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# Development of a 4-Axis Articulate Robot With Vision Based Part Identification System for Pick and Place Operation

[1] Nithin Chandran,[2] Dr.Lalu P.P
Department of Mechanical Engineering
Government Engineering College, Thrissur

***Abstract*— Vision based pick and place operation using colour identification is one of the most researched topic. Machine vision is supposed to be the pioneer future technology. It gives flexibility to identify and manipulate any surrounding object .This thesis focuses on pick and place operation of a 4-axis articulate robot using colour segmentation technique.Various colour segmentation techniques are discussed and a general comparison between K-mean clustering technique and Fuzzy C mean clustering technique is made.The vision sensor used here is a Kinect v2 camera which is a RGB-D camera for depth measurement and coordinate determination .In the experimental setup a set of coloured markers are placed, from which the robot pick the required segmented coloured marker. An important part of industrial robot manipulators is to achieve desired position and orientation of end effector or tool so as to complete the pre-specified task. To achieve the above stated goal one should have the sound knowledge of inverse kinematic problem. The robot kinematics is carried out considering both forward and inverse kinematics. Finally the accuracy of the robot is measured using Kinect sensor**

***Keywords* — Pick and place robot,, image segmentation, inverse kinematics,accuracy measurement**

## I. INTRODUCTION

Over the last few decades,the use of industrial robots has been significantly increased. Mostly these are being used for material handling, welding, painting, assembling of parts, packaging, handling hazardous materials, undersea operations, etc. With the advancement of various technology, the scope of the tasks performed by robots is widened so that it is desirable for machines to extend the capabilities of men and to replace them by robots in carrying out at tiresome as well as hazardous jobs.

Small and medium scale manufacturing industries use conventional methods to pick and place materials from one place to another. This is a time taking process and greater is the chances of error occurrence. The solutions for the aforesaid problem is using robots in pick and place operation. Here operation is automatically done by robots. Robots are more flexible as to the orientation of the object itself, which the robot may even need to identify.

Segmentation is the first key step in object Recognition, scene understanding and image understanding. Segmentation of an image can be done on the basis of some characteristics such as color, objects that are present in the entire image. Color image segmentation is a process of extracting from the image domain one or more connected regions satisfying uniformity (homogeneity) criterion which is based on feature(s) derived from spectral components. These components are defined in a chosen colour space model. A Lab colour space is a colour opponent space with dimension L for lightness and a and b for the colouropponent dimensions, based on non linearly compressed CIE XYZ colour space coordinates. "Lab" colour spaces is to create a space which can be computed via simple formulas from the XYZ space, but is more perceptually uniform than XYZ

An important part of industrial robot manipulators is to achieve desired position and orientation of end effector or tool so as to complete the pre-specified task. To achieve the above stated goal one should have the complete knowledge of inverse kinematic problem. The problem of getting inverse kinematic solution has been on the outline of various researchers and is deliberated as thorough researched and mature problem. There are many fields of applications of robot manipulators to execute the given tasks such as material handling, pick-n-place, planetary and undersea explorations, space manipulation, and hazardous field etc. Industrial robot manipulators are required to have proper knowledge of its joint variables as well as understanding of kinematic parameters. The motion of the end effector or manipulator is controlled by their joint actuator and this produces the required motion in each joints. Therefore, the controller should always supply an accurate value of joint variables analogous to the end effector position.

## II.PICK AND PLACE OPERATION

Pick and place industrial robots speed up the process of picking parts up and placing them in new locations thus will increase the production rates. With many end-of-arm-tooling options available, pick and place robots can be made to fit required production specifications. Consistency is also an advantage of using a pick and place robotic system. The robots can be easily programmed and operated to provide multiple applications if required.

***Fig 1: 4 Axis robot***

Kensuke Harada, Tukuo Tsuji [5] proposed object placement planners for a grasped object during pick and place tasks . The proposed planner automatically determines the pose of an object that is stably placed near a user assigned point on the environment surface. In their proposed method, first the polygon models of both the object and the environment are clustered, with each cluster being approximated by a planar region. The position/orientation of an object placed on the environment surface can be determined by selecting a pair of clusters: one from the object and the other from the environment. Ayokunle A. Awelewa [4] discussed about the development of a three-degree-of freedom revolute robot manipulator amenable to pick-and-place operations in the industry.

