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THE APPLICATION OF IMAGE ANALYSIS METHODS IN SELECTED ISSUE SOLUTION DEDICATED FOR OVERHEAD TRAVELLING CRANE

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Abstract

The paper talk over the proposal of use a combined vision system architecture for solved well known issue occurring in material handling devices (MHDs) exploitation, especially in the crane devices. The described in the presented paper stereovision system for work space mapping and non-contact sensor type for rope angle swinging measure were a part of solutions enabling a full autonomous navigation system (ANS) realized by the overhead travelling crane. In the paper special authors care was dedicated on two issues. The first one was connected with MHDs workspace mapping with built three-dimensional model of their structure. The second part of the paper considering the possibility of attaches image analysis technique into non-contact rope swinging sensor architecture.

In this paper, two main problems were identified: crane workspace visualization and need of develop new type of anti-sway technique. For workspace, visualization technique of author's proposed, well known stereovision, but not in standard architecture (to compose stereovision picture one camera was use). In terms of anti-sway technique, authors choose close-loop control system. Thus was develop non-contact anti sway sensor. The common point of both developed methods (anti sway solution and workspace visualization) is vision methods.

At the end raises a following conclusion: vision systems and image analysis method are perfect not only in acquiring an information about crane workspace and potential obstacles dimension (stereovision), but also useful as a standalone measurements system of chosen and useful crane parameters.

All tests were conducted on the physical model of the scaled overhead travelling crane with 150 kg hosting capability.

Keywords: *image analysis; overhead travelling crane; workspace visualization; non-contact swinging sensor*

1. Introduction

Transport has been always play a stimulus role in the civilization development [1]. Due the fact, that transportation process of the cargo from the starting point to its destination requires a huge numbers of repetitive tasks. Desire of minimization of human oversight at the transportation process was a source of born one of first Autonomous Navigation Systems (ANS) [2]. Any type of the on board (embedded) solutions, integrated with the set of sensors and algorithms enabled autonomous perception, path-planning, other transport modes following capabilities, simultaneously allowing to the mother device at the same time to move independently in the workspace have huge signification, especially when the transport tasks have recurring character and requires repeatability and accuracy [3].

Full operative ANS designed for material handling devices constitutes the crucial issue of shaping the reliability [4], safety [5] of the modern MHDs [2, 6]. However, any activities enabling autonomous navigation (in relation to a specific transport devices type) needs solving a lot of problems connected with autonomous perception establish possibility [7], which allows selecting the optimum route trajectory (routing) with simultaneous resources commit between a variety of possible tasks generation (scheduling) [8-10]. The described problem of built any ANS system show first of all in necessary to identify the material handling operating space identification for allow safety and efficiency transportation process of the cargo from the starting point to its destination [11].

This paper addresses a problem of identification the operating space (with workspace digital virtualization) of specific transport mode – the overhead travelling crane (OTC). Functionality of workspace identification was achieved by use stereo vision system architecture [12-14] based on a single camera stereovision system architecture [15-17].

Nevertheless, the problem of efficiency transportation process (especially realized by the crane type devices) with the non-collision trajectory assumption, require to minimizing the payload swing suspended usually on the rope or chain. Thus, the core of a problem in realizing the ANS solution is obtaining the reliable anti-sway technique for the crane too [18]. Hence, the feedback control systems, based on the contactless detection of the payload sway with using image analysis method, realized in the real time mode was proposed. Additionally the proposed solution may be strong alternative for solution preferring open-loop control technique based on artificial intelligence (AI) method, fuzzy logic (FL) [19-20], genetic algorithms (GA) or even hybrid linked listed methods [8].

2. Autonomous perception system dedicated for OTC devices

2.1. Single camera stereovision system architecture

The OTC device can be described like a large workspace robot [21]. If we interpret the crane hook as robot effector, then is possible to equip cranes mechanisms into cameras for acquire pair of images for poses information about workspace and potential obstacles in stereovision mode [12]. The architecture of stereo vision system, which has been built on the laboratory stand – the scaled double-girder overhead travelling crane, was based on the single camera suspended under crane's trolley. The stereo pair is acquired as the sequence of snapshots of operating workspace during the crane/trolley movement, while the current location of the camera is identified through measuring the crane or trolley position using incremental encoders (Tab. 1). This approach guarantees identical focal length for each snapshot, and additionally the images baseline is closely parallel oriented to the image plane. To acquire the full stereo pair with one camera, the crane must make additional movements for changing the position and picking an extra picture. The main disadvantages of the presented solution (except extra movement) and equipment – encoders mounted on the crane (Fig. 1) are related with the time gap raising between the system taking a first picture [1], making movement and finally completing a stereo pair.

