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Possibility of use a smart camera as a non-contact sway sensor in insufficient light condition – case study

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ABSTRACT

Contemporary handling operation efficiency and safety in cargo transportation realized by the cranes mainly depends on counteractions taken against undesirable phenomena's such as payload swing. The research problem connected with anti-sway problem has been extensively researched over the past decades. Generally the proposed solutions can be classifying as an open and closed-loop control system. The close loop sway angle control system are strongly connected with necessity of physical measuring the angle of the swinging rope. The paper was focused on the non-contact method of measuring the angle of swinging payload with the image analysis technique use. However, in the statement the authors attention was focused on the issue related to the verification that infrared light illuminator can be used in built a non-contact vision sensor for the sway measure insensitiveness on actual exposure light conditions. All experiments and tests were conducted on the scaled physical model of overhead travelling crane with hosting capability of 150 kg.

Keywords: sway sensor, image analysis, night vision, smart camera

1. Introduction

One of the major problems of moving loads with the crane help form the industrial practice point of view involves on induce the free payload swinging effect [1, 2]. The described phenomenon were formed on as a result of the dynamic and/ or nature forces (such as wind) influence. Therefore any activities related with the oscillation frequency and the cargo amplitude counteraction, enabling precise positioning of the payload with reduce their unwanted sway effect to stabilize cargo trajectory are required [3].

In the scientific and branches literature the cargo stabilizing effect were achieved through more or less sophisticated method. However the most commonly there was used control theory with variety architecture of close-loop or open-loop control systems [4-7]. Main advantage of the open-loop control systems type contains possibility of eliminating the feedback. Although the close-loop control system ensures the robustness against envisaged disturbances, but their need of the feedback, so this type of system needs a physical sensor to measure the payload swing. That involves the difficulty oriented not only at hardware and measurement methods point of view but also used algorithms to obtain a final sway characteristic.

The presented in this paper non-contact sway sensor based on payload position measurement vision-based technique constitute an extension on previously described vision system architecture [1, 8], extended by infrared adapted to night vision solution to achieve a non-contact sway sensor insensitive on insufficient light condition. Moreover, a camera sensitivity issue was described as a crucial parameter which allows to obtain image frame in insufficient light condition.

2. Camera sensitivity issue

Light (sunlight as well as others artificial light sources) constitute a foundation of the image quality captured by the cameras [9]. However overabundance dose of light can overexpose the image but generally the image quality will be better when more light is available in the scene. Analogously if the amount of light is insufficient, the captured image will be too dark or very noisy. The amount of light that is required to produce a good-quality image depends on many factors among others camera sensitive. Summarizing if the scene is darker, the sensitive of the camera has to be grater. The sensitivity of the camera is affected by the number of parameters. The first set of them are associated directly with used component in camera architecture, except for a parameter like image sensor module type, size with their grain geometry, camera frame rate and shutter speed and important SNR (Signal to Noise Ratio) factor, some type of camera may have many hardware and software function supporting sensitivity like an auto-iris or binning function available in the CCD matrices. The second set of the parameters affecting on camera sensitivity are connected with used optical architecture of the used lens type and their parameters like a f-number value.

2.1. Camera architecture and their sensitivity effect

The basic each digital cameras component was an image sensor chip. The photosensitive matrices can be manufactured in a technique makes it more or less sensitive to light. Generally the most popular photosensitive sensor modules were manufactured as CCD (Charge-Coupled Device) or CMOS (Complimentary Metal-Oxide Semiconductor) technique. In the scientific [10] and branch [9] literature it is possible to find a lot of studies on use of both types. Except for of the used image sensor chip technology important parameters concern their dimension. The contemporary image sensor was mounted in variety kind of contemporary devices in variety sizes [11]. Size of the image sensor play an important role because each image sensor has small elements that are very sensitive to light. If the more light falls on it, the stronger and better electric impulse is possible to produce. The bigger elements can collect more light than the smaller one in the same period of time. In fact, the image sensor size and single photosensitive grain diameter has effect on final camera sensitivity. Moreover, it is difficult to decide which type of sensor chip are better CCD or CMOS or how to characterize it [12]. However, CCD matrices has higher fill factor defined as a ratio of single pixel area to entire image sensor area than CMOS. Additionally CCD in comparison with CMOS image sensor has a lower noise floor, but unfortunately CCD drain more power during work. High advantage of CCD image sensor constitutes binning function possibility use improving SNR [13] by linking single pixel in the group and summed charges reported by all linked pixels as single pixel. Thus, the binning decrease entire image sensor resolution. In the Figure 1 it was presented CCD binning algorithm. The image resolution decrease what was presented in the Figure 2.

