Path Planning Optimization and Object Placement Through Visual Servoing Technique for Robotics Application

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Abstract: *Visual servoing define a new methodology for vision based control in robotics. Vision based action involve number of actions that move a robot in response of results of camera analysis. This process is important to operate and help robot to achieve a specific goal. The main purpose of visual servoing consists of considering a vision system by specific sensor dedicated to involve control servo loop and task. In this article, three visual control scheme: Image Based Visual Servoing (IBVS), Position Based Visual Servoing (PBVS) and Hybrid Based Visual Servoing (HBVS) are illustrated. The different terminologies are represented through effective workflow of robot vision. IBVS method concentrate on the image features that are immediately available in the image. This experiment is performed by estimating distance between camera and object. PBVS consist of moving object 3-D parameters to estimate measurement. This paper showcases PBVS using kuka robot model. HBVS uses the 2D and 3D servoing by combining visual sensors also it overcomes challenges of previous two methods. This paper represents HBVS method using IPR communication robot model*

Keywords: *Visual servoing, features, coordinates, kinematics, disparity, optimization, motion estimation*

1. Introduction

In recent years, the advances on robotics research have been very effective. Many original problems have been either completely or at least partially solved. Visual servoing refer to use computer vision data to handle control motion of robots [1][2]. Vision data can be to collect from a camera that is mounted on robot manipulator. Another camera can be fixed in the work area so that observe the robot motion. The goal of robot is to react and reach targeted position using the visual data.

The pilot vision of the robot is defined as a "Visual servoing" [3]. The visual servoing is categorized into three different parts. (i) key element-based error function, (ii) the number of camera and their position (eye-in-hand vs. eye-to hand configuration) and (iii) servoing structure though kinematic calculation. Servoing structure is based on classical Image-Based Visual Servoing (IBVS) and Position Based Visual Servoing (PBVS) [2]. IBVS and PBVS are 2D and 3D approach respectively. IBVS is based on the specific set of images that focuses on the main image and it's features. IBVS does not need any pose assessment or any other 3D approaches. It uses the features of the capture object. PBVS is a 3D approach that analyses the position of the robot according to the target object. PBVS uses the digital camera as a key-point to retrieve visual features [4]. It requires robust calibrations and 3D model to reach target position. In the hybrid system, it uses one single camera in hand and configuration of another stationary camera to observe the present object [5]. Hybrid model focuses on positional vision approach to minimize inappropriate result. This paper gives an overview of both IBVS and PBVS approach.

2. Related Work

Till now many visual servoing based algorithm and techniques are implemented. Some of the algorithms and techniques are discussed below:

Gans et al. introduced technique to switch over between IBVS and PBVS [6]. In the case of lower visibility IBVS techniques is applied. However, in complex situation the proposed hybrid switching system again redirects to PBVS. This suggested technique stops the system failure and provide asymptotic stability in IBVS and PBVS.

G. Flandin et al. proposed an idea using eye-to-hand camera. They have used kalman filter [6] to perform positioning at goal area with efficiency. They applied tracking techniques in local image to make sure position in global image.

Denavit et. al suggested a technique that require four parameters to estimate join of two robots. They use kinematics estimation to make a rotation and other transformation of robot joins. The estimation of kinematics can be classified into two categories: (i) forward kinematics and (ii) inverse kinematics.

Fedrizzi et al. introduce ARPlace (Action-related place). The goal is to point on specific position using AR Place. Further, they use probability of position to calculate next position of target object. The probability of visualization representation based on low to high color intensity [7].

Corke et al. presented closed loop positon control system that gives high performance in providing robot positioning commands at high rates. In this system image processing subsection comprised completely of off-the-shelf components. It enables system to identify the target object either or not relative motion between object and camera [8].

3. Control Based Vision

Visual servoing is classified into two different types. Such as (i) camera configuration and (ii) structure servoing. Robot arm motion has several challenges like the camera lens configuration, position estimation, feature extraction, image and video controlling. This issue needs visual servoing to solve the problem.

Basic camera configurations. A camera is used to perform operation by projecting 3D points to the plane of the image. Image cell is more sensitive for the measurement. A camera measures level of intensity, the light etc.

It uses coordinate C = (M, N, O,1) with respect to A = (X, Y,1).

$$A \propto \{ P\ 0 \} C \tag{1}$$

where $P = \begin{bmatrix} fAC & fAc\cot\cot(\varnothing) & C0 \\ 0 & \dfrac{fAd}{\sin\sin(\varnothing)} & D0 \\ 0 & 0 & 1 \end{bmatrix}$

where Co and Do are pixel coordinate for the point Ac and Ad, respectively *f* is the main length and also Ac = Ad.

