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EXPERIMENTAL TESTS OF AN ALGORITHM OF ROLL AND PITCH ESTIMATION USING ONLY OPTICAL INFORMATION

Ua Дослідження відноситься до проблеми проведення експериментальних випробувань розробленої вимірювальної системи на базі зображення.

Проведено серію експериментів для з'ясування характеристик тестової камери. Крім того, для виявлення властивостей розробленої системи проведено серію тестів у контрольованому середовищі. В якості базового датчика використано тривісний акселерометр, який виконував роль інклінометра.

Результати обробки реальних зображень горизонту показали, що розроблена система виявляє лінію горизонту в більшості випадків правильно за винятком складних ситуацій перекриття горизонту та малого перепаду контрасту навколо області лінії горизонту.

Ru Исследование относится к проблеме проведения экспериментальных испытаний разработанной измерительной системы на базе изображения.

Проведена серия экспериментов для определения характеристик тестовой камеры. Кроме того, для выявления свойств разработанной системы проведена серия тестов в контролируемой среде. В качестве базового датчика используется трехосный акселерометр, выполняющий функцию инклинометра.

Результаты обработки реальных изображений горизонта показали, что разработанная система определяет линию горизонта в большинстве случаев правильно за исключением сложных случаев перекрытия горизонта и малого перепада контраста вокруг области линии горизонта.

Introduction

Horizon line recognition and measurement of its position on an image can be useful for control of all kind of unmanned aerial vehicles (UAV) which nowadays are widely used not only in the military and other sectors of the national economy but also increasingly attract attention in a leisure industry.

Some of the approaches to horizon line recognition on an image are presented in the works [1]-[5] which can be roughly divided into: based on analysis of histogram of color information [1], [3]; based on unsupervised classification with different feature extraction techniques [5]; based on edge detection [2], [4].

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One of the most promising approaches from our point of view is proposed in the work [4] which makes use of morphological operators as well as Sobel edge detector [6]. The main idea of the algorithm is that the filtering should be performed in parallel for all three color components of the RGB image in order to obtain the maximum amount of information from each color component. Based on the above mentioned work another algorithm was developed which was described in details in [7]-[10]. It makes use of binary circular mask application in order to enhance the accuracy of horizon line detection.

Goals and delimitations

The goal of this work is to carry out some experimental tests of an image-based measurement system that is able to detect horizon line and calculate it relative position on the image in terms of roll and pitch angles, which assumed to be attitude angles of the camera. The main limitation of the developed system is that it is unable to measure the attitude angles of the camera when the horizon line is outside of the camera view.

Image-based roll and pitch estimation

The values of pitch and roll angles of a camera can be estimated using horizon line position on an image as shown in Fig. 1. Roll angle is proportional to the rotation of the horizon line around image central point (Fig. 2) while the pitch angle can be calculated using the law of linear perspective and value of camera's focal length (Fig. 3).

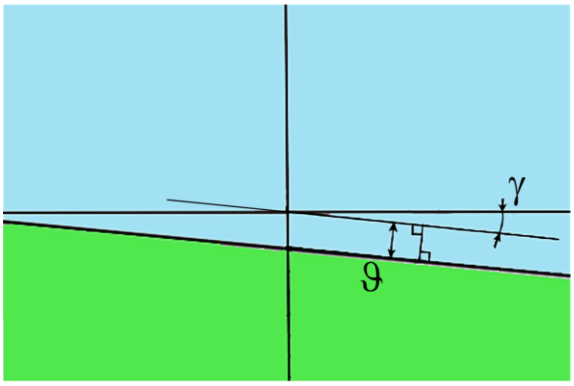


Fig. 1. Horizon line imaging: pitch (ϑ) and roll (γ) angles estimation

In Fig. 2 the line H_1 represents the position of the horizon line when the camera roll angle is equal to zero.

According to Fig. 2 the equation for roll calculation can be written as:

$$\gamma = \operatorname{arctg}\left(\frac{x_2 - x_1}{y_2 - y_1}\right), \tag{1}$$

where $(x_1, y_1), (x_2, y_2)$ are the coordinates of the points of intersection of horizon line H and image boundaries.

