Interactive Robotic Head for Neck Exercises

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***Abstract*— Interactive robot heads are becoming more and more popular in these days and most of the tasks are replaced by robots in these days. As a solution for neck pain which has become a highly attentive illness nowadays due to use of new technological devices with wrong postures by humans, a humanoid robotic head which acts as an exercise instructor is discussed in this paper. The special features of this robot head are user identification and producing unique exercise patterns according to the user. After identifying the user, it can produce the past exercise recordings and the interactive session can be carried out by voice to voice conversation or keyboard inputs from the user. Kinematic Model and Inverse Kinematic Model are developed as discussed in this paper in order to get a more human like robot head with more human like movements. The mechanical structure is developed based on the biological data of a natural human neck. Neck mechanism and exercise instructor overall procedure with basic exercise modes are discussed in this paper. Communication with user, person identification systems, and getting visual feedback of the user movements are also described in this paper. This robot head can be further developed by adding more interactive features.**

Keywords— Interactive features, Kinematic model, face recognition, and object tracking.

I. INTRODUCTION

Knowing the fact that design and development of a human like robot head which will interact with dynamic and rapidly changing external factors is an extremely challenging task, several humanoid heads have been developed during the last decade and it has become a popular research area. More researchers focus on this area simply because humans can have interactions to the man-machine interface in the similar way (speech, gestures, movements etc.), humans interact with each other

Interactions purely depend on the features that are going to be added on to the robot head. Among many illnesses neck pain has become more attentive with the technology development. This is because many people are using laptops and handheld mobile devices with wrong postures. As a result of that most of the young generation as well as elderly people are suffering from neck pain. Neck pain can be seen as a common circumstance among the population. As expected, the prevalence increases with longer prevalence periods and generally women have more neck pain than men [1].

Many people experience neck pain or stiffness in the neck occasionally. In many cases, it is due to poor postures, normal wear and tear of tissues, or overuse of tissues. Most of the times neck pain can be avoided by maintaining correct postural moves as well as practicing neck exercises daily. Neck exercises are a common part for almost any treatment program for neck pain. A typical neck exercise program will consist of a combination of stretching and strengthening exercises. Availability of instructors in this area is much less and most of the times instructors charge very expensive rates. However people haven't much time left to visit an exercise instructor with their busy schedules. This research paper has discussed about Interactive Robot Head (IRH) to assist people regarding neck exercises.

There are few researches in subject of human-robot interactive robots or robot heads for exercises for elderly people. A socially assistive robot (SAR) is a system that employs hands-off interaction strategies, including the use of speech, facial expressions, and communicative gestures, to provide assistance in accordance with the particular healthcare context [2], [3]. Exercise instructors or assistive robots conduct the exercise lessons and user has to follow the procedure according to robot movements [4].

Image processing and image identification became popular in these days but most of the existing robot exercise instructors have not focused on to produce unique exercise patterns by identifying the user. Nowadays user identification systems are also more popular and this paper has combined robot exercise instructor with user identification and many interactive features. IRH can identify the user by identifying the face and then IRH can produce the past exercise recordings and the interactive session can be carried out by voice to voice conversation or keyboard inputs from the user. And also this research underwent where user can change the speed of the exercises, user can select the methods of the exercise and robot head can assess user by examining the motions of the user. And also research carried out to analyse kinematic and inverse kinematic models to implement more human like robot neck with more human like movements

II. SYSTEM DEVELOPMENT

A. Biomechanical Design of the Human Neck

Main focus of the design is to implement an anthropomorphic robot head by using a mechanical structure. Anatomic data of the human neck movement is attained by using basic research [5], [6]. All the hardware selection has been done in order to match with the natural movements of the

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human head. All the movements of neck exercise instructor or the biomechanical design should match with the actual movements of the normal human neck. Natural human neck movements are more complex but ease of the analysis, neck movements are segmented into few major categories as in Table 1 and Fig. 1.

In implementation and controlling of the DC motors have been done by using optical incremental encoders and DC motor controlling has been done by using bi-directional motor controllers. The mechanical structure of the robot head is given in Fig. 2.

Following factors have considered when selecting mechanical actuators and sensors [2].

- DOF, range of motions, joint speed and torque according to detailed specifications as to achieve more anthropomorphic behaviour.
- DC motor selection, selection of proper natural speed of the motors and low gear ratio for the motors to get smooth movements.
- Design of mechanical structure, selection of lighter materials to reduce the weight of the structure.

