be totally different given the difference in resolution. Hence, a joint location in a color frame will be at totally different location in depth frame and so they cannot be overlapped on each other. To counter this problem Kinect SDK provides a Coordinate Mapper. Coordinate Mapper can identify a point in 3D space (depth) and can align it in 2D space (color) and vice versa.

2.5. Motion Tracking using Kinect

Kinect uses various sensors to track different objects present in the environment. Kinect uses a depth sensor to map all the objects present in the environment and its field of vision into a 3D space. The depth sensor basically places various infrared points along the field of view with a fixed and constant pattern. This depth information is provided by the depth frame which can be obtained from the API and can be used for different purposes. The body frame captures the skeletal information in the field of vision of Kinect and can track up to 6 skeletons. The body frame also captures 25 joints of each skeleton. These joints are all the vital joints in the skeleton. Below is a figure which shows the various joints that are tracked:
The body frame keeps track of joints and the information is stored. Every skeleton has an array of joints and each joint when tracked has a position value. The IR transmitter and a monochrome CMOS sensor is used by the Kinect to accurately track the position of the joints. There is an expected value and an observed value obtained using these sensors and difference is calculated and infrared dot points are mapped to determine the depth information for each pixel that is obtained from the color frame or the camera. A Random Forest Classifier is then used to determine the position of the joints based on the depth information that was previously calculated. This technique helps in mapping each pixel to a particular part of the body, i.e. for each pixel it is determined whether it is a part of head or face or hand or leg or background and so on. This process is done repeatedly for each and every frame, and the pixels are then grouped together as a body frame. Since a 2D camera or a video feed cannot be able to
handle this high variability, we do not use the color frame. Below are the frames of individual sensors:

Figure 5 - Infrared frame [17].

Figure 6 - Depth frame [18].
2.6. Advantages of Kinect

The biggest advantage of the Kinect system is that it is low-cost and portable. Kinect costs only a couple of hundred dollars which is comparatively less than any existing, similarly capability devices. The entire setup costs less as it needs just a power source and a computer system to provide data to. Kinect is extremely portable, it does not require huge room space for its functioning. This portability allows the user to use Kinect in any available space eliminating any further cost of space. So, Kinect not only lowers the cost but also cuts on the cost by removing the rent/price of a room required to set up a motion analysis system. Apart from being cost-effective and portable, the biggest advantage of Kinect is its reliability and accuracy. Kinect provides accurate and reliable tracking of skeleton and its joints. Kinect also comes with a Software Development Kit which provides no limit to the developers. The developers can put
Kinect’s capabilities to use in different perspective as Kinect provides various functionalities with its camera, depth stream, infrared stream, skeletal information, face recognition, environment information etc.

In our system, we have used these capabilities of Kinect with medical perspective. We have developed a software which displays a video stream with an outline of the skeleton on the interested body. Kinect can track up to 6 bodies in the frame and we take into consideration only one body which has the best tracking state. We have also used the body frame to track the joints and using vector information we calculate the angles of flexion and extension on particular joints. We have also used the face tracking ability of Kinect to accurately track neck movements. Overall, our system has used a majority of the Kinect’s capabilities and put them into a user-friendly application. The details of that application can be found in the following chapters of the report.

2.7. Limitations of Kinect

As we list a majority of the advantages of Kinect, it also has some limitations. Motion tracking with Kinect is still a new thing and hence a deep study of its capabilities and testing is required to be certain of things. Kinect’s accuracy is yet to be completely tested in the medical domain where reliability is more important than anything else. While testing our application, there were some limitations to the tracking based on the angle and orientation of the body. Kinect’s accuracy increases based on how well it can distinguish different body joints. We found it difficult to track the joints when the joints overlapped each other. This affected its accuracy and hence we came
up with a guide regarding the positions that a patient must stand in to perform the
movements in order to track accurately. Kinect is also sensitive to black material which
does not reflect the infrared beam which causes a bit of indecision in the tracking
system. The frame rate of Kinect currently is 30 frames per second which can be a bit
slow to capture details of fast body movements like throwing a ball or a quick punch
or kick.