## III.IMAGE SEGMENTATION

Image segmentation is the process of extracting information from the image. Image segmentation partitions the image into subparts depending upon the region of interest Based on techniques the image segmentation is divided into two broad categories: similarity based and dissimilarity based .In a region all pixels are similar with respect to some characteristic such as color, intensity, texture etc. whereas adjacent regions are significantly different with respect to the same characteristics. Clustering is the process that depends upon the similarity of pixels values and edge detection depends upon the dissimilarity of pixel values .

Anju Bala,Aman Kumar Sharma [2] proposed an image segmentation algorithm called Image Segmentation using K-means and Morphological Edge Operators (ISKMEO) which is a combination of two image segmentation techniques: K-means clustering and morphological edge Operators. Among clustering algorithms K-means is the most popular clustering technique that helps to cluster the data. The output of the K means clustering is processed with morphological operations and edge operators. The proposed algorithm (ISKMEO) is compared with the traditional k-means and edge detection operators. The results shows that the proposed algorithm segment the image effectively and efficiently K-Means algorithm is an iterative,numerical, non deterministic and unsupervised clustering method that classifies the input data points into multiple classes based on their inherent distance from each other. K-means algorithm is based upon the index of similarity or dissimilarity between pairs of data components.[8]

Fuzzy C-Means (FCM) is an unsupervised clustering algorithm that classifies the image by grouping similar data points in the feature space into clusters. This method separate the input image as regions based on their grouping of similar pixels and the pixels on an image are highly correlated and thus the spatial relationship of neighboring pixels is an important characteristic that can be of great aid in imaging segmentation.Both these clustering is done L*A*B colour space. Lab colour space is a colour opponent space with dimension L for lightness and a and b for the colouropponent dimensions, based on nonlinearly compressed CIE XYZ colour space coordinates.[10]

 

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## IV.OBJECTIVES

- To develop a machine vision system for pick and place operation by a 4 axis robotic arm
- To study the performance of Colour based segmentation of objects using various algorithms(K-mean Clustering and Fuzzy C-mean clustering) and make a general comparison between these clustering techniques
- To estimate the forward and inverse kinematics of the robot
- To measure the accuracy of the 4-axis robot by comparing with the simulation using machine vision technique

## V.METHODOLOGY

### A. *Accuracy of kinect sensor*

Kinect sensors used for the experiment are self-calibrated by default. Hence chances of error in measurement are very less, but accuracy of Kinect depends on prevailing conditions of

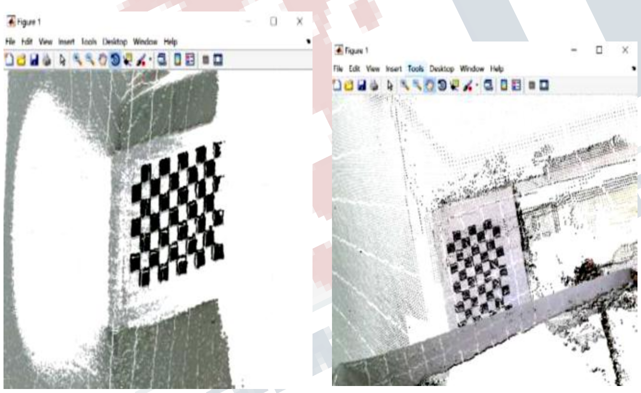

*Fig 2 (a)Point cloud from V1 (b)Point cloud fromV2*

the experiment. In order to ensure that the experimenting environment do not affect the accuracy of Kinect sensors adversely, we checked the accuracy of the sensors manually.