Frame rate is also known as frame frequency rate at which an imaging device produces single images so called frame. The term applies equally to the video cameras as well in computer graphics and various type of motion capture systems. Frame rate is most often expressed in frames per second (FPS) too and is also expressed in progressive scan devices as in hertz (Hz) unit. Frame rate is inseparably linked with camera shutter speed. By reducing camera shutter speed the frame rate are decreases too. By reducing frame rate the image sensor can absorb more light (therefore shutter speed has positive influence on camera sensitivity) to produce single frame. Unfortunately by reducing shutter speed it possible to increase camera sensitivity but anyway the frame may be blurred when recorded object was moved too fast. In the figure 2 it were presented the same scene with three different exposures time forced by the shutter speed. The images were taken with different shutter speed but to present the effect of the CCD binning for each images full 2x2 binning were applied. As a results the mother image was combined together with binning images.

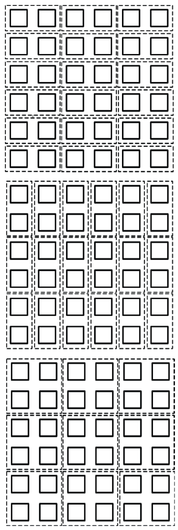

Fig.1. CCD binning: from the top: horizontal, vertical and both 2x2 binning function [own study]

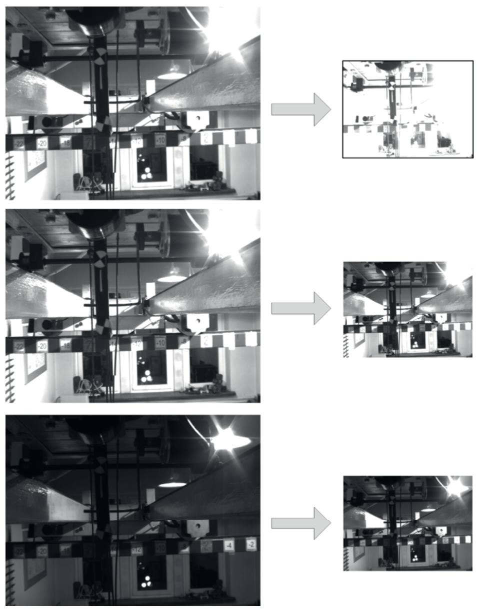

Fig. 2. Images taken with different shutter speed from the top: 1/15, 1/30 and 1/60 s and their equivalents in natural size (on the left side) after full 2x2 binning function applying [own study]

2.2. Signal to noise value

The SNR factor is a commonly used term characterizing the quality of the signal of a measuring system. In case of use image sensor SNR ratio is given by the ratio of the light signal (*S*) to the sum of the noise signal (*N*) [14] presented in expression (1). Commonly the SNR value was expressed like factor expressed in decibels [dB] unit.

$$SNR = \frac{S}{N}, \tag{1}$$

In camera with image sensor the SNR must be interpreted like a ratio of generated number of the charge carriers proper signal to the total number of unwanted charge carriers noises. In image sensor a charge was produce as a result of bombardment photosensitive surface by the photons. Thus, the number of resulting number of electron carrying the signal is dependent on the scene illumination intensity incoming photons producing. This can be described as equation present below (2):

$$S = \frac{\Phi}{h_\nu} \cdot t \cdot A \cdot \eta, \tag{2}$$

where:
Φ – light power [W/m^2],
h_v – photon energy [Ws],
t – exposure time [s],
A – pixel area [m^2],
η – quantum efficiency.