While working with Kinect, we came across such limitations and we figured out
temporary solutions to these limitations. We have created a complete application which
will guide the user in the proper direction in case of discrepancies or inaccurate
tracking. Kinect is definitely the future of motion tracking as it has many valuable
advantages and manageable limitations.
3. Gait analysis using Kinect

Gait analysis deals with the functioning of the joint movements based on parameters like acceleration, velocity and position. Gait analysis determines the capability of a joint of a patient/athlete typically during a rehab session or training session. Gait analysis is important for physical therapists, orthopedic surgeons, and physical trainers etc. to keep track of the progress of a patient or an athlete. A typical gait laboratory consists of multiple cameras mounted on every corner of the room along with a pathway or treadmill depending upon the requirements. These equipment are connected to a computer for data collection. The patient/athlete must wear markers on their joints so that the beams coming out of the infrared cameras are reflected by these markers and the position of the marker is then mapped into a 3D space using computer software. The procedure starts with placing those markers on the patient/athlete’s body which is time consuming. Each marker has to be placed properly by figuring out the best area around the joint which will make sure that the marker does not fall off and gives an accurate measurement. This procedure not only involves human touch but also different factors regarding the markers. The positioning of the markers becomes important for the accuracy of the readings as even 1 cm of difference can cause a lot of variance in readings. Considering the fact that a human is tasked with putting up the markers on the patient/athlete, there is always a possibility of introducing human error which can lead to indifferent readings. Once all the markers are placed, the
patient/athlete must walk down a ramp or run on a treadmill and then the software will calculate the trajectory of each marker in 3D space. The trajectory is then used by a model to calculate the joint movements, and then along with the markers analysis and joint movements, angular motion of each joint is determined [2]. Most labs have floor mounted transducers or pressure plates which determine the direction, location and magnitude along with the moments and ground reaction forces which is commonly called center of pressure. By calculating the computations of net forces and net moments of forces of each joint at every gait cycle, kinetics of gait pattern can be computed.

![Figure 8 - A gait setup](image)

This setup is very costly just from the logistic point of view. Infrared cameras, markers which cannot be reused, pressure plates, computer software, and room space, all of these contribute towards the cost. Annual maintenance cost is also high for these
equipment. Additionally, man power cost is also a major factor. All these factors make gait analysis a costly affair and hence not everyone can afford it. Due to these extreme costs, motion analysis labs are also very limited, which further increases the possibility of longer wait period for people to get their analysis done and their reports.

Our main goal is to make this system affordable and accessible to as many people as possible. The best way to do this is to reduce costs and increase portability along with accuracy. We propose a system which includes a Microsoft Kinect 2.0 and a user-friendly computer software. Kinect does not require a huge space as it can be mounted on devices/stands or kept on a table top. Kinect has its own high-resolution camera fused with depth and infrared stream which eliminates use of multiple infrared cameras. The patient/athlete can simply walk or perform a particular action without requiring any pressure plates. Kinect also does not require any reflective markers to point out the joint locations. Kinect uses body frame which can locate 25 individual joints of the body without the use of any external help. Basically, Kinect eliminates the majority of factors which contribute towards the cost like infrared cameras, room space, markers, pressure plates etc. Kinect also eliminates human touch, as there is no need to place markers, and hence eliminates human error factor which results in more consistent and accurate tracking. We have created an entire application which can perform these actions from a physician’s desk. This capability will be useful for the patients who are in their rehabilitation phase as they will get quick results and their physicians will be able to accurately measure the progress instead of waiting for those high-end motion analysis lab results. The results produced during the testing of our
application were very promising and accurate and it does have a potential to deliver what it is expected to do.

3.1. Body joint tracking

A human skeleton is made of many bones. Bones are stiff and hence they are connected together using sockets or joints. A joint is nothing but a position where two bones are connected. Joints allow the human skeleton to perform different movements and hence a human body can move and do different actions. Gait analysis is performed to figure out the capability of these joints. These capabilities differ from person to person and so Gait analysis is useful in rectifying and enhancing the over capability of a human. In traditional Gait analysis, the entire body movement is captured on video and stored in a database which is analyzed later. This increases the storage space required as it stores the entire video whereas the analyst is only interested in joint movements. Our application eliminates storing of the entire video and stores only the joint data in a local database file. This data is processed in order to find the velocity, acceleration, and position of each joint. Once this data is calculated, it is used by the application for various purposes like charting, visualization, etc.

Kinect has the capability of tracking up to 6 bodies present in its field of vision, but currently we are interested in only one body, that is of patient or athlete. Kinect SDK provides an API which fetches various information from the environment and puts them together in frames. These frames are body frame, infrared frame, depth frame and color frame. To obtain data for the joints, we use body frame. The SDK provides us with a frame that has a body list in it, i.e. an individual body frame for each body present
in the body list. As we are interested only in a single body, we choose the best tracked body from the list. Once the body to be tracked is decided, we obtain the body frame. A body frame tracks 25 individual joints of a body. This information is stored in the joints list of a body frame. Every joint present in the joint list is mapped in 3D space and the position data is represented through x, y and z co-ordinates. The following flowchart represents the process of tracking a joint of a body:

