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ANALYZING OBJECT DIMENSIONS AND CONTROLLING ARTICULATED ROBOT SYSTEM USING 3D VISIONARY SENSOR

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ABSTRACT

Visionary system has been played a significant role in industrial environment especially in controlling the movement of industrial robot from objects to targets. In this paper implemented visionary system for articulated robot system has been build 3D KINECT camera as visionary sensor linked with controller of articulated robot system (lab-volt robot model 5250). This work involves constructing integrated in MATLAB program automatically. It depends on a new approach in analyzing the robotic environment by a KINECT camera. The approach uses colors to detect and recognize the locations object and target. Dimensional properties of object and target (length and center) have been analyzed and calibrated location and orientations for object and target have been conducted. The visionary system shows agreed capability for detecting the location and controlling movement of the articulated robot from object to target with Minimizing errors.

Keywords: articulated robot, control, dimensional properties, KINECT camera, matlab software, visionary system.

1. INTRODUCTION

Robots are quickly being interfacing into our lives, whether we see them or not. They roam our floors to vacuum our messes, build our automobiles, even defuse dangerous explosives, and repeating task. Since they are becoming so vital to society, it is imperative that we provide our robotic system companions with visionary system to increase their efficiency and adaptability especially in industrial robot (Matthew, 2013). Visionary system has been played a significant role in industrial environment especially in controlling the movement of industrial robotics and quality control for objects and targets. The project aims to controlling and to realize robotic arm cell-assisted by 3D camera system, Extraction visual information from the 3D image to control by the movement of robot from object to target as descript in the next section, we used a computer and special software as an external system for acquisition data and processing of these data from the 3D camera system (Belhadj, *et al*, 2013).

The KINECT camera sensor consists of an infrared, IR, light source, IR light sensor, RGB camera, a microphone array with four microphones, a motor to tilt the sensor and an accelerometer to detect the KINECT'S angle relative to the horizon. Both the RGB camera and IR camera have a resolution of 640x480 pixels (VGA) and can deliver an image stream of 30 frames per second (Štrbac, *et al,* 2012). Figure-1, a shows the KINECT camera and the location of the different parts (object and target). The depth sensor is consist from the IR-emitter and the IR-sensor and the locations is to the left of camera while is on the right respectively. "The KINECT uses a class a laser to emit the IR light, and there is there for no risk of eye injury using the KINECT." The "brain" in the KINECT comes from Prime Sense's PS1080 System on Chip as shown in Figure-1, b (Castaldo, 2013). The PS1080 controls the IR emitter and receives input from the cameras and microphones. The depth map are calculated on the chip and all the sensor inputs are synchronized and sent to the host computer via an USB 2.0 interface (Abdul majeed, Mansour, 2013;Abdulmajeed, Mansour, 2014).

(a) (b)

Figure-1. System architecture of the KINECT sensor a) the devices of the KINECT b) the internal components of the KINECT (El-laithy, *et al*, 2012).

VOL. 12, NO. 23, DECEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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2. METHODOLOGY/ EXPERIMENTAL

2.1 Methodology

The theoretical part is including the important sections in the work by installations of articulated robot and visionary Kinect sensor definitions. The first device install the Kinect on PC by installing series open source program (OpenNI, Sensor-Kinect, Sensor-kinect092 and Nite) respectively and then install the Kinect for Windows SDK v1.8 as shown in Figure-2 and system requirements and Minimal hardware specifications required to get up Kinect sensor and running is external power adaptor, USB 2.0, Windows 7 (32-bit (x86) or 64-bit (x64) processor) and Microsoft. NET Framework 4.0 or higher (Demitševa, 2015). The second device is robot arm must be inserting the CD-ROM to control the robot from PC and then interface between the robot controller and PC the special library called LV5250SDK.dll.

