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CALIBRATION AND EVALUATION OF A MACHINE VISION ALGORITHM TO DETECT AGRICULTURAL TRACTOR MOVEMENT

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Abstract

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This research is a preliminary project to fuse GPS and machine vision in order to improve positioning accuracy. A machine vision system has been developed to detect the movement in a tractor. The system, which consisted of a camera focused on the ground and software which processes the images, was probed in three kinds of fields. At the same time, GPS positions were being taken. The results of tests have shown that the trajectories detected by means of the vision system match with the path detected using GPS. This research is an example in which GPS and machine vision can work together.

Key words: machine vision, movement detection, block matching, GPS, trajectory, tractor, fields

Introduction

The positioning systems can be either absolute or relative. The most popular absolute positioning system is GPS. In agriculture, GPS is used in guidance of agricultural tractors (Bell, 2000; Larsen et al., 1994; Stombaugh et al., 1999; Veal et al., 2001). GPS positioning systems are influenced by error sources. In order to decrease these errors, different kind of differential corrections can be used. There exists a large amount of research about GPS precision, as Taylor et al. (2004).

In other part, a relative positioning system used in agricultural research is machine vision. Some papers show the use of machine vision in the guidance of tractors (Wang et al., 2007; Tsubota et al., 2004; Subramanian et al. 2005).

In many situations, the precision of absolute positioning system can be improved using a relative positioning system. The most used theory about the fusion of both positioning systems is based on Kalman filters (Kalman, 1960).

There are many efforts on movement detection via machine vision. It is based on the idea that when something is moved in front of a camera or the camera is moved in front of a fixed object, changes in the resulting images can be used to detect relative movements between the camera and the object. Block matching is a robust and simple algorithm implemented in this research which permits movement detection in the agricultural machinery.

In this study, a block matching algorithm is described to detect movement using vision, then its optimal parameters are obtained, and finally, it was tested

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in three different fields. This research is a previous research to others that fuse vision and GPS, in order to improve positioning accuracy in agriculture. This improvement in precision could perform more accurate automatic guidance which saves fuel and agricultural inputs.

Objectives

The objective of this research is to obtain the optimal parameters of a block matching algorithm, and then, to detect tractor movement from a sequence of images taken from the ground. A program in Matlab 7.0 has been developed to implement the machine vision system. The program detects the tractor trajectory and compares it to the geographical coordinates obtained in a GPS receiver. The machine vision system was tested in three kinds of fields to know in which the results are better.

The aim is to increase the accuracy of the absolute positioning GPS to build machinery which helps in agricultural tasks.

Materials and Methods

Structure of Machine Vision System

Machine vision systems are nowadays more and more popular due to the big amount of problems they can solve. There are many efforts on movement detection via vision systems. One of the machine vision applications is the movement detection, based on the idea that when something is moved in front of a camera or the camera is moved in front of a fixed object, changes take place in the resulting images that can be used to detect relative movements between the camera and the object.

The machine vision system consisted of a colour CCD video-camera, a laptop and software. The frame resolution was 320x240 pixels. Information from the camera was used as the input to the movement detection algorithm. The camera was installed in the frontal area of the New Holland tractor (Figure 1).

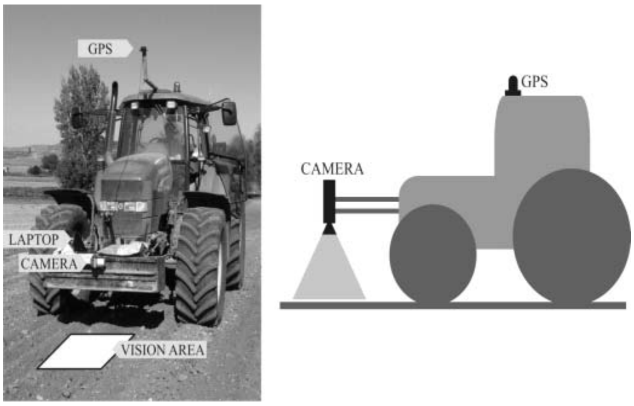


Fig. 1. Global image of the system installed in the tractor. The GPS receiver is placed up. The camera and the laptop computer are in front of the tractor wheels. The camera is focused to the working area. Photographs are taken maintaining the distance constant between the camera and the ground. A long wire connects the GPS to the laptop

The camera was focused to the floor to capture machine vision images maintaining the distance between the camera and the floor constant (Figure 1b).