*Figure 9 - Flowchart of retrieving joint data.*
Kinect has the capability to provide 30 frames per second and we retrieve position data of each joint from each frame i.e. per second we have 30 position points for a particular joint which may or may not be the same. To put this into perspective, a body has 25 joints tracked simultaneously which produces 30 records per joint position data in a second, so we have 25 x 30 which is 750 positional data points every second for a particular body. This data can sometimes be redundant when there is no body movement and hence storing the same data over and over again is not a good idea. On the contrary, if the movement is of high speed like throwing or kicking, we need data from each and every frame to calculate the position, acceleration and velocity data. To overcome this, we have enhanced the existing motion tracking to make decisions based on the data. When a body is not in motion, even then the frames captured by the system provide positional data. This data is similar to the previous frame data and hence does not have much significance in the process of gait analysis. So, by ignoring this redundant data, we eliminate the extra effort spent on processing of this data which is going to yield repetitively similar output consuming lot of computational processing speed. The enhancement algorithm is incorporated during the motion tracking which perform operations on the retrieved data from the frame and produce a filtered output which can be used by the Gait engine and the visualizer to display it on the screen as physical evidence to the interested parties. Below we will go through a deep insight into how this system works along with its workflow and how the current system is optimized with our algorithms.
3.2. Workflow of the System

Given the frame rate and the data retrieved, it is necessary for the motion tracking system to be intelligent to capture the important data points and ignore any redundant data for maximum performance.

![Flowchart of Gait analysis](image)

*Figure 10 - Flowchart of Gait analysis.*
The workflow of the system is shown in the above flowchart. Previously we saw how joint data is fetched from the frame and this data forms the base or the input to the system. We also saw that there may be cases where the data will be redundant due to no movement of the tracked body. There is another possibility too where the data might be irrelevant or inconsistent or dirty based on different factors. For example, if the joints are overlapped, the position data or the angle data may become inconsistent for those two overlapped joints or if the movement is too fast, the position data may be incorrect, and the angle calculated can go offbeat. Similarly, if the angle of the body towards Kinect is not proper, then it may cause difficulty to the Kinect in mapping the joints properly which can lead to incorrect values. Hence, an enhanced motion tracking system must be used to track the joints. The position data is used to calculate the angle made by the joints using vectors. This process is called calculating the Range of Motion (ROM) which we will see in further sections.

The enhanced motion tracking system uses an advanced algorithm which is fast to process the fetched data and based upon certain conditions, decides which data should be used. When a frame is received by the system, it retrieves all the information from it. Each frame has information of all the joints of the body that is selected from the body list. The position data of all the joints i.e. 25 specific joints is present in the frame data. This is raw data and it is just transported from the Kinect sensors to the system through API’s provided by the Kinect SDK. To process this raw data directly, it will cost lot of computational cycles which can delay the entire process. To overcome this problem, the raw data is analyzed and only the relevant data is passed to the system.
All the redundant data is discarded. A filtering algorithm is used to achieve this, and this algorithm provides the enhancement of the tracking system.

A step by step approach is required for this algorithm which can be seen below:

**Filtering Algorithm:**

FOR all joints in joints_list of the body

//check if the movement is out of range
IF the movement is out of range for interested joint THEN

//check if it is due to overlapping of joints
IF joints are overlapping THEN

Use the predicted value for the interested joint.

//check if it is due to fast motion of the joint
ELSE IF the motion is too fast THEN

Use the predicted value.

ELSE

Use current frame value

ELSE

Use current frame value

END FOR
Value Prediction using Exponentially-Weighted Moving Average:

We have used Exponentially-Weighted Moving Average (EWMA) to estimate the predictable value if the obtained value is an outlier or not as expected. The main reason to choose this method was because of its method of operation where EWMA weights samples in geometrically decreasing order so that the most recent samples are weighted most highly while the most distant samples contribute very little [14]. This means that the most recent values contribute more towards predicting the values than the older values. Following are the formulae which are used for value prediction.

- \( P_x = w_1 \cdot CP_x + (1 - w_1) \cdot PP_x \)
- \( P_y = w_1 \cdot CP_y + (1 - w_1) \cdot PP_y \)
- \( P_z = w_1 \cdot CP_z + (1 - w_1) \cdot PP_z \)

Where:

- \( P_x \) is the Position value of \( x \),
- \( P_y \) is the Position value of \( y \),
- \( P_z \) is the Position value of \( z \),

- \( CP_x \) is the Current Position data value of \( x \),
- \( CP_y \) is the Current Position data value of \( y \),
- \( CP_z \) is the Current Position data value of \( z \),

- \( PP_x \) is the Previous Position data value of \( x \),
- \( PP_y \) is the Previous Position data value of \( y \),
$PP_z$ is the Previous Position data value of $z$,

and $wl$ is a constant value between 0 and 1, both inclusive.

