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Image Processing Techniques for Measuring the Acetabular Cup Orientation from Anteversion Angle of Revised Cemented Total Hip Arthroplasty (THA)

Sandhya Tatekalva[#1], Prof.M.Usha Rani[*2] and Dr.M.Maruthi Krishna[@3]

[#]*Research Scholar, Department of Computer Science, Dravidian University, Kuppam.*

[*]*Professor and B.O.S Chair Person, Department of Computer Science, S.P.M.V.V., Tirupati.*

[@]*M.S(Ortho),Trauma and Joint Replacement Sergeon , Sri Maruthi Speciality Hospital, TML By Pass Road,Tirupati, Andhra Pradesh, India.*

Abstract- Presently, the developments made in Cemented Total Hip Arthroplasty is eminent among the hip joints registries. The acetabular anteversion is a key factor after the Total Hip Replacements (THR) process. Measuring the anteversion angle of acetabular cup is a cumbersome task. This paper concentrates over an automatic lucency measurements using predictive modeling model. The acetabular opening cup is projected into 3D spherical coordinates form. We have adopted reliable and accurate method of automatically segmenting, classifying and measuring, the acetabular components of cemented THR. The proposed algorithm contains four phases, namely, Acquisition Phase, Preprocessing Phase, Segmentation Phase, and Angulation phase. The aim of this study is to measure the acetabular cup orientation from anteversion angle between the acetabular axis and coronal plane of the body. The preprocessed image is analyzed to find the boundary of the implants and bone tissue. Then, the segmented image is transformed onto spherical conventions. Further, the transformed image is matched with normal images to find the anteversion angle. A sample set of abnormal radiographic images are collected and the distance value r is estimated for different angles. By assuming different positioning of the acetabular cup, the distance r value is computed.

Keywords: Hip, Cup, Anteversion, Prosthesis, Acetabular and Spherical coordinates.

I. INTRODUCTION

Total Hip Arthroplasty is an optimal surgical method for eliminating incessant hip pain caused by osteoarthritis. It is estimated that huge number of people are undergoing Total Hip Arthroplasty (THA), to get relieved. It is believed that a successful THA can drastically reduce the symptoms and mobility for period of 10 to 15 years. Revision Total Hip Arthroplasty (THA) is the most influencing hip arthroplasty process in India. The revision Total Hip Arthroplasty is defined as the analysis of discovering the factor influencing the failure rate of the Total Hip Arthroplasty. From the failure analysis of Revision THA conducted in two hospitals, at Tirupati. Aseptic Loosening is one of the major indications of Revision THA [1]. The word 'aseptic loosening' is characterized as the gross mechanical instability of the interface between implant and bone bed. Generally, aseptic loosening is formed by the integral events of mechanical and biological process that degrades the adhesion between implants and the bone bed. The reason behind the causes of aseptic loosening is not yet explored. In reality, the risks factors and conditions affecting aseptic loosening are not predictable [2].

A total hip replacement is a surgical procedure whereby the diseased cartilage and bone of the hip joint is surgically replaced with artificial materials. The orientation of acetabular component is one of the fundamental factors that determine the outcome of the Total Hip Arthroplasty in both the short-term and long-term [2].Unconventional methods discuss the rates of dislocation, misconduct of prosthetic components, surface wear, and revisions are the outcomes of the long-term. According to *Lewinnek et al*, the normal anteversion measurement is of $15^{\circ} \pm 10^{\circ}$ and lateral opening, $40^{\circ} \pm 10^{\circ}$ of the acetabular cup component is considered as the 'safe zone'. After the postoperative period of THA, the discrepancy in leg-length and dislocation [3] represents the significant concern in terms of cost, to the patients, surgeons and society.