To evaluate the robustness of the machine vision algorithm, images were acquired in various kinds of fields in lighting conditions. The time to process one whole image was 1.2 s using a core Duo Pentium at 1.66MHz. To decrease the computation time, the colour images were transformed into 8-bit black and white images.

Block matching finds blocks repeated in consecutive frames to estimate movement. The method extracts a block from a photogram i and determines the new position in the following frame i+1 using the matching criteria shown in equation (1).

$$R(i,j) = \begin{cases} 1\_\ if\ \_(Block(i,j) - tolerance) \le \operatorname{Im}age(i,j) \le (Block(i,j) + tolerance) \\ 0\_\ other \end{cases} \quad (1)$$

R is a (block size X block size) matrix which all values are 1 when the block is over the correct position in the image. When the block is over other places, most R values are zero. The tolerance is necessary as the images taken with the camera are noisy. The search compares the block to the blocks from the previous frame separated a step distance in the axis X and Y.

The final block position is determined by means the sum shown in equation (2). BS is the block size.

$$Sum(p,q) = \sum_{j=1}^{BS} \sum_{i=1}^{BS} R(i,j) \quad (2)$$

The result is a movement vector of the block which starts in the centre of the position where the block was extracted and ends in the position (p, q) which maximizes (2). Block matching algorithms are simple and robust. The greater disadvantage is that high computing requirements are needed.

In Figure 2 is shown the flow diagram in which the vision algorithm works together with the GPS receiver.

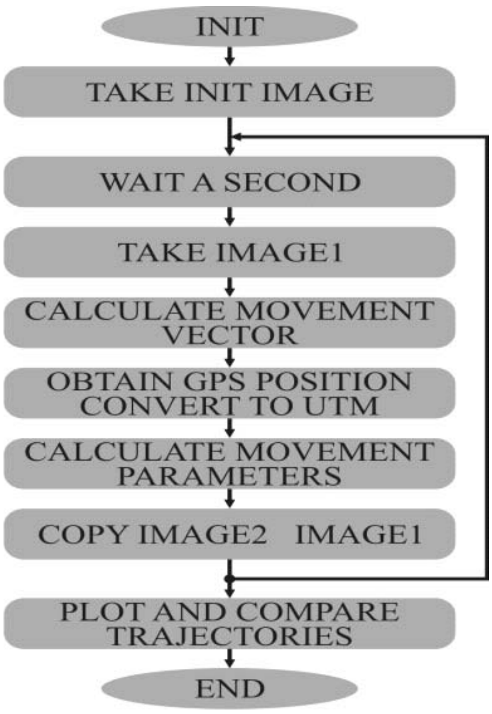


Fig. 2. Block matching and GPS algorithm

GPS System Specifications

A GPS 16LVS Garmin receiver was used to take positions while the tractor was moving. Table 1 shows the receiver specifications. The parameter "static navigation" of the GPS has been turned off, in order to detect movement at low speed. While the vision system was running, the laptop extracted GPS positions from NMEA sentences (latitude and longitude in degrees), and transformed them into UTM coordinates (a system of local x-y coordinates expressed in meters). The GPS system was used in open fields without elements which can deflect the satellite signals.

Table 1 show that GPS positioning accuracy is 15 meters, which is an absolute precision. It means that the GPS position deviation is less than 15 meters.

Table 1
Specifications Garmin GPS 16LVS - GPS receiver module. Manufacturer: Garmin International

General	
Interface	Serial
Adquisition Time	
Cold acquisition time	45s
Warm acquisition times	15s
Hot acquisition times	2s
GPS System	
Receiver	12 channel
SBAS	WAAS
DGPS	DGPS ready
Update Rate	1/second
Accuracy	Position - 15 m, Position - 3 m (With WAAS), Position - 3 - 5 m (With DGPS)
Interface	NMEA 0183, RTCM SC-104 DGPS
Antenna	Built-in
GPS Module Features	Waterproof

However, relative accuracy between a point respects other is much higher. In this research relative errors between positions are more important than absolute errors; as trajectories are obtained respect the initial position.

Machine Vision Calibration

The block matching algorithm implemented in this research is robust although it presents the disadvantage of high process time. In order to reduce it, a system calibration was needed.