Visual area is categorized in two types such as "Eye-to-hand" and "Eye-in-hand". In Eye-to-hand eye is mounted on the robot arm and not allowed to pose any kind of motion. This categories whole workspace cannot be visualized. Hence, this category limits the number of objectives to be achieved. This vision is called an Eye-in-hand [8]. In Eye-to-hand category, the arm can also be visualized the mounted camera in such a way that it can control workspace coordinates with arm movement. Eye-to-hand works on the top of the object and other desired location [9].

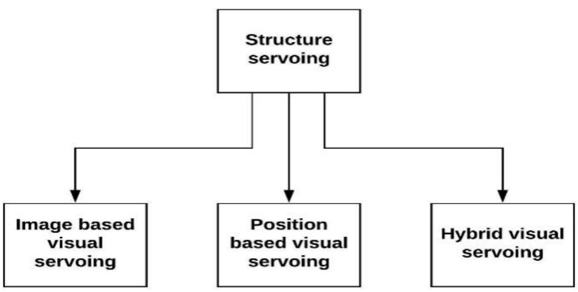

Fig. 1. Structure of visual servoing

3.1. Image Based Visual Servoing / 2D Servoing

IBVS focuses on coordinates of the object and control the robot vision. The captured image features compare with the desired image position to control and specify robot grasp movement [10]. In Control servoing time picture is captured by using camera that focuses on desired features and eliminates error by comparing both images. Such process is useful to decide workspace for robot.

The primary goal of IBVS is to target desire object and eliminate movement according to specified input and references of image [11].

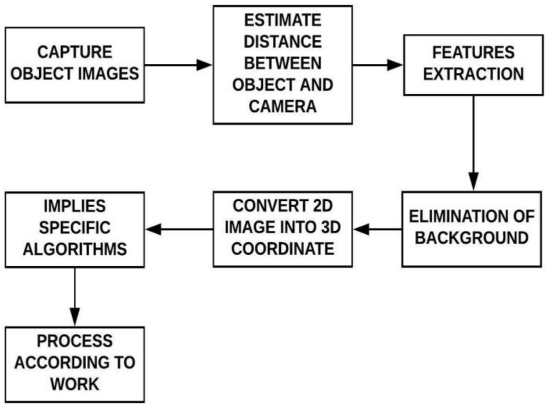

Fig. 2. Image-based visual servoing

The approximation of accuracy, stability and per-formability depend on the camera and target point. The estimation of accuracy and stability is challenging but using the visual features [12], polar, spherical coordinate [13], special movement features and cylindrical it can be estimated.

The Fig. 4 represents the extrinsic parameters [14] for visualization and two camera use for the servoing. These two cameras results are relatively compared.

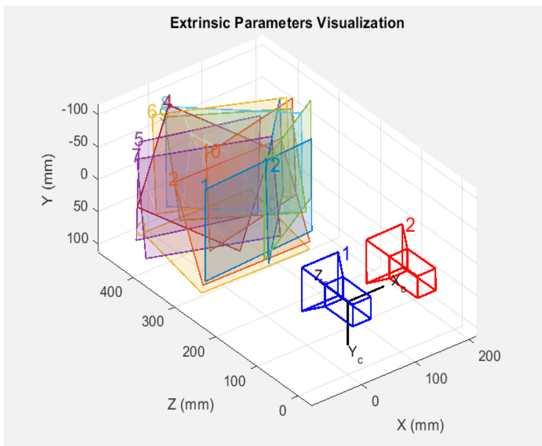

Fig. 3. Extrinsic parameters visualization

From Fig. 4 number (1) and (2) represent the camera uses to estimate extrinsic parameter of the vision respectively.

All scenarios are based on the each and every frame of the camera video file also it computes based on the stereo camera calibration and triangulation method [15] to estimate the focus point.

Reading and rectifying the video frames. The video file reader is used to read camera video frame and display the video file. Rectifying field compute the disparity [16] based on the matching with left camera vision to right camera vision and generate the 3-D plane [17].

Disparity Estimation. The disparity of rectified image corresponding point locates to the same pixel of the row. Corresponding distance is measured pixel of left with pixels of right. This distance called disparity [16] which proportional to the distance between camera points.