1.1 POSSIBILITIES OF THE ASEPTIC LOOSENING

This section describes about the mechanical and biological possibilities of the aseptic loosening in the acetabular component.

a) Mechanical Possibilities on Aseptic Loosening:

In perspective of mechanical possibilities of aseptic loosening, stress and strain are considered as the primary factors [4]. It, greatly, affects the implants-bone while any external force applied to the systems. According to Mjoberg' opinion's, 1986, the quality of implants fixation is trickier. Unfortunately, there is no agreed threshold of migration above which loosening can be predicted. Further it is not possible to compare directly the migration data of different studies (Derbyshire et al. 2009). In addition, it seems that the majority of cemented cups migrate during the first postoperative year and thus the revision rate is poorly predictable after one year postoperatively even in cases with significant migration (Aspenberg et al. 2008).

b) Biological Possibilities on Aseptic Loosening:

In perspective of the biological process, the growth of micro-organisms in the implants is due to the fungal diseases [5]. The intervention of foreign body molecules in the bone-implant fails the THA process. Some micro motions particles are formed before the debris particles enter the systems, that shown in Fig.1. The formation of pathogens is described in Fig.2.

Fig.1. Biological process in the implant –bone interface.

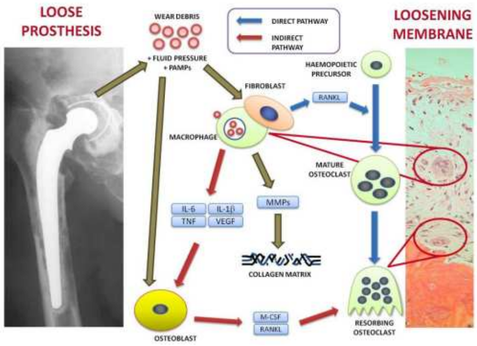

Fig.2. Bio-Chemical process in the acetabular component

In this paper, we study about the orientation measurement from anteversion angle of acetabular cup. Since, the orientation of the acetabular cup plays a significant role in the prosthetic component after THA. We consider the acetabular cup as in 3D spherical coordinate's form, to find the distance on various collected radiographic images. Firstly, the radiographic images are preprocessed using mean filter model. It is followed by Sobel operator to segment the boundary of prosthetic component and bone tissue of the acetabular cup. Then, the segmented image is transformed into 3D spherical conventions. By the use of trigonometric measurements, the distance between the acetabular axis and coronal plane of the body is estimated. The rest of the paper is organized as follows: Section II describes about the different sorts of imaging methods; Section III describes about the proposed algorithm and followed by estimating the loosening distance r, in Section IV. At last, concluded in Section V.

II. CONVENTIONAL DIAGNOSTIC ANALYSIS IN POSTOPERATIVE PERIOD OF TOTAL HIP ARTHROPLASTY (THA)

2.1 Imaging Methods

The reasons behind continuous hip pain are clarified by the conventional diagnostic system [6]. In present medical environment, the state of the loosening after THR is recognized by several diagnostic methods. These are encountered by the imaging methods. The imaging methods are presented in Fig. 3.

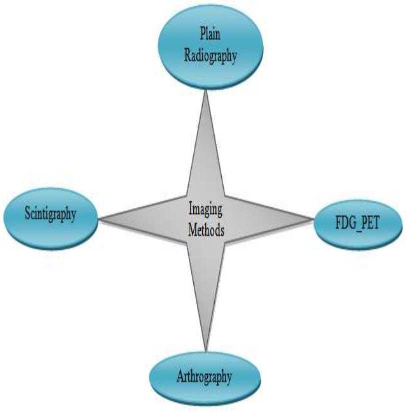

Fig.3. Imaging methods

i) Plain Radiography

Plain Radiography is the first imaging technology used in the medical field. When compared to other images. It is very cheaper than other imaging methods [7].The radiograph image is interpreted by the accurate evidences about the surgical procedures (Cuckler, 2010). The picture of hip is taken in two orientations, i) Hip and pelvis region in anteroposterior orientation ii) Distal view of unhealthy femoral stem (Temmerman et al., 2005). The factors (Ostlere & Soin, 2003) influencing the radiographic picture depend upon the surgical approaches of the THR.

Fig.4. A clear picture of the radiolucent line near femoral component in uncemented THR.