A benchmarking test was created to choose the block size and the step which permit the tractor to move slowly and the program to calculate movement. In Figure 3a is shown the 256x256x8 test image which was used in the calibration. To simulate movement, the image was moved randomly as shown in Figure 3b. The block matching algorithm was run to obtain the movement vector. In Figure 3b the new block position, taken from the centre of Figure 3a, is drawn.

Step variation

In a first simulation, the X and Y step was modified, from one pixel to ten. The algorithm was run ten times with ten random movements in x and y axis to know how accurate is. The Euclidean distance in pixels between the real position of the displaced block and the position determined by the machine vision system was calculated using equation (3), where ε_x

$$\varepsilon = \sqrt{\varepsilon_x^2 + \varepsilon_y^2} \tag{3}$$

and ε_y are the pixel error in X and Y directions.

Figure 4 show that a step less than four gives a 100% of matching effectiveness. The error in pixels is less than 3 in x and y axis. The advantage of using a step equals to four is that the processing time is 1510.18% less than using block matching full search, which uses step one.

Block size variation

In a second simulation, X and Y step are fixed to 4 and the block size is modified to the values 11, 21, 31, 41 y 51 pixels. In the same way that in previous simulation, eight random displacements were done. Simulation results are shown in Figure 5.

The simulation show that a size equal or greater

Fig. 3. (a) Test image centered used to calibrate block matching algorithm

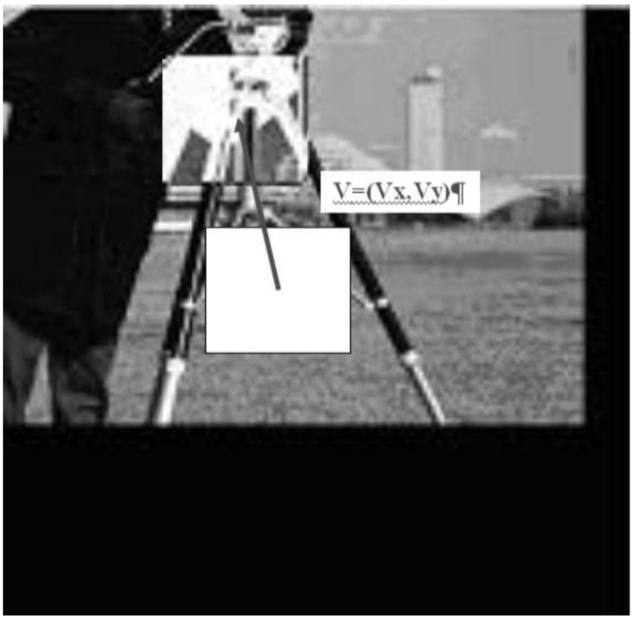


Fig. 3. (b) Test image moved to simulate movement. The movement vector (V) is represented

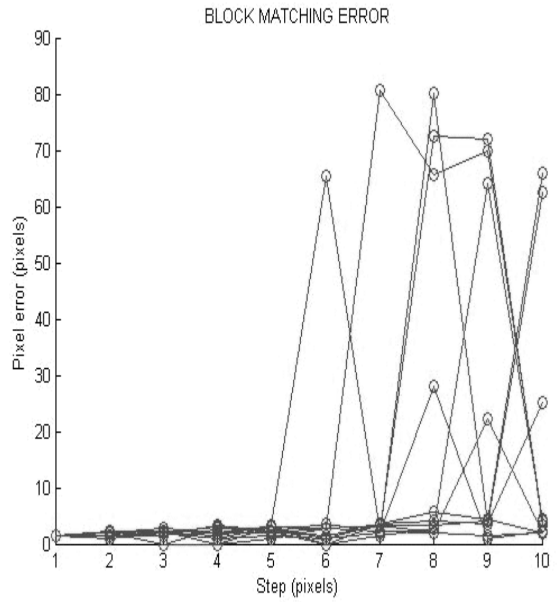


Fig. 4. Block matching machine vision calibration: error distance in pixels vs step. X-axis is the block step search in block matching. Y-axis: error in pixels between the real block position and the position determined by machine vision