According to Fig. 3 the equation for pitch calculation can be written as:

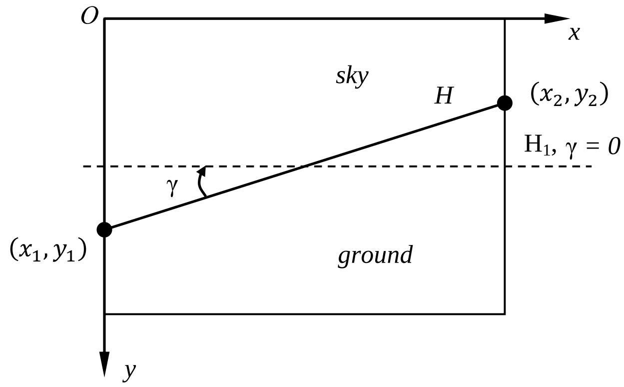


Fig. 2. Roll angle formation on an image

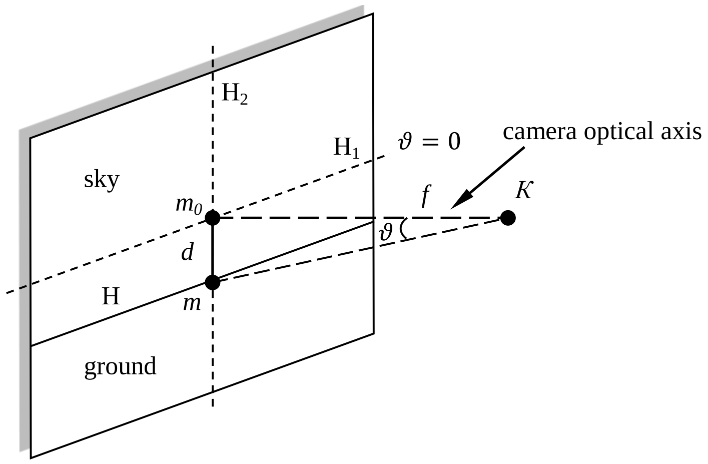


Fig.3. Pitch angle formation on an image

$$\vartheta = \operatorname{arctg}\left(\frac{m - m_0}{f}\right), \tag{2}$$

where *f* is the focal length of the camera in pixels, *m* is the intersection point of the line that connects central point of the camera *K* and line *H*, m_0 is the intersection point of the line that connects central point of the camera *K* and line H_1.

In the work, it is assumed that the positive roll value is obtained from the clock-wise rotation of the horizon line as well as the positive pitch value is obtained when the middle point of a line that represents the horizon falls under the central point of the image.

The described above relationships are implemented using matlab-language and form the algorithm of roll and pitch values estimation.

The algorithm of horizon line recognition was presented in details in our previous works [7]-[10]. It should be noted that it operates based on the number of assumptions, among which:

– the horizon line appears in the image as a longest straight line;
– the sky and ground areas have different color representations;
– the sky area is brighter than ground area.

In this work the RGB images, of the size 640x480 or 720x480 pixels are used as input for an image-based measurement system that consists of two described algorithms. Such an input is chosen because it allows faster processing since it is carried out separately for each color component.

Camera calibration

For experimental tests of the system camera Nikon D3100 together with lens Tamron AF 18-200mm F/3.5-6.3 XR Di II LD Aspherical are used. Important for our study camera's characteristics are presented in Table 1.

***Table* 1.**

Nikon D3100 technical characteristics

Image sensor type	CMOS
Effective pixels	14.2 million
Image sensor size, *mm*	23.1 x 15.4
Total pixels	14.8 million
Image size [Large], *pixels*	4608 x 3072
Pixel size, *μm*	5

The images are captured with constant focal length and have the characteristics shown in Table 2.

***Table* 2.**

Captured image characteristics

Image size, *pixels*	4608 x 3072
Bit depth	24
Vertical resolution, *dpi*	300
Horizontal resolution, *dpi*	300
Color	sRGB
F-stop	f/4
Exposure, *s*	1/40
ISO	100
Exposure bias, *step*	0
Aperture	4
Focal length, *mm*	28

Calibration of the camera is performed using the Camera Calibration Toolbox for Matlab [11]. For the calibration, 20 images of a calibration chessboard made from fixed camera position are used. Each square of the chessboard has a size of 20x20 mm. To obtain calibration images the chessboard at various angles to the image plane is installed as it is shown in Fig. 4.