The radiolucency line between bone and cement is viewed in cemented components and it is identified between implant and bone in uncemented components. This example impedes a precise interpretation of the THR with plain radiographs [8], because these findings can be associated with loose as well as well fixed THR. The ambiguity in diagnosing loosening can be compensated by comparing the current radiograph with a previous post-operative reference (Suckel et al., 2009).

ii) Arthrography

The unsettled pain of the cemented joint is traced by the Arthrography. In order to improve the visibility of the internal membranes of the periprosthetic components and cement-bone interface, the contrasting agents are added to it. By doing so, the sensitivity and specificity of the loosening THR is estimated. Anteroposterior and lateral views are normally the views which are obtained during the examination of the THR. Additionally, arthrography can be executed by using Magnetic Resonance Imaging (MRI) [9] or Computed Tomography (CT) [10]. Arthrographic criteria for loosening are based on the infiltration of the injected contrast agents into the periprosthetic membrane or into the cement-bone interface. Increasing the injected amount of contrast media into the hip joint can be helpful to improve the expressiveness of the achieved arthrogram (Palestro, 2003). One Arthrographic criterion for loosening is the contrast leakage in the interface distal to the intertrochanteric line (Ovesen et al., 2003).

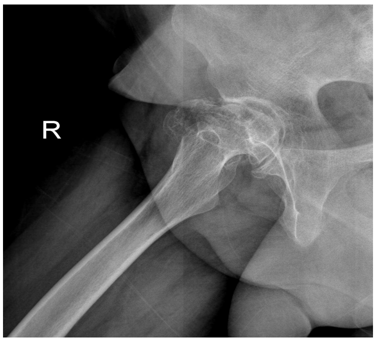

Fig.5. A clear picture of injured acetabular cup before pre- THA.

iii) Scintigraphy

Scintigraphy is the examination of the unhealthy region of the infected THR with white blood cell imaging [11]. A gamma-camera is fixed for the radiation in 2D structure. It is mainly used for examining two-phase and triple -phase bone. It depicts the sensitivity of the triple phase bone. This inconsistency is caused by the use of highly differing scan interpretation criteria.

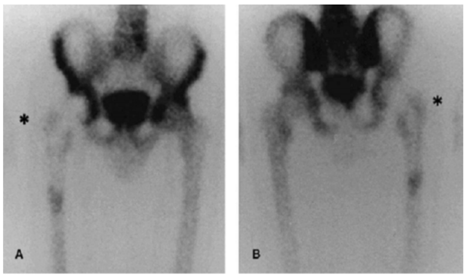

Fig.6. 99mTc bone scans with normal anterior and posterior image of the prosthesis, without signs of loosening or infection

iv) Fluorodeoxyglucose-Positron Emission Tomography (FDG- PET)

FDG-PET works on the basis of Scintigraphy outcomes. Mechanical loosening of the femoral component should show a significant pathological uptake of radioisotopes in the distal part of the THR at the tip and increased periprosthetic uptake [12]. A second substantial lesion in the region of the lesser trochanteris a further signs for loosening and supports the first presumption.

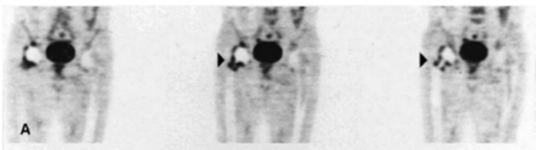

Fig. 7.18F-FDG-PET coronary slices 7 mm thick showing right-sided artificial hip joint in the patient.

2.2 Intelligent Implants

The intelligent implants include highly complicated use of sensors, actuators and signal processing to detect the angle of the loosening after THR. Miniaturization is the main issue of the modern implants systems [13]. A tiny sensor is placed near the femoral and acetabular component after THR. In the field of Microsystems some diagnostic systems reached the status of implantable passive and telemetric prototypes (Bergmann et al., 2001, Marschner et al, 2009). The preferred detected properties, which were mainly considered, are the acoustical in combination with mechanical properties. The detection of micro -motion with an in vivo sensor unit at the distal femoral component was proposed (Hao et al., 2010). The possible parameters to recognize the loosening condition of the THR is depicted in Fig.8.