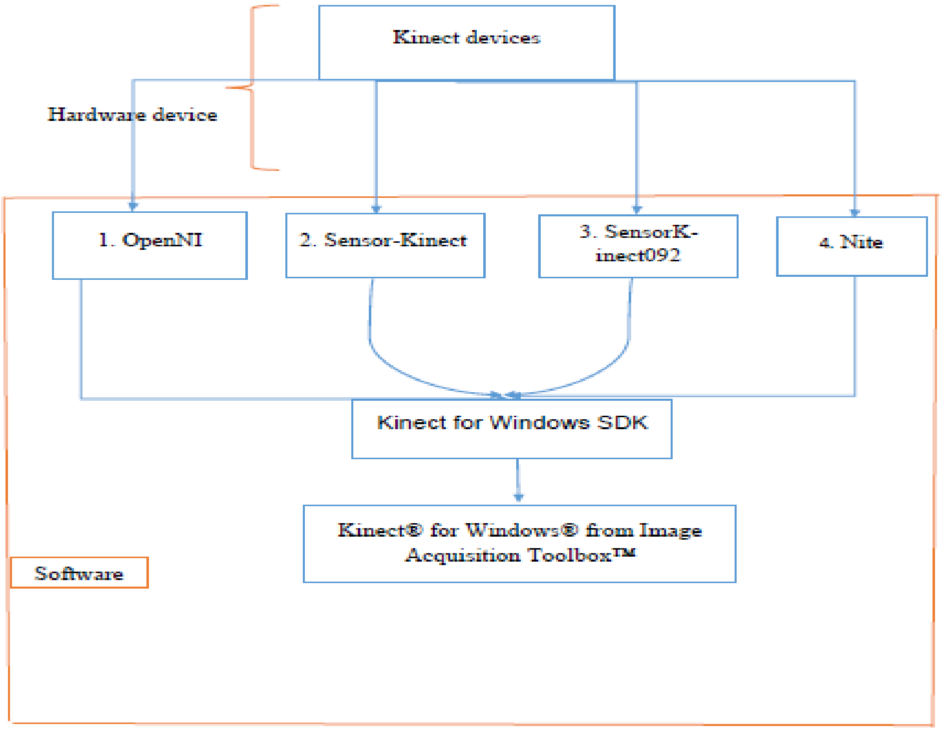

Figure-2. Algorithm of installing KINECT CAMERA sensor on PC.

2.1.1 Data processing

This section is descript to determine 3D image to get the desired output from the images like dimensional properties (length, Area) and center of the object and targets all the operation is depending at the first to the RGB-image. The data processing is divided in two part:

a) Color data processing

Color device is the important section in classification the object and target to determine the desired point in the image, then removing noise by using special filter like median filter, then the last section on the color processing data is the important part to Measure properties of the object and target in image regions. As shown in Figure-3, b.

b) Depth data processing

After processing the color device to classification the object and target and get the region properties for each one in pixel unit, the next step of the section is to determine the actual dimension in meter or centimeter, the depth image is used to determine the actual dimensions. The depth image is collect from the IR-emitter that transmits to any point in the environment and then collects in video and previews these video to get snapshot.

Z0=depthimage(round(bc(1)), round(bc(2)));

Z0 represent the actual depth value of the center object and target in millimeter.

bc (1) center of object and target in X-axis and in pixel units

bc (2) center of object and target in Y-axis and in pixel units

2.1.2 Calibration the Kinect camera

Calibration the Kinect to Extracting Position from depth image after color processing by using the triangular method. So the pixel coordinates that calculate from the RGB image (center, bounding box, ….. etc.) need to be converted the reference point with respect the center of image because the (0, 0) point of any image in the upper-left corner image so that must be transfer these point (0, 0) to the center of the image to determine the actual X and Y of the specific point, this coordinate system is transfer in [8]:

$$y = H2 - x1 \quad (1)$$

VOL. 12, NO. 23, DECEMBER 2017 ISSN 1819-6608
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$x=W2\ \text{-}y1$ (2)

From the main properties KINECTcamera, The field of view (FOV) of RGB camera sensor is 43◦ 57◦ horizontally and vertically, the resolution 480*640. This FOV relates directly to the resolution of the KINECT camera, corresponds to 0.089◦ per pixel in both image axes.as shown below (Fabian, *et al*, 2014):

$\frac{43}{480}$= 0.089583333 in the X-axis
$\frac{57.5}{640}$=0.089583333 in Y-axis

Thus, the vertical angle θv and horizontal angle θh as shown in the Figure-4 and the two equations below as shown in Figure-3, a, b (Fabian, *et al,* 2014):

$\theta v = 0.089x$ (3)

