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Object Tracing Based On Exponential Function

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Abstract

In football podcasting and other games the cameras required to track the ball or players all the time. This paper presents a work done on an object tracking with a movable camera. This work was done to integrate into an active stereo vision platform that uses vergence vision in order to retrieve the 3D position of the target. This required a smooth tracking controller to keep the object within the field of view and avoid generating large blur that affects the quality of the image or leads to loss the feature in the image. The controller was designed based on exponential function to generate a smooth trajectory that decreases when it closer to the centroid of the object. The result of the exponential function helps to keep the target within the center of the image at the accuracy of ±5 pixels

Keywords: Control System; Exponential Function; Object Tracking; Vision

Introduction

Visual tracking is a classical problem has been studied in computer vision and has many applications. The classical visual tracking is used a statistic camera where an object tracked within the field of view of the camera; such process uses in industrial especially on the conveyor belt. Many algorithms were developed for the static camera such as background subtracting that assume the background is static and the foreground is changing [1,2]. Background subtraction has many disadvantages like the introduction of illumination and light changing [3], various moving backgrounds like moving trees or slow moving of the foreground where these two issue has been studied in [4]. Another approach in tracking an object is optical flow. Optical flow is an algorithm depends on feature extraction of the target like using corner detection, Scale-Invariant Feature Transform SIFT [5], then track these feature in the next frames [6]. Many works have been done on this approach to improve the quality and the speed of the tracking [7-9]. In sport the camera tracking the players or the ball where the camera in these case is moving or in humanoid case the head is tracking the moving object. In this case, the problem of object tracking gets more complicated when the issue of moving camera introduced. The object tracking problem introduces to the control system, which required to design a controller suit the camera specification. Many works have been done on this type of issue using different techniques and based on the required task. Won Jin Kim and In-So Kweon (2011) [10] implement object tracking for multiple targets using the homography based motion detection [11] to detect an individual target then an online boost tracker was integrated to combine the separate targets.

In [12] a detection algorithm to track an object in a moving camera was studied. The algorithm base on feature correspondences between frames, then using the information generated from feature matching the properties of motion is computed. Hu et al. (2015) [13] studied a multiple object detection in moving camera. Which the algorithm was presented in their work is using feature detection in the frames. The features are classified into background and foreground where the foreground represent the target. In [14], an algorithm of object tracking in 3D coordinate was studied. The controller used was based fuzzy logic that gives the performance to track the object in 3D coordinate relate to the robot. Where the focus was to control the motor that attached to the camera in order to keep the target within the field of view and the centroid of the camera. In this paper, the work is focusing on the controller system that controls the camera during the tracking process where the primary focus on keeping the target within the field of view. In this work, we are interested in keeping the centroid of the target matching the center of the image during the tracking process. This paper focuses on the control side of the system by integrating an exponential function with the motor controller. To provide smooth object tracking and control the blur that generated during the movement of the camera. The paper is organized as follow: the next section introduces the methodology of the control system, then the setup of the experiment will be shown in section three. In the fourth section, the result and discussion are presented and, finally the conclusions and future development closing this work.

Background and Preliminaries

In this paper, the object tracking was implemented on an active stereo vision platform. The platform is used in studying the dynamic vergence vision that depends on tracking the object. The platform consists of 5 DOF. Each camera has a pen and tilt independently and sharing the same active baseline. The platform is shown in (Figure 1).

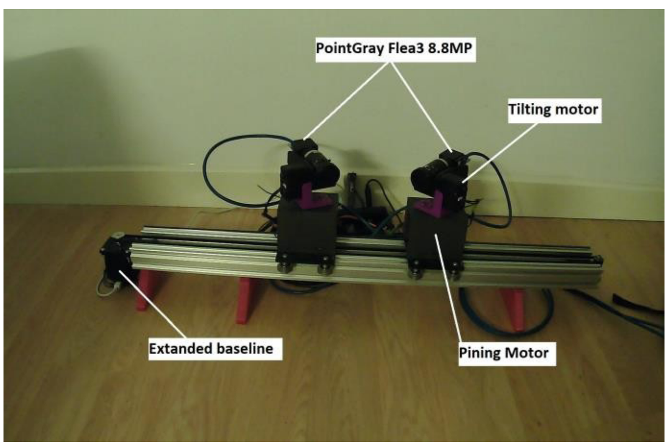

Figure 1: Active stereo vision platform with 5 DOF.