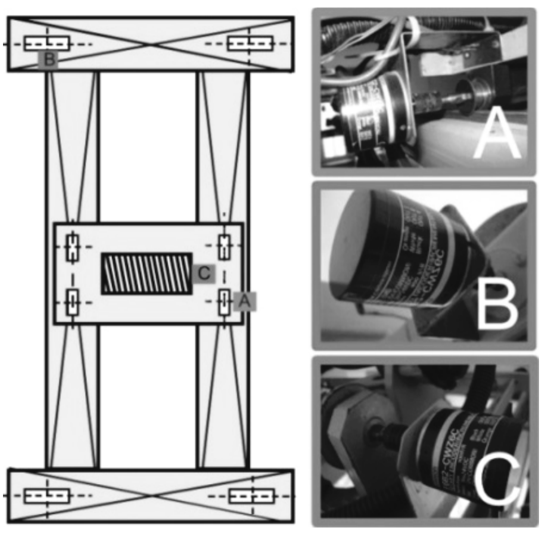

Fig. 1. The rotary encoders mounted on the scaled laboratory model of the overhead travelling crane

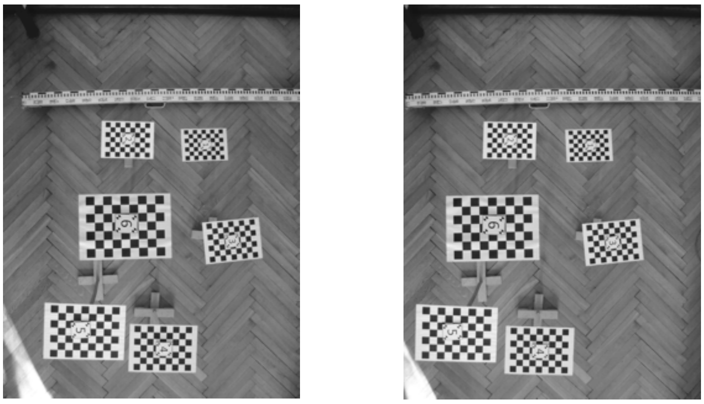

Fig. 2. Stereopicture taken by single camera

Tab. 1. Rotary encoders types mounted on the phisical model of the overhead travelling crane

Measured value	Encoder type	Sensor resolution	Measurement precision
Trolley position (encoder A)	Rotary encoder A/B phase	200 [imp./rot.]	3.14×10^{-4} [m]
Bridge position (encoder B)	Rotary encoder A/B phase	400 [imp./rot.]	7.85×10^{-4} [m]
Payload altitude (encoder C)	Rotary encoder A/B phase	100 [imp./rot.]	4.19×10^{-4} [m]

2.2. Single camera stereovision system architecture

Verification the accuracy of the perspective representation the stereovision system architecture with the single camera was conducted with prepared markers. As a reference, objects were use six white-black checkered pattern (square edge length 0.027 m) objects with the same width and height but difference depth (Tab. 2).

Tab. 2. True and estimated distance with uncertainly range calculated on the dense disparity map base

Marker number	Distance [m]	
	Real (measured) range	Estimated range with perspective uncertainly
1	2.456	2.489 ± 0.096
2	2.209	2.157 ± 0.072
3	1.953	1.903 ± 0.056
4	1.713	1.618 ± 0.041
5	1.453	1.348 ± 0.028
6	1.267	1.198 ± 0.022

To obtain an extra information about camera shifts was use the levelling staff located at the floor. The information about the shifts was integrated directly with the image (Fig. 2.). In the next step, each image from the corresponding stereo pair was combined together. Then the maximum edges displacement was calculated. The maximum obtained disparity was about 27 pixels. Additionally taking into consideration the camera parameters, like an image sensor grain size, focal length of the lenses and other stereovision system geometry parameters [22]. It is possible to calculate depth perspective (disparity) [23, 24] of the stereo pair presented in Fig. 2 with use the equation presented bellow (1).

$$r = \frac{B \cdot f}{d_{RL} \cdot \phi}, \tag{1}$$

where:
r – range (depth perspective),

B – stereovision shift (so-called stereovision base),
d_{RL} – disparity,
f – focal length,
ϕ – average diameter dimension of image sensor grain.

