

Controlling Articulated Robot System using 3D Kinect 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). The 3D visionary sensor is employed to detect a target object, dimensional properties as length and determine its location in 3D environment; 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: Industrial robot, 3D Kinect, visionary system, Object location, Object orientation.

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 [1]. 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 objective was to controlling and to realize a robot cell-assisted by 3D vision: Extraction visual information from the 3D image to control by the movement of robot from object to target as described in the next section, we used a PC and special software as an external system for acquisition data and processing of these data from the 3D Kinect camera [2].

The Kinect 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 and IR camera have a resolution of 640x480 pixels (VGA) and can deliver an image stream of 30 frames per second [3]. Figure (2, a) shows the Kinect and the location of the different parts. For the depth sensor, the IR-emitter is to the left, while the IR-sensor is on the right. "The Kinect uses a class a laser to emit the IR light, and

there is therefore no risk of eye injury using the Kinect." The "brain" in the Kinect comes from PrimeSense's PS1080 System on Chip as shown in Figure (2, b) [4]. 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 [5].

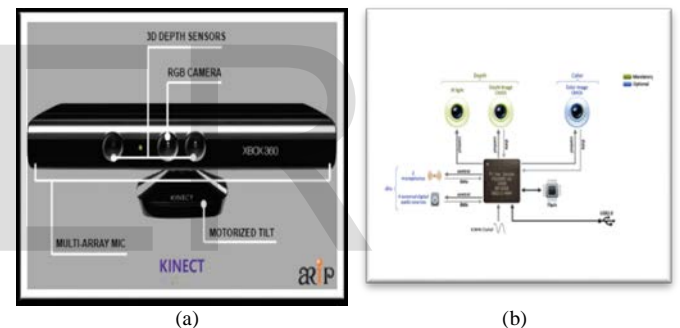


Figure (2) system architecture of the KINECT sensor a) the devices of the KINECT b) the internal components of the KINECT [6]

2 Theoretical parts

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 (1) 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 [7]. 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.

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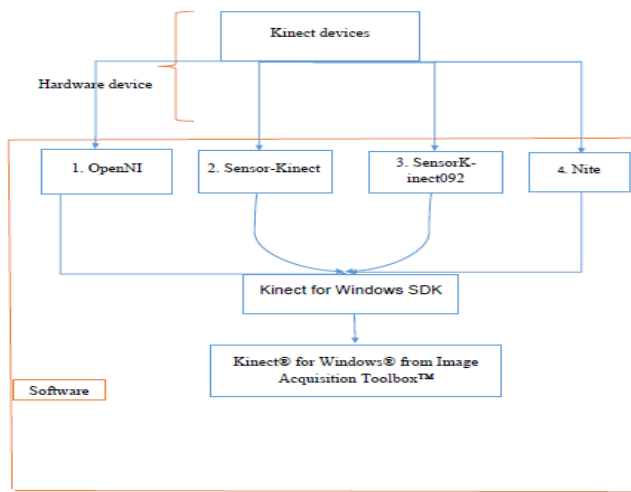


Figure (1) Algorithm of installing KINECT CAMERA sensor on PC

3 Data Processing

This section is described 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:

3.1 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 (5, b)

3.2 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 transmit to any point in the environment and then collect in video and preview these video to get snapshot.

$$Z0 = \text{depthimage}(\text{round}(\text{bc}(1)), \text{round}(\text{bc}(2)));$$

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

4 Calibrations of 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 must be transfer these point (0,0) point in the center of the image to determine the actual X and Y of the specific point, this coordinate system is transfer in [8]:

$$y = H2 - x1 \tag{1}$$

$$x = W2 - y1 \tag{2}$$

From the main properties KINECT, The field of view (FOV) of the Kinect RGB camera is 43° vertically and 57° horizontally, 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 [8]:

$$\frac{43}{480} = 0.089583333 \text{ in the X-axis}$$

$$\frac{57.5}{640} = 0.089583333 \text{ in Y-axis}$$

Thus, the vertical angle θ_v and horizontal angle θ_h as shown in the Figure (4) and the two equation below as shown in Figure (4, a, b) [8]:

$$\theta_v = 0.089x \tag{3}$$

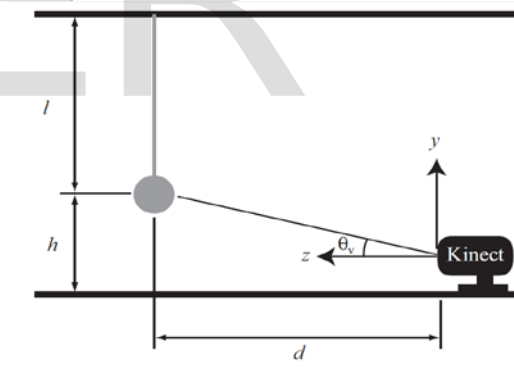
$$\theta_h = 0.089y \tag{4}$$

Finally, the location in Kinect coordinates is found using the known depth z_0 form the code that describes the previous section [8]:

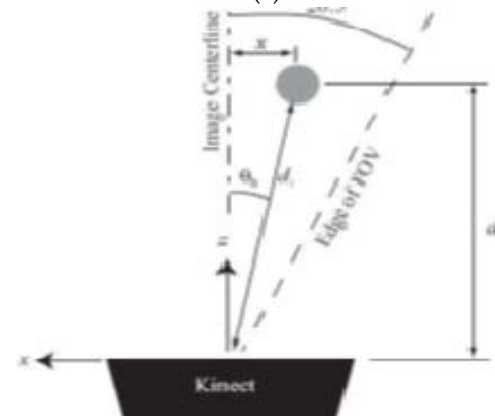
$$X = z_0 \tan(\theta_v) \tag{5}$$

$$Y = z_0 \tan(\theta_h) \tag{6}$$

X and Y is the actual dimension of the target and the object. H2, W2 are the height and width of the image in pixels respectively.



(a)



(b)

Figure (4) Experimental setup KINECT camera (a) side view and (b) top view

5 Dimension of the object and target

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:



Figure (5) describe the locution corners of the parts

Bounding box= [xupper-lift corner, yupper-lift corner, 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:

$$\text{Bounding box1} = [x_{upper-lift\ corner}, y_{upper-lift\ corner}] \quad (7)$$

Second corner

$$\text{Bounding box2} = [(x_{upper-lift\ corner} + x_{width}, y_{upper-lift\ corner})] \quad (8)$$

Third corner

$$\text{Bounding box3} = [x_{upper-lift\ corner}, (y_{upper-lift\ corner} + y_{width})] \quad (9)$$

Forth corner

$$\text{Bounding box4} = [(x_{upper-lift\ corner} + x_{width}, (y_{upper-lift\ corner} + y_{width}))] \quad (10)$$

The advance steps are to determine the actual three dimensional of these point as describe below:

The first step is to determine the depth value for each corner as describe in the previous section same as Z0

$$Z1 = \text{depthimage}(\text{round}(\text{Bounding box1}(1)), \text{round}(\text{Bounding box1}(2)))$$

Depth Second corner

$$Z2 = \text{depthimage}(\text{round}(\text{Bounding box2}(1)), \text{round}(\text{Bounding box2}(2)))$$

Depth Third corner

$$Z3 = \text{depthimage}(\text{round}(\text{Bounding box3}(1)), \text{round}(\text{Bounding box3}(2)))$$

Depth Forth corner

$$Z4 = \text{depthimage}(\text{round}(\text{Bounding box4}(1)), \text{round}(\text{Bounding box4}(2)))$$

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 (4, a and b)

6 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 (5, 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 [9]

Transition reading between the KINECT and the robot can be described below [9]

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

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

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:

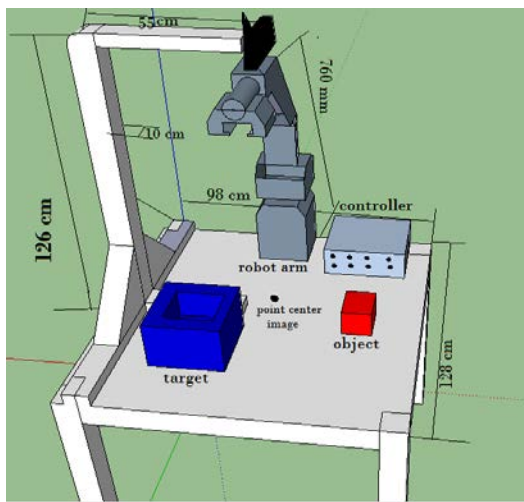
$$T_{base}^{object} = T_{parts}^{kinect} * \text{inverse}[T_{base}^{kinect}] \quad (13)$$

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

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

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.



