VESTRO: VELOCITY ESTIMATION USING STEREOSCOPIC VISION

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ABSTRACT

This paper presents a real-time stereoscopic vision system that estimates the speed and direction of a moving object. Stereoscopic is applied in a real-time image processing system to re-construct a moving object in 3D, and further estimate the object's velocity vector. The developed system, which is called Vestro, can be operated to measure the speed of any moving object, ranging from remote controlled vehicles, snooker balls to human beings, and determine where it is going. We show how 3D analytical geometry and vector operations are utilized to find the velocity magnitude, and the corresponding angular compass direction for a particular motion. In-lab experiments prove that the developed Vestro system produces velocity estimation with an accuracy of more than 94%.

1. INTRODUCTION

Developments in the field of image processing gives rise to the necessity of tracking, identifying, classifying, and defining moving objects using vision sensors in a real-time basis. The information obtained from these operations is used to monitor parameters such as the type, size, count, and speed of objects in view. Together with this, stereo vision has also become a vital part of the field, with application in areas of 3D re-construction, image correspondence, and depth recovery. Applying the concept of stereo vision in a real-time image processing system is an interesting, yet challenging task.

With the steady progress in the area of stereoscopic vision, Vestro is developed with a purpose of estimating the speed and direction of movement. The system uses two Charge Coupled Device (CCD) cameras calibrated in parallel optical axes, and the moving objects are processed in real-time by a dedicated workstation.

The previous work in motion estimation can be broadly divided into two groups. One group utilizes vision sensors to track moving objects, such as the systems in [1], [2], [8], and [11], while another group uses an approach based on magnetic loop, infrared or ultrasonic sensors (systems [9] and [12]). While the latter methods are feasible, they tend to be very expensive to implement and difficult to maintain. The technique of using vision sensors however, requires only two cameras and a workstation. The Vestro system is expected to reduce the overall setup and maintenance cost, as compared to other similar systems, while efficiently attain accurate measurements of speed and direction.

2. STEREO ANALYTICAL GEOMETRY

Finding velocity vectors using the Vestro system involves two major steps, getting the velocity magnitude, and obtaining the angular compass direction. Figure 1 shows a Vestro setup diagram with relevant geometry and vector parameters, which are utilized to find the required equations for velocity vector estimation.

The ball in Figure 1 moves from point P at coordinates (X_1, Y_1, Z_1) to point Q at coordinates (X_2, Y_2, Z_2). The movement is defined by the vectors $\check{R}$, $\breve{U}$, and $\check{N}$ with the relationship

$$\check{R} = \check{U} - \check{N}$$

If the ball makes an angle θ_1 during the movement from P to Q, then by applying the cosine law and vector dot product, the distance vector $|R|^2$ is defined as

$$|R|^2 = |U|^2 + |N|^2 - 2|U||N|\cos\theta_1, \text{ where}$$
$$\theta_1 = \tan^{-1}(Z_2/X_2) - \tan^{-1}(Z_1/X_1)$$

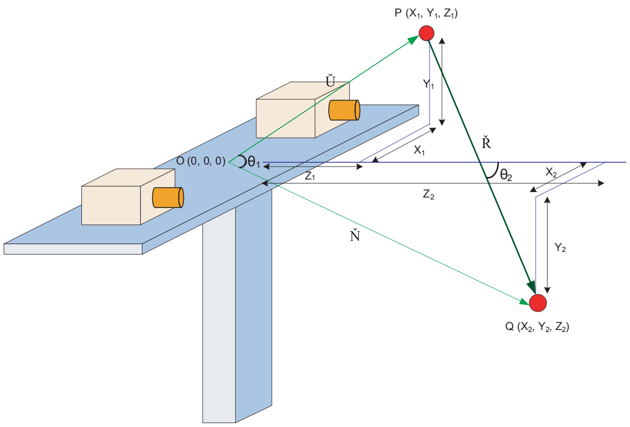

Figure 1: Physical setup diagram and the relevant geometry and vector parameters for the Vestro system.

Taking the square root of $|R|^2$, and the derivative with respect to time, the velocity magnitude is obtained as

$$|V| = d|R|/dT$$

The values of image depth (Z_1 and Z_2) and 3D re-construction ((X_1, Y_1) and (X_2, Y_2)) are calculated using the stereo triangulation equations [7].

Compass direction is obtained from comparing the depth and the x-axes displacement from two different positions. The angular direction is defined as

$$\theta_2 = \tan^{-1} ((X_2-X_1) / (Z_2-Z_1))$$

The next section provides a high level abstraction of the Vestro system, and presents an overview of how the above equations and stereoscopic concepts are applied to perform velocity vector estimation.

