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COMPUTER VISION-BASED SYSTEM TO WORK OUT ACCURATE PALET POSE LOCATION IN AUTONOMOUS FORKLIFT TRUCKS

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Abstract.-

This article describes the work package executed in the Institute of Informatics and Automation concerning the design and tune-up of the computer vision system of an automated forklift truck based on another project [1]. The project has been financed by the CeRTAP consortium of the Catalan Government, which is in charge of making agile the technology transfer between universities and the industrial field.

The computer vision system consists of an infrared laser source that projects a plane roughly parallel to the floor. A camera located thereinbefore the laser source and fitted out with an infrared filter grabs an image of the nearby foreground. The image is adequately processed to detect the pallet and compute its position and orientation with respect to the coordinate system of the truck, so that the truck can fork it autonomously.

Key words.- Forklift automation, 3D Reconstruction, Camera calibration.

1 INTRODUCTION

Computer vision has not been used in general applications due to its lack of robustness in the presence of illumination variations and also due to computer complexity. Actually, autonomous navigation is usually based on fusing ultrasonic sensors and odometer data. Recently, range finders based on time-of-flight principle has experimented intentness despite costliness. However, computer vision shows a desirable performance in specific applications. For instance, it has been widely used in industrial inspection [2]. Moreover, some efforts have been done using structured light in order to reduce computer complexity [3].

The CeRTAP consortium was created in 1996, is supported by the government of Catalonia and is in charge of facilitating the technology transfer between universities, research centres and industry. CeRTAP joins together 13 research groups of several universities and research centres with more than 200 investigators and is supporting 5 technology transfer projects. This paper is focused on one of these projects: the automation of a forklift truck to automate the tedious task of loading pallets in industrial pick and place applications. The Institute of Informatics and Applications is in charge of the computer vision system that should detect the pallet in the nearby foreground of the truck. Hence, the objective of the project is to develop an autonomous forklift truck able to segment the pallet in the image, compute its pose with respect to the vehicle and calculate the trajectory to fork it.

The article is structured as follows. First, section 2 deals with the project specification and describes the computer vision system proposed. Section 3 is focused on image processing and pallet segmentation in the 2D image. Section 4 describes the related geometry and system calibration with the aim of computing the 3D pose of the pallet. Finally, section 5 discusses some experimental results. The article ends with conclusions.

2 PROJECT SPECIFICATION AND SYSTEM DESCRIPTION

The objective of the project is to detect the 3D position and orientation of an standard EPAL pallet of 800 mm x 1200 mm located in the nearby foreground of the truck in a range of 700 mm up to 1500 mm with an accuracy larger than 10 mm in position and 2º in orientation. The aim is to give the loading trajectory that the forklift truck should follow in order to fork the pallet.

The specification of the problem considers the following situations:

1. A single pallet is present in the image.
2. The pallet position is in a range between 700 mm and 1700 mm.
3. The pallet orientation is in a range of ± 20º with respect to the forking area of the pallet.
4. The whole pallet is completely imaged by the camera.
5. The loading area is illuminated with artificial light free of the infrared wavelength from the sun.

The problem has been solved using computer vision consisting of an infrared laser and a camera with an IR filter. The laser has an output power of 1 mW. (EyeSafe), 850 nm. of wavelength and 80º of aperture. The 1mW output power constraints the use in distances between 250 mm and 2000 mm. The camera has been fitted out with optics of 3.5 mm, also an IR 850 nm. filter is used to filter the infrared response of the camera. Optics permits to capture images with a large vision scope covering the whole loading area where the pallet is located.

The laser projects a plane roughly parallel to the floor which intersects with the loading side of the pallet producing three collinear straight segments which are projected through the optics of the camera and onto the image plane. The camera is fixed in the top of the truck at 1200 mm with an angle of minus 15º from the floor plane grabbing and image of the foreground area of the truck.

3 IMAGE PROCESSING AND PALLET SEGMENTATION

Image processing includes noise reduction, image enhancement and edge detection with the aim of computing the straight line equation of the laser in the image and hence the skid blocks of the pallet loading area.

The calculation of the laser's line equation is done with an undistorted image where lens distortion has been previously removed by using the coplanar method of Tsai [4]. Lens distortion is explained in section 4. Hereafter, the first problem to solve is to determine the threshold of binarization. This threshold is chosen depending on illumination conditions and has to be appropriate for every pallet location in the range of considered distances and orientations.

The first option was to calculate the laser line equation by means of a linear regression. However, linear regression was discarded because it was quite sensitive to noise. Besides, the implementation of the Hough transform proposed by Duda and Hart exhibits a robustness in the presence of noise [5].