The cameras used in the rig are colour Point Grey Flea 3 (FL3- U3-88S2C-C) camera with 8.8MP and frame rate of 21 FPS. The sensor is Sony IMX121 with a resolution of 4096 x 2160, 12-bit ADC, and the pixel size is 1.55 µm. The camera has a global rest shutter at a speed of 0.021 ms to 1 s.

A Dynamixel xl430-w250-t motor was used. These motors have an absolute magnet encoder with 14 bit which gives a resolution of 0.088°. The maximum speed of the motor is 60 rpm. The communication between the motors and the PC using a USB2Dynamixel dangle, with a power supply of 12V. The control system was designed using Robot Operating System ROS [15] on a desktop PC with Ubuntu 16.04. The PC has Intel Core i7-7700K 4.2 GHz Quad- Core Processor, with DDR4 3200MHz Memory RAM.

Camera Model

The pinhole camera model is the standard model used to describe a space point relate to the camera origin (Figure 2). Point P is a world point in front of the camera. This point coordinate $[XYZ]^T$ is relate to camera origin. A projection of this point

$$p = [u,v]^T$$

is shown on the camera plane π when a connected line between P and the origin of the camera O. (u, v) is the corrected coordinate of the image plane which transform the centroid to lay on the z axis of the camera origin. The relationship between the point P and the camera origin O describe using trigonometry, where two right angle triangle is form and describe in equation (1) and equation (2).

$$\frac{u}{X} = \frac{f}{Z} \quad (1)$$

$$\frac{v}{Y} = \frac{f}{Z} \quad (2)$$

f is the focal length of the camera and describe the perpendicular distance between the origin O and image plane

π. Using these two equations help to determine a scaler position of point P, due to the missing of Z.

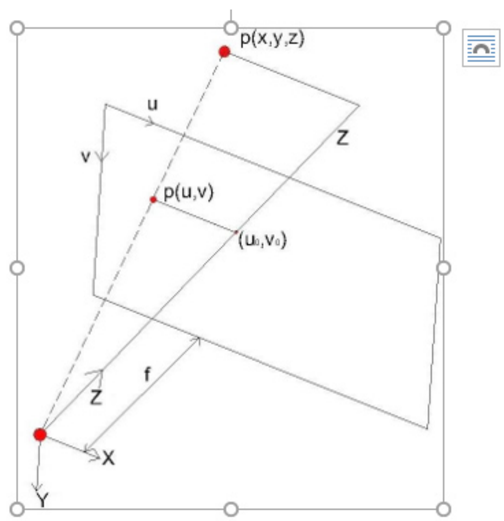

Figure 2: single camera model.

The ability to move the eyes focus on a fixation point is referred to as vergence vision. This cue is used by human and different kinds of animals. In this work, the control system was designed to work with an active stereo vision that has five degrees of freedoms. The system was designed and built to keep the origin of the cameras collide with the rotating axis of the motors. Because if the rotating axes are not aligned with the origin of the camera a large displacement will occur during the tracking and this will lead to losing the target.