Area calculation:

Coordinates of A,B and C from Kinect v1 are:A(-0.1092,0.05927,0.635), B(-0.0833,0.05932,0.635),C(0.1752,0.05822,1.237)

Area = AB X BC = 25.90 X 24.891 = 644.676 cm2

Actual area = 25 X 25 = 625 cm2

Error = (|Actual area – Measured area|)/Actual area = (|625-644.676|)/625 = .03148 = 3.148 %

Coordinates of A,B and C from Kinect v1 are: A(0.08293,-0.01995,1.269) ,B(0.1065,-0.01982,1.261) , C(0.1297,0.08295,1.253)

Area = AB X BC = 24.89 X 25.26 = 628.7214 cm2

Actual area = 25 X 25 = 625 cm2

Error = (|Actual area – Measured area|)/Actual area = (|625-628.7214|)/625 = .00595 = 0.595 %

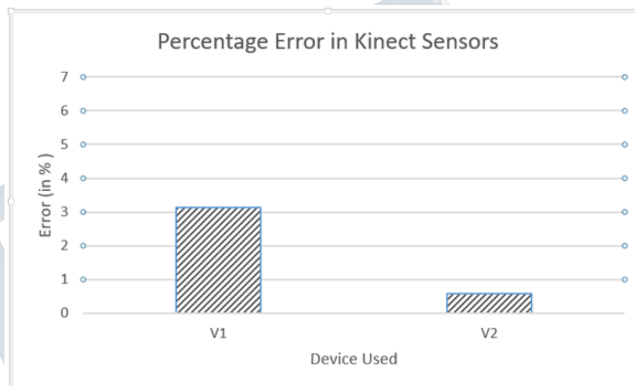


*Fig3: Percentage error in kinect sensors*

Hence comparing the area measured using Kinect V1 and V2 we can see that V2 give a better accuracy than V1 and overall error is less than 5%.

For interfacing robot with the PC,an Arduino UNO board is used and is interfered with Matlab software

### B .*Forward and inverse kinematics*

Kinematics play an important role in robotics and usually D-H convention is used for its calculation. This are different for different robotic manipulators. Denavit-Hartenberg method that uses four parameters is the most common method for describing the robot kinematics. These parameters $a_{i-1}$ , $\alpha_{i-1}$ ,

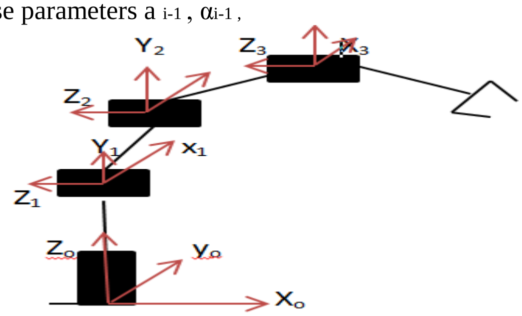

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*Fig 4: Robotic arm coordinates*

di ,and θi are the link length, link twist, link offset and joint angle, respectively.
d = ffset along previous z to common normal
θ= angle about previous z fromold x to new x
a= length of common normal
α = angle about common normal from old z axis to new z axis
The following D-H parameter table is obtained for the robot

| Link | $\theta_i$ | $\alpha_i$ | $a_i$ | $d_i$ |
|---|---|---|---|---|
| 1 | $\theta_1$ | -90 | 0 | $d_1$ |
| 2 | $\theta_2$ | 0 | $a_2$ | 0 |
| 3 | $\theta_3$ | 0 | $a_3$ | 0 |
| 4 | $\theta_4$ | 0 | $a_4$ | 0 |

Here a2=95 mm,a3=95 mm,a4=25 mm ,d1=10mm
Next is to find the forward transformation matrix.the general transformation matrix is given as:
$T_{i}^{i-1}$= RX (αi-1) Dx (ai-1) Rz (θi) Qi (di)

$$\begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Then the individual transformation matrix is found as

$$^{base}_{end\_effector}T = {}^{0}_{1}T\,{}^{1}_{2}T \ldots {}^{n-1}_{n}T$$

Where,

$$^{Base}_{end\_effector}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

On substituting the D-H parameters to the transformation matrix,we get the following matrices