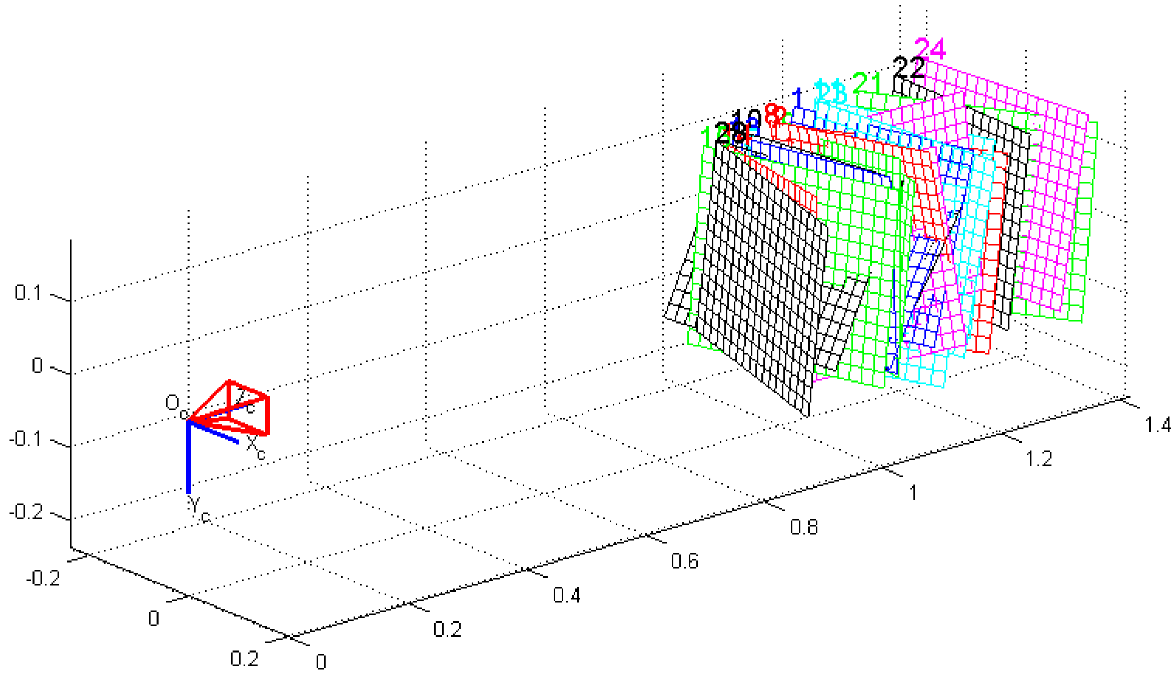


Fig. 4. Positions of calibration chessboard for which are obtained calibration images

The results of calibration presented in Table 3. An example of calibration image as well as its undistorted version are shown in Fig. 5.

***Table* 3.**

Calibration results

Focal length, *pixels*	$fc = [\ 5902.01;\ 5892.37\ ] \pm [23.51; 23.18]$
Principal point, *pixels*	$cc = [\ 2250.11;\ 1292.83] \pm [17.38; 17.03]$
Distortion coefficients, *pixels*	$kc = [-0.02;\ 0.66; -0.01;\ 0;\ 0] \pm [0.01;\ 0.29;\ 0;\ 0;\ 0]$

Fig. 5. Initial and undistorted calibration image

In Table 3 maximal radial together with tangential lens distortions are represented by elements of kc, which are rather small.

Experimental pitch and roll estimation

As a reference for the roll and pitch estimated by developed program a built-in 3-axis accelerometer of phone Nokia Lumia 710 is used. The sensitive axis of the accelerometer are approximately located in the same horizontal plane as a bottom of the camera is located that allow us to get the reference values of roll and pitch angles of the whole system. During the experiment, 16 test images of a scene that include a long line element (simplified horizon line) at different roll and pitch angles are obtained. The example of the test image is shown in Figure 6. In order to accelerate the processing the test image size is reduced to the resolution 720x480 points. Also, it should be noted that the part of test image that represents the ground area was artificially darkened in 25 units in order to meet the made assumptions.

Fig. 6. Test image with simplified horizon

The results of horizon line detection on 16 test images (Test image 1-16) are presented in Fig. 7.

Fig. 8 shows the software estimated values of camera roll and pitch angels (blue bars) with respect to accelerometer data (red bars) as well as estimation errors for these angles. It should be noted that here estimation errors appear rather as a difference between accelerometer measurements and values calculated by the developed software than absolute measurement errors.

In order to understand how the system will perform in conditions more close to reality, another set of the images (Test image 17-28) representing the real view of the horizon line in different weather and lighting conditions was processed by developed software and the results are shown in Fig. 9. Also, the approximate values of the corresponding roll angle were calculated. In this case, the calculation of the pitch angles is inappropriate since no information about focal lengths is available.