In the same way it is possible to describe noise signal (*N*) which comes from photon or Poisson noise associated with the particle nature of the light (3):

$$N = \sqrt{\frac{\Phi}{h_\nu} \cdot t \cdot A \cdot \eta}, \tag{3}$$

Additionally it is necessary take into account other sources of possible noise comes from image sensor like noise raises during reading the information form image sensor and noise formed by image sensor. However, the final noise equation has the form presented in equation (4):

$$SNR = \frac{\frac{\Phi}{h_\nu} \cdot t \cdot A \cdot \eta}{\sqrt{(\frac{\Phi}{h_\nu} \cdot t \cdot A \cdot \eta)^2 + n_{CCD}^2 + n_r^2}}, \tag{4}$$

where:
n_{ccd} – CCD image sensor electron noise,
n_r – read out image sensor electron noise.

2.3. Camera lenses impact on the sensitivity

From the camera sensitivity point of view in optical system architecture the most important role play the f-number parameter. In optic literature it is also known as aperture, focal ratio, f-ratio or f-stop) [15, 16]. F-number is the ratio of the focal length in reference to the diameter of the entrance lens pupil [17]. The f-number N is possible to calculate with use simple expression (5):

$$N = \frac{f}{D}, \tag{5}$$

where:
f – focal length of the considered lens [mm],
D – diameter of the entrance pupil [mm].

Establishing that is no change in light transmission efficiency through the small distance, the lens with a greater f-number produce darker images of the scene. The brightness of the acquired image in relative to the brightness of the scene decreases with the square of the f-number. Therefore, by doubling the f-number automatically we can obtain the brightness decreases by a factor four. The f-number is extremely useful because this value informs about the amount of light that arrives to the photosensitive sensor module. Same architecture and type of used lenses plays an important role in camera sensitivity issue too. A wide angle lens captures light from all over the scene, analogously a zoomed lens catches the light only from a small part of the scene. Naturally, the lens that is zoomed out gives a brighter image than one that is zoomed in. In normal exposure condition this difference is imperceptible but in very low light situations, the focal length of the lens affects the camera sensitivity.

3. Light illuminance disturbances free - noncontact vision base sway sensor architecture

In normal light condition image analysis method are good purpose for measure the sway angle of the swinging rope [18]. Unfortunately the light exposure is very dynamic parameter and difficult to measure. Additionally the presented previously solution [18] wasn't robust to work properly in low light situation. Even worse the minimum illumination interval wasn't determined.

3.1. Minimum illumination parameter

Minimum illumination parameter is strongly related with camera sensitivity issue and refers to the smallest dozen of light that can produce an image with useable quality for adopted image analysis algorithm. Many of the previously described in the chapter 2 camera factors can be manipulated like that the camera can collect more light even the scene isn't illuminated as well as in nominal condition. Minimum illumination is usually presented in lux (lx) unit. However, the process of measuring light sensitivity is complicated. There are several causes of this. The most important reason is determined by necessary of understanding a fact that under illuminance with lux meter help, the measuring method is itself no accurate, because lux meter and the cameras do not collect the same information about light. Thus when we talk about illuminance measure with lux meter, the reading have only information about the scene illumination in the point where the sensor was located. This information can only create a reference point about the amount of light collected by the camera but it is impossible to exactly determine it. To obtain information about an amount of light that is possible to gather by the camera and specify the range when it is possible to create a good quality image and when is not, were conducted an experiment set depending on measure illumination of the scene with and without the IR illuminator during twenty-four hours cycle. However, the average dozen of available amount of light in specific place is strong correlated with geographical coordinate, actual season and the whether condition. Additionally it is not possible to measure in the same twenty-four hour cycle scene illumination with and without IR illuminator which makes more difficult obtain characteristic interpretation. Nevertheless it was conducted an experiment depending on measure illumination of the scene with and without the IR illuminator during twenty-four hours period. To obtain the scene illumination the lux meter was fixed under the crane trolley in distance ~200 mm from camera lens in such a way that light sensor of the lux meter was in camera field of view (Fig. 3.). In the Figure 4 it were presented two types of illumination characteristic presented in the same logarithmic scale. The darker colour of the chart represents the results obtained without IR illuminator, while the lighter one are correlated with measurements with IR illuminator. It can be observed that in a large period of time (approximately 62% of the twenty-four hours period) the scene illumination doesn't allow perform effective image analysis (scene illumination in the range between 0.1-4 lx). Whereas applying the IR illuminator with twilight sensor reduce this problem what can be observed as characteristic peak (scene illumination at the 410 lx level) responsible for turn on the IR illuminator by twilight sensor when the amount of light isn't sufficient.