3. THE VESTRO SYSTEM

The structure of Vestro is illustrated in the flowchart of Figure 2. Real-time video is rendered by two CCD cameras, and displayed in the Vestro system that is capable of processing images in real-time. The system starts with capturing a set of images at a rate of 25 frames per second. After pre-processing (*filter, de-interlace, etc.*), the images are frame differenced to detect and track motion. Once Vestro detects motion of the same object on both images, it will perform stereo matching to find object disparity. Image depth is calculated from disparity, and the object is re-constructed in 3D. From the current and previous values of re-construction, velocity vector operation is performed to find the speed and direction of the movement.

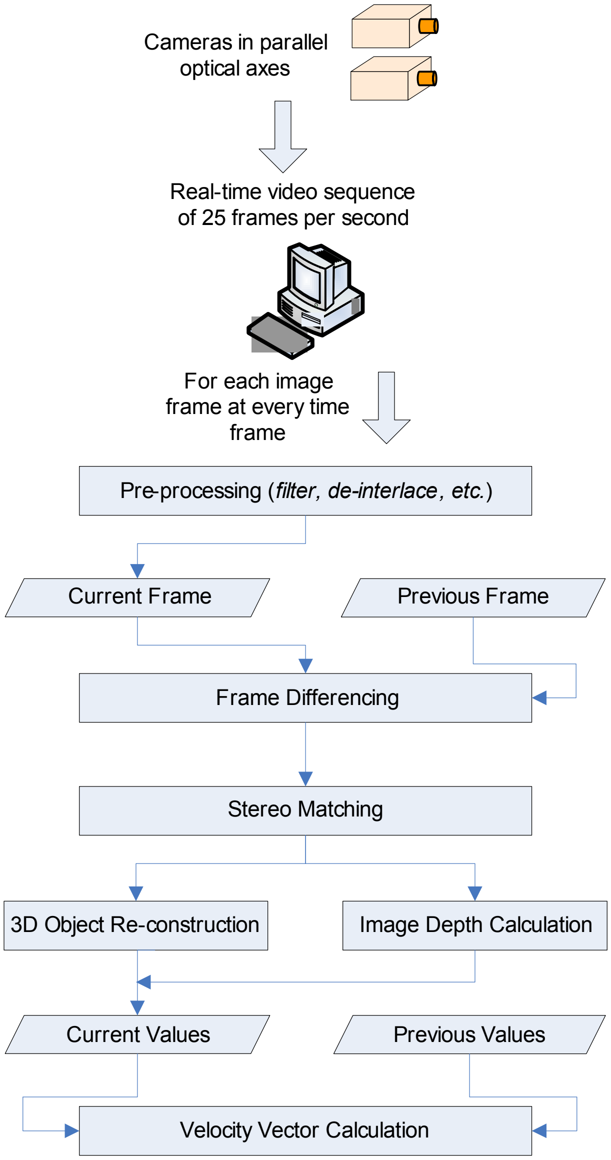

Figure 2: Flow chart of the Vestro System. The process above occurs every 30 milliseconds to continuously monitor moving objects and subsequently, finding the speed and direction.

4. EXPERIMENTAL RESULTS

Preliminary in-lab testing and experiments are performed using Vestro. We take the velocity vectors acquired from experiments and compared them with actual values for several moving objects.

Figure 3 shows a screenshot of part of the Vestro system to estimate speed. The actual speed of the remote controlled car is initially determined using the conventional methods of a measuring tape and a stopwatch. Five values were measured, and the actual speed is taken as the average of all the values. From this, we obtained an actual speed of 0.463 m/s. Vestro is now used to measure the speed of the car. Twenty consecutive experiments are conducted using Vestro. The car is controlled to move in the North-East direction relative to the cameras, and we let Vestro determine its speed. The results produced are compared with the actual speed measured earlier. From the tests, we obtained an average speed of 0.454 m/s, which corresponds to a speed estimation accuracy of 98.1%. Figure 6 is the graph that compares the actual and experimental speed for the remote controlled car.

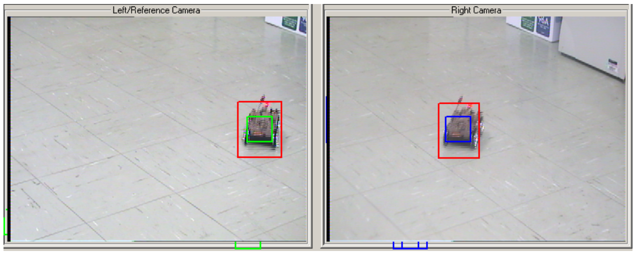

Figure 3: Screenshot of Vestro stereo images. The speed of the remote controlled car is pre-determined, and compared to the experimental value.

Figure 4 is another screenshot of the Vestro system, but now used to estimate the angular compass direction. The actual angular direction is initially determined by aligning a track at 22.5° North-East. A ball is rolled along the track, and readings of the direction estimation made by the Vestro system is recorded for verification. Again, twenty consecutive experiments are conducted. For all the tests, Vestro produces the correct direction (North-East), with an average angular compass value of 22.9°. This corresponds to 98.3% accuracy for angular compass direction estimation. Figure 7 summarizes this result for all 20 experiments.

