2018 18th International Conference on Control, Automation and Systems (ICCAS 2018)
Oct. 17~20, 2018; YongPyong Resort, PyeongChang, GangWon, Korea

Real-Time Vision-Based Localization of Planar Cable-Driven Parallel Robot

Muhammad Awais[1], Jae-Hyun Park[1], Jinwoo Jung[2], Eun-Pyo Choi[1]
Jong-Oh Park[1*] and Chang-Sei Kim[1*]

[1] Department of Mechanical Engineering, Chonnam National University, Gwangju, Korea
[2] Medical Microrobot Center, Chonnam National University, Gwangju, Korea
(jop@jnu.ac.kr, ckim@jnu.ac.kr) * Corresponding author

Abstract: Cable-driven parallel robot (CDPR) is a special class of parallel manipulators where the motion of end-effector (EE) is controlled by flexible cables attached to it. In industrial robotics field, CDPRs have quite a high usability. Recently, kinematics and dynamics of CDPRs have been analyzed intensively. But still, there is a problem in identification of position and orientation which need to be researched. In this study, we developed a real-time vision-based localization technique for EE of planar CDPR. We developed a robust algorithm which includes camera calibration and real-time monitoring of a visual marker. A planar CDPR with two translation and one rotation parameters used for proving ground. The results prove the reliability of developed vision system.

Keywords: Cable-driven parallel robot, Localization, End-effector, Camera calibration, Visual marker

1. INTRODUCTION

Conventional parallel robots are a special class of industrial robotics where rigid links used as actuators. In automation industry, these parallel robots are widely used because of high speed. But their workspace is limited due to rigid links. Cable-driven parallel robot (CDPR) is a kind of parallel robots where rigid links are replaced by flexible wires. They have been broadly researched in recent times because of their special advantages: low end-effector (EE) weight, inertia as compared to traditional parallel robot mechanisms [1], potentially large workspace [2], high payloads and simple mechanical structure.

Over the last decades, localization of CDPRs in 2D and 3D is an important research area in cable robotics. In recent years many vision systems developed which can be used for recognition of position and orientation of CDPRs. The Polaris system of NDI is one kind of such system. This system is an optical tracking system which also detects retro-reflective marker features. NDI describes all measurement values very precisely but doesn't explain any accuracy variations [3]. Another optical tracking system is, Visualeyez of PTI Phoenix Technologies. This system can be used for 1D accuracy by 0.15 mm within range of 1.2 m [4]. There are many developed visual servoing techniques applied to parallel robots but in these techniques, EE pose was measured indirectly because those are based on 3D visual servoing [5,6].

The research work presented in this study focuses on the use of a visual marker for the real-time vision-based localization of CDPR. Visual markers are an important part of augmented reality applications. A bright pattern is drawn in the center of the coded square marker. Sample visual markers are shown in Fig. 1.

Fig.1 Sample markers

2. SYSTEM DESCRIPTION

This section introduces the planar CDPR and vision system's architecture as shown in Fig. 2. Here the movement of the EE is limited to a single XY plane. So planar CDPR has only 3 DOF. As all four wires of CDPR are in one plane, hence the only constraint to keep EE in the plane is given by stiffness of the mechanical structure. In order to observe position and orientation of the EE for localization, the camera is fixed at top of rigid frame and marker is fixed on EE. Our planar CDPR is comprised of a rigid frame, four winches which control the length of cables, a low-level controller, a PC for high-level control and an EE that contains a marker for localization of CDPR.