TABLE I. NECK MOVEMENTS

Exercise name	Description	Moving motors and angles
1.Flexion	The movement in which the chin is lowered down toward the chest	Rolling Motor Down 50^{0}
2.Extension	The neck is extended, as in looking upward toward the ceiling	Rolling Motor Up 50^{0}
3.Lateral rotation	These are simply direct lateral rotation to either side	Rotation Motor Left 70^{0} Right 70^{0}
4.Lateral flexion	Trying to place the ear upon the shoulder through a sideways movement of the neck, directing the ear toward the shoulder tip on both sides	Tilting Motor Left 45^{0} Right 45^{0}

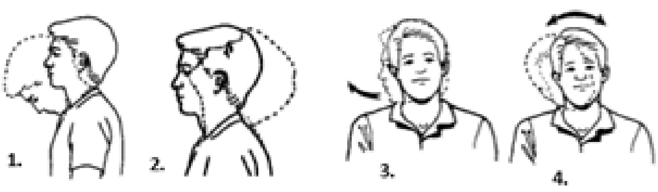

Fig. 1. Neck Movements

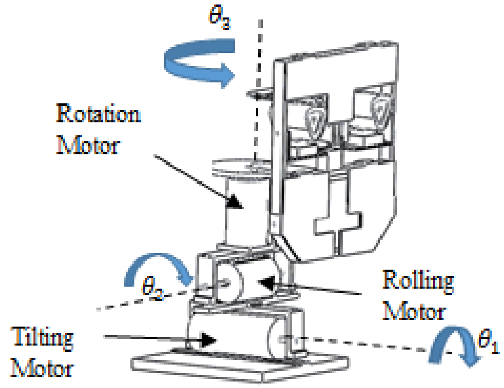

Fig. 2. Motor Arrangement of IRH

B. *Design of Controlling System of Neck Exercise Instructor*

Neck exercises basically consist of basic neck movements shown in Table 1 .Therefore, controlling the neck mechanism precisely plays a vital role. Neck mechanism consists of 3-DOF. To implement real world neck exercises to interactive robot head, 3 motors are controlled concurrently. Implementing kinematic model is also essential to achieve that.

C. *Robot Kinematics*

Coordinating system which have been defined and considered for the kinematic analysis is shown in Fig. 3. A kinematic analysis has been carried out for the robotic head using the Euler angle method to determine the trajectory of a pre-specified point on the head with the variation of rotational angles of actuating motors in the neck section. Based on the prior studies done, kinematics is the geometry of pure motion which considered without reference to force or mass. In here the kinematic model has been used to determine motion and geometry of the head with respect to the base frame. In kinematic model each motor has been considered as a frame and face of the head has been also taken as frame.

In forward kinematic, when the angles of the three motors are known, the coordination of the point (P_u, P_v P_w) of the frame 4 can be calculated w.r.t the base frame which is known as P_x, P_y P_z. The midpoint of the face which is the origin of the frame 4 has been considered as the end point of the robot. Midpoint of the face w.r.t the base frame can be written as in (1)

Variables in the following equations are as per the Fig. 3.

$$\begin{pmatrix} p_x \\ p_y \\ p_z \\ 1 \end{pmatrix} = \begin{pmatrix} l\cos(\theta_2)\cos(\theta_3) + h\sin(\theta_2) \\ l(\sin(\theta_1)\sin(\theta_2)\cos(\theta_3)+\sin(\theta_3)\cos(\theta_1)) - h\sin(\theta_1)\cos(\theta_2) - b\sin(\theta_1) \\ l(-\sin(\theta_2)\cos(\theta_1)\cos(\theta_3)+\sin(\theta_1)\sin(\theta_3)) + h\cos(\theta_1)\cos(\theta_2) + b\cos(\theta_1) + a \\ 1 \end{pmatrix} \quad (1)$$

According to the ranges of θ_1, θ_2 , θ_3, all the positions where midpoint of the face can move by using this model can be calculated. Using MatLab the scatter graphs for the midpoint of the face of the robot head have been plotted and given in Fig. 4.