3-D Reconstruction. 3D coordinate points are used from the disparity map which generated by left and right camera red-cyan glasses. It converts directly to the meters and generate the cloud streaming point. The cloud point visualizes vertical axis and is directed by the streaming point [18].

Detect the people and Distance measurement. It detects the people with the use of system object focus point. The detected people's distance measure using the centroid point taken from the 3D coordinate. It calculated results using the two camera and detected people.

$$D = sqrt(sum(centroid\ of\ 3D * ^\wedge 2) \quad (2)$$

where D respect to distance between the camera and generated centroid point.

Write video and analyses the rest of the video file. Until so far used 3-D coordinate process, detect the people and generate meters for measurement in specific frame of the video data. For every frame it processes same as previous, read, rectifies and converts into grayscale, computation of the disparity, generation of the 3-D cloud point. Hence, those process to detect the people by using centroid of people. This Centroid point helps to find the distance in the meter.

3.2. Position Based Visual Servoing

PBVS method focuses on the 3D information of the object. In this method, object coordinates captured are in 2D there by it converts into 3D graph and tracks the object [19] [20].

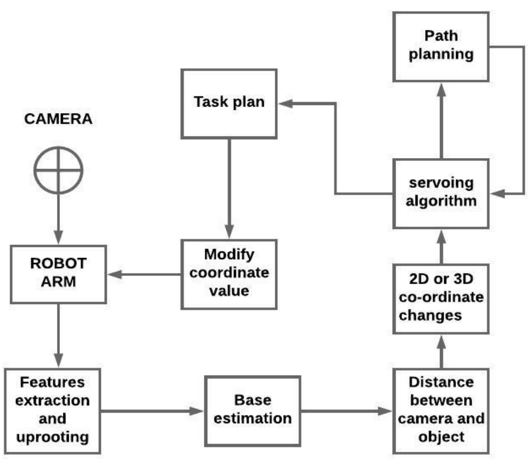

Fig. 4. Position based visual servoing

The diagram process shows the process of robot movement to grasp the object.

In PBVS number of algorithms and kinematics inverse operations are used for path planning. kinematic operations [21] focuses on the forward and inverse operation [22]. Robot movement handles various path and focuses on the current and desire position.

Features extraction. Features are the key-point for servoing. It extracts and matches the current features [23]. The qualities of feature are not always dependent on the type of features, extracted results and image techniques but it also the vision of the robot system. Features are easy to identify and can be measured with higher accuracy.

The distance between camera and object. The main objective of this process is to estimate motion and trajectory based tracking to approximate the object. This process is performed by path finding and route optimization algorithm [24].

2D or 3D coordinates changes. Object detection and position approximation while sometime captures unclear position is captured. This results are challenge for generation of 3D coordinate to solve the mention problem. The position is estimated by separately converting 2D image into 3D.

Servoing algorithm and path planning. Robot path selection is performed using the number of different algorithm such as ant colony optimization [25] [26], cyclic coordinate descent [27] [28], particle swarm optimization [29] [30]. Algorithm results generate number of possible solution is selected among them the shortest path without obstacle.

Task plan. Task plan process is executed after algorithm results and those result is directly applied to make robot to reach at the target position. However, at servoing time there can be circumstances that obstacle may be present in the route of the workspace. In that scenario, it again analyzes the obstacle avoidance algorithm [31] and again generates best path to reach the target.

Model-based visual servoing. This approach uses to project the coordinate from initial position to targeted workspace. Model based visual servoing is computed based on the knowledge of the 3D coordinate.

The control strategies are used for driving the robot using single camera. It uses the Visual Servoing Platform libraries (ViSP)

Overall, in PBVS the sensitivity and calibration of the camera is required to reduce the error during the control.

3.3. Hybrid Based Visual Servoing

The two previous method IBVS and PBVS plays important role in HBVS to handle the position of the robot. HBVS method of servoing is mainly used the 2 ½ D servoing [32] and movement Partition based [33].

HBVS suitably combines unique benefits of both IBVS and PBVS. The tracking system combines inputs from the camera and sensors to estimate the moving target position. Color segmentation to finds the target image region with the associated moving target object.

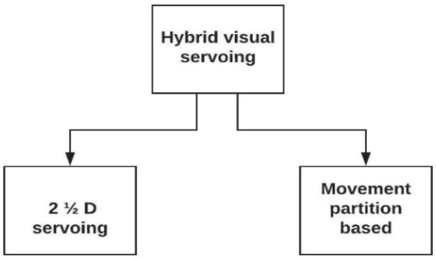

Fig. 5. Hybrid visual servoing

HBVS overcomes disadvantage of IBVS and PBVS. It does not require the fully completed 3D model for the object analysis [34]. HBVS method reduces the rotation for all robot DOFS. This pure rotation is based on the optical axis and combines or switching in between the IBVS and PBVS when it necessary.

