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Measuring dynamical parameters for spherical objects: Application for sports training

E. Lluna[(a)], V. Santiago Praderas[(a)], F. Brusola[(a)], B. Defez[(a)], I. Lengua Lengua[(a)]

[(a)] Universidad Politécnica de Valencia. CITG – Edificio 8L. Camino de Vera S/N, E-46022 Valencia, Spain.

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Corresponding author:
Victor Santiago
Tel.: +34 96 387 95 18
Fax.: +34 96 387 95 19
e-mail: vicsanpr@upv.es
Address:

Abstract

Measurement of dynamical parameters like velocity or spin of spherical objects in movement is important for different purposes in areas like sports training, ballistic, games, aerospace applications, etc. To obtain these data, many different non contact measurement techniques have been applied. Common techniques include image processing, radar, ultrasound or optical devices. Most of the mentioned methods have important drawbacks to be used in real applications. The paper describe a developed device to measure dynamical parameters of moving objects based on electro-optical sensors and its application to sports training .The device avoids most of the drawbacks and can be used on the field or in industrial environments.

1 Introduction

Measurement of dynamical parameters like speed or spin of spherical objects is important for different purposes in areas like sports training, ballistic, games, aerospace applications, etc. Many different techniques and algorithms, like image processing [1][2], Doppler-radar [3][4] or electro-optical devices [5][6] have been used to measure such parameters.

Most of the mentioned methods have several important drawbacks that prevent them to be used on practical systems. Image processing methods require high-speed cameras that are expensive, it is also very dependent on the position of the cameras in relation to the object trajectory and the techniques are complex and it is not easy to do in real-time. Radar devices present similar drawbacks. Most commonly used methods are based on electro-optical devices. Two or more optical sensors are placed in the trajectory of the object to measure the time spent by the object to travel between detectors and calculate the velocity [7][8]. These procedures give the mean velocity in the area between the detectors.

The proposed device uses large detection area optical barriers to measure the instant velocity and position of the object when crossing the barrier, providing the instant velocity at this point. The fact of measuring the instant velocity and position in two points allows us to calculate other dynamic parameters like accelerations and then the forces that are acting on the object.

2 Device description

The developed device consists in two large detection area optical barriers, similar to the ones described in [9][10], placed at a fixed separation distance. The object trajectory must pass through the two barriers. Fig. 1 shows the prototype built and used for the tests.

Fig. 1 Final Prototype Image

Each optical barrier consists in two lines of detectors mounted along the Y and Z axis. Fig. 2 shows the axis convention used and represent, as red lines, the detection lines from the detectors placed in the Y axis. There are also horizontal lines from the detectors placed along the Z axis. Each detector consists in a pair emitter-receiver built using a low power laser as emitter and a phototransistor as receiver. Let call *activation* to the fact that an object is placed between the emitter and receiver cutting the reception and *deactivation* when the object stops cutting the beam from the emitter.

Fig. 3 shows the block diagram of an optical barrier. Main blocks are the power supply, a control CPU and the lasers and phototransistor blocks. The CPU controls the laser through a relay that switches on and off the power supply line. The phototransistor signal is connected to I/O pins in the CPU. A microcontroller is used because it simplifies the electronic design because all the required peripheral, like memory, EEPROM, timers, I/O, etc, are included in a single package. Each optical barrier gets connected through an RS-232/USB port.