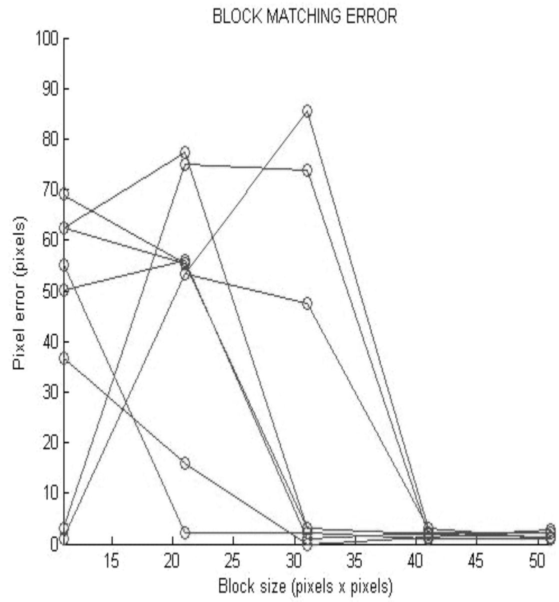


Fig. 5. Block matching machine vision calibration: error distance in pixels vs block size. X-axis is the block size in block matching. Y-axis: error in pixels between the real block position and the position determined by machine vision

than 41 pixels is enough good to obtain the accuracy required.

Crossing the results from both simulations, a 41x41 pixels block size and a step 4 can be use in this block matching algorithm processing 8-bit grey scale images. However, this calibration is a minimum as real images taken from fields in which the tractor is moving are noisy due to the vibrations. The noise makes that a step less than 4 and a block size greater than 41x41 pixels are required.

Tested Fields

Once the vision system was calibrated three probes were done in several kinds of fields in a New Holland tractor. The GPS and the vision system were running at the same time. Probes were done in lighting conditions in Aguilar de Bureba (Burgos) in the North of Spain.

The machine vision algorithm was tested in stubble field, in ploughed field and in sunflower stubble field. They are shown in Figure 6.

Results and Discussion

The vision system was able to detect movement correctly in all fields. The speed meter in the tractor showed 0.7 km/h (0.435mile/h), which equals to 0.194m/s. This average speed is also obtained in the vision system and in the GPS receiver. The velocity in the vision system is not constant due to the vibrations transmitted from the motor to the camera as shown in Figure 8. Using GPS, the speed is also not time invariant due to error sources which affect the precision. In Figure 9 is plotted.

The vision system detects the 105 m (0.0653 miles) straight trajectory. Comparing the plots in Figure 7, we can affirm that vision system obtains a better result when the tractor is in a ploughed field, as the vision trajectory fits to the GPS trajectory better. Also, the total length trajectory (vision and GPS) are closer.

The texture is very important in vision system results. The system does not work if the floor colour is homogeneous. In these three cases, field textures permit the system to detect the tractor trajectory. Ploughed field offers better results due to the stones, which help to detect moved blocks easier than straw in the stubble field and sunflower straws in sunflower field.

There is a limitation in the maximum speed of the tractor, as the vision system can only work if the block taken in iteration i is present in the image in iteration i+1. To increase the maximum speed, the blocks were taken from the upper part of the images instead of taking them from the centre. It has the disadvantage that the system is not able to detect movement if the tractor moves rear. Another way to get a higher maximum speed is to increase the height of the camera respect field as it permits to capture a bigger amount of field. It also has the disadvantage that if field is taken too far, details, which are necessary to the vision system to work, are not captured. An auto focus camera permits to appreciate little details in a great range of height.