Visualization of equation (1) was presented in the Fig. 3.

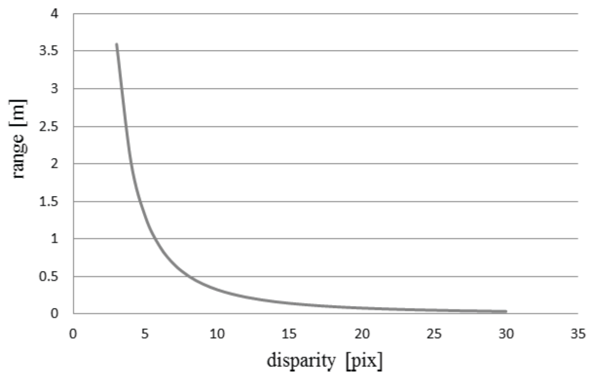

Fig. 3. Stereopicture taken by single camera

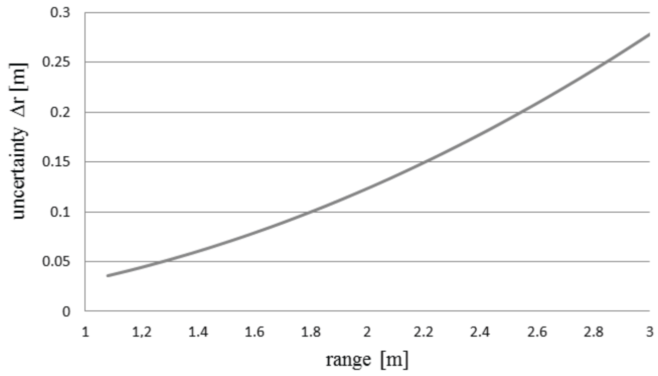

Fig. 4. Perspective uncertainty range visualization

Also, it should be noted that the shift of the same object in two independent stereovision images decreases together with increasing distance to object e.g. for infinity disparity equals zero. Additionally – by transformation the equation (1) [22]. It is possible to calculate the uncertainty of the calculated range (perspective). The estimated uncertainty of the stereovision system parameters can be described by simple expression (2):

$$\Delta r = \left(\frac{r^2}{B \cdot f} \right) \cdot \phi \, , \tag{2}$$

where:
Δr – uncertainty range.

In the Fig. 4 was presented full uncertainty characteristics of the tested single camera stereovision system. The obtained results show that uncertainty increases with the distance between camera lenses (image plane) and the mapping object surface (object plane).

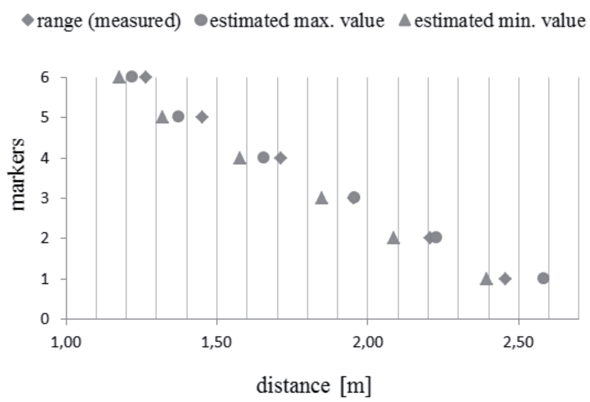

Fig. 5. Summary of results obtain from the one camera stereovision system – perspective uncertainty range visualization

Analysing the data presented in Fig. 5, it can be seen, that estimating depth (mapped perspective) for markers numbered as 1, 2 and 3, together with uncertainly value, contains the measured value. However in the case of markers numbered as 4, 5 and 6 the calculate depth are undervalued. The average error did not exceed a 0.12 m for the minimum estimated value and 0.059 m for the maximum estimated value, which not exceed 5% of total distance in relation to the maximum mapped depth.