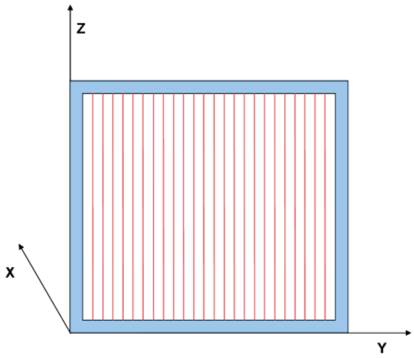

Fig. 2 Axis convention

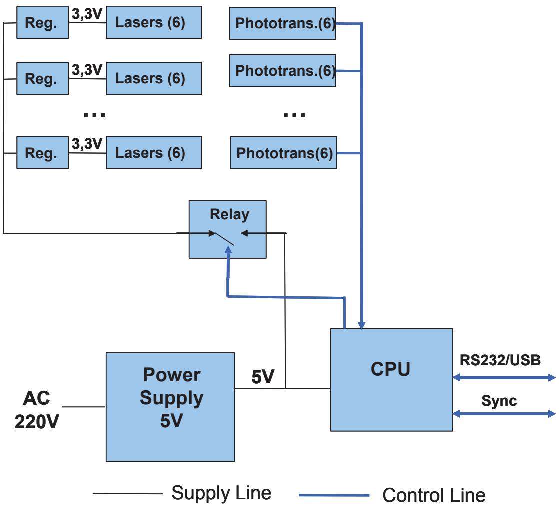

Fig. 3 Optical barrier block diagram

The main functionality of the barrier is provided by the firmware that runs in the CPU. The firmware working mode consists on waiting for commands received through the RS-232/USB port and then processes it. The processing consists on performing some actions depending on the received command. The more important command initiates a data capture. Fig. 4 shows the flow diagram of the data capture command.

The data capture process is initiated switching on the lasers. The input from the receivers is read and stored to be used as reference value. A timer is started to initiate the time count. The receivers are polled to detect a change in the input (comparing with the reference value stored) that will signal a detection start and to detect when the input comes back to the initial state that means the detection has finished. When all the detections are finished or a timeout expires, the capture command finishes and the captured data is sent via the same RS-232/USB port. Timeout can expire if no ball is sent as security mechanism to switch off the lasers. Both optical barriers are synchronized using a special line to assure that the timers are started at the same time in both barriers.

The information measured in the optical barriers is time, the time the detection starts and ends for each affected detector. There are four detection lines corresponding to the Y and Z axis in both barriers and the procedure is carried out in all detection lines.

The information is sent to an external computer. The software running in the external computer is responsible to use the time information to perform the calculations and obtain final parameters like velocity, spin and position. The calculations are carried out in an external computer to give more flexibility to the system.

The program that runs on the external computer is called the Control Application and it has been specially designed to be used on soccer training. The application extracts information about the velocity and spin and includes a database to store user information and keep track of the information obtained in trainings. Fig. 5 shows the application window after a capture and Fig. 6 shows the application window for user configuration. Modifications in the Control Application allow changes in the scope of the application or in the algorithms used easily without changes in the optical barriers.

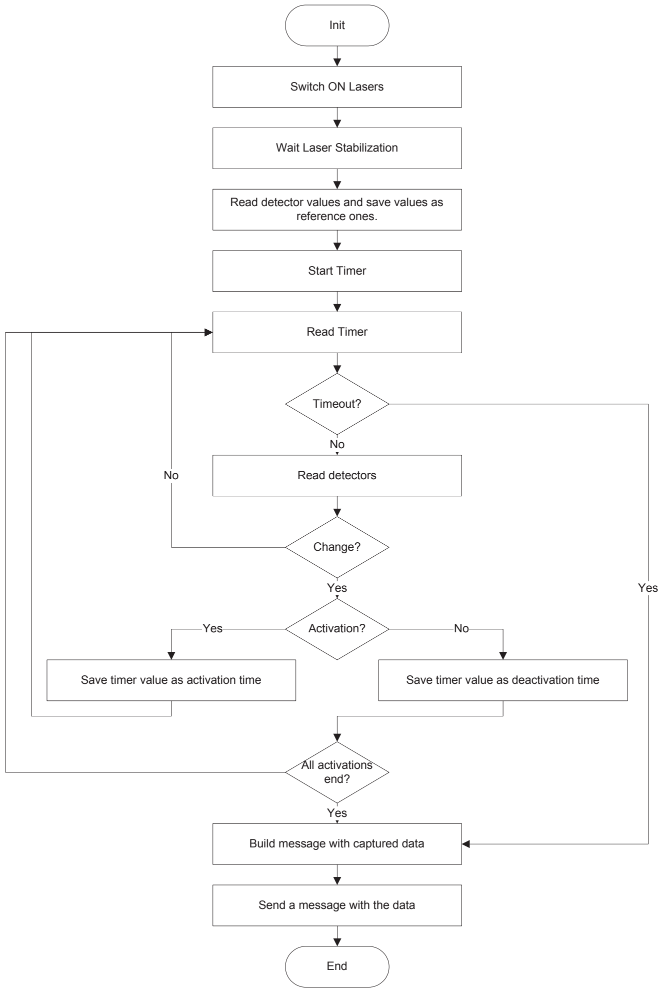

Fig. 4 Data capture command flow diagram

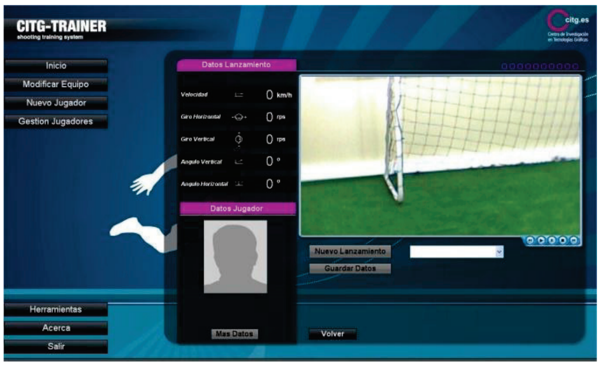

Fig. 5 Control Application Results.