(a)



(b)

Figure (5) a) sketch the system googlesketchup b) the vision system with robotic

7 Experimental works

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 describe 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.

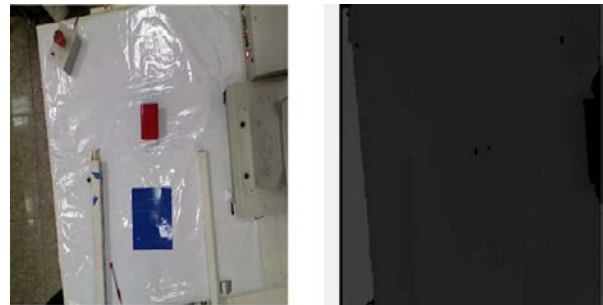
Second is the high level that important propertied used in QUALITY CONTROL in production line, to determine the corner of the object and target in three dimensions to determine the Area and volume of the object and target.

Study Cases:

We have study two cases the first case is in plane and the second advance case is in every place in the environment as shown below:

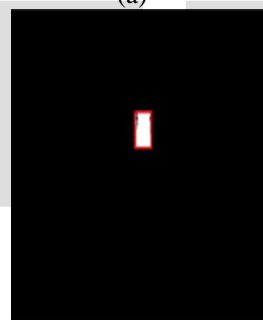
Case 1: The plane surface of the environments:

From Kinect get two image depths and RGB Image and processing the RGB image, then to determine the actual two dimensions of the x-axis and y-axis as described in the previous section

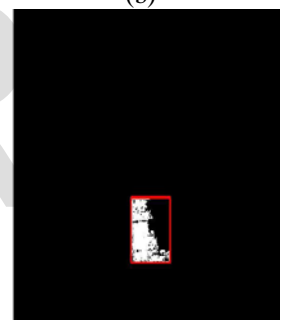


(a)

(b)

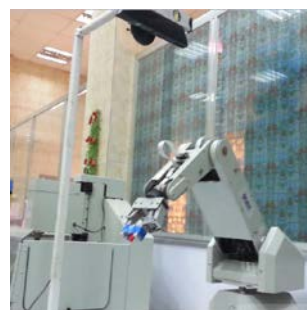


(c)



(d)

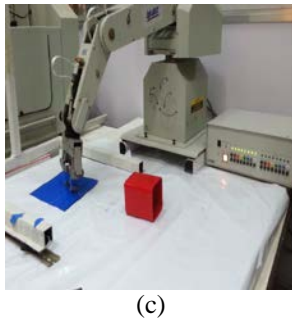
Figure (5) KINECT capture a) RGB-image, depth image, c) object detection image, target detection image.



(a)



(b)



(c)

Figure (6) a) move robot from initial position, b) end-effector reach to the object center, c) end-effector move from center object to target.

Case 2 deferent depth value

The second of the experimental work is the important main case in the research by place the object and target in deferent depth from the KINECT camera sensor and deferent the size of the object that taken in case1 so that the change in size of part to find the actual dimension it is advance method.



Figure (6) a) move robot from initial position, b) end-effector reach to the object center, c) end-effector move from center object to target.

8 Result and discussion

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

Calibration of the KINECT CAMERA

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.

