Tittle of Project

Hybrid Eye-to-hand and Eye-in-hand Visual Servo System for Parallel Robot Conveyor Object Tracking and Fetching

Abstract-

This system aims at integrating robot arm and image processing algorithm for further application. The vision servo algorithm is proposed to recognize the workpiece on the conveyor. Meanwhile, the vision servo would apply both recognition and tracking method to estimate the position and orientation of the workpiece every frame. Taking the advantage of the proposed vision method, the robot arm could pick the workpiece on the belt after tracking in arbitrary ideal picking position. All workpieces in the belt are allowed to be arbitrary placed, and, the vision servo should detect the picking point and estimate the pose very accurately. As the result, workpieces would be arranged by specific order and pose by parallel robot. The descriptive condition above is special designed for industrial application. Hence the system are of much academic interest and applied value.

Pomblem Statement and Motivation

For the pick and place case, the monocular eye-to-hand seems to be the only choice for parallel robot. This method functions good for stationary objects, even in the application with 3D-printer based on parallel robot Configuration. Monocular eye-to-hand camera is often mounted on the fore-end of the robot holder so that the parallel robot arm would not appear in the FOV of the camera. A relatively wide FOV of this camera is not enough for the case of moving objects. Once multiple objects appear in the FOV of eye-to-hand camera, the decision should be given at once, or the objects will be out of the FOV. Sometimes the fast parallel robot arm couldn't handle all pieces in the view which means some objects should be fetched without visual servo. Certainly, if these workpieces moves uniform linearly, the velocity estimation will help the arm to fetch them out of the view. However, the fetching accuracy will decrease sharply with unstable moving velocity of the object or the accumulative error of the estimation algorithm.

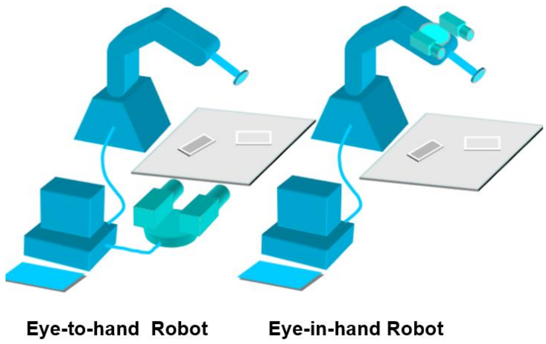


Fig. 1

Research Approach and Innovation

Under hybrid multi-camera configuration, richer information of the object could be obtained to overcome difficulties mentioned above. An eye-in-hand camera mounted on the robot arm could acquire the pose information and update the estimation frame by frame which is suggested to take over the region out of FOV of eye-to-hand visual servo system. In fact, there is little implementation on parallel robot, which has high speed and accuracy, and is suitable for this hybrid system.

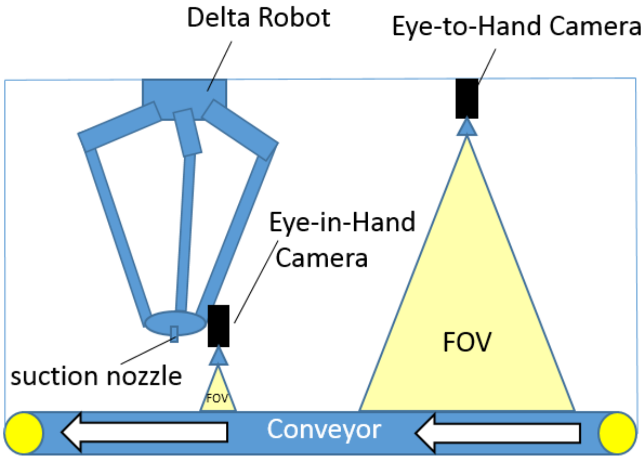


Fig. 2

The focus of our work is to construct a hybrid eye-to-hand and eye-in hand visual servo system for parallel robot to handle the case of multiple objects tracking and fetching. The configuration of our system is shown in Fig. 2. The eye-to-hand visual system fitted with a low resolution camera is proposed to estimate the poses (position and orientation) of the multiple workpieces quickly. Meanwhile the planning algorithm of fetching priority is designed to make the robot fetch the pieces in a shortest moving path.

And the information of the pieces which could be possible to be fetched, such as the pose and velocity, are transferred to the eye-in-hand visual servo system with a high resolution camera mounted on the end-effector of the parallel robot. Since the mounting position is very close to the conveyer belt, the eye-in-hand system has a very narrow FOV. Via the movement of the robot arm, the eye-in-hand system could wait in the estimated position calculated by the eye-to-hand system. Once the workpiece moved into the FOV of the eye-in-hand system, the end-effector will track with the same velocity, and the piece would always appear in the FOV of the eye-in-hand camera. After updating the estimation of relative position, the end-effector will fetch the piece and move to the next waiting position.

