관성센서 결합 로봇 시각 서보잉

Robot Visual Servoing with Support of Inertial Sensors

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1. INTRODUCTION

Although Visual Servoing experienced nearly 30 years of development, it is still the opening area for many researchers. There are some major reasons for that aspect. Firstly, the development of processors speed and vision system is always slower than the desire of this research field. Other reason is that robotics and vision are both large area, Visual Servoing is the connection between them; therefore, it includes many complicated issues to be considered for researchers. And of cause, this is a very exciting topic in which people hope to model the living thing, here are the eye and body integration.

This work aims to develop an Eye in Hand Image based Visual Servoing system [3], with the purpose of tracking the 6 dof moving object. This is not the up-to-date topic but how fast the tracking system works is the challenge that we have to face with. Our method helps develop a coupling between inertial sensors and Visual Servoing system. The method take the high speed advantage of inertial sensors (firstly, accelerometer) to deal with the limitation of image processing delay. By using this, the control frequency of the servo system is improved greatly. That means the control performance will improve as well.

Our system has the common components such as normal Visual Servoing system excepts one IMU is attached to the object that we want to track. In this paper, only accelerometers are used. Object with landmarks on it is translated only. We use a manipulator to hold the stereo camera and move it to the desired relative pose between camera and object. Then, we manage to keep the distance between camera and object constantly.

About control method for Visual Servoing, there are some branches include optimal control [4], LQG and Pole assignment (Papanikolopoulos), H_∞ Robust controller (Martinet), General Predictive control (Gangloff)..etc..and the most effective one is the task function approach by Chaummette [1],[2]. In this paper, task function approach is considered and continuously developed.

There are numerous applications for our Visual Servoing For example, if we want to apply some operation on a moving object, we must track the translation and rotation of its needed surface. This prospect allow the ability of robot can be work in practical environment with unwillingly platform. Another application is in cinematography where people hope to keep the camera follows the fast action. Manipulator with large arm can be used to hold the camera and turn the angles as desired. And there still be many other applications on many fields need to continue research on tracking moving object using Visual Servoing such as mobile robot, vehicle, industrial robot..ect..

2. NOMENCLATURE

${}^{I}\mathbf{f} \equiv \begin{bmatrix} {}^{I}u & {}^{I}v \end{bmatrix}^T$: is the feature point in image frame

$\mathbf{J}_v \in \mathbb{R}^{2k\times 6}$:visual Jacobian, is the interaction matrix between the moving velocity of camera with respect to object and the velocity of the feature points

$\mathbf{J}_r(\mathbf{q}) \in \mathbb{R}^{6\times 6}$:Robot end-effector Jacobian connect from Cartersian velocity to joint space velocity

${}^{c}_{b}\mathbf{R}$: Rotation matrix from camera frame to body fixed frame

3. VISUAL SERVOING WITH INERTIAL MEASUREMENT

Visual Servoing system is well developed by many researchers. The up to date control method with stability investigation is Task Function Approach by Chaummet. However, the limitation is that the tracking error was not solved completely. In this section, the Visual Sevoing feed-forward method using information from inertial sensors is discussed. The methodology diagram is given by Fig. 1.

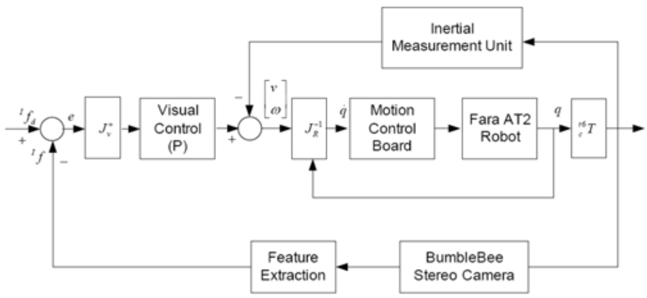


Fig. 1 Block diagram of Visual Servoing system with inertial measurement

First, considering the case when desired pose is fixed, only camera frame moves to match ${}^{I}\mathbf{f}(t) \to {}^{I}\mathbf{f}^*$. Define the error of vision based control scheme:

$$\mathbf{e}(t) = {}^{I}\mathbf{f}(t) - {}^{I}\mathbf{f}^* \quad (1)$$

The interaction between camera velocity and image feature is given by:

$$ {}^{I}\dot{\mathbf{f}} = \mathbf{J}_v \, {}^{c}\mathbf{v}_b \qquad (2)$$

Where, $\mathbf{J}_v$ is well known stereo image visual Jacobian follows N. Maru [1]. In case of moving object, Eqs.(2) is expressed:

$$ {}^{I}\dot{\mathbf{f}} = \mathbf{J}_v \left({}^{c}\mathbf{v}_0 + {}^{0}\mathbf{v}_b \right) \qquad (3)$$

We take the derivative of Eqs.(1) and then substitute to Eqs. (3)

$$ \dot{\mathbf{e}}(t) = \mathbf{J}_v \left(-{}^{0}\mathbf{v}_c + {}^{0}\mathbf{v}_b \right) \qquad (4)$$

Here, exponential controller is based on error as: $\dot{\mathbf{e}} = -\lambda\,\mathbf{e}$. So, control command is given by:

$$ {}^{0}\mathbf{v}_c = \lambda \hat{\mathbf{J}}_v^{+}\mathbf{e} + {}^{0}\hat{\mathbf{v}}_b \qquad (5)$$