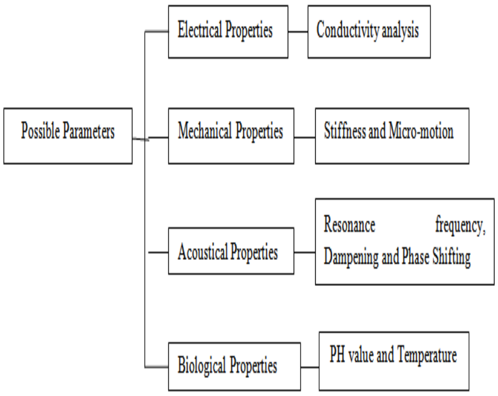

Fig.8. Possible parameters for intelligent implants

III. ORIENTATION OF ACETABULAR CUP DETECTION FRAMEWORK

3.1 General Presentation Of Arthroplasty

The term ‘arthroplasty’ defines an operative procedure in which the painful arthritic joints are replaced by the prosthetic materials or rearranging the joints [14]. The important parameters near hip area after insertion of the prostheses are shown in Fig.9.

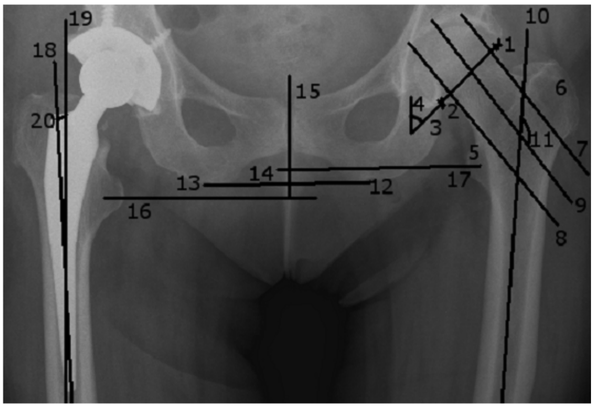

Fig.9. Important parameters near Hip Region

The parameters are described as follows [15-18]:

1) The point is superior where thigh-bone meets the pelvis which is known as the superior margin of the acetabulum.
2) The point is inferior where thigh-bone (Femoral head) meets the pelvis which is known as the inferior margin of the acetabulum.

3) The segment that joins by superior and inferior margin of the acetabulum is known as femoral head axis or acetabulum axis.
4) The angle created by the acetabulum axis with the vertical line. This angle has to be the same for both of the femoral bones.
5) The part located in the upper left part of the femoral body is known as lesser trochanter.
6) The part located in the upper right part of the femoral body is known as greater trochanter.
7) The tangent to the superior cortical of the femoral neck.
8) The tangent to the inferior cortical of the femoral neck.
9) The axis between 7 and 8 forms as cylinder is the femoral neck axis.
10) The axis of the cylinder that approximates the femoral body is known as femoral body axis or diaphyseal axis.
11) The angle determined by the neck axis and the diaphyseal axis is known as cervico diaphyseal angle. Depending on the value of this angle, it can be determined whether the patient needs or not a prosthesis. If the angle has values between 125 and 135 degrees, the thigh-bone is considered to be in normal ranges.
12) The lowest right part of the pelvic bone is the right ischiadic tuberosity.
13) The lowest left part of the pelvic bone is the left ischiadic tuberosity.
14) The line determined by the two ischiadic tuberosities is referred asischiadic line
15) The vertical reference line, that is perpendicular on the ischiadic line, in its middle.
16) The line starting from the center of the lesser left trochanter, parallel to the ischiadic line
17) The line starting from the center of the right lesser trochanter, parallel to the ischiadic line; the distance between lines 16 and 17 represents the vertical distance between the two thigh-bones. If this distance is greater than a chosen threshold, there is an indication of a difference between the lengths of the two femoral bones that has to be resolved surgically (in most cases).

    After inserting the prosthesis, some parameters are considered as:
18) The diaphyseal axis of the femoral bone (the same as parameter 10).
19) The diaphyseal axis of the prosthesis or the axis of the prosthesis' body (the axis of the cylinder that approximates the prosthesis' body).
20) The deviation of the prosthesis (the angle determined by lines 18 and 19). This parameter will be computed in several radiographic images, following the evolution of the same patient.

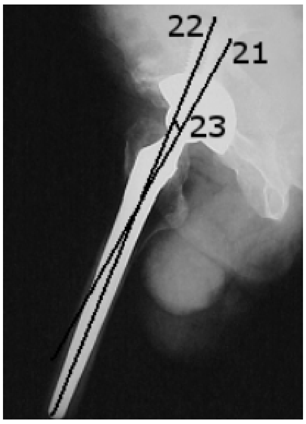

Fig.10. Parameters important in Hip Replacement, extracted from an anterior-lateral radiography, after the insertion the prosthesis

21) The axis of the prosthesis' neck
22) The axis of the prosthesis' body
23) The anteversion angle (the angle determined by the axes 21 and 22). If this angle has its value situated between 5 and 10 degrees, it's considered to be in normal ranges.