Coordinate Transformation

As we all known, the camera coordinate differs from the parallel robot's one. A coordinate transformation is necessary for this system. Assuming the fetching point P under camera coordinates [x,y,z] projects onto the image plane with coordinates [u,v], we want to find the velocity relationship between camera coordinate and image plane coordinate. Let $\dot{r} = [T_x, T_y, T_z, \omega_x, \omega_y, \omega_z]^T$ represents the translation velocity T and angular velocity ω, and only translation part should be considered as the workpieces only flow in x-y direction. Let $\dot{f} = [\dot{u}, \dot{v}]^T$ represents the velocity of workpiece in image plane. Image Jacobian matrix J, which is widely used in visual servo[12][13][14][15][16] , indicates the relationship we need as $\dot{f} = J\dot{r}$, and is given by [17]

$$\begin{bmatrix}\dot{u}\\ \dot{v}\end{bmatrix} = \begin{bmatrix} -\frac{\lambda}{z} & 0 & \frac{u}{z} & \frac{uv}{\lambda} & -\frac{\lambda^2+u^2}{\lambda} & v \\ 0 & -\frac{\lambda}{z} & \frac{v}{z} & \frac{\lambda^2+v^2}{\lambda} & -\frac{uv}{\lambda} & -u \end{bmatrix} \begin{bmatrix} T_x \\ T_y \\ T_z \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix}$$

To simplify this problem to 2D space, the height of workspace is set to the same level. It means every point in the image has the same depth value with parallel robot coordinate, in other words, z is a constant. As workpieces don't rotate around the camera in our application, the angular velocity ω could be ignored. Under these condition, the image Jacobian is modified as

$$\begin{bmatrix}\dot{u}\\ \dot{v}\end{bmatrix} = \begin{bmatrix} -\frac{\lambda}{z} & 0 \\ 0 & -\frac{\lambda}{z} \end{bmatrix} \begin{bmatrix} T_x \\ T_y \end{bmatrix}$$

Priority Planning

Workpieces are continuously feeding on the conveyer belt with random position. A pick and place task is shown in Fig. 3.

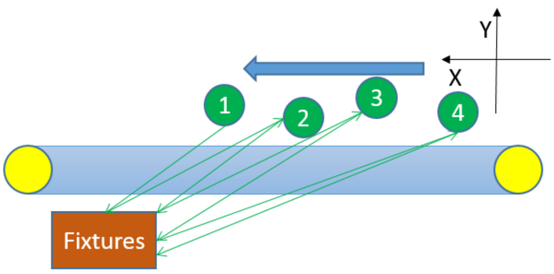


Fig. 3

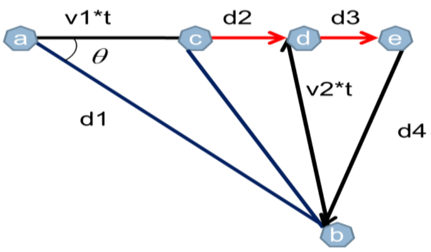


Fig. 4

We define the cost of picking one workpiece by the consuming time that end-effector starts from the box until it complete the job and return to the box again. More details are illustrated in Fig.3. When end-effector starts from position b, there is a workpiece at position a. Let v1 be the velocity of the conveyer, v2 be the velocity of parallel robot, and t is the time workpiece moving from position a to position c. In the ideal case, after time t the workpiece and end-effector meet at position c. But in a realistic condition, there should be a distance d2 for buffering. With all these value, the period of time t calculated and the total cost T is given by

$$T = t + \frac{d_3 + d_2}{v_1} + \frac{d_4}{v_2}$$

To achieve an intelligent order planning system, a directed graph whose edge weight stating the cost between the operations is constructed first. In this case, cost means the operating time. Minimum cost is equal to the shortest time which is desired. And the nodes stand for the candidate fetching pieces. The labelled number of the piece is clear shown in every node. Three constrains are set to trim unsuitable edges mentioned above. First constrain is that workpiece with lower cost have higher priority than higher cost one, that is to say, the direction of edges start from lower cost workpiece to higher cost one. Another one is that, some paths which cost too much time are removed from the graph since the parallel robot can't complete these task in time with limited line speed. Finally, only the path includes the most nodes are kept.
By adopting these constrains, a clear graph is produced for any shortest path algorithm. The change between constrains are shown in Fig 4.