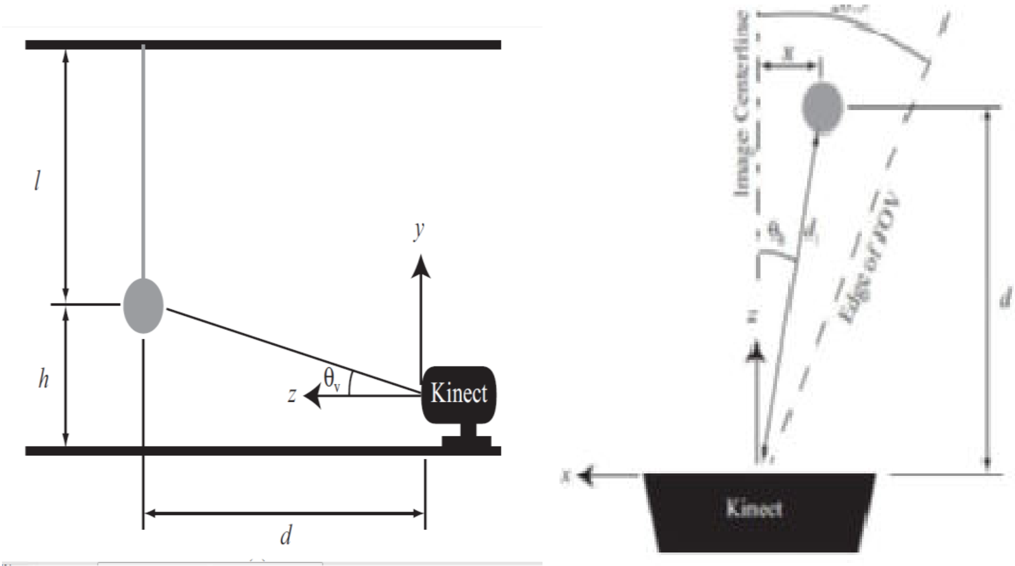
$\theta h = 0.089y$ (4)

Finally, the location in depth camera coordinates is found by using the known depth z0 form the code that descript the previous section (Fabian, *et al*, 2014):

$X = z0 \tan(\theta v)$ (5)

$Y = z0 \tan(\theta h)$ (6)

X and Y: the actual dimension of the target and the object.
$H2$, $W2$: the height of image and width of image in pixels.



(a) (b)

Figure-3. Experimental setup KINECT camera (a) side view theory and (b) top view theory.

2.1.3 Dimension of the object and target from image

In special PC software code is basic in determine the dimension called bounding box from this code can be measured the dimension of parts, the output from this code is the upper-corner (x and y) of the object and target and the number of pixel in the width and height of the object and target from these information can be determine the position of the four corner in two dimensional in the pixels units as shown in Figure-4.

Figure-4. Descript the locution corners of the parts.

Bounding box= [$xupper{-}liftcorner$, $yupper{-}liftcorner$, $xwidth$, $ywidth$]

The dimension of each corner will description below:

From the color device can be found the position of the corners but in pixel units

First corner:

Bounding box1= [$xupper{-}liftcorner.yupper{-}liftcorner$] (7)

Second corner

Bounding box2= [($xupper{-}liftcorner+xwidth,upper{-}liftcorner$] (8)

Third corner

Bounding box3= [$x_{upper-lift\ corner}.\left(y_{upper-lift\ corner}+y_{width}\right]$ (9)

Forth corner

Boundingbox4= [$(x_{upper-lift\ corner}+).(y_{upper-lift\ corner}+y_{width})$] (10)

VOL. 12, NO. 23, DECEMBER 2017 ISSN 1819-6608
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The advance steps are to determine the actual three dimensional of this point as descript below:
The first step is to determine the depth value for each corner as descript in the previous section same as Z0
Z1=depthimage (round (Bounding box1 (1)), round (Bounding box1 (2)))
Depth Second corner
Z2=depthimage (round (Bounding box2 (1)), round (Bounding box2 (2)))
Depth Third corner
Z3=depthimage (round (Bounding box3 (1)), round (Bounding box3 (2)))
Depth Forth corner
Z4=depthimage (round(Bounding box4(1)), round (Bounding box4(2)))

After determine the depth value for each coroner can be easily calculate the another two dimension by using the equations from (1) to equation (6) and as shown in Figure (3, a and b)

2.1.4 Angle of sloping of the object and target from image

To determine the angle value of the object or target, we have four points each two values from these points is nearest in value, so the large average of the first two nearest points is subtract from the second small average nearest points, and the results of the subtraction are the first important values to find the sloping angle of the object and target. This section is important to determine the orientation of the object and target. The depth of sloping is shown in Figure-5.