Calibration of the X and Y plane:

Improve the result of the Kinect calibration in software PC, figure (7, 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:

$$xfeta = 1.1446 * xkinect + 0.34945 \tag{11}$$

For the y-axis:

$$yfeta = -4 * 10^{-5} * ykinect^3 + 0.0082 * ykinect^2 + ykinect - 0.35 \tag{12}$$

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

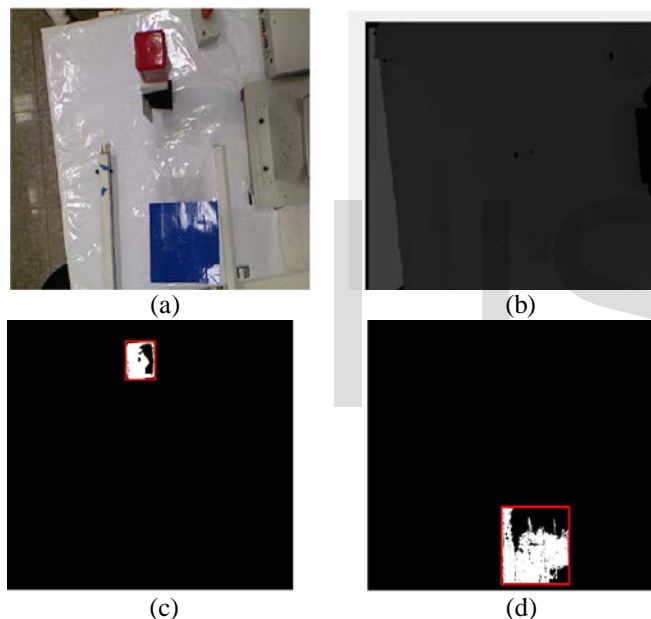
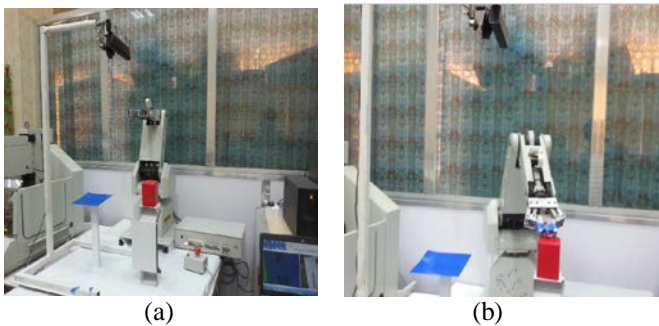


Figure (6) KINECT capture a) RGB-image, depth image, c) object detection image, target detection image.



(a)

(b)

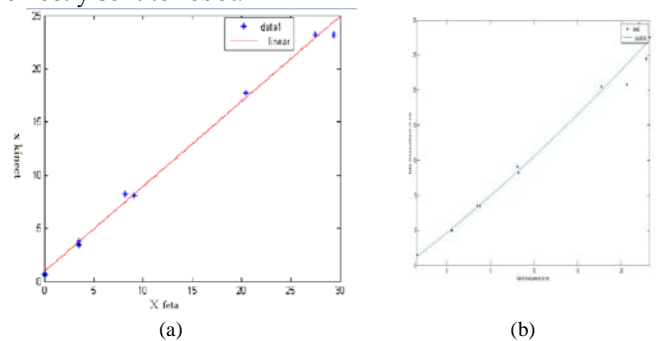


Figure (7) improvement of the calibration of KINECT and the fitting these data a) x-axis b) y-axis

Case1:

Determine the center of the object and target

The object and target in same plane, in table (1) show the procedure of measurement of the actual dimension of the two places object and target:

Table (1) result of case1 a) the Sequence of calibration of Kinect, b) the corner of the object, c) the corner of the target

(a)

procedure	object	target
Depth (mm)	976	1053
Bc (center in pixel)	[323.685,187.2717]	[313.1108,348.7828]
Xap (pixel)	-3.6850	6.958
Yap (pixel)	52.7283	-108.354
thetaH (degree per pixel)	-0.3301	0.6233
thetaV (degree per pixel)	4.7236	-9.7065
Xtheta (degree)	-0.0056	0.0109
Ytheat (degree)	0.0828	-0.1710
Xactualkinect (mm)	-5.4463	11.4561
Yactualkinect (mm)	80.8426	-180.1147
X baserobot (mm)	480.483762	497.097162
Ybase robot (mm)	122.46312	-143.6147
Zbaserobot (mm)	39.15384	-116.15384
Bounding box (pixel)	[303.5,159.5,40,55]	[283.5,292.5,93,100]
Area (pixel)	1868	4623