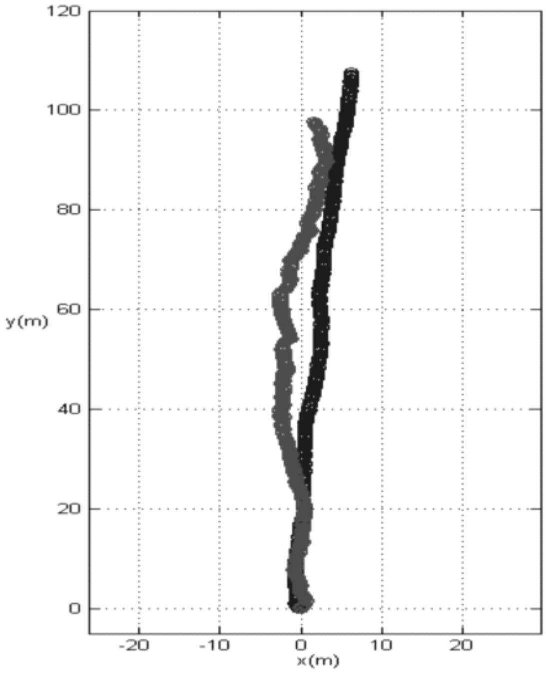
6a

6b

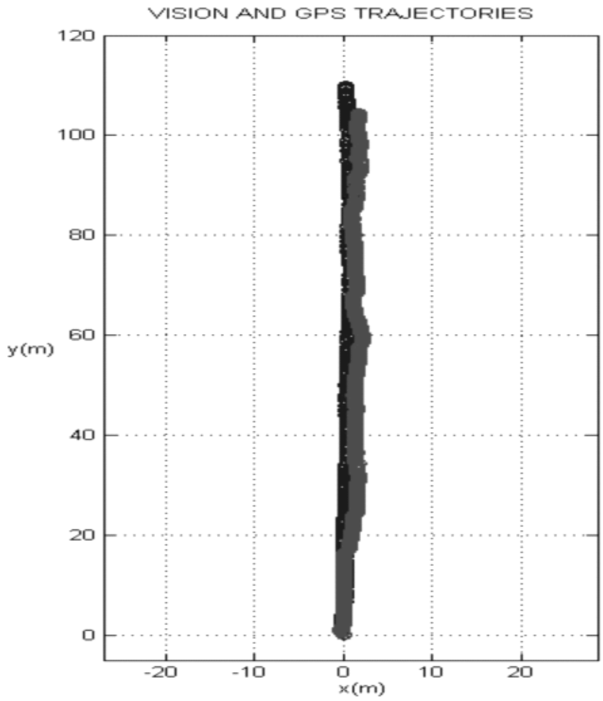
6c

Fig. 6. Different fields tested: (a) Stubble field, (b) Ploughed field, (c) Sunflower stubble field

In general, the vision movement detection performed reliably. On a few occasions, the probes had been repeated to avoid the tractor shadow on the images taken by the machine vision system. To obtain accurate results the illumination conditions had to be good. To avoid this strong dependency, we could have used a torch, connected to the tractor battery. In the first probes, we also adapted the tractor speed to 0.7km/h to make sure that the vision system was working correctly. To obtain precision information from GPS it was also necessary to choose fields where there were no big elements such as hills, in order to avoid reflections in the satellite signals.



7a



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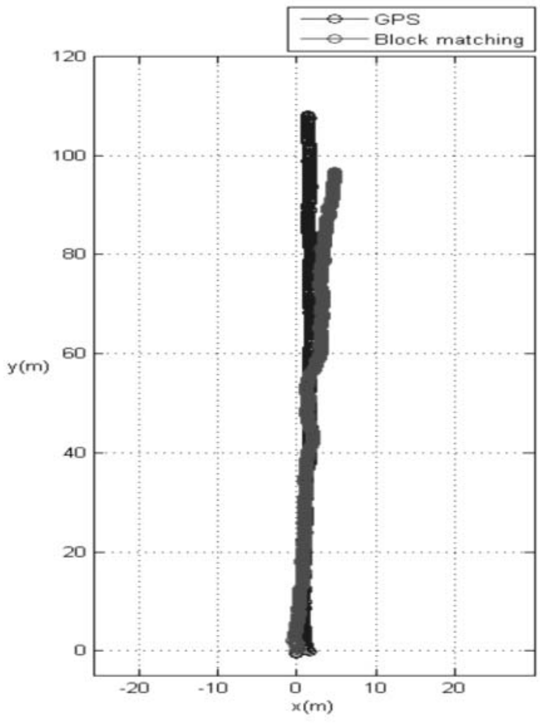

7c

Fig. 7. Trajectories of machine vision system and GPS in (a) Stubble field, (b) Ploughed field, (c) Sunflower stubble field

Conclusions

The objectives of this block matching and GPS research were all accomplished.

First, the block matching implementation was tested to obtain the minimum block size and the maximum block step. The simulation results were that a minimum 41x41 pixels block size and a maximum 4 step were needed to ensure a minimum of effectiveness. This parameters permit to limit the machine vision process time and to get a high matching effectiveness ratio.

The vision system was able to detect satisfactorily the tractor trajectory along the row-crop. These trajectories also match with GPS data. In little movement vision trajectory is more accurate than GPS. Vision and GPS system can be used together to increase the precision in the movement detected. In future researches, curve trajectories can be tested to know how the vision system performs. The vision system also can be modified to permit the tractor to move at a speed over 0.7 km/h (0.435mile/h).