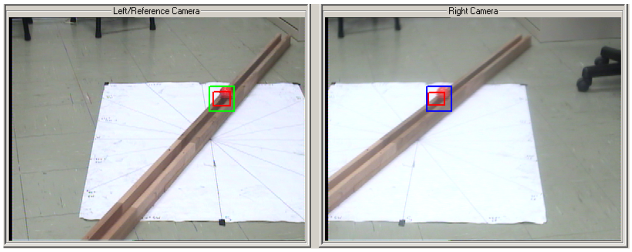

Figure 4: Screenshot of Vestro stereo images. The angular direction of the wooden log is pre-determined, and compared to the experimental value.

Outdoor field tests were also conducted to verify the technique in the program, for as far as about 50 meters from the cameras. Figure 5 is a screenshot of the program to find the velocity of the man in the video. Again, several readings were taken by both, the program and the actual average speed of the man (using a stopwatch and a long measuring tape). This time however, the results were not as accurate as the first two experiments. This is due to the inconsistency in the speed of the person running. Even with the existence of acceleration in the run, we nevertheless achieved a speed estimation accuracy of 94%. Results for the speed are shown in the graph of figure 8, while direction (90° East actual direction) is given in the graph of figure 9.

Figure 5: Person running. The actual speed of the person is compared with the result given by Vestro.

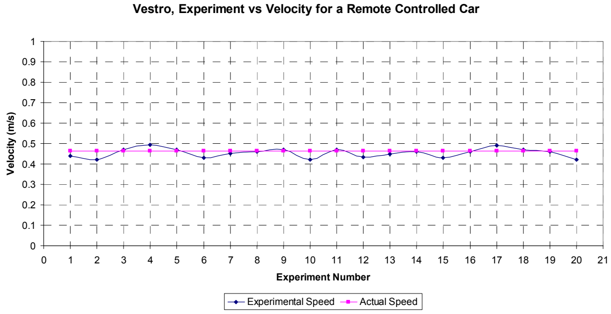

Figure 6: Result of the velocity magnitude experiment that compares experimental and actual values from 20 experiments.

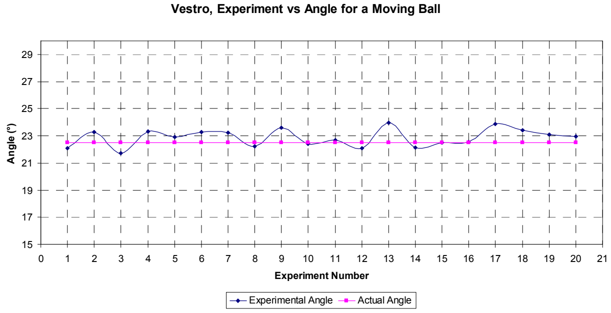

Figure 7: Result of the angular direction experiment that compares experimental and actual values from 20 experiments.

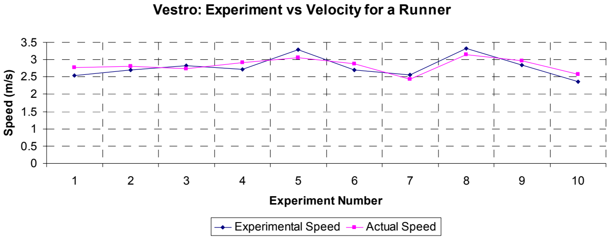

Figure 8: Result of the speed experiment that compares actual and experimental values.

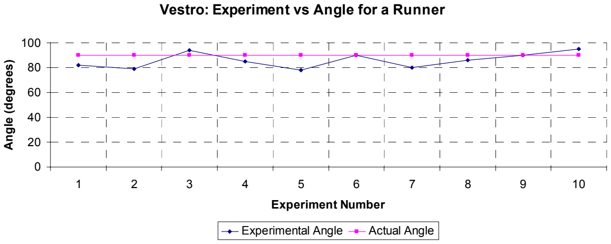

Figure 9: Result of the angular direction experiment that compares actual and experimental values.

5. DISCUSSION

In this paper, we have developed a real-time stereo vision system that effectively measures the speed and direction of a moving object. The algorithms used are derived directly from stereoscopic analytical geometry. A substantial part of processing, and the dominant factor that influences the result is the stereo triangulation technique. Better accuracy in depth recovery and 3D re-construction would in turn give a higher accuracy in velocity vector estimation. Thus, the methods of stereo matching, and object tracking are constantly under revision. The previously developed methods of Adaptive Window [4], Multiple Baselines [5], and other techniques are studied and analyzed for relevance.

The Vestro system defines the object's movement. However, the ultimate goal is to come up with a system that is capable of not only to estimate motion, but also to identify and classify the objects accordingly. For that, the Vestro system is expected to be integrated with other modules such as the Multiple Object Tracking and Recognition. Having such systems with greater precision, accuracy and robustness thus demands more research and developments in the field of image processing.

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