2.3. Conclusion

The problem of crane workspace mapping is solved in this chapter through stereovision system based on the single camera unit installed under the trolley of a crane. This step allow to acquire the stereo pairs from an independently snapshots taken during the crane bridge or trolley motion. The single camera stereovision system was mounted and adapted on the laboratory stand. Obtained results prognosis well for future scientific work connected with implementation on larger (industrial) devices. However, it should be noted that the laboratory conditions are significantly different that industry environment. Pollution, dust suspended in the air, heterogeneous lighting level of the crane hall can make difficult implementation of the proposed method.

3. Anti-sway crane control system supporting designed payload trajectory keep

3.1. Payload sway – crane issue

The problem of ensuring the safe and efficient cranes operations in automated manufacturing processes involves the automation of the operating workspace identification (which was discussed in the second chapter of this paper), non-collision and time-optimal path planning and precise following of a payload along the designed path usually in the real-time mode by crane motion mechanisms. The research problem connected with anti-sway problem [6, 9, 10, 18] has been extensively researched over the past decades [25-26]. In generally the taxonomy of proposed and described solutions can be classifying as an open and closed-loop control system. An anti-sway crane control problem is generally solved in the scientific works using open loop or closed-loop control approach. The open-loop control usually utilizes the optimal control theory, where the optimal path planning of a payload is determined through minimizing the assumed function, which corresponds to the sway angle and its time derivatives or to the energy consumption that ensures transferring the nonlinear system from the initial state to the final state. The close loop sway angle control methods are strongly connected with necessity of measuring the angle of the swinging rope under dynamic effect of the suspended cargo in real time mode. This solution requires of use the special, reliable sensor [8] for measuring rope angles in received reference system.

3.2. Non-contact vision sensor for sway angle measurement

The sway angle of a payload measurement system was based on the intelligent camera type of Sony XCI V3 [18] mounted under the crane trolley (Fig. 2). The measurement method consists in extracting the specified region of snapshot with full width resolution and part of height resolution to reduce the number of processing pixels in each recorded frame (strong recommend to limit amount of data to process in period). The sway angle of a rope is determined based on the plot of rectangular region with isolated rope edge and the parallel line of image height. The communication system between the controller and vision system is realized based through the OC server/client architecture [1]. On the Fig. 6 there were presented not processed screen shots captured by smart camera.

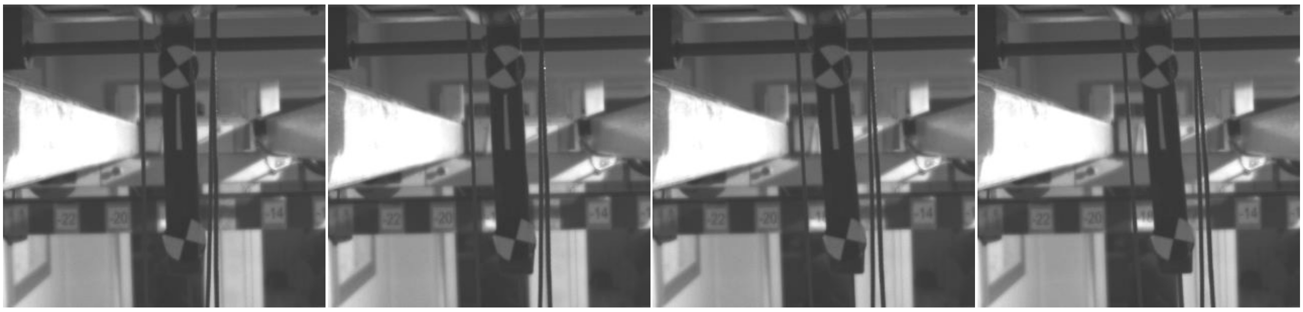

Fig. 6. Snapshots taken in in different period: t_0, t_0+163 ms, t_0+303 ms and t_0+471 ms