Comparing the trajectories between tested fields,

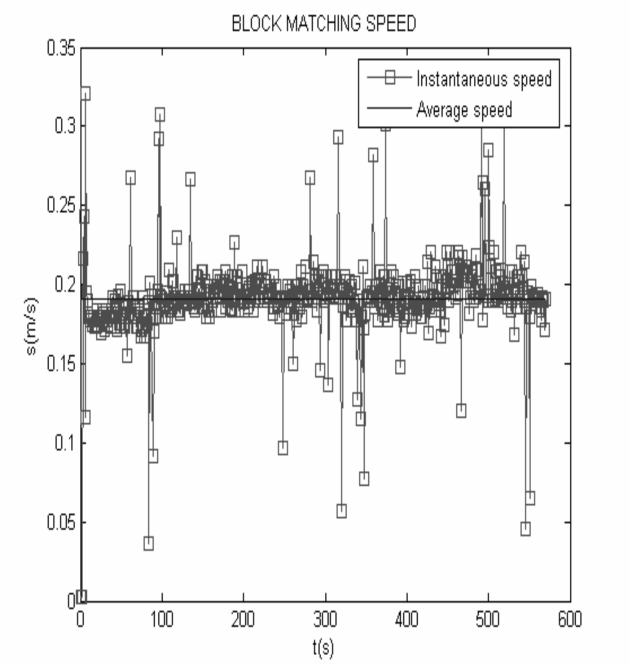

Fig. 8. Instantaneous and average speed in block matching algorithm

ploughed field offered better results due to the texture, which is crucial in matching effectiveness. Ploughed field has stones, which help to detect moved blocks easier than straw in the stubble field and sunflower straws in sunflower field.

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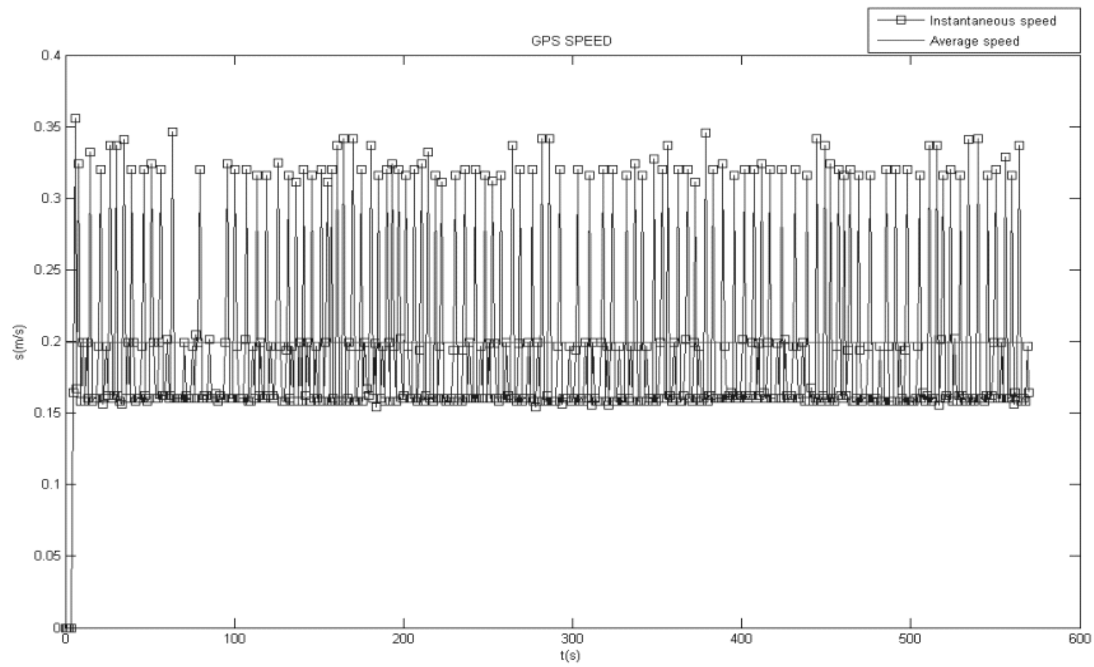

Fig. 9. Instantaneous and average speed with GPS while the machine vision was processing

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