The stereo image vision taken by the gripper model which compare with the original images. It generates 3D coordinates point and measure distance by stereo image [35]. The number of filters are applied to matches the result for minimizing the drawback and error. Due to that reason it used combination of two camera result (eye-in-hand and eye-to-hand) [36] [37].

On the other method, re-projection method may minimize error though using the numerical solution of camera projection. It uses the number of projection point instead of stereo images. The number of camera to generate frame for different measurement method and select path related to object [35].

4. Qualitative Analysis Through Real-Time Application

The experiment is conducted for three different methods such IBVS, PBVS and HBVS for the qualitative assessment. These three experiment are implemented using different robot models.

4.1. Image Based Visual Servoing / 2D Servoing

In IBVS the algorithm and other flow of the result analysis is measured by calculating the distance between camera and object.

As show cases in fig. 6 the image taken from the video frame is captured by the camera. The specific frame is rectified by red – cyan glass. The rectified image combines the anaglyph graph. It interprets the 3D effect and rectified image based on horizontal epipolar line. From fig. 7 lts aligned into row direction. Finally, the disparity of rectified stereo images are calculated.

The method generates 3D cloud point according to the disparity of rectified frames. According to the 3D cloud point it takes centroid and detect the people and measure the distance as shown in fig. 9.

Fig. 6. The image taken from the camera and rectified by red-cyan glass

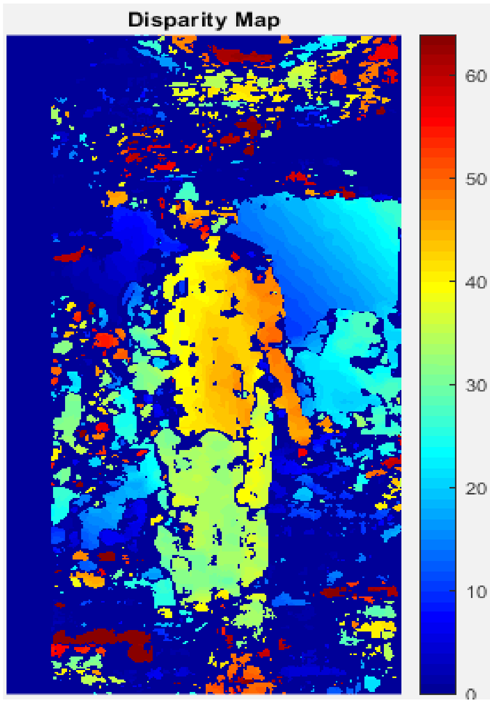

Fig. 7. Generated disparity map according to rectified frame

4.2. Position Based Visual Servoing

PBVS estimate the calibration, pose parameters and the matrix computation to make an accurate and stable to result. PBVS analyses result quite positive in comparison with IBVS. PBVS extract information from the vision sensor and handle robot motion.

The example of PBVS is represented that is implemented on webot robot simulator with kuka model [38] and matlab. Webot simulator and kuka model helps to move object from initial location to target

