The Intelligent Diagnosis and Treatment of Postural Deformities by Analyzing Kinect™ Camera Data

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There is a growing prevalence of postural deformities and an increased need for a quick and accurate diagnosis. Common postural deformities include genu varum, genu valgum, and wry neck. We have created a method to diagnose and help treat these postural deformities using an inexpensive and accessible Kinect™ camera. A major advantage of this approach is that it allows individuals to go through the amelioration process with the least requirement of an orthopedic doctor's supervision. The Kinect™ camera is a gaming device provided by Microsoft capable of body tracking, joint coordinating and motion capturing. If the user stands at a proper distance from the camera, the system receives the coordination of the user body's joints, which can be analyzed to implement the diagnosis and treatment of postural deformities. Here we collected Kinect™ data from 90 adolescents and validated the results against the diagnosis of an orthopedic doctor. We found that this system with the calculated accuracy of approximately 89 percent, can be used as a reliable diagnostic tool. In addition to being a diagnostic tool, users can use the Kinect™ camera system in treatments, in the form of different exercises based on medical best practice. Since the Kinect™ camera is capable of motion capture, the user can be monitored and guided during the treatment phase. Our results show that the system provides sufficient validity to be implemented to diagnose and help treat postural deformities which can save individuals and healthcare systems time and money.

Constant muscle tone facilitates balance and stability in body joints. In normal posture, antagonistic muscle groups work in different directions in order to stabilize the body and keep it in a state of balance. Upsetting this functional balance between opposing muscle groups may lead in time to the development of postural deformities. Postural deformities are such as genu valgum (knock-knee), genu varum (bow-leggedness), asymmetric shoulder (uneven shoulders) [1]. These deformities are increasing among students and workforces

because of the environment they work in [2].

Previous research has presented the risk factors in hand-arm tasks leading to neck and upper limb musculoskeletal disorders (MSDs) among workers (employees or self-employed) [3]. As shown in Figure 1, workforces mainly suffered from disorders related to the skeleton structure.

Figure 1) Relative occurrence or the prevalence (shown on the x axis) of the type of work-related health problem [3].

Postural Deformities in Students

Students represent another at-risk population for postural deformities [2]. A study that was performed on students of the Czech Republic shows that 40 percent of students between the ages of 11 to 15 had poor posture [4].

Kinect™ Camera

The Kinect™ is a low-cost sensor that allows the real-time measurement of depth information (by triangulation) and the acquisition of RGB (Red, Green and Blue) and IR (Infrared) images at a frame rate up to 30 fps (Figure 2). The Kinect™ is composed of an RGB camera, an IR camera, an IR-based projector, a microphone array, a tilt motor and a 3-axis accelerometer. Kinect™ for Xbox one or Kinect™ V2 is an updated version for Kinect™ for Xbox 360 and it is the version used for our system. The reason that we chose Kinect™ for Xbox

was the enhanced accuracy of this camera and some added features like Gesture Builder (its function in the project will be explained later) that were required for our project.

Figure 2) Kinect™ for Xbox one

GPA (Global Postural System)

Global Postural System was created by the GPS medical center to diagnose the postural deformities in addition to visiting a doctor (Figure 3). To achieve this aim, this system uses a combination of hardware and software. It consists of a set of data acquisition devices that can be used for patient data collection during an examination, image acquisition devices, a computer and the relevant data management software. This system uses a completely different method from the system we created using the Kinect™ camera and only contains the diagnosis phase of rehabilitation and also the hardware of this system is expensive.

Figure 3) the Global Postural System

Importance of Project

Postural deformities are increasing among people and becoming a serious issue in school children and workforces. Diagnosing and treating these deformities rapidly not only prevents further damages caused to patient's health but also saves money and time. Many people neglect the importance of diagnosing and treating these deformities for reasons like the heavy fees for doctor's referral, not being able to spare some time for the treatment process, and living in a disadvan-

tagged area. The system that we built can help to solve these problems by reducing the cost of diagnosis, being accessible and being visually attractive that increases the user's interest in the rehabilitative process.

The objective of the project is to investigate a novel cost-effective method to diagnose musculoskeletal deformities. This approach aims to accelerate the medical process by gathering diagnostic data and implementing treatment phases in one system and using an accessible device. This will reduce the requirement of an orthopedic doctor in the diagnosis and treatment of the postural deformities. It is important to mention that until the system reaches the maximum accuracy this system cannot delete the role of the doctor, and the system has reached its maximum accuracy when each diagnosis that is done by the system matches the diagnosis of a proficient doctor.

We created a software program using the Unity game engine to diagnose and treat postural deformities. The environment of this system is designed as a doctor's office to increase the interaction between the user and the program (Figure 4).

Figure 4) The environment of the project

The implementation of this project requires specific data from the user's body such as the x, y and z coordinates of the joints in 3D space that this camera provides alongside other features like motion capturing and gesture building used for implementing other phases of the projects. Since the project is based on a medical purpose, it must impart sufficient accuracy. The Kinect V2™ has the potential to be used as a reliable and valid clinical measurement tool [7]. Therefore, in this project, we used Kinect V2™ as a proper sensor.