For supervising smart camera, actions it was compiled a dedicated embedded system. The algorithm dedicated to swing angle measure was spited on the four phases. In the first phase, single image was taken by the smart camera. Next, the image was shrunk to the region with definite dimensions *h* x *w* pixels (so-called ROI). Then the formed ROI in the second phase was subjected of binarization conversion type with a suitable range of threshold (assigning the value as *0* or *1* to each pixel). This step enables to isolate the rope edges from each image for angle extraction, independently from environmental background and natural lighting level changing. The applicability of described method of contact-lees strand angle measurement depends on the close loop control system adaptation possibility. Thus, there is a need to determine the sampling rate of the presented measuring system. On the base five hundred loops were estimated a time for each stage realization. The obtained results were presented in Tab. 3. Additionally on the Fig. 7 was presented an exemplary rope swinging angle run extracted with the described vision system help.

Tab. 3. Algorithm steps for image analisisi in non-contact vision system forrope angle extraction – time consuming

	$t_{average}$ [ms]	σ* [ms]	t_{min} [ms]	t_{max} [ms]
Step 1: *Image acquiring*	5.38	1.89	4.00	12.0
Step 2: *ROI creating*	2.96	0.2	2.65	3.45
Step 3: *Threshold image*	2.08	0.52	1.00	3.00
Step 4: *Edge finding*	10.35	0.99	9.36	13.6
Step 5: *Geometry measure*	10.64	0.92	9.68	13.0
Step 6: *Variable sharing*	31.33	1.78	27.34	36.3
Total time:	62.74	-	54.03	82.35

* standard deviation

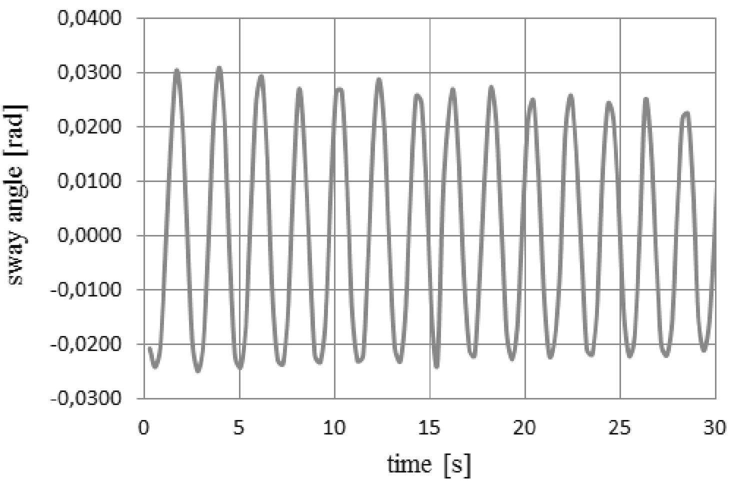

Fig. 7. Free sway rope measured with the vision system

3.3. Conclusion

The presented contact-less sensor allows using the close-loop control systems to counter excessive sway of the suspended load during transport process. In practice, it is an important step in positioning accuracy, safety and reliability of the goods handling process by all material handling devices, in which payload was shifted with the help of ropes. However, it should be noted that the described non-contact measuring system at now was implemented only in one direction, so in this form it is impossible to use it directly as full functional anti sway sensor. However, at the moment the main unsolved disadvantages are related with high sensitivity of described method to all kind extraneous disturbances connected with electromagnetic interference, especially connected with light visible radiation. The impossibility of use presented non-contact vision sensor in darkness is a second important fault.

4. Final remarks

The paper describes the important elements of the application for built full functional ANS for overhead travelling crane. In this paper, two main problems were identified: crane workspace visualization and need of develop new type of anti-sway technique. For workspace visualization authors proposed well-known stereovision technique, but not in standard architecture (to compose stereovision picture one camera was use). In terms of anti-sway technique, authors choose close-loop control system. Thus was develop non-contact anti sway sensor. The common point of both developed methods (anti sway solution and workspace visualization) is vision methods.

At the end raises a following conclusion: vision systems and image analysis method are perfect not only in acquiring an information about crane workspace and potential obstacles dimension (stereovision), but also useful as a standalone measurements system of chosen and useful crane parameters.

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