Stability analysis:

Considering the Lyapunov function defined by the squared error norm:

$$ L = \frac{1}{2}\left\| \mathbf{e}(t) \right\|^2 \qquad (6)$$

$$ \dot{L} = \mathbf{e}^T \dot{\mathbf{e}} < 0 \qquad (7)$$

$$ \mathbf{e}^T \dot{\mathbf{e}} = \mathbf{e}^T \mathbf{J}_v \left(-{}^{0}\mathbf{v}_c + {}^{0}\mathbf{v}_b \right) \qquad (8)$$

$$ = \mathbf{e}^T \mathbf{J}_v \left(-\lambda \hat{\mathbf{J}}_v^{+}\mathbf{e} - {}^{0}\hat{\mathbf{v}}_b + {}^{0}\mathbf{v}_b \right) \qquad (9)$$

$$ = -\lambda \mathbf{e}^T \mathbf{J}_v \hat{\mathbf{J}}_v^{+} \mathbf{e} + \mathbf{e}^T \mathbf{J}_v \, \xi \qquad (10)$$

The Lyapunov condition for asymptotically stable system is satisfied if $\mathbf{J}_e \mathbf{J}_e^{+} > 0$ and $\xi = -{}^{0}\hat{\mathbf{v}}_c + {}^{0}\mathbf{v}_b$ is small enough. When using inertial measurement unit to estimate ${}^{0}\hat{\mathbf{v}}_c$, this condition is almost warranted.

One phenomenon is that when object is fixed, tracking error is zero; when object is moving with constant velocity, tracking error is constant and when object moves with acceleration, the tracking error is slop rising. We consider the following simulation example:

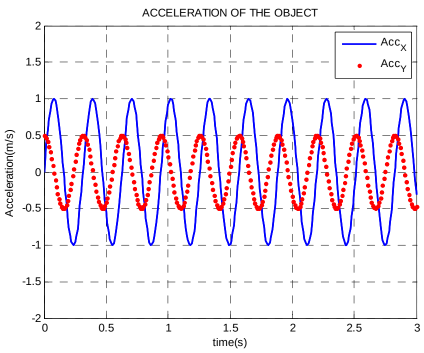


Fig. 2 Sinusoidal acceleration along x and y axis are applied to object

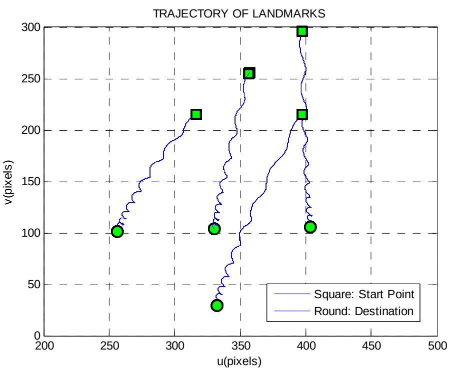
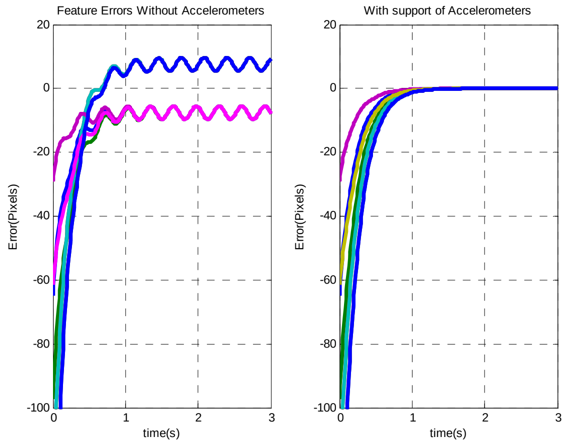


Fig. 3 Object converge to destination pose under the exerting of external acceleration. The object contains 4 landmark which are set on the triangle.

Feature errors are investigated under two case: with and without the support of accelerometers. Stereo Image Based Visual Servoing Simulation is developed in Matlab Simulink.



(a) (b)

Fig.4 Conventional VS (a) in comparison with our new method (b)

Real implementation: Framework of algorithm's simulation has been done include: robotics computation using ROBOOP C++, Fara AT2 robot manipulator control is developed on VC++. PGR library is used for stereo image capture with BumbleBee camera. OpenCV is used for image processing. Some initial result is shown in the below figure.

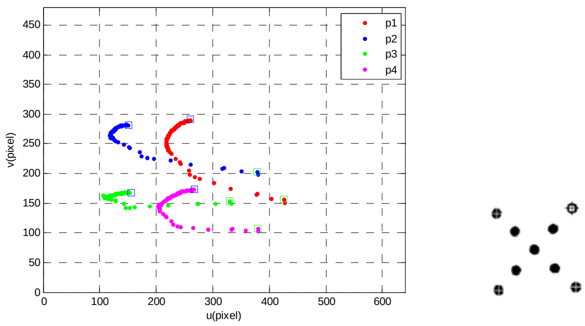


Fig. 5 (a) Visual servoing converges in case of static object
(b) Landmark designed for black and white image processing

CONCLUSION

The paper proposes a novel method of Visual Servoing with support of inertial sensors. With this method, tracking error in case of object's free movement is compensated completely. While simulation give great result, real implementation is still developing.

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