An advantage of having this system in the Unity engine is the ability to create a skeleton model of the user's body with 3D objects using the Kinect™ camera. The main feature of this camera which was the most practical for our purpose was the body tracking feature. The tracked body comes with some data that is also received from the user's body such as the coordination and the orientation of 25 joints.

Having the coordination of the joints in three dimensions (x, y and z), we could draw a skeleton of the user's body in 3D (Figure 5).

Figure 5) The drawn skeleton

Having the skeleton in 3D had medical purposes, for instance, if the doctor or the user wants to examine the skeleton they can zoom in and examine it closely (Figure 6).

Figure 6) Zooming into the Skeleton's Structure

Creating a Profile for the Patient

Before entering the program, users will go through a profiling process in which some personal information, such as height, weight, and age will be received from them. As the profile is created, an email will be sent to the patient's doctor so that the doctor would have access to this data (Figure 7-9). The reason for sending this personal information to the doctor is that, in some cases, the doctor needs to be able to check if the deformity is caused by the patient's weight or if

it's because of the patient's age. After the final diagnosis, the intensity of the user's deformity will also be emailed to the doctor.

Figure 7) Entering in the user's account

Figure 8) Receiving the personal info of the user

Figure 9) Providing a profile number for the user

The Rehabilitative Process

The rehabilitative process is divided into two parts: 1) the diagnosis and 2) the treatment. The diagnosis phase includes the diagnosis of three deformities: wry neck, asymmetric shoulders and genu varum. The diagnosis of these deformities is mostly based on the coordination of the joints received by the Kinect™ camera which measures in millimetres. Having the joints' coordination, we could diagnose by

comparing the position of the user's joints with the standard position they are recommended to have.

1.1) Diagnosis of the asymmetric shoulders

In standard posture, the shoulders are supposed to be on the same axis meaning that their y variable must be almost equal in the frontal plane. As the difference of their variable increases, the intensity of the deformity also increases.

We collected this Δy of shoulders in millimetres and if this difference gets more than 1cm, then a disability score will be assigned (Figure 10).

Figure 10) As shown in the figure Δy is the determinative variable for the intensity of the asymmetric shoulders, as the Δy increases the shoulders will more be in an asymmetric position. Having the Δy , we can diagnose the deformity by comparing the given data from the user's body and medical references [1] in which the standards of these data are discussed.

1.2) Diagnosis of wry neck

In the wry neck condition, the patient's neck is not in a straight line and bent toward the left or right shoulder. The method for diagnosing this deformity is to compare the variable of the head and the neck of the user's body in the frontal plane. When this difference goes over 1 cm, the deformity is seen in the user's body (Figure 11).

Figure 11)As shown in the figure Δx is the demonstrative variable for the intensity of the wry neck, as Δx increases the neck is more bent towards the right or left shoulders.

This deformity is also diagnosed by comparing the Kinect's™ data and the discussed data in the medical references [1].

1.3) Diagnosis of genu varum

In this deformity, when the patient is standing in a standard position (legs closed), the distance between the knees will be calculated using the variable of the left and right knees (Figure 12). Based on this distance, the deformity will be diagnosed by comparing this distance to the standard's available references [1]. The distance that the deformity starts from is 12 cm.

Figure12) As shown in the figure Δx is the demonstrative variable for the intensity of the genu varum, as Δx increases the knees are more distanced from each other and the intensity of this deformity also increases.

Drawing the Live Charts

Using the methods declared above we were able to diagnose three deformities. To provide the user with this diagnosis, we showed the diagnosis done on each frame on a live chart (Figure 13). The data of these live charts include the intensities of these deformities. In agreement with clinical practice, each chart has four possible results: zero, one, two or three; and each number states an intensity except for number zero which is shown when the user does not stand in the anatomic position or proper distance in front of the camera. More details about this can be found in the calibration process section.

Figure 13) The drawn live charts for the intensities of the user's deformities

A result of one means that the deformity is not seen in the person's body whereas two means the deformity is clearly seen in the user's body. When the value of the chart is three, the deformity is highly intense in the user's body.

The Calibration Process

Two parameters will affect the results during the diagnosis process: the posture of the user and the distance that the user is from the camera. The user must stand in an anatomic position approximately 2 m distanced in front of the camera. The user's body must be held in an upright position. If the user stands in a T-pose or has the arms crossed or legs open, a valid diagnosis would not be reached. In the calibration process when the user enters the diagnosis phase, the posture and the position of the user will be checked to declare whether the user is in the proper distance and has a normal posture. If the user is standing too close to the camera or has an invalid posture, the data of the live charts will change to zero and the skeleton of the user will not be drawn until the user changes his/her posture (Figure 14,15).

Figure 14) The user is standing in an improper distance from

the camera so an alter is shown, the skeleton is disabled and the intensity of the deformities is shown zero.

Figure 15) while the person is standing in an improper posture the same sequence of actions will happen but the distance of the user is prioritized from the posture of the person.