$$T_1 = \begin{vmatrix} c1 & 0 & s1 & 0 \\ S1 & 0 & -C1 & 0 \\ 0 & 1 & 0 & d1 \\ 0 & 0 & 0 & 1 \end{vmatrix} \qquad T_2 = \begin{vmatrix} c2 & -s2 & 0 & a2*c2 \\ s2 & c2 & 0 & a2*s2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$T_3 = \begin{vmatrix} c3 & -s3 & 0 & a3*c3 \\ s3 & c3 & 0 & a3*s3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \qquad T_4 = \begin{vmatrix} c4 & -s4 & 0 & a4*c4 \\ s4 & c4 & 0 & a4*s4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Thus the final complete transformation matrix is:

$$^{base}_{end\_effector}T = T_1 * T_2 * T_3 * T_4$$

After simplication of the above matrices using Symbolic math toolbox in matlab,we got the gripper position coordinates as,
$px=c\theta 1[l2c\theta 2+l3c(\theta 2+\theta 3)]+l4c\theta 1c(\theta 2+\theta 3+\theta 4)$.. (1)
$py=s\theta 1[l2c\theta 2+l3c(\theta 2+\theta 3)]+l4s\theta 1c(\theta 2+\theta 3+\theta 4)$...(2)
$pz=[l1+l2s\theta 2+l3s(\theta 2+\theta 3)]+l4s(\theta 2+\theta 3+\theta 4$..(3)
Where s stands for sine and c stands for cos and px,py and pz are end effector coordinates.
Next is to find the inverse Kinematics solution. We end up with a set of four nonlinear equations with four unknowns. From this solution we can generate the equations to carry out the Inverse Kinematic solution. We get solution from equations (1) to (3), by dividing, squaring, adding and using some trigonometric formulas:
$\theta_1 = \tan^{-1} \frac{Py}{Px}$ (4)
$\theta_2 = \tan^{-1}(c, \pm\sqrt{(r^2 - c^2)}) - \tan^{-1}(a,b)$ (5)
$\theta_3 = \cos^{-1}(A^2 + B^2 + C^2 - l_2^2 - l_3^2/(2*l_2*l_3)$ (6)
$\theta_4 = \emptyset - \theta_2 - \theta_3$ (7)
Where,
$a = l_3 sin\theta_3$, $b = l_2 + l_3 \cos\theta_3$, $c = dz - l_1 - l_4 \sin\emptyset$ and
$r = \sqrt{(a^2+b^2}$
In addition $A = ( dx - l_4 cos\theta_1 \cos\emptyset)$,
$B = ( dy - l_4 sin\theta_1 \cos\emptyset)$,
$C = (dz - l_1 - l_4 sin\emptyset)$

## VI.EXPERIMENTATION

The experimental setup for the work is as shown in figure:

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*Fig 5: Experimental setup*

The setup consist of a 4-axis articulate robot and a base with different coloured markers.It is required to pick the markeby colour segmentation technique.

The coloured marker which is to be picked up is found out by Image segmentation technique.But before that the effectiveness and accuracy of the segmentation techniques used has to be found out.For this both KM and FCM cluster techniques are tested under the following conditions

Case 1:Image having circular RGB colours 4
Case 2:Image of real world objects captured by mobile camera
Case 3: Real world objects under cluttered or messy environment
Case 4 : Real world objects under coloured background
Case 5 : Other polygon shapes are considered
Case 6 : Under cluttered environment

The comparison between KM and FCM is done on considering the time taken and the circularity level of the segmented image Circularity = $4 * \pi * Ap2$

The time taken is the effective computation time taken by each algorithm to segment the image.Based on these two results we can make a general comparison between both the clustering algorithms.

Next is to identify the position of the blue marker using Kinect sensor. The coordinates which we obtain is measured from the center position of the Kinect camera.But we need to get the exact position of the marker from the Robot center.

For this we randomly take any point and consider that as a reference point from the marker position.Then the difference between these two point will give the coordinates of the marker position.