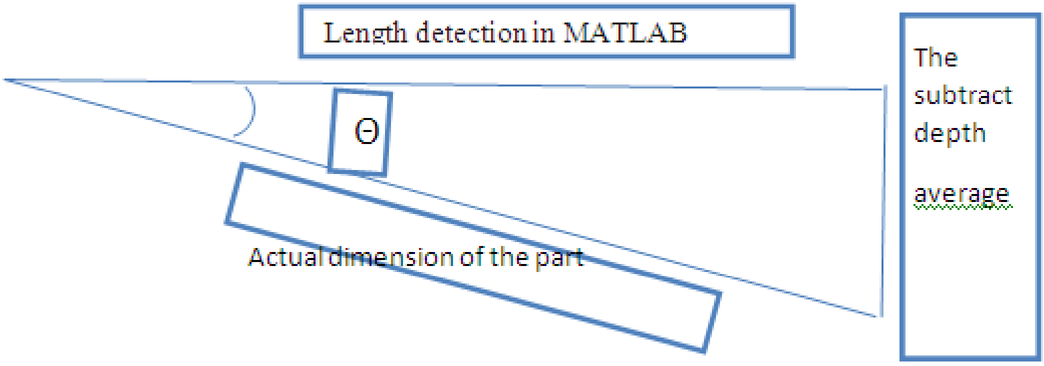

Figure-5. The sloping of the part.

2.1.5 Robotic vision system

This section is show the robotic vision system and transfer data from Kinect to articulated robot by using technique of transformation from sensor to the base of the robot coordinate using the homogeneous coordinate transformation matrices as illustration in Figure (6, a, b), the red color is the object and the green color is the target, the vision is used to inspect the information's of the object and target then send the data to robot controller to controlling the movement of the end-effector between the object and target

Transition reading between the KINECT and the robot can be described below (Rajput, 2009).

$$T_{parts}^{kinect} = \begin{bmatrix} -1 & 0 & 0 & x_{kinect} \\ 0 & -1 & 0 & y_{kinect} \\ 0 & 0 & -1 & z_{kinect} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

$$T_{base}^{kinect} = \begin{bmatrix} -1 & 0 & 0 & x_{base} \\ 0 & -1 & 0 & y_{base} \\ 0 & 0 & -1 & z_{base} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (12)$$

The position of the object and target with respect to the base of robot can be calculated from KINECT reading as shown in the equation below:

$$T_{base}^{object} = T_{parts}^{kinect} * invese[T_{base}^{kinect}] \quad (13)$$

$$T_{base}^{object} = \begin{bmatrix} -1 & 0 & 0 & x_{kinect} \\ 0 & -1 & 0 & y_{kinect} \\ 0 & 0 & -1 & z_{kinect} \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{x} \ \text{inverse} \begin{bmatrix} -1 & 0 & 0 & x_{base} \\ 0 & -1 & 0 & y_{base} \\ 0 & 0 & -1 & z_{base} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (14)$$

$$T_{base}^{object} = \begin{bmatrix} 1 & 0 & 0 & x_{base11} \\ 0 & 1 & 0 & y_{base11} \\ 0 & 0 & 1 & z_{base11} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (15)$$

After getting the position of the object and target with respect to the base of robot now ready to give order to the robotic arm to pick up the object and place in target position.
(1): when the two axes (KINECT and base robot) are opposite direction. (1): when the two axes (KINECT and base robot) are same direction. (0): when the two axes (KINECT and base robot) are perpendicular in direction.