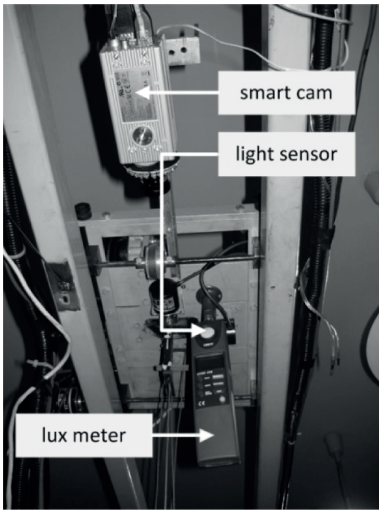

Fig.3. Twenty-four hours scene illumination test – lux meter position on the crane [own study]

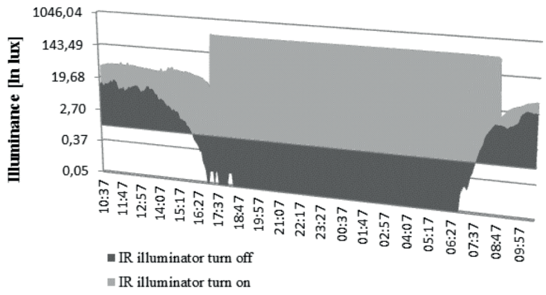

Fig.4. Twenty-four hours scene illumination characteristic with and without the IR illuminator [own study]

3.2. Infrared radiation as solution for insufficient light condition

Light is a form of electromagnetic radiation. The wavelength of visible to the human eye light is approximately in the range between 400 nm (violet colour) to 700 nm (red colour). However, some type of digital camera, especially black and white architecture can detect light outside human eye range even in so-called infrared range between 715 – 950 nm, what is useful during night time. Infrared illuminator with 36 IR diodes were built. The illuminator was equipped by photoresistor as a twilight sensor (Fig. 5.).

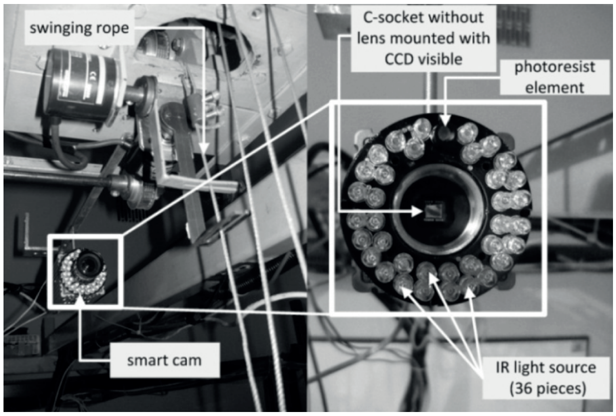

Fig.5. Infrared illuminator integrated with smart camera device [own study]

In the set of Figure 6-8 it were presented the images of the same scene taken in different light condition: in night time, with IR illuminator and in daylight. On the right side there were presented the tonal range of the pixels brightness for all images.

The histograms of the captured images (night image with IR illuminator compare with the daylight scene) are very similar. Any notable differences are mainly determined by the actual scene background. But in both cases the edges of all ropes are fully visible what is the most important from the vision-base non-contact swing sensor point of view. In presented configuration the vision-based sway sensor are full operational in twenty-four hours mode.