Object Tracking

In object tracking, the moving speed of the target affects the detection part in the system, where this depends on the shutter speed of the camera. Shutter speed is defining the time the camera exposed to the light. The higher the shutter speed leads to less motion blur [16]. The motion blur can be computed using equation (3)

$$B_m = v \times ST \qquad (3)$$

Where B_m is motion blur size, v is the velocity of the moving object, and ST represent the shutter speed. Equation (3) use to computer the blur occur due to the motion of the object or the camera's motion. The motion blur uses to determine the maximum speed of the moving camera or the object in order to match it with the detection algorithm. The quality of the detection algorithm depends on the features in the image where a large motion blur could lead to mixed the features or erase them (Figure 3). As shown in (Figure3) the feature of the image has been mixed and erase, where the detections algorithm fails to detect the fundamental features such as corner and lines. From this, we know that the motion blur has a significant effect on the detection algorithm.

Figure 3: Motion blur generated due to the fast camera motion.

A standard object tracking algorithm is used in this work because the focus on implementing the control system is the task of this paper. An open-source library was used in this paper as a tracking algorithm. The library used in this work is Aruco [17] which used a pattern to identify the centroid of the pattern. This algorithm depends on detecting the corners and lines which will have a major effect on the detection when the camera speed passes the limited speed. The control system used in this work is based on exponential function. The reason for using an exponential function is the behaviour generated using it. As described in motion blur that affects the quality of the object detection algorithm, where at substantial differences the camera can move fast but when the target gets close to the center a more resolution image required which need a smooth movement. At the same time using a camera as a feedback sensor, the oscillation behaviour is unwanted. The control system in this work represented as motor and camera used as feedback sensor. The block diagram is shown in (Figure 4) where the output of the system is the position of the object about the camera centroid. The input to the motor is the angular velocity $\dot{\theta}$ in rpm, which computed by the exponential function equation (4).

$$\dot{\theta} = \exp^{(q \times \lambda)} \times \beta \qquad (4)$$

Where $\dot{\theta}$ is the angular velocity in rpm, β is control constant that control the range of the output to meet the range of the motor. While λ is the constant describe the shape of the output. q is the input to the exponential function where this has to be always positive. The direction of the output velocity $\dot{\theta}$ is corrected using the sign of the q before taking the absolute of this value equation (5).

$$\dot{\theta}_{corr} = \frac{q}{|q|} \times \dot{\theta} \qquad (5)$$

Where $|q|$ is an absolute q always positive.

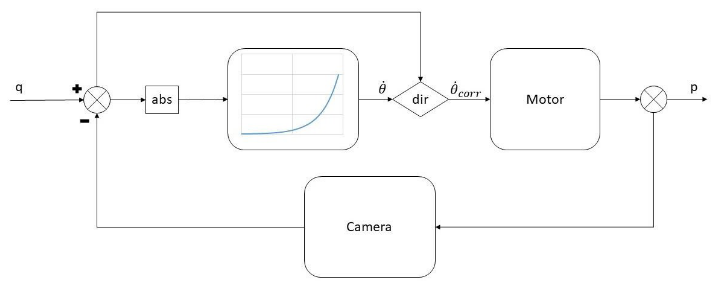

Figure 4: The block diagram of the object tracking.

Experiment Setup

The control system was evaluated using a static target and moving target, where the static target test places the target in front of the platform at a different position then start the system from the default position (zero position of the motors). This will give information about the system as when introducing a step input where the behavior of the system will be studied. The second test it a moving object. Where an object fixed on a cantilever attached to the motor. The speed of the rotating of the motor can be control which will define how fast the target can move. The size of the image was used in this setup is 2084 x 1042 (4.4 MP). The object detection returns the centroid q_{target} of the target in image coordinate which the origin is at top left corner of the image. Therefore, a remapping to these coordinate was applied to move

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the origin coordinate to the center of the image plane; which is the origin of the camera and the rotating axis. Using the new coordination, the output of the $q\ (u,v)$ has range of $(-1024,1024)$ pixel.