3.2 Problem Formulation and Proposed Algorithm

Loosening of the prosthesis components is the long term issue prevails in the Total Hip Replacement (THR). In previous works, manual operations are followed by some protocols, to recognize the loosening status. By doing so, time consumption is high for evaluating the subjective method. This paper concentrates over the automatic lucency measurements using predictive modeling. We have developed a reliable and accurate method of automatically segmenting, classifying and measuring, the orientation of acetabular components of cemented THR. The proposed algorithm contains four phases, namely, Acquisition Phase, Preprocessing Phase, Segmentation Phase, and Angulation phase.

i) Acquisition Phase

Acquisition phase is the first phase in the proposed algorithm. Firstly, the anteversion angle of radiographs images is collected from the BIRRD

Hospital and Sri Maruthi Speciality hospital, at Tirupati. The sample images are shown in Fig.11.


(a)


(b)


©

Fig.11. Sample Images- Cemented Hip Replacement in Radiographs


(a)


(b)


(c)


(d)

Fig.12. (a) Overview of acetabular components (b) Cemented Acetabular component (c) Lateral and anterior-posterior view (d) Fracture of the acetabular component

Fig.13. Loosening of the acetabular component

ii) Preprocessing Phase

Preprocessing phase is the second step of the proposed algorithm. Subsequently, the radiographs images are noisy and inconsistent in nature. In order to obtain high accuracy outcomes, the radiographs images are preprocessed. Mean filter is an efficient technique used for removing the grain noise in the images. Some mask operations are performed over each pixel by preserving the edges of the preprocessed images. Each of the components of the image which fall under the mask are averaged together to form an output pixel. Let the image I represented in m * n size. It is generally given as:

$$f(x,y) = \frac{1}{m*n}\sum_{i=0}^{i=m}\sum_{j=0}^{j=n} f(\mathrm{a,b}) \quad (3.1)$$

Here, m and n are the size of the image in pixels

f(x,y) denotes the mean value of the pixel in a window

f(a, b) denotes pixel value of the image of the coordinates i,j.

iii) Segmentation Phase

After the prosthesis is inserted, the important parameters considered are 18, 19, 20, 21, 22, and 23. The sobel operator [30] is designed to detect the boundary of the implant- bone interface. The boundary of the prosthesis component is detected in two directions, vertical and horizontal direction. The use of improved sobel operator will dynamically adjust the mask coefficients using the gradient function. The pseudocode of an improved sobel operator is described as:

1) Let Img_x and Img_y are the group of points that carry horizontal and vertical derivatives of the image.

2) The horizontal derivative of image is calculated as:

2.1The Img_x is computed as:

$$\begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix} \quad (3.2)$$

2.2 Apply Img_x to the input image.

2.3 Detect the boundary of the implant to bone interface in horizontal orientation.

3) The vertical derivative of image is calculated as:

3.1 The Img_y is computed as:

$$\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix} \quad (3.3)$$

3.2 Apply Img_y to the input image.

3.3 Detect the boundary of the implant to bone interface in vertical direction.

4) Mask the computed outcomes to the input image distinctively.

5) The magnitude of the input image is given as:

$$|I| = \sqrt{Ix^2 + Iy^2} \quad (3.4)$$

6) Converting the magnitude into vector form, is given as:

$$\phi(\mathrm{Img}_x, \mathrm{Im}\,g_y) = \arctan(\mathrm{I}) \quad (3.5)$$

7) From the eqn. 3.6, the boundary of an input image is detected.