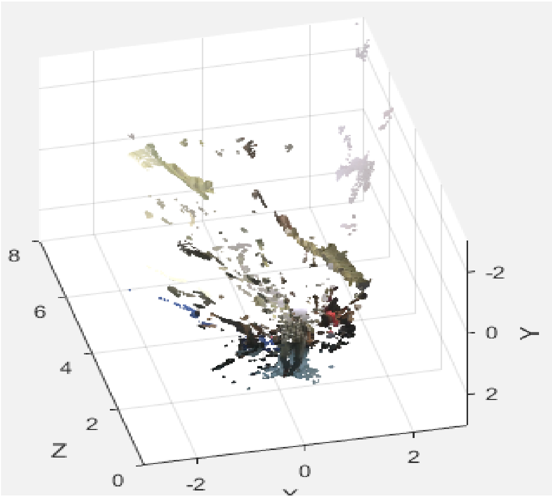

Fig. 8. 3-D coordinate point and cloud point

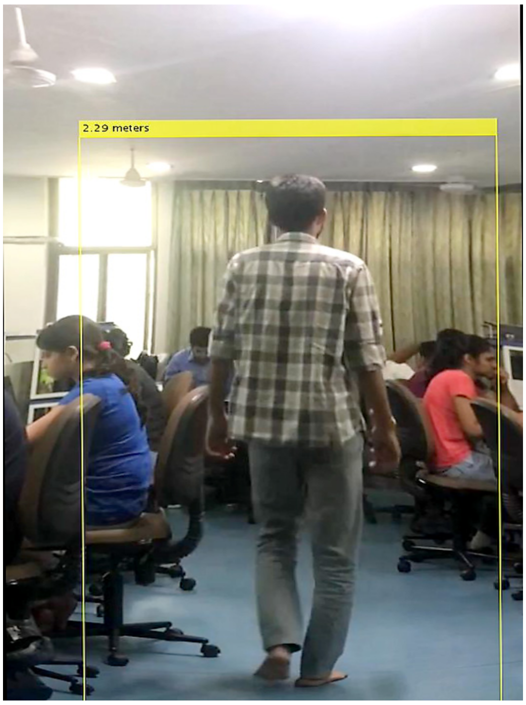

Fig. 9. Detected person and distance from the camera using meter as a unit

location with the help to robot DOFS and grippers. Gripper helps to grab the object by detecting the position and object place of another workspace area [38] [39].

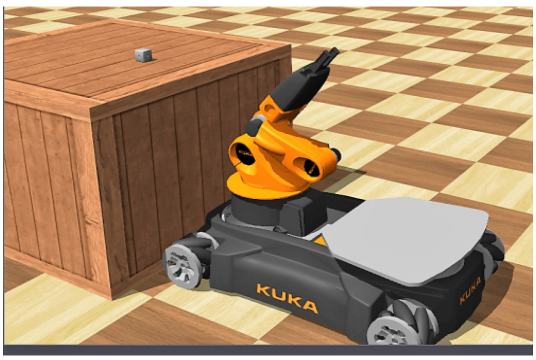

Fig. 10. Detecting the object

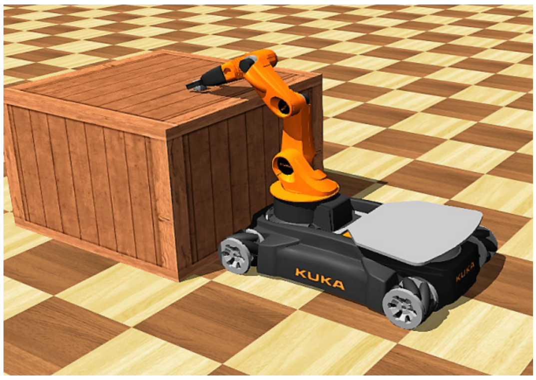

Fig. 11. Catching through gripper

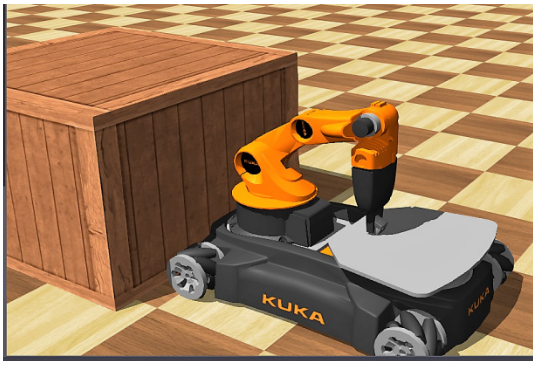

Fig. 12. An object placed on the plate

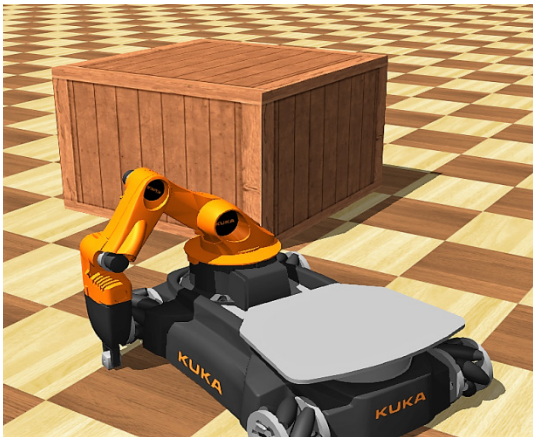

Fig. 13. The object moved to another location from the box

In Fig. 10 at the initial stage the robot identifies the pose of object. The mounted camera in gripper detects the cube and holds object placed on the box. As seen in fig. 11 the held object is placed to the plate of the robot and object is moved to another location from the box. According to the fig. 13 reaching at target location robot DOFS again picks and places object from the plate to destination.