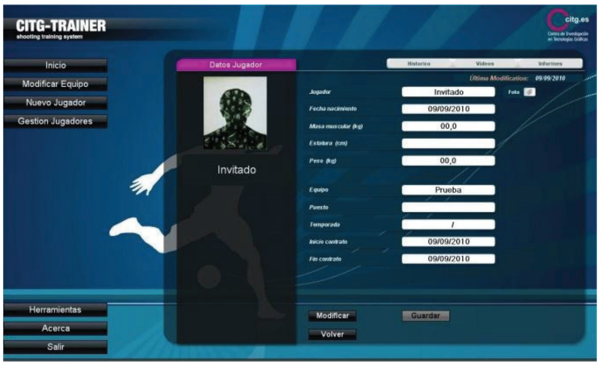

Fig. 6 Control Application. User info.

3 Parameter measurement

From the basic timing information provided by the optical barriers parameters like velocity or spin rate are calculated.

The velocity is calculated in each of the optical barriers and this way two velocity vectors are obtained in each transit.

The velocity value (*v)* is calculated using the time measured for a transit (*t*) and the diameter of the object (*e*) using the expression:

$$v = \frac{e}{t} \quad (1)$$

This value corresponds to the velocity value in the movement direction, the module of the velocity vector. The incidence angle *θ* can be calculated from the delay in the activation of two consecutive detectors. A perpendicular incidence angle means that all the detectors are activated symmetrically. Deviations from the perpendicular are seen as delays on the activation time for consecutive detectors respect the perpendicular case. The incidence angle, from geometrical considerations, can be expressed as:

$$\theta = \arcsin\left(\frac{dt_{12}}{td_{sep}}\right) \quad (2)$$

Where *d* is the ball diameter, t_{12} the time delay between consecutive detector activation, *t* the transit time and d_{sep} the distance between detectors.

Fig. 7 shows the activation time for detectors in the case a perpendicular trajectory (the pattern is the same in both detection lines, vertical or horizontal). Flat line means no detection in this detector; change from 0 to 1 indicates the beginning of the detection and change from 1 to 0 the end of the detection. It is clearly seen the symmetry of the detections. Fig. 8 shows the case the trajectory is not perpendicular, the detection time for each detector is the same than in the perpendicular one, but the time the detections begins have changed, some detections start in advance and some other are delayed.

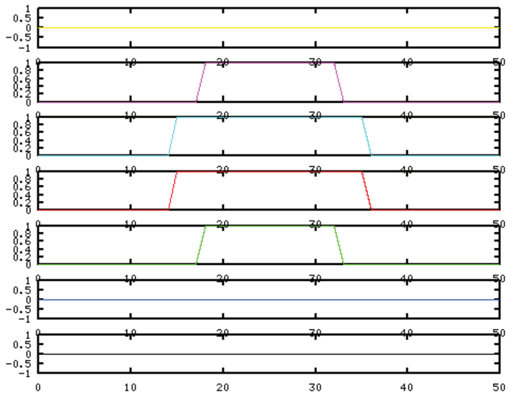

Fig. 7 Time diagram for a perpendicular trajectory.

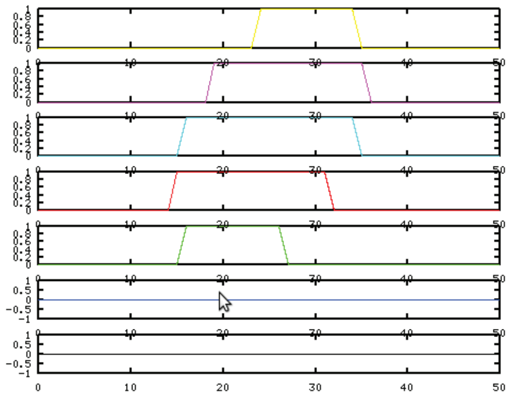

Fig. 8 Time diagram for a no perpendicular trajectory.