The maximum speed of the motor that should move at to avoid blur image was calculated using equation (3) where in the worse scenario the maximum distance between the target and the platform is 2 meters. The maximum angular speed of the motor $\dot{\theta}_{max} = 60\ rpm$. Convert the angular speed to linear speed using motion equations $v = 12.5\ m/sec$. Now put these value with the camera speed shutter $ST = 0.021\ ms$ into equation (3) the blur motion $B_m = 0.26\ mm$. This value converted to a pixel in order to check the detection algorithm requirement to detect the object in motion. The exponential function was designed to meet the input pixel size and the output angular speed. From equation (4), there are two parameters need to optimize λ and β, one responsible on controlling the behavior of the trajectory of the motion and the other parameter responsible to control the speed of the trajectory respectively.

(Figure 5) shows the experimental setup the static target where the target place in front of the platform at different positions in x range from (400 to 2500) mm and y from (-500 to 500) mm. The second experiment is to track a moving target. This experiment will determine the performance of the controller. A Stepper motor with speed controller is connected to a cantilever, and on the other end of the cantilever, the target is fixed. The Stepper motor is controlled by speed in rad/sec, and the linear velocity of the target was calculated as well in order to compare it with the blur motion. The setup of the experiment is shown in (Figure 6) where this time the detection algorithm was used is based on colour detection just to simplify the process.

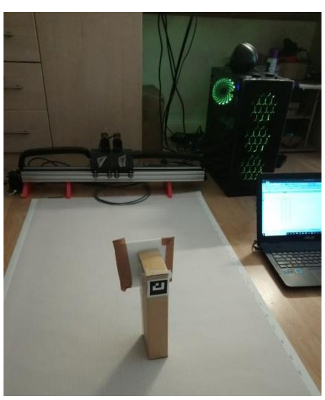

Figure 5: The experiment setup with the static target.

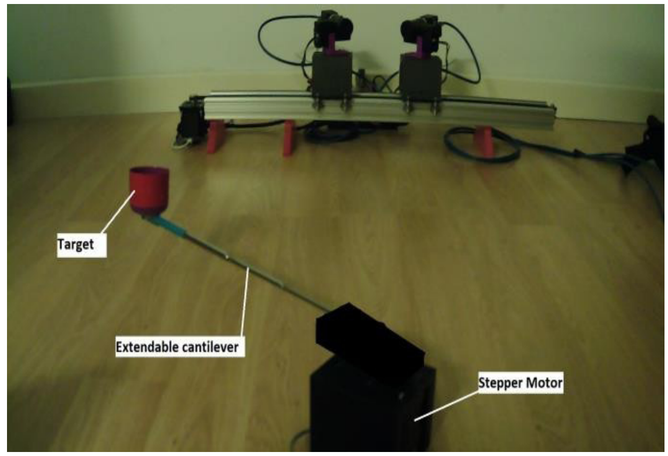

Figure 6: Moving object tracking experiment setup.

The cantilever is used in the experiment can be extended at different length which helps to generate more data that help to improve the performance. The length of the cantilever is set to 200,400, and 500 mm.

Result and Discussion

In this part, the result of the testing is presented. The output result of the system was divided into three different lambda λ (0.0010, 0.0015, 0.0020). In each λ, there are 4 control β that responsible on controlling the angular speed of the camera motor. (Figure 7-9) shows the results of the static experiments where each figure compare the different running of different β.

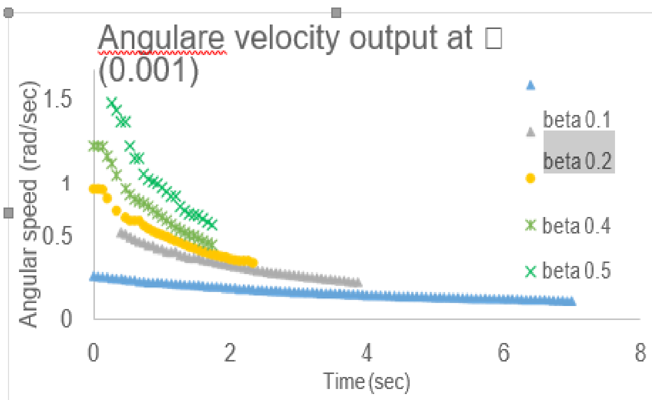

Figure 7: Angular velocity of the motor at lambda 0.0010.