3. CABLE ROBOT SYSTEM

A CDPR is a parallel kinematic manipulator mainly consists of an EE, cables, and winches. In this study, we used four wire-driven cable robot. This planar cable robot

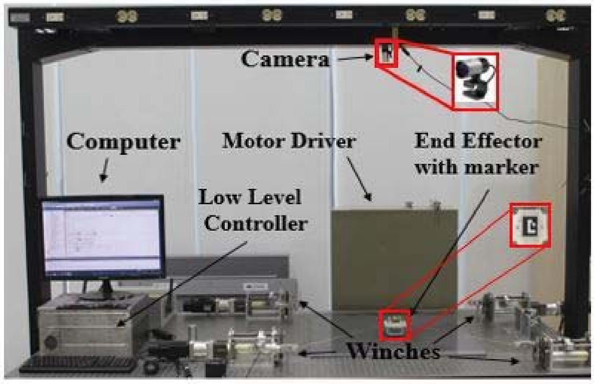


Fig. 2 Planar CDPR with the installed camera at the top

system was developed in [7]. In planar CDPR, there is just need of only four winches which makes it cost effective as compared to 6 DOF CDPR where at-least seven are needed.

In this paper, CDPR used is fully restrained because of four cables. The mechanical structure of cable robot system consists of actuators (winches) and four cables attached with winches, four servo motors, pulleys and an EE. The cables connect the EE to the winches which control the EE pose by changing the wire lengths. Schematic diagram of cable robot system is shown in Fig. 3. Length of wires changes continuously with the motion of EE. So it is necessary to include an omnidirectional guidance mechanism into the winch. The Center of gravity must lie close in the movement plane for the stability and to avoid vibrations during acceleration of EE. In order to reduce lateral deflection, a main shaft was supported by two bearings at both ends. The load cell is used for the measurement of tension in each wire. The control input to winches is computed using a kinematic model, which considers the EE and geometry of frame under the supposition that the fixed points at the EE and contact points of winch are time invariant. A winch design for planar CDPR is shown in Fig. 4. which was developed in [7].

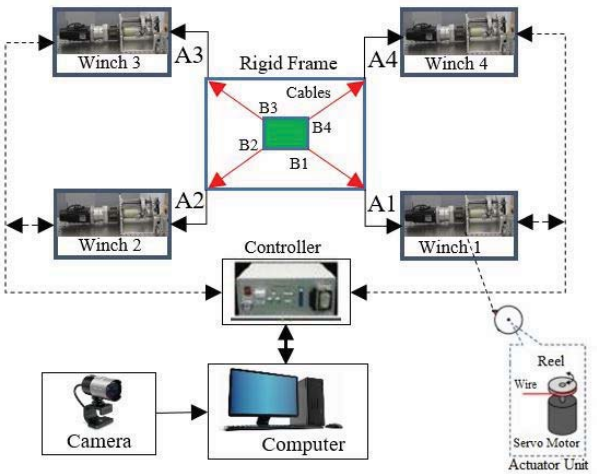


Fig. 3 Schematic of Cable Robot System with camera

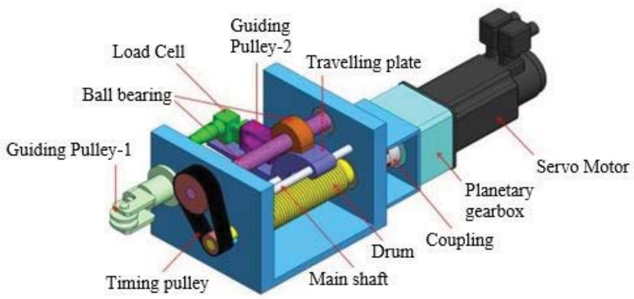


Fig. 4 Winch system for the experiments

4. VISION SYSTEM

The visual marker in developed vision system can be defined as 7x7 squares array. Outer two columns of the marker are usually zero. For successful detection of the marker, we measured the marker size and find the calibration parameters by camera calibration [8]. Camera intrinsic parameters can be found from the following matrix:

$$K = \begin{bmatrix} \alpha_x & s & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where α_x and α_y are scale factors in the x and y coordinates and both are proportional to focal length f of camera. Skew pixel is shown by s and it will be non-zero only when x and y are non-perpendicular. Number of pixels per unit distance in x and y directions can be found by following:

$$k_x = \frac{\alpha_x}{f} \text{ and } k_y = \frac{\alpha_y}{f} \quad (2)$$

Coordinates of the image center are called principal point and computed as follows:

$$c = [x_0, y_0] \quad (3)$$

To find translation and rotation, we computed external parameters [R|t] that is a 3×4 matrix. R represents a 3×3 rotation matrix and t translational vector. It can be computed as follows:

$$[R|t] = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_x \\ R_{21} & R_{22} & R_{23} & T_y \\ R_{31} & R_{32} & R_{33} & T_z \end{bmatrix} \quad (4)$$