Once the laser line equation was calculated, the threshold is decreased in order to obtain an image where all the segments of the pallet appear even whether the noise increases. The threshold should be low enough to come up with all the laser projections at any given distance. Nevertheless, the image will contain a lot of noise that would affect the segmentation if it is not considered. Hence, the scanning area searching for the pallet segments is reduced along the line calculated before. This process consists in going over the line and checking whether a pixel is part of a segment or not.

The scanning process begins in the middle of the image and a scanning window is moved to the left and to the right. This window identifies if the point that is being processed is black (non-active) or white (active).

The window used (1x7) is centered in the pixel that belongs to the line. If the number of blacks points in the window, of the total checked, is bigger than a percentage (85%), this point is considered black, otherwise is considered white. Then, white points are analysed to determine whether they are part of the ground or noise. In order to overcome this task, 2 windows (1x15) scan parallel to the line the slightly shifted upwards and downwards. Hence, a white point is set to black if one of these windows has a certain number of white points (maximum=15, tolerance=2).

Moreover, if during the scanning process the number of white points consecutively classified as black is larger than a maximum (we have chosen 5), the scanning in that direction is cancelled. This circumstance emerges when the window reaches the border of the pallet, so the scanning points are part of the ground which can be classified whether black or white depending on the colour of the ground. The next image shows this case:

Figure 1. The image show the laser line boundary detection.

Finally, the last step involves a close operation on the segments of the pallet caused again by noise. Then, the line is scanned to detect the distance between 2 consecutive points (in the *x* axis). If this distance is greater than a maximum, the first pixel is discarded. However, when the distance is minor, the pixels between these 2 points are considered white. Then, the number of segments is checked. If the number of segments detected are lower than expected, the threshold will be decreased and all the process is repeated. Besides, if the number of segments is greater, the shortest segment is considered as noise and so discarded.

Figure 2 show the whole process of laser straight line segmentation. Figure 2a show the captured image which intensity and contrast has been modified with the aim of showing up the detail. Figure 2b show the obtained results, the image is printed in negative to enhance visualization.

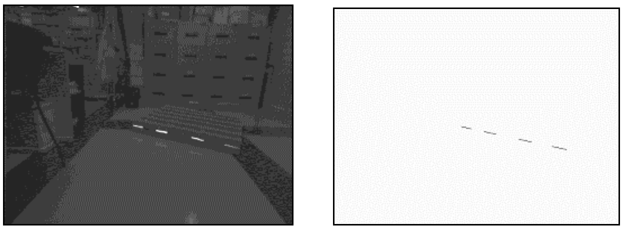

Figure 2. An example of captured image and the obtained results.

4 GEOMETRY AND SYSTEM CALIBRATION

Once the segments of the pallet are detected, the distance and orientation of the pallet with respect to the forklift truck can be computed. The distance is calculated with respect to the mass centre of the pallet related to the truck coordinate system, while the orientation is related to the y-axis of the truck coordinate system, as shown in figure 3. The whole process is explained in the following paragraphs.

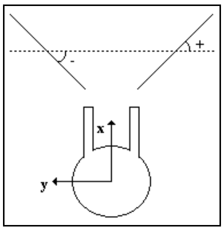

Figure 3. Truck coordinate system and orientation computation.

First of all the system has to be calibrated off-line. The calibration process is divided in two parts. First, the parameters to remove lens distortion are calculated. Second, the reference lines used to calculate the distance are acquired.

The first step is overcome by using the coplanar method of Tsai, which gives the first order parameter of lens distortion. The second step is overcome placing the pallet at distances (between 70 and 150 cm. in increments of 10 cm.). For every position, an image is captured and the straight line equation of the laser is computed. Once the whole process is completed, linear interpolation is used in order to cover the whole image and distance range.

Then, for any acquired image the two farthest end points of the segments have to be detected by searching for the two pixels whose x coordinate is larger and smaller, respectively. Then, with the *y* coordinate of these pixels, we apply 3 calculations. To do this, the *y* coordinate has to be expressed respect x=0 because the lines of interpolation are calculated for this position.

1.- The first calculation converts the coordinates *y* as a function of the average slope of the reference lines and calculates the pallet distance for the given image from these new coordinates:

```
y=y_pixel-average_slope_all_lines*x_pixel;
aprox1_dist=a[i]*y+b[i];
```

Where a[i] and b[i] are the parameters of the line interval that contains *y*.

2.- The second calculation is done with the average slope of the 2 reference lines that contains the distances obtained in the previous pass:

```
y=y_pixel-((slope[i]+slope[i+1])/2.0)*x_pixel;
aprox2_dist=a[i]*y+b[i];
```

Where slope[i] and slope[i+1] are the reference line slopes that contain *aprox1_dist*; and a[i] and b[i] are the parameters of the line interval that contains *y*.