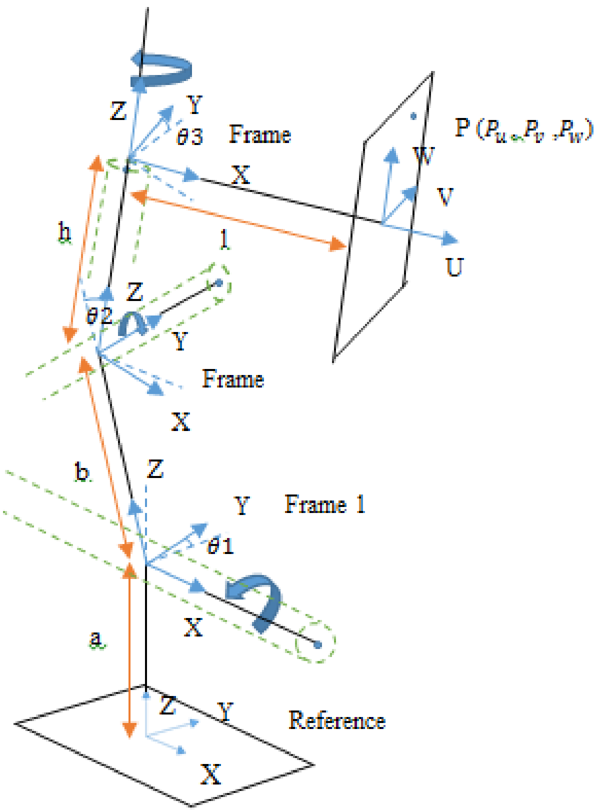

Fig. 3. Link Coordinate Frames

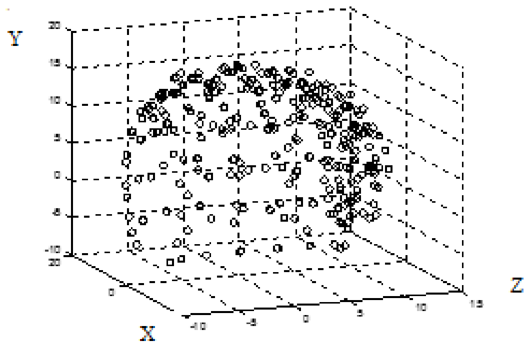

Fig. 4. Scatter graph for the midpoint of the face

To move robot head to given position (P_x, P_y, P_z) motor angle should be calculated. Now the P_x, P_y, P_z values are known and then, θ_1, θ_2 and θ_3 can be calculated by solving simultaneous equations (4),(5) and (6) derived from inverse kinematic model, Let's say $P_x = U$, $P_y = V$, $P_z = W$ then,

$$l\cos(\theta_2)\cos(\theta_3) + h\sin(\theta_2) - U = 0 \tag{2}$$

$$l\big(\sin(\theta_1)\sin(\theta_2)\cos(\theta_3)+\sin(\theta_3)\cos(\theta_1)\big) - h\sin(\theta_1)\cos(\theta_2) - b\sin(\theta_1) - V = 0 \tag{3}$$

$$l\big(-\sin(\theta_2)\cos(\theta_1)\cos(\theta_3)+\sin(\theta_1)\sin(\theta_3)\big) + h\cos(\theta_1)\cos(\theta_2) + b\cos(\theta_1) + a - W = 0 \tag{4}$$

D. *Robot Kinematics*

To calculate values of θ_1, θ_2 and θ_3, there are several methods. When such an equation system is solved it can end up with more than one solution. So, the result angles must be limited to natural human movements. In this research Newton Raphson method has been used to solve the above nonlinear equations. These equations have been solved by using MatLab and MatLab header is linked to C# user interface of the robot head. The motor angles are fed to Ardiuno Board via serial communication in C# platform.

III. EXERCISE INSTRUCTOR OVERALL PROCEDURE

Overall functional block diagram is given in Fig. 5.

When user presents in front of the robot instructor, first instructor tries to match the user with previous data and if user is in the saved database, exercise instructor starts to continue the exercise with past records and if user is a new one then instructor starts a new account for the user and initiate exercise procedure from the beginning. Exercise angles and speeds can be adjusted according to the command given by the user and all