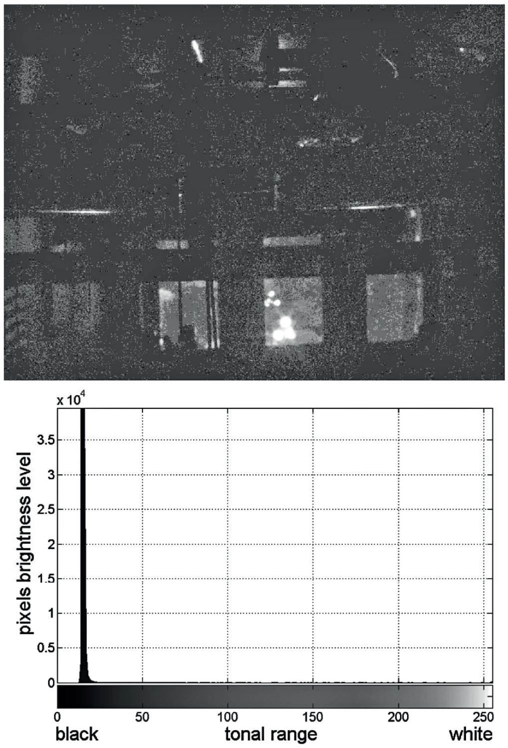

Fig.6. Image captured by the smartcam in the total darkness (scene illuminance below at 1 lx) and their histogram [own study]

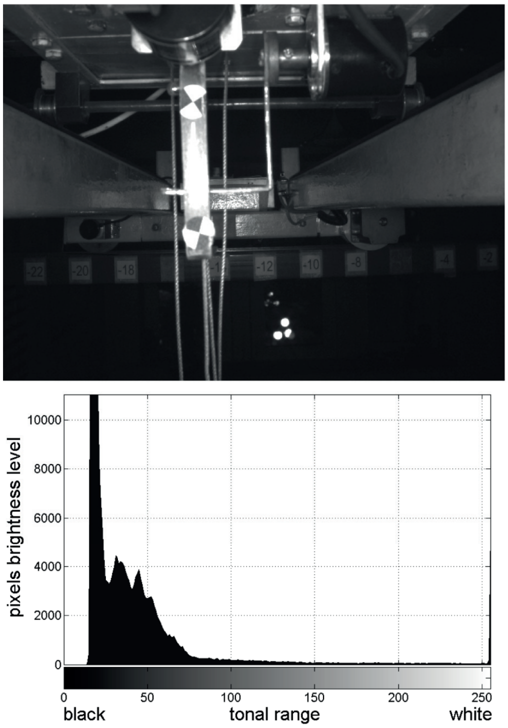

Fig.7. Image captured by the smartcam of the night scene with infrared illuminator on and their histogram [own study]

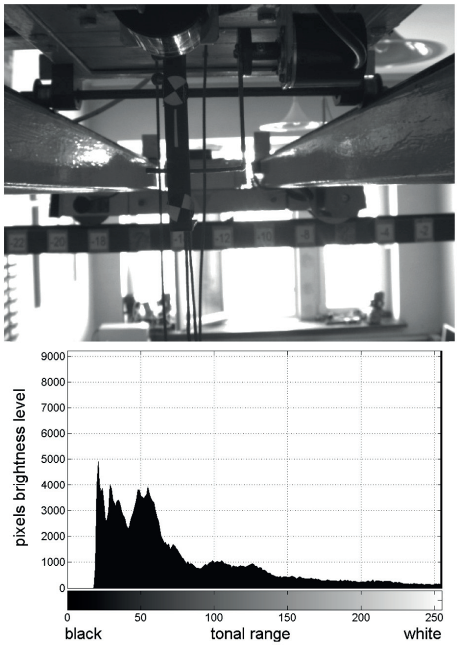

Fig.8. Image captured in the daylight condition [own study]

4. Conclusion

In the paper it was formed and described camera sensitivity issue. Unfortunately even the most sensitive cameras can have a problem in proper image acquisition in low light situation. The scale of the problem grows, when from the acquired images must be extracted some specific information on the image analysis base technique. Additionally in the paper it was presented a method solving the problem concerning an issue to use smart camera as a non-contact vision-base sway sensor in twenty-four hours mode. The problem was solved through the using image capture device with fixed IR illuminator with built in twilight sensor. However, in the statement the author's attention was focused on the issue related to the verification that infrared light illuminator can be used in built a non-contact vision-based sway sensor robust against light illumination variation. Finally the usefulness of infrared illuminator was confirmed.

The dynamic development of the machine vision systems type and the great potential of image analysis technique with regard to computing power grow including smart camera devices, constitute an interesting alternative to other variants sway sensors, especially when the vision sensor can work in twenty-four hour mode.

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