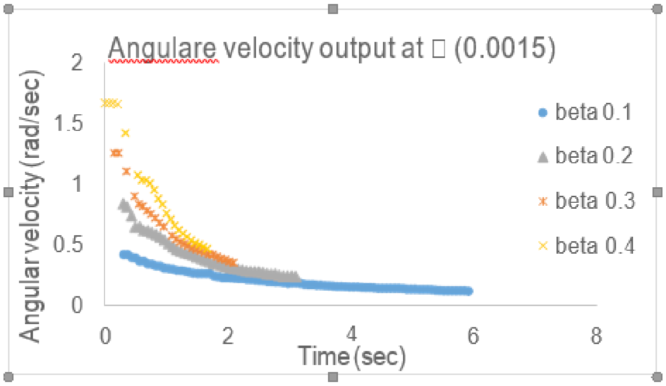

Figure 8: Angular velocity of the motor at lambda 0.0015.

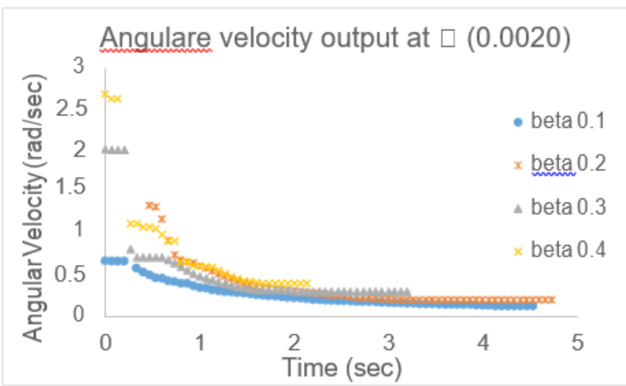

Figure 9: Angular velocity of the motor at lambda 0.0020.

The output of the experiment shows that the system can track the target at the maximum speed of the motor where β =0.5. However, the time take for the system to center the target with the camera is range from 1.5 to 7.5 seconds, which depend on the λ and β. The increase of β lead to increase in the tracking speed. This increase in β leads the system to change the behavior of the exponential function output where the output become more step.

In (Figure 8,9) shows the increase of the beta leads to increase in the speed of tracking the object in the same time this cause the camera to lose the target as a result of the increase of the blur that effects the feature detection at the beginning of the tracking process. Moreover, based on this output the maximum angular velocity should be set to 2 rad per seconds, which is half the speed of the theoretical velocity that calculated in the experiment setup section. The output of the system in all cases has followed the exponential output as is wanted with a confidential of 90%.

Using the exponential in object tracking system help the system to track the object at a different position, and fix the gaze point with the centroid of the target with an error of ± 5 pixels, which this improve the performance a lot in the next process.

There is an issue with the lambda, where the increase of the lambda leads to steep in the angular velocity when the object is far away from the center; then the angular velocity drops to a minimum while still, the object is far from the centre. Difference setup of lambda is shown in (Figure10). The increase of the value of lambda leads to the drop of the speed control value β to maintain the speed within the limited.