**Visualization:**

A major effort has been put into the visualization part of this system, which is often considered to be one of the important aspect of any software. An application has to be user friendly i.e. the user interface should be easy to understand, clearly display the results and easy to use. Most of the motion analysis softwares that are available have cluttered user interface which make it difficult for any non-technical person to use them. They have to undergo some kind of training to use these software applications. The user interface of our system is clean and easy to navigate. The visualization is of prime focus as it provides visual evidence and validation of the movements. This helps a lot as it provides real time evidence of the movements, and the physician along with the patient or athlete can correct themselves during the analysis. The application is made of various examinations along with Gait analysis. The various examinations are for Upper extremity, Lower extremity and Spine. These examinations are used to calculate the Range of Motion (ROM). Range of Motion examination is mostly used in the rehabilitation process. The user interface provides retractable panels which can be customized as per the needs of the user. The panels change automatically based upon the examination selected. The video feed is displayed in the center of the application so that it is properly visible. Below is a screenshot of the user interface of our application.
In the screenshot we can see that the majority of area in the application is given to the visualizer, whereas the retractable panels are on the right and left corner. A skeleton is drawn on the body present in the video feed and the interested joints are highlighted. We will see the details about the application later in the following chapter.
3.3. Gait Engine

The enhanced motion data obtained from the enhanced motion tracking is provided to the gait engine where the position data is used to calculate position, velocity and acceleration. This computed data is used to determine any abnormalities present in the human body. The gait engine provides position, acceleration and velocity for all the joints and this data is further enhanced/filtered to increase accuracy and efficiency.

3.3.1. Calculating Position, Velocity and Acceleration

The position data provided by the tracking system is raw data and it needs to be filtered in order to remove redundancy and outlier data. To achieve this, we have implemented a two-step process where in the first step the values are predicted using Exponentially-Weighted Moving Average (EWMA). In second step, we apply a multi-stage Kalman filter which normalizes the calculated data. This is an iterative process which executes for every frame. Following are the formulae used for calculating position, velocity, and acceleration.

Previously we saw how Exponentially-Weighted Moving Average works and hence we will just list the formulae here with the nomenclature staying the same.

**Position:**

- \( P_x = w1 * C_P_x + (1-w1) * P_P_x \)
- \( P_y = w1 * C_P_y + (1-w1) * P_P_y \)
- \( P_z = w1 * C_P_z + (1-w1) * P_P_z \)
Velocity:

The basic formula for calculating velocity is to calculate the difference between the current and previous position divided by time.

\[
Velocity = \frac{(\text{Current}_{\text{Position}} - \text{Previous}_{\text{Position}})}{\text{time}}
\]

Using the nomenclature used to calculate the predicted position, and given that the frame rate of Kinect is 30 frames per second, the formula becomes:

\[
Velocity = \frac{(CP - PP)}{1/30}
\]

\[
Velocity = (CP - PP) \times 30
\]

Where, CP is the current position and PP is the previous position.

Calculating for the co-ordinates in 3-dimensional space, using the same nomenclature:

\[
Velocity_x = (CP_x - PP_x) \times 30
\]

\[
Velocity_y = (CP_y - PP_y) \times 30
\]

\[
Velocity_z = (CP_z - PP_z) \times 30
\]
**Acceleration:**

The basic formula for calculating acceleration is to calculate the difference between the current and previous velocity divided by time.

\[ \text{Acceleration} = \frac{(\text{Current}_{\text{velocity}} - \text{Previous}_{\text{velocity}})}{\text{time}} \]

Using the nomenclature used to calculate the velocity, and given that the frame rate of Kinect is 30 frames per second, the formula becomes:

\[ \text{Acceleration} = \frac{(CV - PV)}{1/30} \]

\[ \text{Acceleration} = (CV - PV) \times 30 \]

Where, CV is the current velocity and PV is the previous velocity.

Calculating for the co-ordinates in 3-dimensional space, using the same nomenclature:

\[ \text{Acceleration}_x = (CV_x - PV_x) \times 30 \]

\[ \text{Acceleration}_y = (CV_y - PV_y) \times 30 \]

\[ \text{Acceleration}_z = (CV_z - PV_z) \times 30 \]
3.4. Post Processing – Filtering

The data obtained after calculating position, acceleration, and velocity still contains noise and error. To reduce this noise and error we used a filtering technique known as Kalman filtering. Kalman filtering is used to produce estimates of accurate variables based on a series of measurements which contain statistical noises and other present inaccuracies. Kalman filtering works in two steps. The first step involves estimating the state of current variables along with their uncertainties. In the second step, these estimated values are then updated using weighted average to estimate the higher certainty [15].