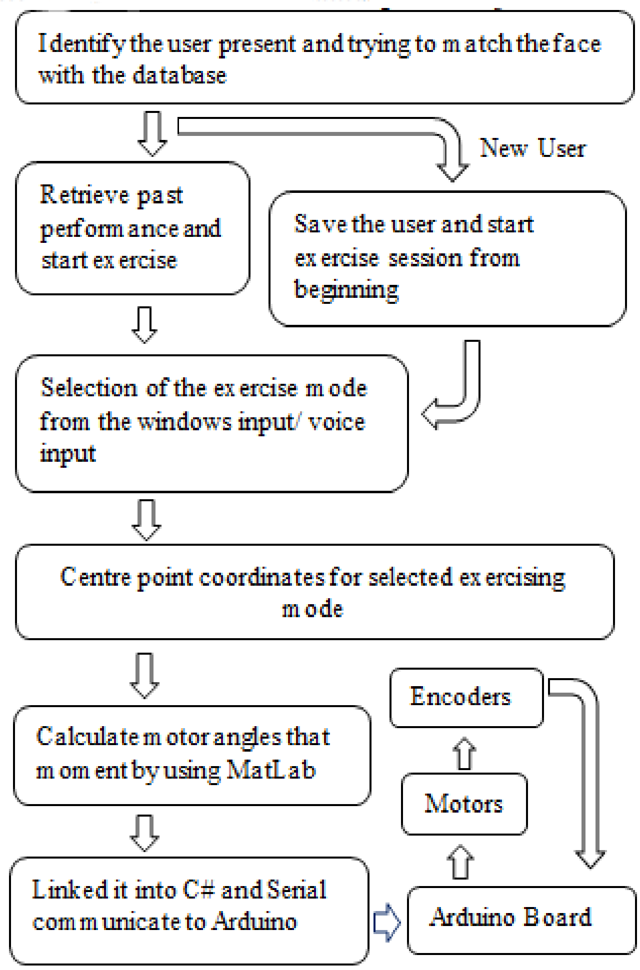

Fig. 5. Block Diagram for the overall procedure

the motor controlling is done by using Arduino board driven motor drivers. Position feedback to the controller has been taken by the optical encoders.

A. Basic Exercise Mode

1) Flexion and Extension: Tilt your head backwards while stretching your neck muscles. Hold this for five seconds and then tilt your head down to rest your chin on your chest. Gently tense your neck muscles and hold for five seconds. Repeat five times.

2) Lateral flexion: Tilt your head down towards your shoulder, leading with your ear. Gently tense your neck muscles and hold for five seconds. Return your head to the centre and repeat on the opposite side. Repeat five times on each side.

3) Lateral Rotation: Turn your head towards one side, keeping your chin at the same height. Gently tense your neck muscles and hold for five seconds. Return your head to the centre and repeat on the opposite side. Repeat five times on each side.

4) Full Rotation: Rotate neck clockwise five times and then again keep calm another ten seconds and again rotate it to counter clockwise.

B. Communication with User

The Microsoft .NET Framework is a software technology that is available with several Microsoft Windows operating systems [8]. Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop console and graphical user interface applications along with Windows Forms applications [9]. Microsoft Speech Application Programming Interface (SAPI) is an API developed by Microsoft to allow the use of speech recognition and speech synthesis within Windows applications [10]. The System.Speech.Synthesis namespace can be used to access the SAPI synthesizer engine to render text into speech using an installed voice [11].

Communication with user can be done in two ways. Normal keyboard inputs and speech commands are the two main methods used in this paper. Windows Visual Studio C# used as graphical user interface, by clicking options available in the windows form user can select the options. And also by commanding using voice, user can select the operating mode. By using speech synthesizing robot instructor gives feedback to the user.

C. Person Identification System

This system is used to enhance the user friendliness of the exercise instructor robot head, which means because of using such system user is not needed to enter his/her details and health condition every time to the system. Using two web cameras system will detect the person and recognize the face with existing database. So if the system has recognized the person, it will provide necessary assistance to the user to do the exercises. And also most importantly with the time robot head will automatically update the status of the user, so it will update the exercise schedule automatically depending on the user capability. As an example let's assume one particular user did sufficient exercises in one particular schedule, so next time system will automatically change the schedule to the next level for that user.

If the detected person is not recognized, system will allow the user to enter the details to the database. Since this is a human interactive robot head, user can either use voice or key board inputs to update the required data fields which appeared on the screen. All of those required information will be read out by the robot head so the user can maintain more human like interactions with system. Flow diagram of the person identification system is shown in the Fig. 6.

In this system two web cameras are used. Although the face detection can be done using a single camera, with the use of two cameras accuracy of the process can be increased. This is done as follows.