4.3. Hybrid Based Visual Servoing

In HBVS method robot model exchanges the object by IPR robot and it carry the object from one bucket and places into other bucket. For exchanging robot communication uses the color code communication using 3D model and the kinematic operations. In Kinematic operations the inverse operation, forward operation and Jacobean matrix operation [40][41].

Although all the communication of HBVS are used through either Eye-in hand or Eye-to hand process.

Two IPR robot model are placed for exchanging the object with the help of webot simulator. The different languages such C, C++, Matlab and Python are used for the core purpose.

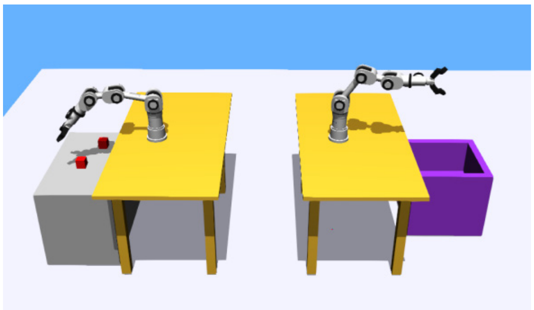

Fig. 14. Position of two IPR models

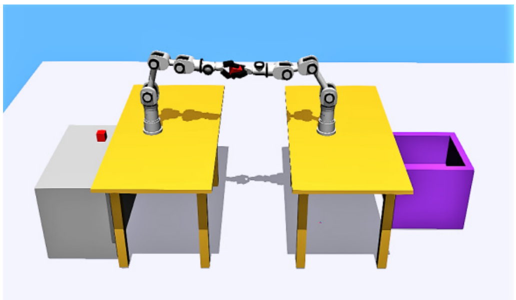

Fig. 15. Object exchange by IPR robot

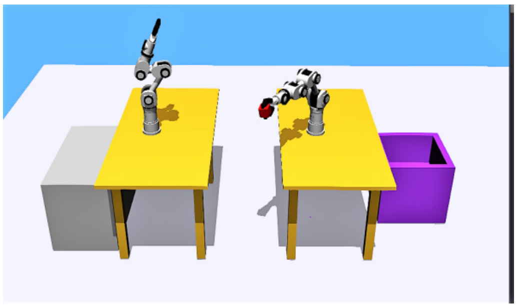

Fig. 16. Object shared by IPR robot

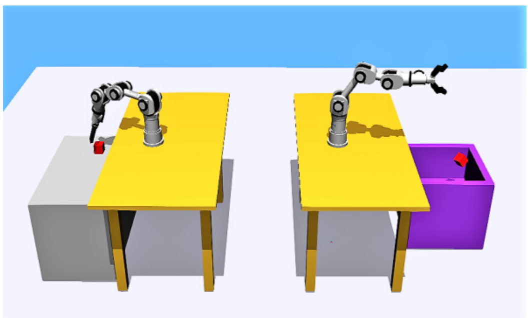

Fig. 17. Object placed at destination location

The two IPR model position are shown in Fig. 15 to take object from initial location through gripper. The model contact with each other and shares the object as in fig14. The shared object to reach at target location by their path through multipoint mediator [42]. The given results from fig. 15 after reaching at target location robot un-holds the gripper and drops the red cube inside the box.

These simulation results represent object communication with IPR communication robots. Servoing camera helps to capture initial location of object and analyses the presence of object at given = location. Robot gripper holds the object and uses the optimal route via the kinematic operation and path optimization algorithm. There are several path optimization algorithms such as particle swarm optimization, ant colony optimization, cyclic coordinate decent, etc. It generates shortest path for servoing system which provides better time complexity and faster operation.

This work can be further enhanced by integrating object tracking techniques with visual servoing to improve the performance as well as accuracy [43] [44] [45].

5. Conclusion

Visual servoing is a technique which is used for controlling autonomous dynamic system. A number of application from object grasping to mobile robot navigation is now possible. This paper consists different techniques such as IBVS, PBVS and HBVS. IBVS model in which image based distance measuring of the object is being done using two cameras stereo vision. In PBVS method object pick and place operation perform using the kuka robot model. Another, the experimental results of HBVS is used to solve and improve image-based and position-based visual servoing and IPR collaboration robot model used for exchanging object from initial location to target location. In future this can be extended for resolving calibration error, path planning, obstacle avoidance, estimating shortest path.

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