![Figure 12 - A graph comparing filtered and unfiltered values.](image)

The above graph shows the results observed on selected data. The noise and inaccuracies in the data before the filtering process and the smooth, predictable values obtained after the filter is applied can be clearly seen.
4. Application Development

We have developed an application named as “Orthopedic Analyzer” which has the capability of calculating Range of Motion (ROM) and Gait analysis. The application is developed using C# language in Visual Studio and is a Windows desktop application. We chose Windows based desktop application as most of the offices run on Window’s operating system and it is easy to use as well. We used Visual Studio to develop this application which is an Integrated Development Environment (IDE) used for developing different C# based applications.
4.1. System Workflow

![System workflow diagram]

Kinect device captures all the data present in its field of vision or environment and passes it on to the interfaces present in its SDK. The data captured by Kinect is presented to the application via these interfaces. Our application then uses this data for multiple purposes such as visualization through video feed, real time on the fly joint angle calculations, range of motion calculation and gait analysis. All of these functionalities are based on the data provided by the Kinect API’s.

4.2. Application Architecture

Any software application that is being developed must have a core architecture in its design which provides stability as well as flexibility. Stability in an application means that the application is consistent with its output based on accuracy
and reliability. Flexibility allows the application to incorporate new functionalities without compromising on the stability aspect. The design of any application determines its shelf life and usability. The approach that we have taken to develop this application is just like any real world corporate application would use. A large amount of work and focus has been put into its usability aspect which includes the user interface and its ease of use to an average person. There are various technologies that are used for software development like Console application, Windows Form application, Windows Presentation Foundation (WPF), etc.

We chose Windows Presentation Foundation (WPF) as it is a dedicated technology used for developing desktop based applications with richer user interface. The rich user interface is provided through next generation designer language called eXtensive Markup Language (XAML). XAML is used solely for user interface and it provides great user controls to place the GUI controls in proper space and format. XAML consists of tags which are more or less like those used in XML or HTML. After deciding the technology, we had a choice of which design principles to be used. We opted for the Model-View-ViewModel (MVVM) pattern which has advantages like modularity, separation of concerns, extensibility and stability.
MVVM pattern consists of 3 different layers viz. view, view model and model. View consists of all the user interface parts which will interact with the user. View model supports the view and handles all the communication from and to the view. Model is like a business logic layer where all the logic is written and decisions and calculations are made. The communication is in a sequence where a user does an action on the view and the view communicates this action to the view model. View model then locates the appropriate model and sends this information received from the view to that model for processing. The model uses the data and performs data processing and communicates its result to the view model. After receiving the result from the model, the view model then takes the result and communicates it to the view and then view displays it for user validation. The most important advantage of this design is its separation of concerns where the user interface is not directly dependent on the business logic, hence this makes the entire application flexible to incorporate different functionalities that may come in the future.
4.3. Orthopedic Analyzer – the application

In any modern-day application, user interface is the most important aspect of an application. A major effort was put into achieving this goal and we have developed a clean and perfectly working application; we call it “Orthopedic Analyzer”.

The application consists of various exams which are listed at the top so that they can be easily accessible. When the application is started, the exams are positioned on the top and a blank space can be seen below it. This blank space is for the controls based on the examination selected. Currently, there are 3 examinations which are “Upper Extremity”, “Lower Extremity” and “Spine” which are used for calculating Range of Motion (ROM), there is also “Gait analysis” option.
When a particular examination is selected, we can see in the following screenshot how different controls are aligned with a constant video feed at the center of the application.

![Screenshot of Upper Extremity examination.](image)

*Figure 16 - Screenshot of Upper Extremity examination.*

It is evident from the screenshots how clean the user interface is and how easy it is to understand. The above screenshot shows the parameters involved in the Upper Extremity examination. Upper extremity consists of shoulder and elbow joints along with the carrying angle for both the hands. All the possible movements of a particular joint are listed separately so that they can be tracked properly. We will see more about the user interface and the functionalities of the application in following topics.
4.4. Orthopedic Analyzer – the functionality

The two major functionalities supported by this application are Range of Motion (ROM) calculation and GAIT analysis. We will start with GAIT analysis and then the Range of Motion.

GAIT analysis

The above screenshot shows the GUI of application when GAIT analysis is initialized. All the surrounding panels are retracted back so that the video can capture the maximum area of the application. This is done because we will be recording the movement first. There are four functionalities offered by the application for GAIT analysis. This application first records the entire movement and while doing that, it also calculates the position, acceleration and velocity of the joints and stores them in a file so that the data can be reviewed.
The four functionalities offered by the application are:

![Functionalities of application for GAIT analysis](image18)

*Figure 18 - Functionalities of application for GAIT analysis.*

When the “Record” button is clicked, the application starts recording the movements present in its field of motion and while doing that the SDK passes all the data to the application. The application then starts high speed computation of the variables and calculates results for each frame data that is being provided. When the “Record” button is pressed the text changes to “Stop” button and hence it is evident that recording is in progress.

![Recording for GAIT analysis in progress](image19)

*Figure 19 - Recording for GAIT analysis in progress.*
The user then can click on the “Stop” button and stop the recording. Once the recording is stopped, the computation is also stopped, and the frame data is simply ignored by the application. Now that the motion/movement is captured, processed and stored by the application, it can be reviewed. To review the entire motion/movement, the user must click on the “Review” button.