When doing face detecting, first compare the number of possible areas detected as faces by both cameras, and only if they are equal then proceeds further. By doing this, it will be helpful to eliminate some of the false detections of faces occurred by a single camera occasionally. This is not guaranteed for 100% accuracy of the face detection but it gives reasonably a higher accuracy than using a single camera.

"Eigen Object Recognizer" [12] is used for the face recognition purposes. Again the accuracy of the process is in between 30% to 70%, it depends on the data base size and various other factors. But such kind of accuracy level is accepted for this research because the main purpose here is to use person identification as a supportive function to get human like interaction with the user.

D. Visual feed back of the user movements

Getting visual feedback of the head movements of the user is very useful to the interactive robot head because system can track the head movements of the person who is doing the exercise and give feedback to the person about the performance of the exercise. As an example when the exercise required is tilting up and down, system can get the visual feedback of the user and give responses to the user as whether the exercise is correct or not, speed of the exercise is adequate or not, etc.

To track the user head movements, this project has been used object detection via blob detection method. This method has been facilitated through cvblob library which has included in Emgu CV. Although there are several methods of detect objects in real time like using canny edge detector, SURF [7] etc. This method has been used to this project because of its fast detecting ability. In more advance detection algorithms like SURF, it has reduced frame rate significantly which cannot acceptable in this project, because in order to track accurately of the head movements high frame rate is a must.

In order to track the head movements of the user, he needs to wear a specific colour cap. By filtering out other colours from the frame and using blob detection the specific colour area of the image can be tracked. Then by tracking the centre point of the detected blob area, system will get the feedback of the head movement. As an example when centre point is varying only in Y axis up and down, system will take that as the up and down tilt exercise

IV. Results

By extracting the relevant points of the two exercises (flexion and extension and lateral flexion) from the plot in Fig.4 following plots (in Fig. 7) have been obtained. Using plots in Fig. 8 and inverse kinematics model, angles of the three motors up to which they should rotate are calculated and fed to the motor drives to implement the relevant exercises. Head movements corresponding to those angles are given in Fig. 8.

Similarly the points of the movement of flexion and extension of the robot head can be calculated from inverse kinematic model.