In the figure below,the yellow point is the reference point taken and the coordinate of the point is obtained using the kinect sensor and K-mean segmentation technique

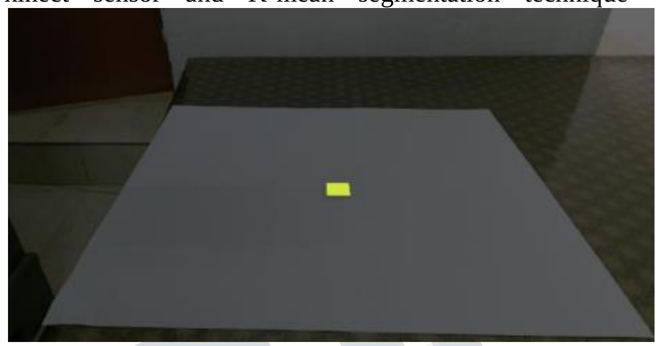

*Fig 6: Segmented reference point*

Coordinates obtained =(0.1004,0.1325,0.6150) in m

Using same method,the coordinate of the blue marker is measured by segmenting and using the kinect sensor as shown below:

*Fig 7: Segmented marker point*

Coordinates measured=(0.0989,0.2224,0.76)

For getting the exact center position of the robot the height of the robot has to be considerd from the base position.Height of the robot from the base is 9cm.Thus the exact center position of the robot is obtained as (0.1004,0.2225,0.6150)

Finally the position of the marker is measured as the difference between these two points.

So, the actual coordinate of the marker obtained is (0.0015,0,0.145).Using this position inverse kinematics is carried out to obtain the required angles.

## VII.RESULT AND DISCUSSION

A. Colour based image segmentation

Case 1: Image having circular RGB colours (K=4)

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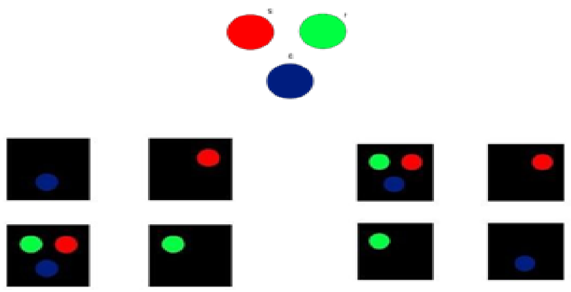
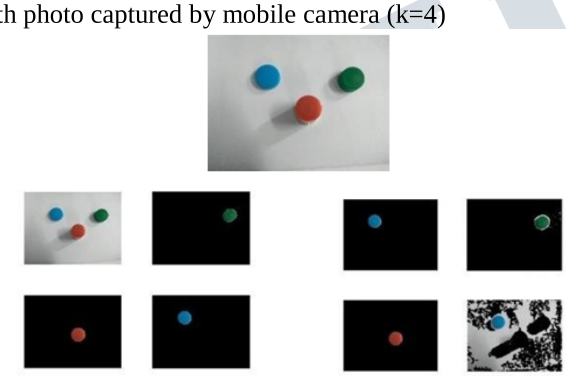


KM FCM

| | | Kmean | FCM |
|---|---|---|---|
| Time | | 0.8594 | 2.2969 |
| Circularity | R | 0.9534 | 0.9534 |
| | G | 0.9517 | 0.9534 |
| | B | 0.9653 | 0.9653 |

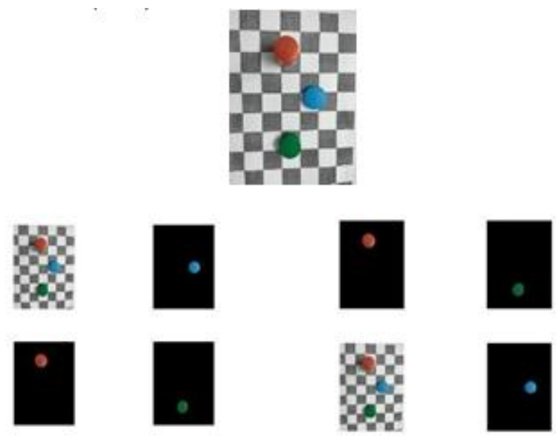
Case 2: Clustering is carried out with real world object with photo captured by mobile camera (k=4)