As in this study we used planar CDPR, so our robot is in a XY plane with Z = 0, so homography H that maps a point $N = (X, Y, 0)^T$ on to this plane and its corresponding 2D point n under the projection P = K [R|t] is

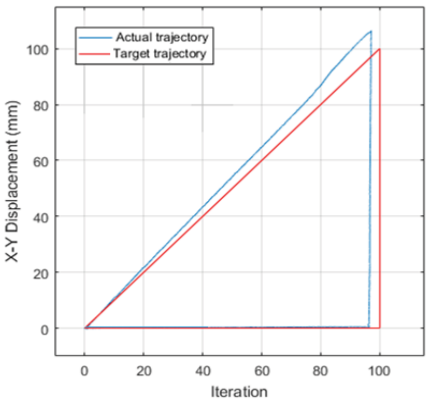
$$\breve{n} = K\,[R^1\ R^2\ R^3\ t] \begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} \quad (5)$$

$$\breve{n} = K\,[R^1\ R^2\ t] \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}$$

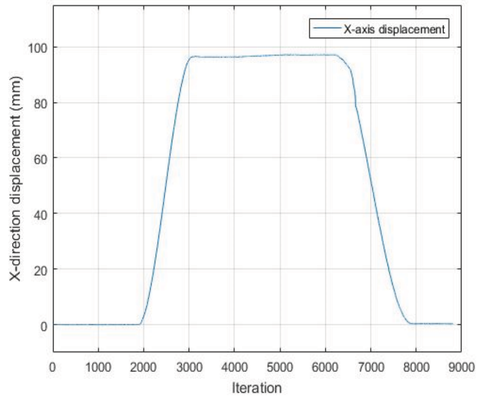
$$H = K\,[R^1\ R^2\ t] \quad (6)$$

To compute above-mentioned equations, we used point pairs world-camera. We can process an image of planar visual marker for the extraction of features and then detection of those features in the scene to obtain matches. We just need 4 pairs to compute homography using direct linear transform. For translational and rotational parameters of planar CDPR we can employ following model:

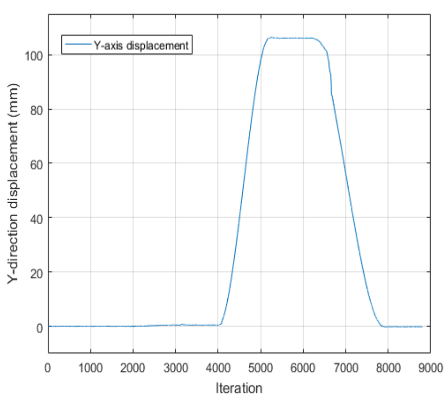
$$\theta = \tan^{-1}(2.(X.Y - K.Z), K^2 - X^2 - Y^2 + Z^2)$$
$$x_m = x.\cos\theta - z.\sin\theta \quad (7)$$
$$y_m = z.\cos\theta - x.\sin\theta$$



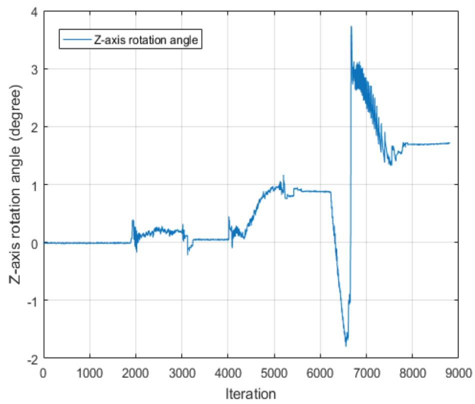
(a) Target trajectory vs Actual trajectory



(b) X-direction distance



(c) Y- direction distance



(d) Z-axis rotation angle

Fig. 5 CDPR motion in the triangular trajectory

Where K, X, Y, and Z are parameters from homography. In terms of planar CDPR, θ is the rotation about z-axis and x_m, y_m are planar coordinates of the marker attached to EE. x is the relative position of marker and z is the distance between camera and marker.