![Figure 20 - Screenshot of review of captured motion/movement.](image)

As the user clicks the “Review” button, the entire video feed is replaced with a Unity 3D visualizer giving various other options. This Unity 3D visualizer is hosted as a web document in the local server where the data stored in the file while recording is given as an input. During the review process the entire Kinect video feed is replaced with a web browser which hosts a Unity 3D web application. If the user clicks on the “Show Traj” button, the entire movement is replicated in a 3D space. The user can
zoom in/out while the movement is being replicated or the user can view it from all possible angles by just moving around the mouse.

The application also displays the calculated values in the form of charts during the review phase. The position, acceleration and velocity data for every joint is displayed in the chart while the review process is happening in parallel.

The above screenshot shows the charting functionality of the application. The user here has zoomed in the replicated movement to bring it in focus and the calculated parameters are charted and displayed in the side panels. This functionality is very handy as the user can see the data visually through the chart, also see the repeat of the entire movement recorded. If the user wants to return to normal video mode, then the user can click on the “Video” button and real time video feed will be displayed in the center. Microsoft provides its own visualizer called “KStudio” which provides many other
general options and if the user wants to have a look at them then the user can open the application by clicking on the “KStudio” button.

**Range of Motion (ROM)**

The application provides three different examinations which are used to calculate the Range of Motion. Range of motion is a range of angle at which any particular joint can move in a full extent, usually referred as Flexion and Extension. Kinect provides data for 25 different joints and these 25 joints are divided into upper extremity (upper body), lower extremity (lower body) and spine (lumbar spine). The three examinations cover all the joints; therefore, the range of motion can be calculated for all the joints. The user interface of the application provides retractable panels which are used to display the angles in real time when the body is performing a movement.

*Figure 22 - Screenshot of Upper Extremity exam without the retractable panels.*
Figure 23 - Screenshot of Upper Extremity with the retractable panels.

The retractable panels are customized based on the examination selected, depending upon the examination selected, the options change inside the panels. For each joint depending upon the movement capability, the motion is determined to have flexion, extension, abduction, adduction, rotation, bending and carrying angle. At any given time, the application will allow the user to track only one angle. This validation is useful as it makes the user focus on a single joint at a time and the reading can be accurately monitored. The capability of the application to display the real-time movement along with the angle calculation removes the necessity of any human touch. This capability makes the entire process a touch free process which is preferred by the patients/athletes.
Figure 24 - Screenshot of application recording the movement of Elbow joint.

The above screenshot shows the application in action while monitoring the elbow joint. It can be seen that the “Update” button is turned into the “Stop” button and the background color also changed from green to red. This is done to draw the attention of the user that angle calculation of a joint is in progress. To calculate angle for any other joint, the current process must be stopped. Following are some more screenshots which show the application in action and its customizability which can be used by the user at will.
Figure 25 - Screenshot of calculating Right knee angle with only Right leg panel in view.

Figure 26 - Screenshot of calculating Left knee angle with only Left leg panel in view.
The user interface makes sure that the angle calculation is neat and clean so that there is no visible lag while displaying the changing values. The layout used to display the angles is of prime importance. The following figure shows an example of the layout.

![Shoulder Layout](image)

*Figure 27 - Layout of fields for shoulder joint angles.*

The above figure shows a general layout of fields. The layout is for shoulder joint, monitoring the joints Flexion, Extension and Current angle values. All the values are “N/A” by default for the joint that is not being monitored.

![Elbow Layout](image)

*Figure 28 - Layout of fields with angle values for elbow joint angles.*

When a particular joint is monitored, the “Update” button is changed to the “Stop” button with its background. Flexion value is the maximum the elbow has bent, and the Extension value is the value to which the joint is extended. These values change
as new thresholds are reached as the movement happens. The Current field tracks the current angle of the joint and it keeps on changing throughout the movement, tracking the exact angle of the joint. To stop tracking a particular joint the user must click on the “Stop” button and the angles are recorded. These angles do not change until and unless the user clicks on “Update” again.