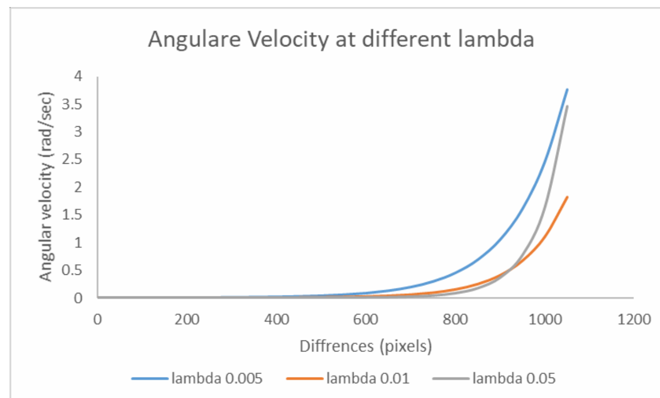

Figure 10: Exponential function at different lambda

Moreover, the result shows that using exponential function. Help to improve the settlement time of the system and avoiding fluctuating. In object tracking using the movable camera, the fluctuating of the camera leads to increase in the error which the system loses the target. Therefore, the selected lambda and beta was chosen in order to give the best performance was to select a small lambda (λ = 0.001) and combine it with large beta (β = 0.5). This combination was selected due to the output performance which help the system to keep tracking the target without losing the target.

The results of tracking moving object are shown in (Figure 11-13) These results show the differences between the object center and zero coordinate of the image. Three cantilever length was used in the experiment where it leads to maximum linear velocity of the object to 0.76 m/sec. As figures shows that the controller keep the target within the field of view. The increase in object speed lead to extend the distance of the object to the origin of the image.

At speed of 90 deg/sec with cantilever length of 500 mm the control system start to suffer lose in the target as shown in (Figure 13). These occur due to the presents of large motion blur that effect the output of object tracking.

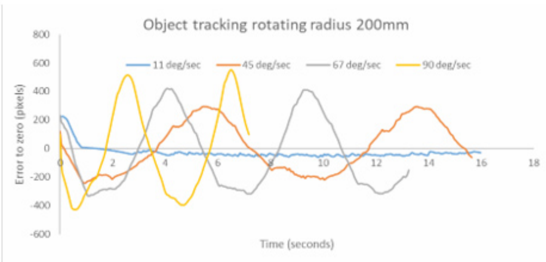

Figure 11: object tracking using cantilever length 200 mm.

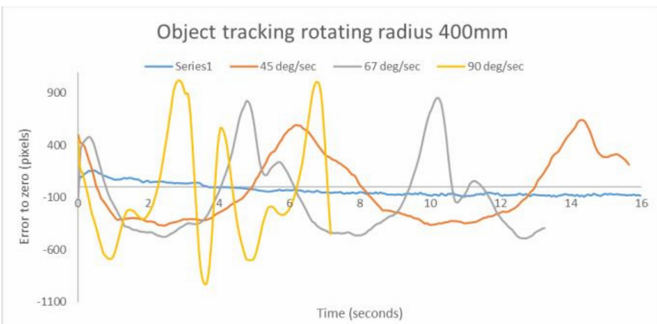

Figure 12: object tracking using cantilever length 400 mm.

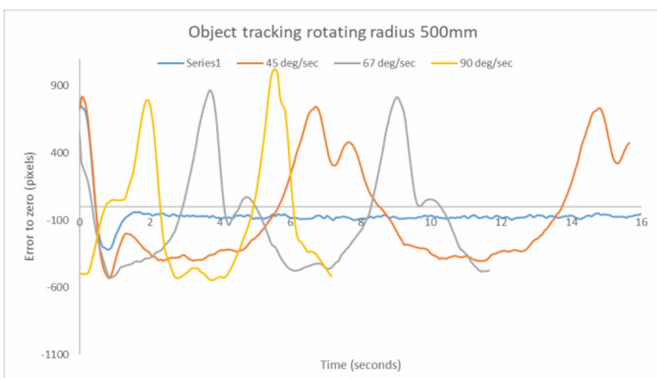

Figure 13: object tracking using cantilever length 500 mm.

Conclusion

To conclude, this paper present a work was done on an active stereo vision with five degrees of freedoms. The control system of object tracking using the portable camera was studied.

The controller was designed to use the exponential function in order to track the object. The functions show the ability to track the object with a good speed that maintains the image with no blur. Moreover, the control system help to improve the track the object with an accuracy of ±5 pixels which lead to improvement in deploying the vergence system. This improvement was due to the nature of the exponential that show linear behaviour when the target gets closer to the center of image.

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