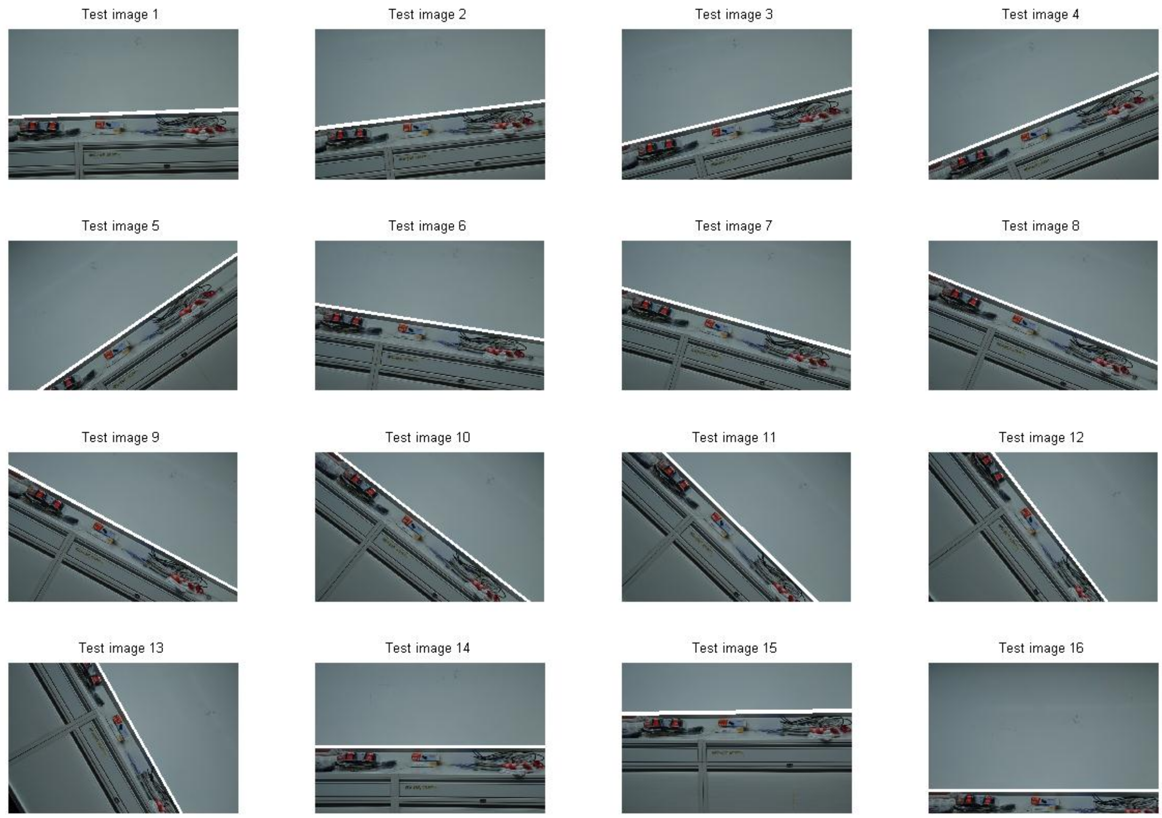
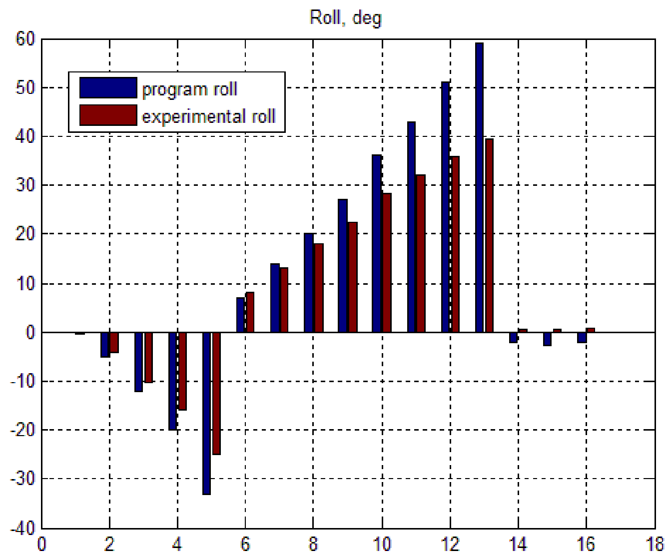
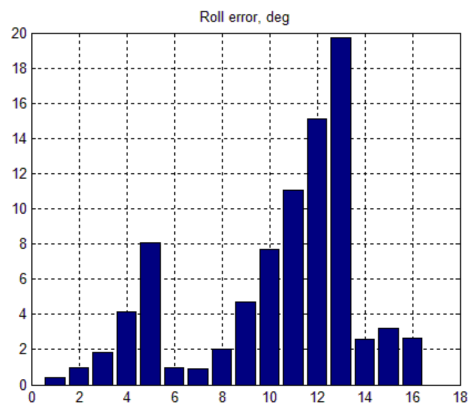