KM FCM

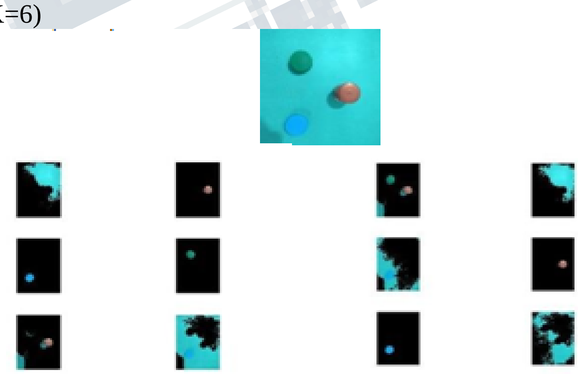
| | | Kmean | FCM |
|---|---|---|---|
| Time | | 0.8594 | 2.2969 |
| Circularity | R | 0.9534 | 0.9534 |
| | G | 0.9517 | 0.9534 |
| | B | 0.9653 | 0.9653 |

Case 3 : Real world objects under cluttered or messy environment(K=4)



| | | Kmean | FCM |
|---|---|---|---|
| Time | | 19.48 | 120.20 |
| Circularity | R | 1.07 | 1.06 |
| | G | 1.22 | 1.26 |
| | B | 1.07 | 1.07 |

Case4 :Real world objects under coloured background (K=6)



| | | Kmean | FCM |
|---|---|---|---|
| Time | | 30.68 | 397.54 |
| Circularity | R | 1.18 | 1.24 |
| | G | 1.55 | 1.56 |
| | B | 1.07 | 1.05 |

The result for each conditions show that k-mean is showing better results compared to FCM .Also computation time isless fro kmean.The circularity of each colour segemented for the above discussed conditions are

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shown below:

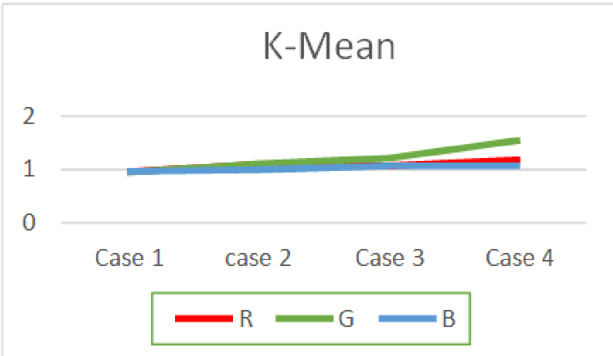


***Fig8: Circularity result using K-mean***

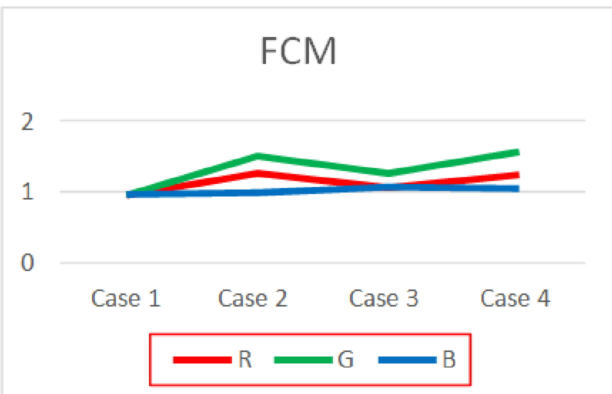


***Fig9: Circularity result using FCM***

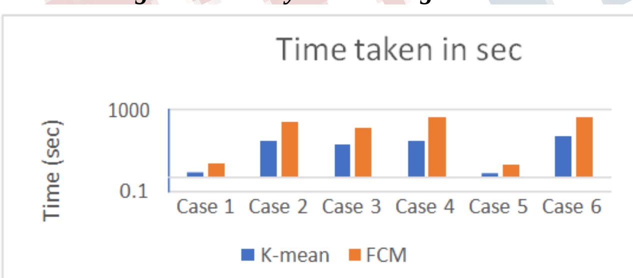


***Fig 10: Time comparison between K-mean and FCM***

Here blue colour is showing better circularity compared to other colours.So we selected blue as the marker to be segmented

### *B. Forward and inverse kinematics*

The position of the marker is (0.0015, 0, 0.145) After running the matlab code for inverse kinematics solution,the values obtained are

| | Angle (in deg) |
|---|---|
| Base rotation ($\theta_1$) | 0 |
| Shoulder rotation($\theta_2$) | 80 |
| Elbow rotation($\theta_3$) | 140 |
| Wrist rotation($\theta_4$) | 40 |

After the execution of the result, the gripper was 2cm away from the final position.The gripper position is measured using Kinect and obtained as (0.0023,0,0.0160) Hence error in coordinate position is shown as given below

Error percentage in x coordinate = 0.46%

Error percentage in y coordinate =0

Error percentage in z coordinate = 10%

### C. *Accuracy measurement of robot*

The accuracy of the robot is measured using the Kinect camera and the simulation software.