Using the calculated *v* and *θ* values for each detection line, the values of v_x, v_y and v_z are obteined.

The main error source in the velocity calculation comes from the gap between detectors because the calculation uses the diameter of the object as a known fixed value but in a real transit, depending on the position of the centre of the object in relation with the detectors, the real transit measured could not correspond to the actual diameter but a smaller value. This error can be expressed as:

$$\delta d = d - 2\sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d_{sep}}{2}\right)^2} \quad (3)$$

Where *d* is the diameter of the object and d_{sep} is the separation between two consecutive detectors. For a typical soccer ball with $d=0.20\ m$ and using $d_{sep}=0.05\ m$ the error is under 2.7%. If the separation is reduced to 0.01 m, the error falls under 0.1%.

4 Experimental results

Several experiments have been carried out to test the developed device. All the tests were done using a soccer ball. Because of the nature of the shoots, manual kick, no special launching device was used, the velocity range is limited to low values between 1 to 10 m/s. The incidence angle of the shots is not important because the system gives a 3D vector.

The velocity measurement test consists on measuring the v_x component using two calculation methods. One calculation method uses each optical barrier to calculate the instantaneous velocity in the barriers position (v_{x1} *and* v_{x2}) and the second method calculates the mean velocity (v_{x12}) in the space between barriers by measuring the time the object takes to fly from one to the other barrier. Only the X component is tested because the second method is limited to the X axis because the time measured is for the travel along this axis. The v_{x12} value must be equal to the mean value of the two velocities calculated in both barriers:

$$v_{x12} = \frac{(v_{x1} + v_{x2})}{2} \quad (4)$$

Table 1 shows test results at low velocity range.

Test	V_x(m/s)	V_{x12}(m/s)	Error(%)
1	4.37	4.48	2.56
2	6.32	6.49	2.53
3	8.16	8.39	2.72
4	9.39	9.52	1.46

Tab. 1 Experimetal results.

The optical barriers used in the test have a d_{sep}=*0.05 m*. The measured error is under 2.8% that meets the expected range because it is caused by the separation among detectors.

5 Conclusions

An operational instrument has been developed to measure dynamical parameters of a moving object. The instrument has been used for sports training. The measurement algorithms used avoids most of the drawbacks found on previous instruments of that type being independent of the position of the measurement device in relation to the object trajectory. The procedure used to measure velocity gives instantaneous values in two points enabling the possibility to calculate accelerations and forces acting on the object.

Apart of its current use for sports training, the device is an open platform to continue working on the measurement of dynamical parameters of moving objects.

References

[1] John Eric Goff, Matt J. Carre. Trajectory analysis of a soccer ball. American Journal of Physics, Vol. 77(11), November 2009.

[2] A. Beuhler, F. Castro, A. Polak. CMOS Camera with Integral Laser Ranking and Velocity Measurement. US Patent 6860350B2, March 2005.

[3] Y. Aloin, A.Calif. Doppler Radar Method and Apparatus for Measuring Projectile's muzzly velocity. US Patent 1989.

[4] M.Scheneider, E.Eckenfels, S.Nezirevich. Doppler-radar: A Possibility to Monitor Projectile Dynamics in Rail Guns. IEEE Transactions on Magnetics, Vol. 39, No.1, Jan 2003.

[5] A. Kaur, R. Vig, R. Bhatnagar. Study of Different Measurement Systems and Design Circuitry with Intensity Modulated Measuring the Velocity of Projectile. International Journal of Electronic Engineering Research. Vol.1, No.2, 2009 pp 101-108.

[6] M. Sanchez-Pana, M.Y. Fernandez, R. Zaera. Cost-effective optoelectronic system to measure the projectile velocity in high-velocity impact testing of aircraft and spacecraft structural elements. Optical Engineering. Vol. 46(5), May 2007.

[7] S.T. Lu, C. Chou, M.C. Lee, Y.P. Wu. Electro-optical target system for position and speed measurement. IEE Proceedings-A. Vol.140, No.4, July 1993. pp 252-256.

[8] G.S. Gill, A. Kumar. Velocity Measurement System for Small Caliber Projectiles. WCE 2008. Vol.1, July 2-4, London UK.

[9] E. Musayev. Laser-based large detection area speed measurement methods and systems. Optics and Lasers in Engineering. Vol.45, 2007, pp 1049-1054.

[10] E. Musa, M. Demirer. Laser based light barrier having a rectangular detection area. Optics and Lasers in Engineering. Vol. 48, 2010 pp 435-440.