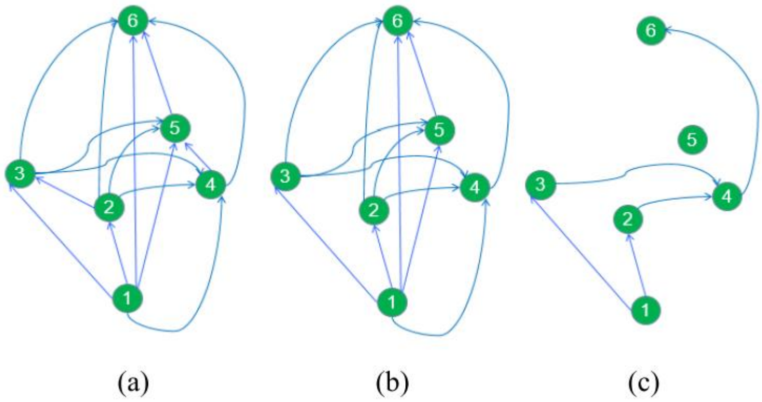


Fig. 5

Expected Results

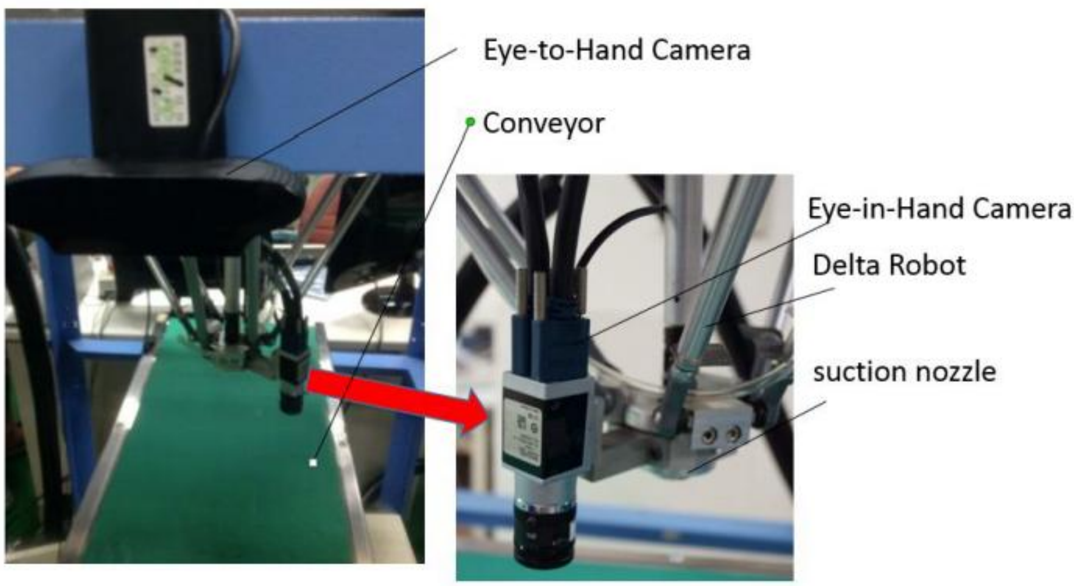


Fig. 6

In this experiment, we want to show the result in two aspects: the first one is high success fetching rate, and the second one is the improvement in the picked number after applying our priority planning system.

In the first part the workpieces are randomly delivered in y direction and with a proper interval for next piece. This experiment explores the success fetching rate and success placement rate for the hybrid system. The result shows that the hybrid system continuously fetched up to 52 pieces, only 3 out of 52 pieces are not put in the fixture. The success fetching rate reaches 99% and success placement rate reaches 94%. The miss fetching should be caused by unstable of socket or lag of computer.

In the next part we delivered the workpieces with the same pattern, the same position in the same time, to evaluate the performance of the planning system. We put some pieces close to another one on purpose let the parallel robot doesn't have enough time to fetch every workpiece. In this way, if parallel robot always tries to fetch the leading one, there must be some pieces missed. The result is as follows, without the planning system, 12 pieces out of 20 pieces are fetched. With the planning system, 17 pieces out of 20 pieces are fetched. It is excited that the planning procedure achieves 40% improvement in fetching amount. In the case of 40 workpieces with the same placement pattern, 25 pieces are fetched without planning, and 35 pieces are fetched with planning. The improvement is also close to 40%. The result of success fetch and success placement shows in Table I, and the planning result is shown in Table II.

TABLE I

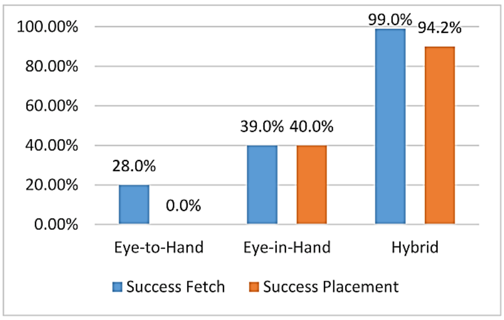
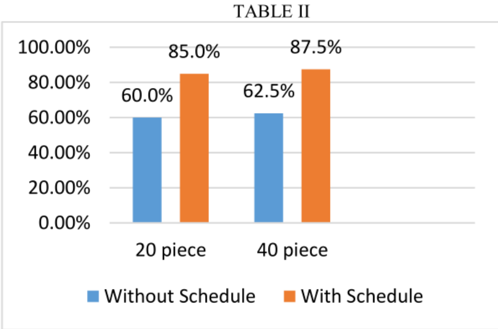


TABLE II



Industrial Applications and Its Impact

The hybrid system configuration allows operation in a variety of situation than that of the single configuration either eye-to-hand or eye-in-hand. The eye-to-hand system provided fetching priority planning with its big FOV. The eye-in-hand system tracks and fetches the workpiece precisely with its high resolution camera. Based on the complemental merits of the two system, we implement and successfully demonstrate the hybrid system on parallel robot.