Fig. 7. Results for line detection for 16 test images

Visual examination of Test image 18 shows that the horizon line was detected improperly. It occurred because of a weak contrast drop between the sky and water areas as well as high contrast drop between water and ground areas. Also in Test image 23 the improper detection is due to overlapping of the horizon line by the hills. In all other cases, the horizon detection is performed correctly.





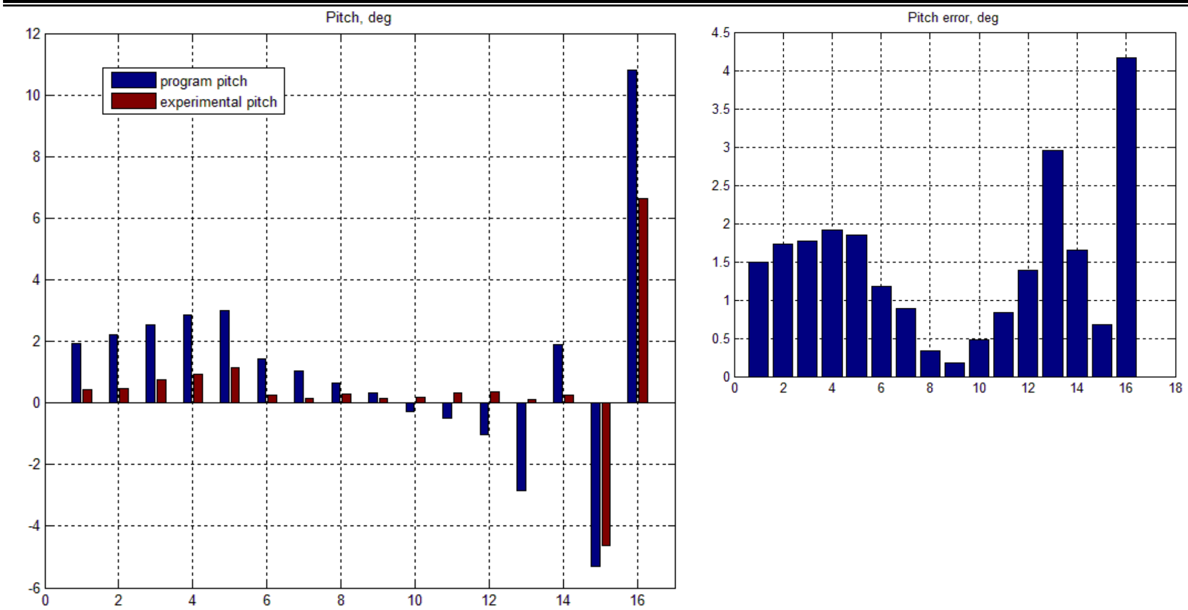


Fig. 8. Software estimated values of camera roll and pitch angels with respect to experimental data and angles estimation errors for 16 test images

DISCUSSION and CONCLUSIONS

In this work, the set of experimental tests of an image-based measurement system that is able to estimate camera angular position (roll and pitch angles) by means of horizon line detection on the image is carried out. At the heart of the system lies horizon line recognition algorithm that is built according to the assumptions that the horizon line appears in the image as a longest straight line; the sky and ground areas have different color representations; the sky area is brighter than ground area. The algorithm showed good results in line detection from the point of view of human vision on a sequence of the test images obtained under controlled conditions.

In order to understand what kind of the distortions the camera lens introduces and how they affect the obtained images the calibration was carried out. It was discovered the lens introduces very small distortion (< 0.7 *pixel*) that mostly appears in the corners of the image. In the developed software instead of using re-projection of each test image the binary circular mask that eliminates the most distorted areas of an image are used. The usage of the mask can also accelerated the image processing.