5. EXPERIMENTAL RESULTS

In the experiment, the camera is placed on top of planar CDPR, it is calibrated using a calibration grid. In this study, we used square shaped planar marker because it provides at-least 4 co-planar corresponding points so that we can use just one single marker for camera calibration. A supposition is that a vision system returns the same results when same inputs are given. For better results in localization, camera calibration must be accurate, it affects the position parameters. Camera frames obtained from a digital camera (Microsoft LifeCam Studio) are transferred at 30 fps via a USB cable to PC.

Firstly, verification of marker detection is done then we find the position of the marker relative to the camera. The distance between camera and marker is kept almost 1.3 m. As our vision system is able to detect visual marker, we prepared an experiment to move planar CDPR in a triangular trajectory. The size of the marker used for triangular trajectory is 43 mm. From the results in Fig. 5, it is clear that CDPR's pose in every frame while tracking reference trajectory is accurate and a triangle of its movement is closed. XY Planar distances and rotation along z-axis are also shown in Figs. 5(b), 5(c) and 5(d). The results prove that the accuracy and precision of determining the real-time pose are Good. For the second experiment, we changed the marker size for the square trajectory to see how a change in size behaves. Size of marker for this is 60 mm. On detection of the visual marker, the 3D axis is drawn on it as shown in Fig. 6. For the larger size of marker results of square trajectory are shown in Fig. 7. The moving CDPR follows square trajectory and it is more precise and accurate now as compared to the smaller marker in triangular trajectory.

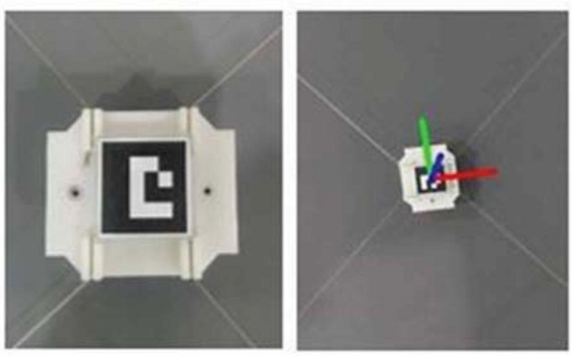
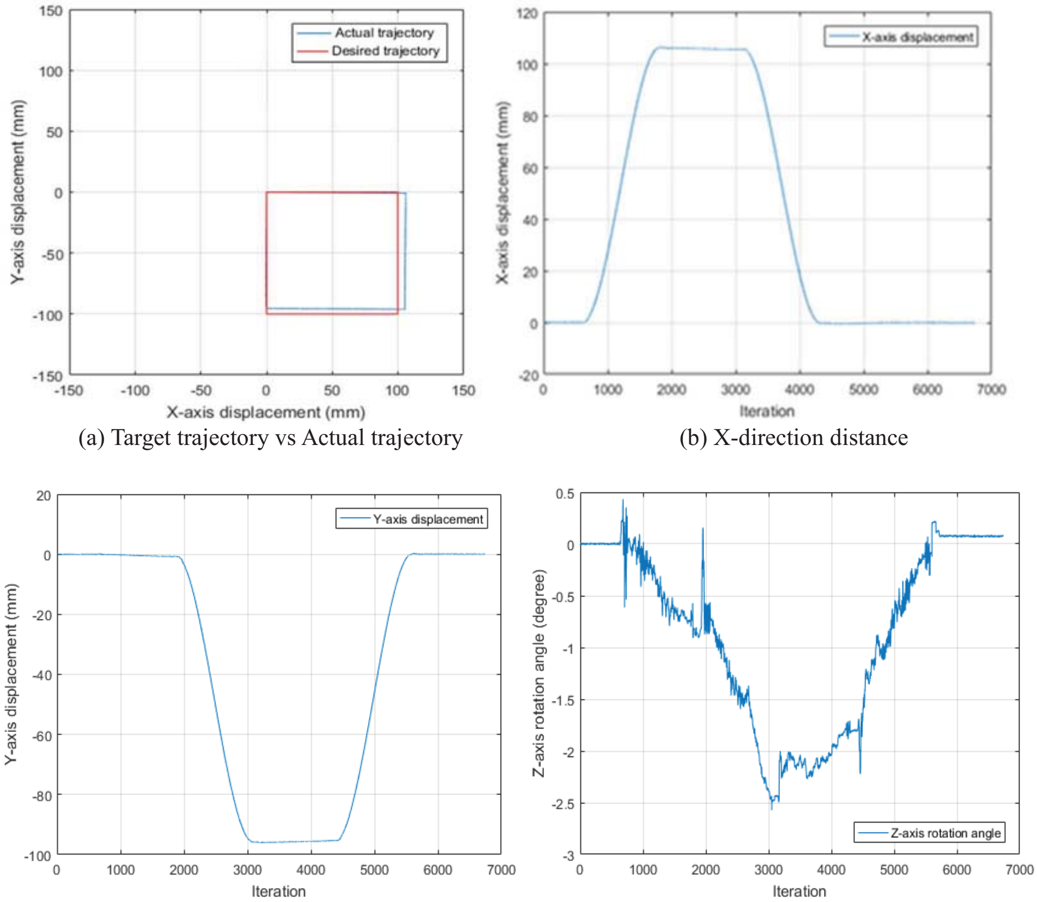