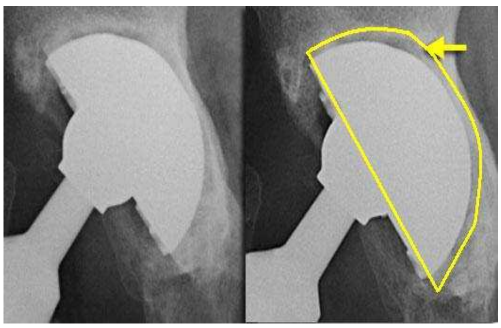

Fig.14. Boundary detection of implant –to- bone interface (Indicated in yellow line)

iv) Angulation Phase

Angulation phase is the final step of the proposed algorithm. The purpose of this step is to measure the orientation between the implant and bone tissue. Now, let us assume that acetabular cup as in 3D spherical form. Generally, the anteversion angle of the prosthetic component should 5 to 10° which is studied by Lewinnek GE et al. If it deviates from the normal degree, then the loosening angle and distance from the bone tissue are measured. The fig.15 depicts the spherical conventions of input image.

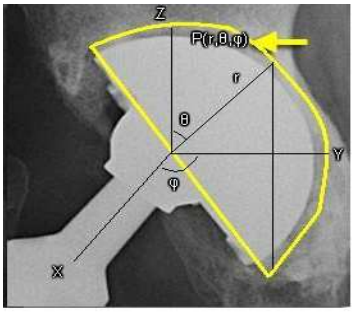

Fig.15. Spherical coordinates conventions of an input image

The angle between implant and bone tissue is estimated from P(r, φ, θ). Here, r is the distance from the prosthesis's body to the bone tissue, r>0; θ is the loosening angle between prosthetic body to the bone interface; φ is the angle between the anterior pelvic plane and the coronal plane of the body. Firstly, the angle between anterior pelvic plane and the coronal plane of the body, φ is estimated. It suggests the solution for predicting the θ. Generally, the anteversion angle is presented as:

$$\text{Anteversion angle}_{\text{Acetabular cup}} = \arcsin\left(\frac{\text{acetabular axis}}{\text{coronal plane of the body}}\right) \quad (3.7)$$

The above eqn.3.7 depicts the anteversion angle of the acetabular cup. The inclination between acetabular axis and coronal plane of the body is the purpose of our research study. The loosening angle is measured from two orientations, namely anterior view OPQ and posterior view OPP'. The bone-tissue Z at anterior view is given as:

$$z = r\cos\theta \quad (3.8)$$

The posterior view of the bone tissue from implant s is given as:

$$s = r\sin\theta \quad (3.9)$$

By combining anteroposterior view, the loosening angle is measured from the following equations,

$$x = r\sin\theta\cos\varphi \quad (3.10)$$

$$y = r\sin\theta\sin\varphi \quad (3.11)$$

$$y = s\cos\theta \quad (3.12)$$

From the entire estimated angle, the loosening distance from the implant to bone tissue r is

$$R^2 = x^2 + y^2 + z^2 \quad (3.13)$$

By the eqn, (3.9), and (3.11), the angles between two triangles, anterior view OPQ and posterior view OPP' are measured. Thus, by finding r, the distance from between acetabular axis and coronal plane of the body is calculated. By doing so, the orientation status of the prosthetic component is measured.

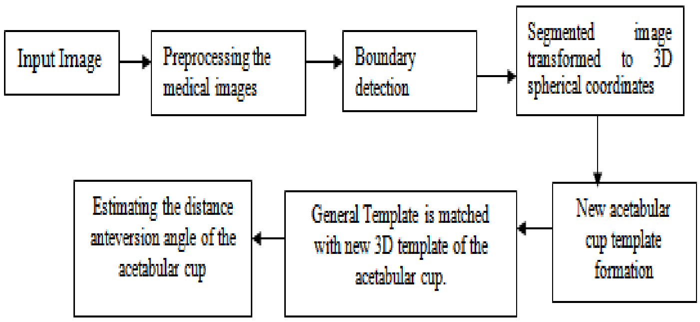

Fig.16. Proposed Block diagram

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, we explain about the experimental analysis of the proposed algorithm. Samples of anteversion view of radiographic images are collected from the hospitals that underwent cemented THA. The collected images are preprocessed using mean filter model and boundary of the region between coronal plane of the body and acetabular component are detected. Let us consider different dislocating angles as shown in Fig. 16.The variables are ranged from:

$$0 \leq r < \infty$$

$$0 \leq \theta \leq \pi$$

$$0 \leq \varphi < 2\pi$$

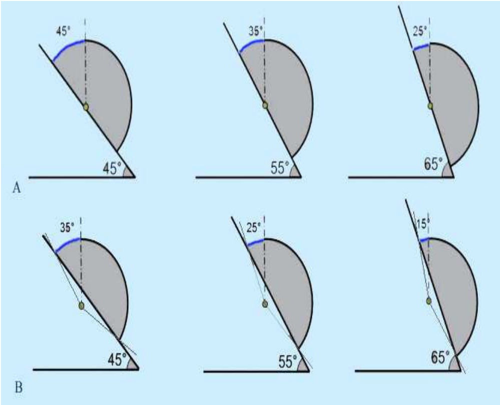

Fig.16. Different sorts of acetabular cup orientation

Input images	θ	φ	R (Constant)	s	x	y	z	R
Img1	45	45	4	2.82	1.99	1.42	2.828	3.730
Img2	35	55	4	2.29	1.31	1.87	3.276	3.9993
Img3	25	65	4	1.69	0.71	1.53	3.624	3.9972
Img4	35	45	4	2.29	1.61	1.87	3.276	4.4690
Img5	25	55	4	1.69	0.97	1.53	3.624	4.0515
Img6	15	65	4	1.03	0.43	0.99	3.864	3.9930

Table 4.1. Distance r value computation.

From the table 4.1, it is inferred that the distance between acetabular axis and coronal plane of the body of various input images. Similar studies have been done by other researchers. Olivecrona et al [26] studied about the orientation of the acetabular cups in 10 registries. They depicted that normal degree of 0° to 52° were evaluated with error rate of 2.9°.This was further enhanced by using trigonometric methods by Liaw et al. In addition Liaw et al [27] used his own protractor method to get the mean ± SD of the error of 0.96° ±0.74°. These protractor methods are convenient than the others since they do not require a calculator or computer. Furthermore, they incorporated the inverse trigonometric function into protractor conversion method. The most common disadvantages are to find the ends of long axis and short axis. Fabeck [28] applied direct measurement using a protractor that was designed without any incorporation of trigonometric function. However, the radiologist usually has difficulty in following the long arc of the circles during the measurement. Widmer invented his own protractor through his linear regression equation that ranged from 7 to 41° with error rate of 9.8°.

V. CONCLUSION

The acetabulum anteversion is an important study after Total Hip Arthroplasty. The optimal degree and distance from anteversion view of the acetabular cup is not yet clearly defined. But, it lacks in predicting the acetabular cup orientation in the view of coronal plane of the body. And it's also a tedious task for medical person to measure the distance from anteversion angle of the acetabular component. In this paper, we propose a novel automatic detection of acetabular cup orientation between acetabular axis and coronal plane of the body. The proposed algorithm contain four phases namely, i) Acquisition phase ii) Preprocessing phase iii) Segmentation phase and iv) Angulation Phase. Firstly, the images are preprocessed using mean filter model. It is followed by Sobel operator to segment the boundary of prosthetic component and bone tissue of the acetabular cup. Then, the segmented image is transformed into 3D spherical conventions. By assuming different positioning of the acetabular cup, the distance r value is computed. In related to previous models, our proposed algorithm efficiently predicts the acetabular cup orientation in rapid manner.

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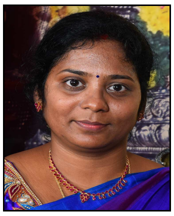

Mrs. Tatekalva Sandhya MCA, Research Scholar, Dravidian University, Kuppam, Andhra Pradesh, India. Email: geetasandhya@gmail.com

Dr. M. Usha Rani MCA, Ph.D., Professor BOS Chair Person Dept. of Computer Science Sri Padmavati Mahila Visvavidyalayam (Women's University) Tirupati-517502 (A.P), INDIA. Phone(Off) : 91-0877-2284521 (Res): 91-0877-2243021, (M)9247562666 E-mail: musha_rohan@yahoo.com

Dr.M.Maruthi Krishna M.S.(Ortho),
Managing Director, Trauma and Joint Replacement Sergeon, Sri Maruthi Speciality Hospital, Door No 20-3-88/G, TML By Pass Road, Tirupati - 517501, Leela Mahal Circle.