One more challenge was to overcome one of the shortcomings of Kinect. To track the joints properly, it is necessary for a body to face the Kinect in right direction, angle and distance. To overcome this, we added the info button with an icon of “i” besides the “Update/Stop” button which can be seen in the screenshot. When this info button is clicked, it opens a small window and shows exactly what movement must be done for that particular joint, what angle and what distance a person should stand in front of the Kinect. This visual guide is developed in Unity 3D which displays a 3D human model performing the movements. Following are the screenshots of visual guidance provided by the 3D human model for the knee joint:

Knee Right
This guide when opened, keeps repeating itself and the patient/athlete can watch and learn the movement further removing the human touch aspect by removing the passive movement guide. Once the user is satisfied with the movement and the reading, the user can take readings for all the joints. The application gives the user an option to store all the recorded values in a text for record. The user can use this option and save the entire data in a notepad file and can open it later for reference. The data is stored in an orderly manner which is easily readable and presented in a proper format. The three exams are distinguished and as well as the joints. The Range of Motion part was done in collaboration with another student working in the same direction [16]. Following are the screenshots of the notepad file storing the angles that we calculated during a demo.
<table>
<thead>
<tr>
<th></th>
<th>Upper Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right Hand</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shoulder</strong></td>
<td></td>
</tr>
<tr>
<td>Flexion/Extension</td>
<td>-124 230</td>
</tr>
<tr>
<td>Abduction/Adduction</td>
<td>82 28</td>
</tr>
<tr>
<td>Rotation</td>
<td>Internal 132 120</td>
</tr>
<tr>
<td><strong>Elbow</strong></td>
<td></td>
</tr>
<tr>
<td>Flexion/Extension</td>
<td>5 142</td>
</tr>
<tr>
<td><strong>Carrying Angle</strong></td>
<td>Angle 16</td>
</tr>
<tr>
<td><strong>Left Hand</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shoulder</strong></td>
<td></td>
</tr>
<tr>
<td>Flexion/Extension</td>
<td>-102 235</td>
</tr>
<tr>
<td>Abduction/Adduction</td>
<td>225 9</td>
</tr>
<tr>
<td>Rotation</td>
<td>Internal 96 113</td>
</tr>
<tr>
<td><strong>Elbow</strong></td>
<td></td>
</tr>
<tr>
<td>Flexion/Extension</td>
<td>0 136</td>
</tr>
<tr>
<td><strong>Carrying Angle</strong></td>
<td>Angle -17</td>
</tr>
</tbody>
</table>

*Figure 29 - Screenshot of notepad file showing values for Upper extremity exam.*
<table>
<thead>
<tr>
<th></th>
<th>Right Leg</th>
<th></th>
<th></th>
<th></th>
<th>Left Leg</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Extremity</td>
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<td>Flexion</td>
<td>Extension</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Right Leg</td>
<td></td>
<td></td>
<td></td>
<td>Hip</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Side</td>
<td>Abduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Abduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Knee</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Extension</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 30 - Screenshot of notepad file showing values for Lower extremity exam.
### Spine

#### Cervical Spine

<table>
<thead>
<tr>
<th></th>
<th>Flexion</th>
<th>Extension</th>
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</thead>
<tbody>
<tr>
<td>Flexion/Extension</td>
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<tr>
<td>Lateral Bending</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>-16</td>
<td>31</td>
</tr>
<tr>
<td>Lateral Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>-55</td>
<td>65</td>
</tr>
<tr>
<td>Total ROM</td>
<td>Angle</td>
<td>206</td>
</tr>
</tbody>
</table>

#### Lumbar Spine

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<th>Extension</th>
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</thead>
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<td>Flexion/Extension</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lateral Bending</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lateral Rotation</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Total ROM</td>
<td>Angle</td>
<td>5</td>
</tr>
</tbody>
</table>

*Figure 31 - Screenshot of notepad file showing values for Spine exam.*
4.5. Experimental results

We tested out gait systems several times along with the range of motion capability. The range of motion results were impressive, with accuracy around 97%-98%. To test the gait functionality, we performed a walking demo. The first walk was a normal walk which resembled a walk of a person with no injuries or no abnormalities in the joints. The system recorded the entire motion (walk) and performed various computations and came up the output values for position, velocity and acceleration. The system wrote all the calculated values in a text file and displayed these values in a chart system during the review process. We took screenshots of these charts separating them on basis of values concerned with position, velocity and acceleration. Then, we tried to resemble the walk of a person who may have undergone a surgery for example hip replacement surgery and recorded the values along with the charting. We took screenshots of these charted values as well for comparison. Following are the screenshots placed in order to compare for the three different walks viz. normal walk, limp walk and duck walk that were recorded. We analyzed the results and to validate our system we will use the position data for comparison for all the three different types of walk. We will also show the charts for the overall comparison for position, velocity and acceleration for these three walks. All the proceeding screenshots are the charts from our system.
Below are the charts for comparing the position data for all the three different walks. We chose Hip Centre joint as it will give us relative information about the right and left hip. In the position data, we will compare the X values as they will display the potential variance and displacement.

Figure 32 - Position data of X co-ordinate for normal walk.