To evaluate the accuracy of the developed system in roll and pith estimation the accelerometer data were used as a reference. Estimation errors were assigned rather as a difference between inaccurate accelerometer measurements and values calculated by the developed software than absolute errors. The difference between software calculated and measured by accelerometer values in the roll estimation is in the range between 0,5° (Image 6) and 19° (Image 13) and exponentially increases with increasing rotation angle. The difference in pitch estimation is in the range between 0,2° (Image 9) and 4,1° (Image 16) and some cross-correlation with roll angle is observed. Such results can be caused also by the imperfection of accelerometer as an inclinometer. Thus, the additional tests with more accurate reference units should be carried out.

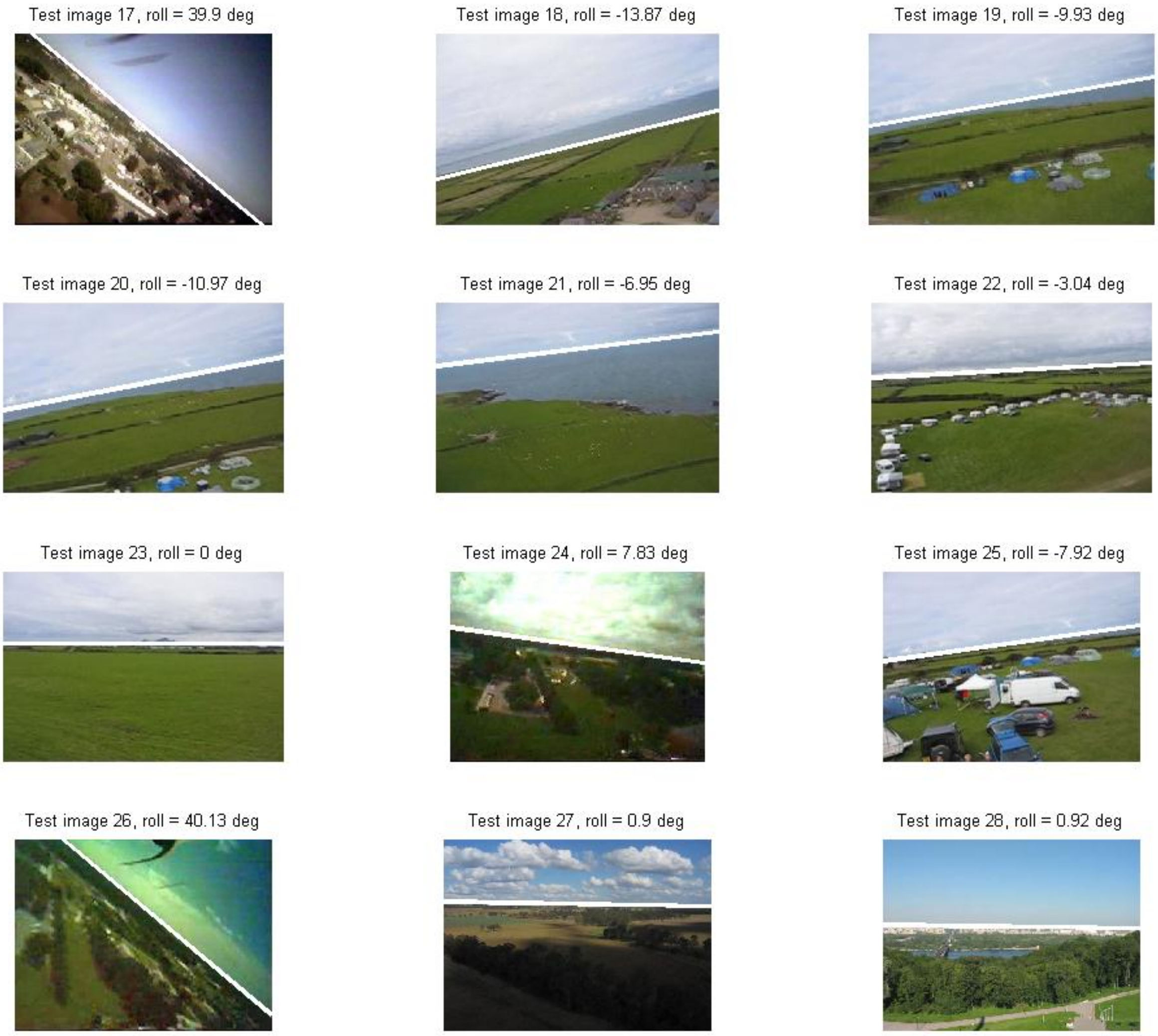


Fig. 9. Results obtained on a set of landscape images

Processing results of real horizon images showed that the developed system detects the horizon line in most cases correctly excluding the hard cases of overlapped horizon and low contrast drop around horizon line area.

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