The Marker-Based Method

Kinect™ camera's body recognition is a marker-less process which is done using machine learning algorithms. Any device using this method can come with inaccuracies. The accuracy of this camera was compared to a valid system called Vicon that uses marker-based diagnosis. According to the results, the 3D differences between Vicon and Kinect V2 movement signals were found to be between 1 and 2cm, except for the higher values for feet and ankles ($\text{diff3D} > 5\text{cm}$). Signal to noise ratio provided information about Kinect™ V2 landmark stability and indicated larger noise behaviour in feet and ankles [7]. These joints do not affect the diagnosis of the deformities except for genu valgum which is diagnosed using the ankles' variable. In genu valgum, the suggested method was the marker-based method. In this method, specific markers will be attached to the user's ankles and the coordination of these markers will be calculated using an image processing procedure. During the diagnosis of this deformity, the coordination of the markers will be used instead of the coordination that is calculated by the Kinect™ camera. As the accuracy of the marker-based method is higher than the marker-less method, this method was discussed for the solution to this problem.

Averaging Process

An averaging method was used to increase the accuracy of the current system. Kinect™ camera receives about

frames per second depending on different parameters. Doing the final diagnosis based on the data of one frame would not be accurate enough, so to have a valid diagnosis we averaged the data of the user's body (the coordination of the joints) in 90 frames and made the diagnosis based on the averaged data (Figure 16-18).

Figure 16) The final diagnosis is based on the averaged data

Figure 17) If the user's posture gets out of the valid form during the averaging process an alter will pop on to check whether the user wants to save the data of the averaging or wants to do the process all over again.

Figure 18) If the user's posture gets out of the valid form during the averaging process an alter will pop on to check whether the user wants to save the data of the averaging or wants to do the process all over again.

Treatment of Deformities

Exercise is the primary treatment of these deformities which is based on their diagnosis. The treatment for each deformity is also defined in medical references [1]. The repetition and timing of the exercise are based on the intensity of the deformity. The instruction for each exercise is given to the user at the beginning of the treatment phase. The motion capturing capability of the Kinect™ device gave us the ability to control the user's movements and to clarify whether the user is doing the exercises correctly or not (Figure 19, 20). Visual Gesture Builder is a software for defining a gesture or movement for Kinect™ camera. We used this software to teach Kinect™ the correct movements that must be done by the user.

Figure 19) as the user enters the treatment of the asymmetric shoulders an instruction for the exercises will be given to the user.

Figure 20) The monitoring section of the treatment phase has two parts, in the first part, if the user does the exercise correctly the statement will be true and in the second part the completeness of the exercise that varies between 0 to 100 will be in the range of 80-100.

The Raw Data Section

The raw data section is created for doctors and medical purposes. In this section, the user can have access to the data was used to make the diagnosis of the deformities; this data consists of the Δx of knees, Δy of shoulders, the angle of knees, the slope of the shoulders, markers' coordination and the Δx of head and neck joints. We provided this data so that the doctor would be able to see the information of the user's body himself/herself for any medical purposes (Figure 21).

Figure 21) The raw data panel will be opened as the user clicks on the receiving raw data and the coordination of the markers is also shown on this panel.

Measurement of Accuracy

To measure the accuracy of the system, it was examined on 90 adolescences between the ages of 16 and 18 (the examination was done on this age range because deformities are more common in these ages) [2]. These adolescences were picked randomly from several schools and this process was done under the supervision of an orthopedic doctor and an expert in physical education in their exercise classes. Informed consent was obtained from all the participants for being included in the study. Since the study took place on the subjects under 18, a parent or guardian have also signed and returned a form consenting to the involvement of their child. The consent form included an explanation for the purpose of the study, its procedure, the risks and discomforts it may cause (in this study no harm was caused on the human body), its benefits, their right to withdraw or refuse and confidential data collection that came about in the study. As a result, this experiment demonstrated that the program we created has the validity for diagnosis and treatment.

The accuracy of the system was compared to the diagnosis of orthopedic doctors. If the system's diagnosis matched the diagnosis of the doctor, it would count as a correct diagnosis and if not, it would be an error. The results are shown in the chart below (Figure 22).

The adolescents experienced the experiment three times for each deformity, and the accuracy of each experiment was calculated (the correct diagnoses to all 90 diagnoses ratio). Eventually, the three averaged accuracies of the three experiments were also averaged, representing the final accuracy of the deformity's diagnosis. The accuracy of the wry neck diagnosis was calculated about 90 percent, for the asymmetric shoulders, it was calculated 91 percent and for the genu varum, it was about 86 percent. Therefore, the validity of the system in average was about 89 percent.

Figure 22) The accuracy of the system for each deformity. For each adolescence, the deformities were diagnosed by our system three times and each data was compared to the doctor's diagnosis and error bars show the standard deviation.

Combining Kinect™ camera's features with the marker-based and averaging method gave us a system with the reliability for a medical diagnosis. This system can be practical in places in which the environment often leads to these deformities. This system can also be used instead of a doctor in disadvantaged areas in which there is a lack of medical care; it also can be used in any place with a large number of users such as clinics. In all of these conditions, this system can be used for several years instead of hiring a doctor, which leads to a reduction in costs. This system may finally absorb

the user's interest in the amelioration process because of the game-like atmosphere of the system.

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