VOL. 12, NO. 23, DECEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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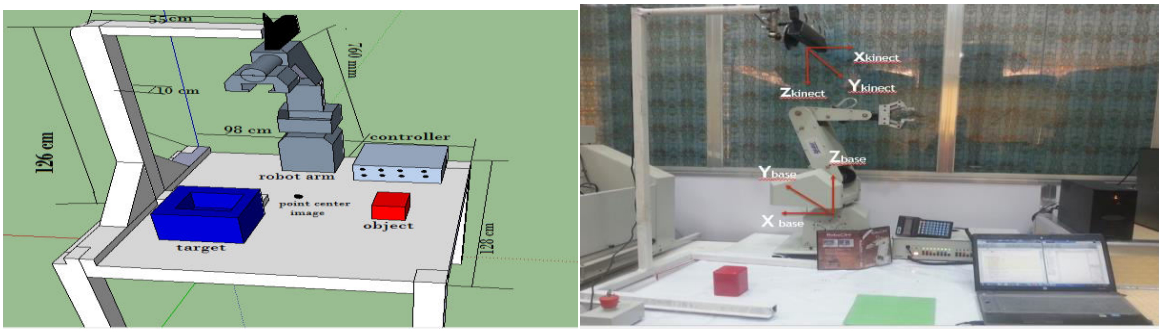

(a) (b)

Figure-6. (a) Sketch the system by Googlesketch up (b) Vision system with robotic.

2.2 Experimental work

This work tries to emulate human in two essential points: arm structure, visual sense that also emulate human in 3D sensing. Before going in to descript the experimental of the research, we can subdivide this work in to two main:

First is to determine the location of the object and target in three dimensions in different depth with respect to the KINECT and transfer it values with respect of the base of the robot arm.

Second is the high level that important propertied used in quality control in production line, to determine the corner of the object and target in three dimensions to determine the Area and volume of the object and target and the orientation of the parts.

2.2.1 Case study

Many practical experiments were implemented using the robotic system to ensure the validity of this work approach in controlling the robotic arm motion to pick up the object and place it to the target from the KIECT camera sensor.

From KINECT get two image depth and RGB Image and processing the RGB image, then to determine the actual two dimension of the x-axis and y-axis as descripted the previous section as shown in Figure-7 The case study is place the object and target in unknown place in the environment of the robot and the environment of the KINECT sensor and different in depth and orientation as shown in Figure-8 that show the steps of the movement of the articulated robotic system from initial point (Home position) to the center of the object and then move to the center of the target.

(a) (b) (c) (d)

Figure-7. Image captured from KINECT a) RGB image, b) Depth image, c) Object detection image, d) Target detection image

VOL. 12, NO. 23, DECEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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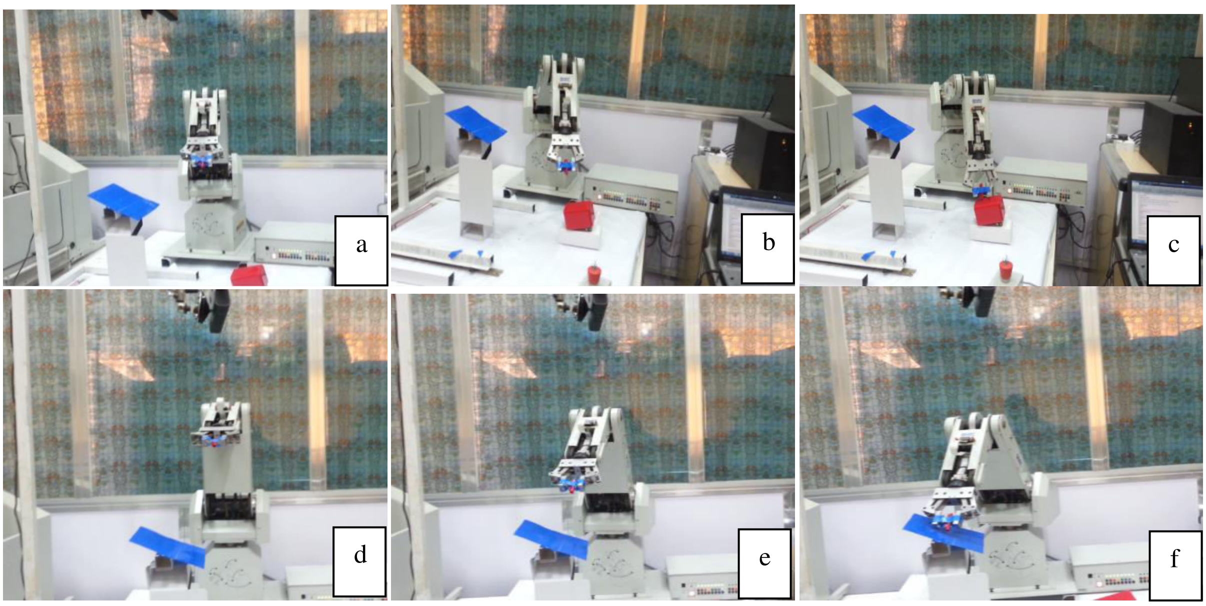


Figure-8. Experiment of cases (a, b, c) Moving the end-effector to the center of the object, (d, e, f) Moving the articulated robot from center of object to the center of the target

3. RESULTS

In this section well discuss the calibration and the experimental result of the case that show in the previous section.