Distance from base to gripper is to be calculated. Knowing the coordinate values, we can easily calculate distances by using distance formula. $\sqrt{[(x_1-x_2)^2+(y_1-y_2)^2+(z_1-z_2)^2]}$

At different position like at homeposition, Base rotation($\theta_1$) =120 °, Elbow rotation($\theta_3$) =60 °, Elbow rotation($\theta_3$) =45 °

Wrist rotation($\theta_4$) =30 °, Wrist rotation($\theta_4$) =45 °, Elbow rotation($\theta_3$) =60 ° and Wrist rotation($\theta_4$) =45 ° the coordinates of both base and gripper of the robot is measured using Kinect v2 sensor and the following distances are obtained:

| **Home** | **$\Theta_1$=120** | **$\Theta_3$=60** | **$\Theta_3$=45** | **$\Theta_4$=30** | **$\Theta_4$=45** | **$\Theta_3$=60, $\Theta_4$=45** |
|---|---|---|---|---|---|---|
| 0.221 | 0.286 | 0.238 | 0.266 | 0.287 | 0.266 | 0.274 |

Next the distance in Kinematic simulation software is measured and the following result were obtained

| **Home** | **$\Theta_1$=120** | **$\Theta_3$=60** | **$\Theta_3$=45** | **$\Theta_4$=30** | **$\Theta_4$=45** | **$\Theta_3$=60, $\Theta_4$=45** |
|---|---|---|---|---|---|---|
| 0.238 | 0.28 | 0.245 | 0.240 | 0.273 | 0.271 | 0.292 |

The distances calculated in various cases are shown below graphically in Fig8.4 below

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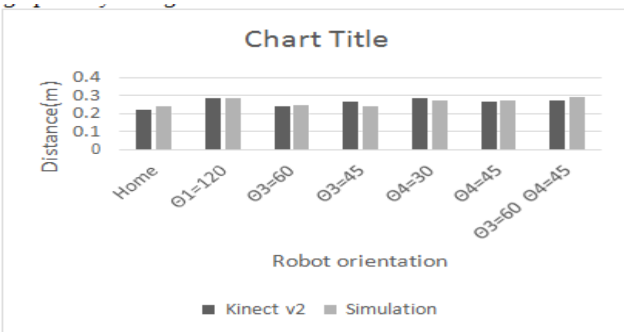


***Fig 11:Graph result of accuracy***

The robot's measured error is given below:

- Home position = 6.96 %
- Base rotation(120 º) =0.48 %
- Elbow rotation(60 º) =-2.84 %
- Elbow rotation(45 º) =-10.99 %
- Wrist rotation(30 º) =5.15%
- Wrist rotation(45 º) =1.60%
- Elbow rotation(60º) and Wrist rotation(45 º) =6.07%

## VIII.CONCLUSION

This thesis focused on pick and place operation of a 4-axis articulate robot using colour segmentation.There are many colour segmentation techniques available and clustering technique is one among them.Basically two types of clustering methods namely,K-mean and Fuzzy C mean are considered in this work.A general comparison is made between them under different conditions and is concluded that K-mean produces relatively higH quality clusters with better computation speed .FCM takes more time for computation and it performance is not upto the level when the image has more noise ,but under cluttered environment FCM gives better results compared to K mean.Kinect sensor camera gives better depth information which was used to determine the coordinates of the segmented marker position.Forward and inverse kinematics are carried out effectively in order to pick the marker.There was error in execution which may be due to combined errors in kinect sensor and servomotors usedfor robotic manipulators.Finally the accuracy of the robot is measured using Kinect sensor and compared with the simulation software.

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