(b)

Corner name	(z-axis)	x-axis	Y-axis
Upper-left	976	34.424	124.2711
Upper-right	973	-35.0052	123.8891
Lower-left	976	24.4211	38.1694
Lower-right	973	-35.0052	38.0527

(c)

Corner name	Depth(z-axis)	x-axis	Y-axis
Upper-left	1050	59.1637	-87.2098
Upper-right	1050	-93.8255	-87.2098
Lower-left	1048	59.051	-225.5960
Lower-right	1050	-93.8	-256.1

Calculation of the actual dimension of the object and target:

a-The object:

From table (1, b) for the second and the third column can be easily calculate the value of the two axis as well shown below the results:

Width=24.4211-(-35.0052)=59.4263 mm in x-axis
Height=124.2711-38.1694 =86.1017 mm in y-axis

b-The target:

From table (1, c) for the second and the third column can be easily calculate the value of the two axis as well shown below the results:

Width=59.1637-(-93.8255)=152.9892 mm in x-axis
Height= -87.2098-(-256.1)=138.8902 mm in y-axis

Case 2

Determine the center of object and target

In table (2) show the procedure to measure the actual dimensions for the object and target:

Table (2) result of case2 a) the Sequence of calibration of Kinect, b) the corner of the object, c) the corner of the target

(a)

procedure	object	target
Depth (mm)	586	904
Bc (center in pixel)	[291.3409 72.6245]	[365.544 416.4868]
Xap (pixel)	28.6591	-45.5444
Yap (pixel)	167.3755	-167.4868
thetaH (degree per pixel)	2.5674	-4.0800
thetaV (degree per pixel)	14.9941	-15.8103
Xtheta (degree)	0.0448	-0.0713
Ytheat (degree)	0.2678	-0.2832
Xactualkinect (mm)	26.2758	-50.5019
Yactualkinect (mm)	156.9531	-200.4809
X baserobot (mm)	511.36962	435139262
Ybase robot (mm)	200.57362	163.9809
Zbaserobot (mm)	350.84616	228.84616
Bounding box (pixel)	[265.5, 38.5, 63, 67]	[297.5, 332.5, 150, 137]
Area (pixel)	2772	11923

Corner name	Depth(z-axis)	x-axis	Y-axis
Upper-left	590	51.7913	192.7942
Upper-right	584	-6.3919	190.8336
Lower-left	588	51.6157	126.9511
Lower-right	584	-6.3919	126.0875

(b)

Corner name	Depth(z-axis)	x-axis	Y-axis
Upper-left	711	24.4663	-104.1198
Upper-right	699	-141.7879	-102.3625
Lower-left	715	24.6039	-268.8102
Lower-right	696	-141.1812	-261.6670

(c)

Calculations of the actual dimensions for object and target:

a- Object

From table (2, b) for the second and the third column can be easily calculate the value of the two axes as well shown below the results:

Width=51.7913-(-6.3919)=58.13832 mm
Height= 192.7942-126.9511 =65.8131 mm

b- The target

From table (2, c) for the second and the third column can be easily calculating the value of the two axes as well shown below the results:

Width = 24.4663- (-141.7879) =166.2542 mm in x-axis
Height = -104.1198-(-261.6670) =157.5672 mm in y-axis

The error in dimensional of the two cases between the output from the Kinect and measured from the second device called feta as shown in table (3)

Table (3) The error of the dimensional measurements.

Case study	Error object	Error target
Case 1	1.55737	4.10189
	1.38983	4.0098
Case 2	1.686168	2.79507
	0.91869	2.14328

9 CONCLUSIONS

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

- 3D calibrated images have been obtained by using two images (RGB and depth), and the results of this calibration are shows good results with minizing errors.
- From 3D images many information have conducted about the object and target such as Area, line and centroid.
- Orientations and location of the object and target have been obtained thought digital 3D images reading.
- 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.
- 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.
- 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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