3.1 Calibration of the KINECT CAMERA

3.1.1 Calibration of the depth

The depth value error in the plane is from (0 to 1 cm), at the center of the image is equal to 1044 mm and in the upper-left corner is 1050 mm with the same plane in the center and in the upper-right corner is 1053 mm and the lower-left corner is 1050 mm and the last corner (lower-right) is equal to 1050 mm, the minimum value of depth is equal to 497 mm less than value the result is zero.

3.1.2 Calibration of the X and Y plane

Improve the result of the Kinect calibration in software PC, Figure-9, a and b show the center of the object and target get from Kinect these data is fitting, after fitting the error is very good the result is linear relation between x-axis and quadratic relation between the y-axis as shown below:

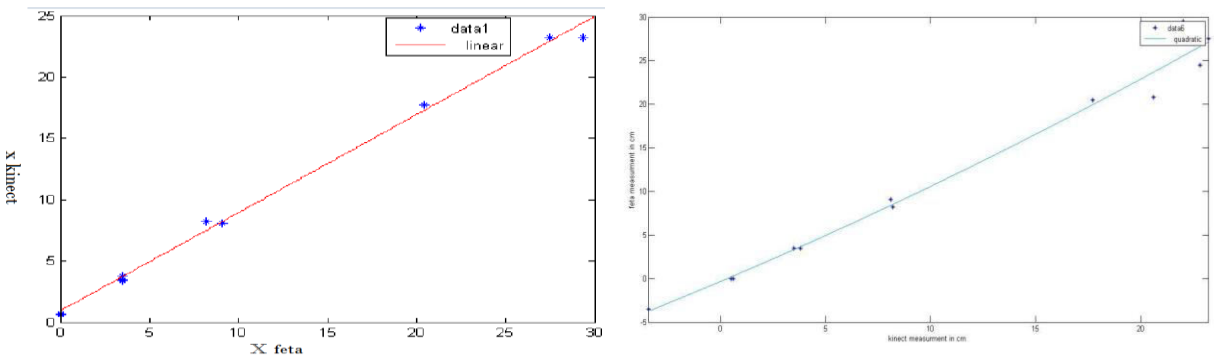
For the x-axis:

$$xfeta=1.1446*xkinect+0.34945 \quad (11)$$

For the y-axis:

$$yfeta=-4*10-5*ykinect3 +0.0082*ykinect2+ykinect-0.35 \quad (12)$$

The input for these equations is Kinect results and output is directly sent to robot.



(a) (b)

Figure-9. Improvement of the calibration of KINECT and the fitting these data a) x-axis b) y-axis.

ARPN Journal of Engineering and Applied Sciences

3.1.3 Discussion the Results of Calibration of theKINECT CAMERA:

Table-1 shows the result of determining or measuring of the actual dimension of the two place object and target.

Table-1. The dimensional of case study that show in Figure-9.

procedure	object	target
Depth	904	658
Bc	[323.9878 97.3354]	[307.0661 374.5423]
Xap	-3.8978	12.9339
Yap	142.6646	-134.5423
thetaH	-0.3492	1.1587
thetaV	12.7804	-12.0528
Xtheta	-0.0061	0.202
Ytheat	0.2268	-0.2135
Xactualkinect	-5.5094	13.3082
Yactualkinect	-205.0581	-140.4955
X baserobot	480.132062	498.94
Ybase robot	248.67862	103.99
Zbaserobot	32.84616	278.846
Bounding box	[303.5, 65.5, 41, 65]	[237.5, 293.5, 152, 165]
Area	2075	19709

The corners of the object are as shown in Table (2).