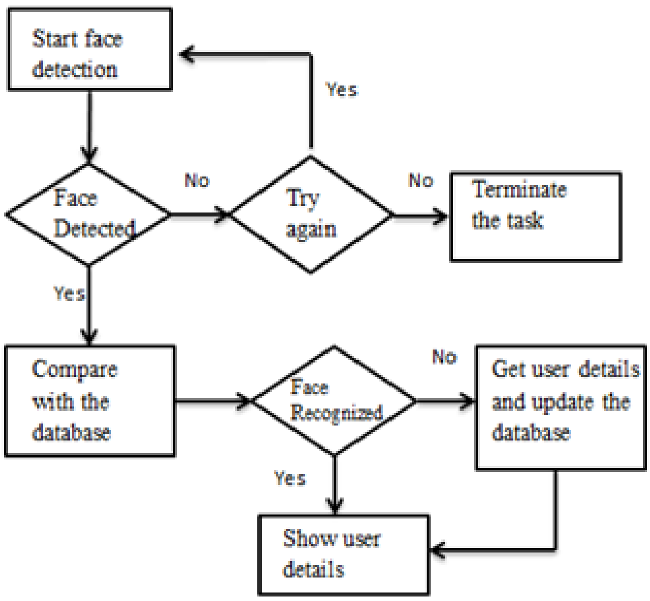

Fig. 6. Face recognition flow diagram

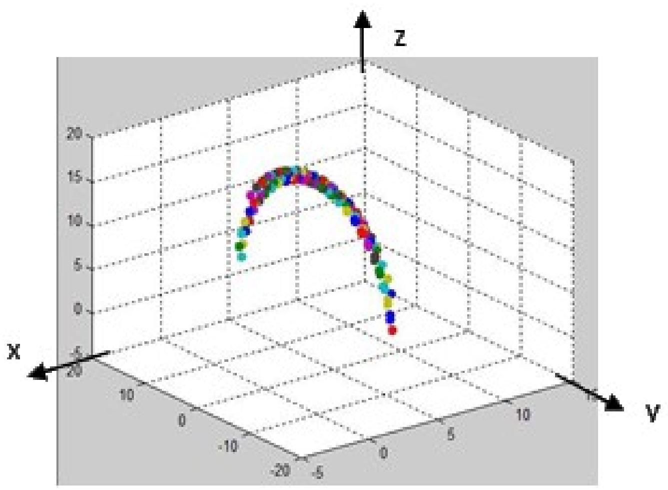

Fig. 7 Head center point movement path corresponding to lateral flexion

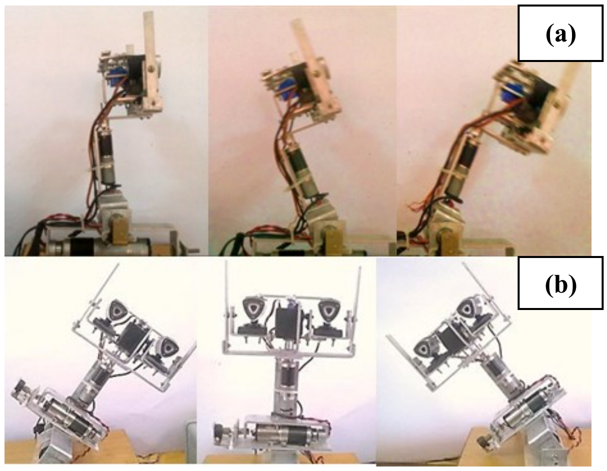

Fig. 8. (a) Flexion and extension (b) Lateral flexion

User is sitting in front of the robot and following the instructions of the robot head. Robot head can track the movement of the red cap and decide whether user is following the instructions correctly or not. Fig. 10 shows the path of the movement of red cap which is captured by image processing when user is doing the lateral flexion exercise shown in Fig. 9. In Fig. 9 right hand side image shows the original image and the left shows blob detected image.

V. Conclusion and Further Development

The research is about a robot head as an instructor with feedback to the user to conduct neck exercises methodologically. User can communicate with robot head either verbally or using keyboard inputs.

It has been identified that the main limitation of object detection method is colour of the cap should not be within anywhere else in the image. To overcome this limitation it would be better if an algorithm can be developed to detect the face which is independent of the orientation since the existing

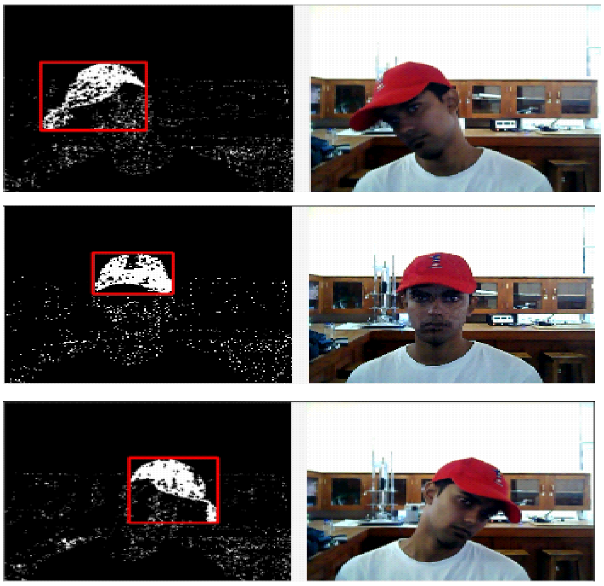

Fig. 9. Blob detected image with the original image

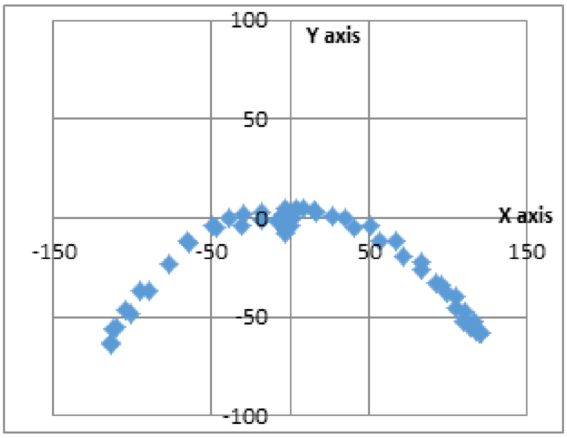

Fig. 10. Centre point path of the movement of red cap with lateral flexion

methods are orientation dependent.

Currently IRH is developed for exercise instructor interaction. However this can be further improved with the use of advanced algorithms in image processing, sound recognition, sound localization and optical character recognition up to a level which is having several other multi model interactive features with humans in order to make it make it more and more human like.

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