3.- The last calculation is done with a weighting of the slopes of the 2 reference lines that contain the distance calculated in the previous pass. The weighting is calculated with respect to the distance to the reference line distance:

```
coef_pond1= (dist[i+1]-aprox2_dist)/(dist[i+1]-dist[i]);
coef_ponf2=1-coef_pond1;
weighted_slope=slope[i]*coef_pond1+slope[i+1]*coef_pond2;
y=y_pixel-ponderated_slope*x_pixel;
aprox3_dist=a[i]*y+b[i];
     Where dist[i] and dist[i+1] are the distances of reference that
     Contain the distance aprox2_dist; slope[i] and slope[i+1] are
     the reference line slopes that contain aprox2_dist; and a[i] and
     b[i] are the parameters of the line interval that contains y.
```

After obtaining the distance of both farthest end points, the computed distance is given by averaging them:

$$d = \frac{\text{dist\_left\_extreme} + \text{dist\_right\_extreme}}{2}$$

Then, the orientation is easily computed by known the distance (d) and the size of the real size of the pallet:

$$\alpha = \sin^{-1} \frac{\left|\text{dist\_left\_extreme} - \text{dist\_right\_extreme}\right|}{\text{pallet\_width}}$$

where, if dist_left_extreme > dist_right_extreme then $\alpha = \alpha \cdot (-1)$.

5 EXPERIMENTAL RESULTS

A C++ application for QNX has been developed to study the performance of the whole process. The forklift has been implemented in a Pioneer 2 DX mobile robot of ActivMedia, the camera has been assembled on its top and the laser at the bottom of the robot.

Several situations of distance and orientation have been tested with the robot in the laboratory, where the environmental conditions have been adapted to simulate an industrial warehouse.

5.1 Calibration Precision

In order to calculate the calibration error, the discrepancy between real and calculated distance at the calibration distances, is calculated and shown in the following table.

Real	Approx.1	Error1	Approx.2	Error2	Approx.3	Error3	Approx.4	Error4
70	70,46	0,46	69,815	-0,185	69,75	-0,25	70,285	0,285
80	80,01	0,01	80,01	0,01	79,785	-0,215	80,409	0,409
90	90,15	0,15	90,29	0,29	89,635	-0,365	89,564	-0,436
100	99,775	-0,225	100,33	0,33	99,68	-0,32	100,390	0,390
110	110,435	0,435	110,37	0,37	109,41	-0,59	109,542	-0,458
120	119,12	-0,88	121,91	1,91	119,565	-0,435	121,036	1,036
130	129,74	-0,26	128,65	-1,35	130,88	0,88	131,217	1,217
140	139,72	-0,28	140,815	0,815	138,76	-1,24	140,625	0,625
150	148,91	-1,09	149,075	-0,925	150,09	0,09	150,710	0,710

Results exhibit a calibration average error of 0.5535 cm. and a standard deviation of 0.426 cm.

5.2 Interpolation Precision

The following table show a part of the obtained results when the pallet is located at different distances and orientations. In such situations, the average error is 0.61 cm and standard deviation 0.56 cm in distances, and 0.98º and 0.81º in orientation.

DISTANCE (cm.)			**ORIENTATION (º)**		
Real	**Approximation**	**Error**	**Real**	**Approximation**	**Error**
72	72,554078	0,554078	-22,8	-22,277898	0,522102
85,25	85,773541	0,523541	-18,9	-17,141478	1,758522
91	92,794256	1,794256	-13,89	-14,527021	-0,637021
109	109,638264	0,638264	-7,47	-7,138016	0,331984
127	127,135473	0,135473	0	0,061838	0,061838
132	132,637842	0,637842	8,6	8,369396	-0,230604
140,50	141,066808	0,566808	11,53	12,255845	0,725845
155,50	155,941062	0,441062	18,05	18,839770	0,78977
161	161,272553	0,272553	26	25,673472	-0,326528
175	174,928971	-0,071029	37	37,670187	0,670187
AVERAGE ERROR		**0,61**	**AVERAGE ERROR**		**0,98**
ST. DESVIATION		**0,56**	**ST. DESVIATION**		**0,81**

6 CONCLUSIONS

This article describes a pallet localization system useful for autonomous forklift trucks in industrial environments when the pallet is close to the truck. The detection is based on image processing using the infrared laser projection that intersects with the loading side of the pallet.

The main problem found has been the use of infrared light. Constant illumination conditions are needed to obtain the best results. Using a low power laser, there is the problem of noise introduced by a powerful source of infrared light (as the sun). For this reason, the pallet detection has been implemented in two phases. In the first one, the laser line equation is calculated and in the second, the segments of the pallet are obtained.

The error is independent of distance and orientation, for this reason, the truck can realize the trajectory to fork the pallet without calculating the pose when is approaching the palet.

The system could be improved implementing the algorithm in hardware. The system takes about 5 seconds to calculate the distance and orientation of the pallet.

7 REFERENCES

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