Table-2. The result to calculate the corner of the object in case study. a) the three dimensional of each corner, b)the information to calculate the 3D.

(a)

Corner name	Depth(z-axis)	x-axis	Y-axis
Upper-left	899	22.464	250.7
Upper-right	895	-36.40	249.6
Lower-left	916	22.91	157.6
Lower-right	914	-37.17	157.2

(b)

variable	Upper-left	Upper-right	Lower -left	Lower -right
Xap	16	-26	16	-26
Yap	174	174	109	109
thetaH	1.433	-2.32	1.43	-2.21
thetaV	15.58	15.58	9.76	9.764
Xtheta	0.025	-0.04	0.025	-0.040
Ytheat	0.027	0.27	0.172	0.17

The corners of the target are as shown in Table (3).

Table-3. The result to calculate the corner of the target in case study. a) The information to calculate the 3D, b) the three dimensional of each corner.

(a)

variable	Upper-left	Upper-right	Lower-left	Lower -right
Xap	80	-72	80	-72
Yap	-54	-54	-218	-218
thetaH	7.1	-6.45	7.16	-6.4
thetaV	-4.8	-4.83	-19.2	-19.5
Xtheta	0.12	-0.11	0.1257	-0.11
Ytheat	-0.08	-0.08	-0.35	-0.35

(b)

Corner name	Depth(z-axis)	x-axis	Y-axis
Upper-left	702	88.26	-59.4
Upper-right	685	-77.4	-57.9
Lower-left	622	78.20	-220
Lower-right	613	-69.3	-217

3.1.4 Calculate the actual dimension of the object and target

3.2.1 Object

From the second and the third column in Table-5.11 a, the value of the two axes can be easily calculated as shown here:

Width =22.464-(-36.4033) =59.04933 mm
Height = 250.7939-157.6376 =92.3624 mm

3.2.2 The target

From Table-5.12 a for the second and the third column can be easily calculate the value of the two axis as well shown below the results:

Width =88.2683-(-77.4404) =165.7087 mm
Height =-59.4113-(-220.6183) =161.207 mm

3.3 Calculate the angle of sloping of the object and target

Figure-6 shows how to calculate the sloping angle.

3.3.1 For object

From the depth [899, 895, 916, 914]

Average small $=\frac{899+895}{2}=897$ mm

Average large $=\frac{916+914}{2}=915$mm

The subtract of the average=large average-small average =915-897=16 mm

And the dimension of the object equal to (59.04, 92.36) then:

The sloping angle of the object

Because the deference between the nearest large and small are large value so we assume the object is sloping in one axis (y-axis):

$\tan(\theta)=\frac{16}{92.3624}=0.173230665$

θ=9.82785° the angle of sloping the object in y-axis

The actual dimension of target in y-axis (Actual dimension of the part):

Y=Height*cos(θ)
(13)
Y=92.3624*cos(9.857853) =91.00698535 mm

3.3.2 For target

From the depth [702, 685,622, 613]

Average small $=\frac{702+685}{2}=693.5$ mm

Average large $=\frac{622+613}{2}=617.5$ mm

The subtract of the average=large average-small average =693.5-617.5 =76 mm

And the dimension of the object equal to (165.70, 161.20) then

The sloping angle of the target:
The sloping in one axis (y-axis):

$\tan(\theta)=\frac{76}{161.207}=0.4714$

θ=25.241231° the angle of sloping the object in y-axis

The actual dimension of target in y-axis (Actual dimension of the part):

Y =Height*cos(θ)
Y =161.207*cos(25.24) =145.81 mm

4. CONCLUSIONS

From building 3D visionary sensor system for controlling the articulated robot system these conclusions point have been conducted:

a) 3D calibrated images have been obtained by using two images (RGB and depth), and the results of this calibration are shows good results with minimizing errors.
b) From 3D images many information have conducted about the object and target such as Area, line and centroid.
c) Orientations and location of the object and target have been obtained thought digital 3D images reading.
d) Transformation matrices between the visionary system and the articulated robot system have been obtained to transfer the data of the visionary system to the robot system.
e) Controlling the movement of the robot by using 3D image analyzed by computer software linked with controller of articulated robot has been obtained with acceptable errors.
f) Addition of visionary system (Kinect) have been developed performance robotic system and gave a better control for system with competitive price (200$) (Kinect and frame).

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