(a) (b)

Fig. 6 Marker (a) simple, (b) with image processing



(a) Target trajectory vs Actual trajectory

(b) X-direction distance

(c) Y- direction distance

(d) Z-axis rotation angle

Fig. 7 CDPR motion in the square trajectory

6. CONCLUSION

This paper deals with the vision-based localization of CDPRs using a visual marker. The experiments were done and that shows the feasibility of developed vision system. Performance of vision system highly depends on detection and tracking of the visual marker. Moreover, camera calibration and size of the marker are also important parameters in localization.

ACKNOWLEDGMENTS

This research was supported by Leading Foreign Research Institute Recruitment Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (MSIT) No. (2012K1A4A3026740).

REFERENCES

[1] J. S. Albus, R. V. Bostelman, and N. Dagalakis, “The NIST robocrane,” *Journal of Robotic Systems,* Vol. 10, No. 5, pp. 709–724, 1993

[2] R. L. Williams II, J. S. Albus, and R. V. Bostelman, “3D cable-based Cartesian metrology system,” *Journal of Robotic Systems*, Vol. 21, No. 5, pp. 237–257, 2004

[3] Polaris system, NDI. http://www.ndigital.com, 2006.

[4] Visualeyes system, PTI phoenix technologies. http://www.ptiphoenix.com, 2006.

[5] L. Weiss, A. Sanderson, and C. Neuman, “Dynamic sensor-based control of robots with visual feedback,” *IEEE Transaction on Robotics and Automation,* Vol. 3, pp 404–417, 1987

[6] S. Hutchinson, G. D. Hager and P. I. Corke, "A tutorial n visual servo control," in *IEEE Transactions on Robotics and Automation,* Vol. 12, No. 5, pp. 651-670, 1996.

[7] X. Jin, J. Jung, J. Piao, E. Choi, J. O. Park, and C. S. Kim, “Solving the pulley inclusion problem for a cable-driven parallel robotic system: Extended kinematics and twin-pulley mechanism,” *Journal of Mechanical Science and Technology*, Vol. 32, No. 6, pp.2829-2838, 2018.

[8] Z. Zhang, "Flexible camera calibration by viewing a plane from unknown orientations," *Proc. of the Seventh IEEE International Conference on Computer Vision*, pp. 666-673, 1999.