Figure 33 - Position data of X co-ordinate for limp walk.
The charts show proper variance and displacement along the X axis during these walks. If we see at the data of normal walk, the total variance is in the range of 0.08 m, compared to that of limp walk which is around 0.15 m and duck walk which is 0.27 m. The displacement clearly points out the abnormality in the walks apart from the normal walk. The chart comparison also depicts the kind of walk the person was doing, as in duck walk, the chart is showing a pattern similar to a sine wave which suggests that the person is swaying on both the sides. Comparing it with the limp walk, the chart clearly shows the dip towards the negative side, which means that the right hip is having an abnormality. Following are the charts for all the three walks showing the position, velocity and acceleration data in all the X, Y and Z axes.
Figure 35 - Position chart for normal walk.

Figure 36 - Position chart for limp walk.
Figure 37 - Position chart for duck walk.

Figure 38 - Velocity chart for normal walk.
Figure 39 – Velocity chart for limp walk.

Figure 40 - Velocity chart for duck walk.
Figure 41 - Acceleration chart for normal walk.

Figure 42 - Acceleration chart for limp walk.
This validates the systems analysis, as it can record and display the difference between a normal and abnormal walk. When a person who is injured and has undergone a hip replacement surgery tends to sway towards right and left while walking, this swaying is depicted in the X-axis and therefore we can see the fluctuation in the charts for X-values. Hence, by just plotting the charts, the system can analyze and give visual evidence to the physician about the existing abnormality. This system can also be used to track the progress of a patient as the data can be stored in a file for each review. Then even a local physician can refer to this data and check the progress made by the patient over time.
5. Conclusion and Future work

During development and testing of this application and working with the Kinect, we realized that this kind of approach had a lot of scope in the healthcare domain. Kinect not only can be used for developing games, but can also be used for motion analysis labs. Kinect is not a perfect device for motion analysis as it has its own disadvantages and shortcomings, but with proper post processing and enhanced data processing these shortcomings can be overcome, as we have displayed in this research. We have successfully developed a near commercial software which performs this enhanced data processing and considerably increases the accuracy and reliability of this motion analysis device. The goal of this research was to come up with a cost-effective solution which will be able to perform motion analysis just like the labs, which have high cost logistics, instruments and complicated softwares. We chose Microsoft Kinect because it has the lowest tradeoff for cost against accuracy, stability and reliability.

A traditional motion analysis lab consists of high tech cameras, huge space, complex computer software, high end logistics and human touch involvement. Due to all these expensive factors, there are very few number of labs. This low number adds a lot of overhead as the demand is ever rising and the supply is over worked and is always catching up. This scenario is sometimes acceptable if it is in a consumer domain, but when it comes to the health domain and people’s health it can cause huge undesired
effects. We have tried to address this issue and have been successful in laying a foundation with our application. We have explored the Kinect’s motion tracking capability and fused it with 3D modelling of the human body, with the help of high performing algorithms, we have managed to achieve the enhanced post processing. We have packaged all these capabilities into this application and the result we get is far more accurate, reliable and stable.

In this research, our prime focus was to cut down the cost without compromising on the accuracy and reliability. Our system just requires a Microsoft Kinect which costs a couple of hundred dollars and a computer system with a decent configuration which costs around $500-$700. The total cost of our system is just around $1000 which is very affordable by a local physician. We have eliminated a lot of factors which constitute the cost-effectiveness. Our system does not require huge space, hence renting or owning a space especially for motion analysis is not needed. This system does not require multiple high tech infrared cameras as the camera and other sensors present in Kinect provide all the required data. This too contributes towards cost effectiveness. This system also eliminates any requirement of pressure plates which also adds towards cutting the cost.

We are successful in making this system a touch free system. In traditional system, a personnel was required to put on all the markers, and the readings totally depend on the placement of those markers on the human body. This practice is bound to introduce some sort of human error which can lead to inaccurate readings. Our
system does not require use of markers and hence there is no need of physical touch. The system also has a visual guide as to how the movements must be performed so that the patient can watch, observe and repeat the same movement thus eliminating any passive movements.

In all, we have developed a sophisticated software application which can be used for motion analysis such as Range of Motion calculation and GAIT analysis. We have laid the foundation for other interested parties to take note of our work and can come up with their own technology which will eventually improve the health domain and reduce the costs. We hope our work will be put to use and could inspire others for the betterment of human kind.

**Future Work**

There are certain limitations to the Microsoft Kinect as of now. The view angle of the Kinect is static and limited currently. To track certain joint movements, the patient must stand at a particular distance and at a particular angle for maximum accuracy. In our views, future work can be done to solve this limitation. Currently, the ankle joint is a difficult joint to track as the tracking system does not align the joint properly and is pushed upwards when the foot is above the ground. Some work in this direction or a permanent fix is also possible for this problem in the future.

The gait analysis system currently consists of static charting. Real time interactive charting capability would be an enhanced functionality. This functionality could include zoom in/out of charts and real time plotting as the motion is reviewed.
We have taken a step towards the future and we expect that with the help of proper technology and enhanced algorithms, the current system can be improved.
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