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VIDEO DISTANCE MEASUREMENT METHOD BASED ON THREE FOCUS POSITIONS

BY

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Abstract. Several precision technologies require video measuring systems that perform fast an extensive number of routine measurements and deliver high accuracy outcome. The quality of achievement is intrinsically determined by the measurement technique where with the applications that operate these systems are designed. The paper advances a simplified and at the same time comprehensive approach, proposing a new video distance measuring method using a single camera. It is designed to assess the distance at which the visual task is from the camera, using three adjacent focus positions. Practically, the method involves two stages: calibration and measurement. Calibration is realized only once for each camera type and involves setting the measuring range for all positions of the focus lens where maximum clarity is obtained. Distance measurement involves the use of the maximum sharpness position of the lens and the correlation with the sharpness values of the positions next to the maximum sharpness position.

Keywords: distance measurement; image; video camera; lens; focus.

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1. Introduction

Video technologies are indispensable for advanced production processes, as provide high utility, versatility and reliability. Their capability to handle high sampling rates, especially when dealing with hundreds of part features, and the ability to measure multiple images of points and patterns very quick, lead the difference between the video systems used for measurement. Technically, they use specialized optics to provide a flat image of a part to a high resolution camera. The light levels of pixels are converted to electrical signals, which are assessed by software algorithms to accurately determine edges. High quality optics and autofocus bring up an accurate and true image, providing edges for repeatable dimensional measurement. Poor quality lens can induce measurement errors by distorting the part image (inducing a false image). Though, distortion occurs most often when measuring part features that are not in the center of the lens' field of view. Advanced measurement systems minimize distortion by using only high-grade lenses, and some premium (but expensive) metrology software packages have field of view distortion compensation built in to mitigate distortion that adds to measurement uncertainty (Thomas, 2018).

Methods for determining the distance based on stereo vision are widely known; they involve the use of two cameras between which the distance is established (Liu and Chen, 2009) or use a single camera, but require a reference. For most of the latter, the reference is the size of the object of interest (named in the paper as visual task) (Kim and Cho, 2012; Sasaki *et al.*, 2017), and for the others the reference is the distance a camera moves from the object (Xu *et al.*, 2018). Also, there are known methods for estimating the distance by defocusing a reference placed on the investigated object (Murawski, 2015), methods for measuring the distance based on neural networks trained by sets of characteristic images of the object of interest (Yin *et al.*, 2017) and methods without complex calculation, related to anatomical dimensions of a person such as iris diameter or based on an established relationship between the interpupillary distance (in number of pixels) and camera to object distance (Rahman *et al.*, 2009). Methods for determining the distance without using a reference are based on the correlation between the distance and the position of the focusing lens (Subbaraoand Tyan, 1998).

2. Method Description and Application

The paper exhibit a method for video distance measurement based on three focusing positions, comprising a calibration step and a measurement step. *Calibration* is performed only once for a camera type and involves setting the measuring range for each position of the focus lens for which maximum clarity is obtained. *Distance measurement* involves using the maximum sharpness position of the lens and correlating it with the sharpness values of the lens positions next to the maximum sharpness position. This method brings two main advantages: allows the realization of video distance measurement applications without reference and increases the measurement's resolution, implicitly the accuracy of distance measurement. The technique can be implemented in automotive, *e.g.* for inter-vehicles distance measurement in autonomous driving and traffic mobility (but with multiple similar measurement systems), even when both camera and subject are moving. Precision of measurement depends on the camera's performance, specifically on focusing speed and on the focal length. High performance cameras admit adjustments for subject shift sensibility, meaning auto-focus can be enabled from the camera's software and set to locked-on if the focus has to remain steady, or if focus has to be kept on a particular target without being affected by other subjects. If adjusting settings to continuous focusing mode, the camera detects the moving subject and refocuses accordingly to keep the sharpness of the visual task. Environmental factors, as the colour of the visual task similar to the background colour or a low luminance contrast may affect the quality of the measurement.

Physical objects moving in the environment at differing focal distances from the camera generate dynamically a variation of lens' perceived clarity. Thus, the proposed video distance measuring method was tested on Logitech Pro C920 webcam equipped with Carl Zeiss® optics, having 16-step autofocus10 cm and beyond. The camera autofocus is by default responsive, suitable for short or medium distances where the visual task is moving quickly. The focus stabilization is fast achieved (it takes 0.38 s in good light or 0.89 s in low light conditions), even if the visual task moves around a little in the frame. To obtain sharp images with long target distance, manual focus is needed to be enabled from the camera settings, by moving the slide bar left. Also for applications with a fixed focus webcam that isn't constantly searching for visual tasks in motion, the auto-focus must to be switched off from Logitech's Capture software, in addition to several other picture adjustment settings. The webcam has a 4-bit focus, equivalent to 16 distinct lens positions.

The experimental stand is rendered in Fig. 1, consisting of:

1. Web camera,
2. axis for linear motion with slider,
3. camera test chart - array of 140 colors: 24 patches from original ColorChecker, 17 step gray scale and 14 unique skin tone colors,
4. US Digital S1 single-ended optical shaft encoder, used for position feedback, connected to DAQ (7). It measures the angular position of the load shaft, having a high resolution of 0.0235 mm (4096 counts per revolution in quadrature mode / 1024 lines per revolution), with single +5VDC supply. Its ball-bearings version makes it suitable for high-speed and ultra-low torque applications, tracking to 10 000 rpm.

5. Faulhaber DC brushed micromotor (2230 series), 4.7 mNm rated torque, 0.29 A rated current, 4160 min^{-1} rated speed, 7.5 W, 83% max. efficiency, speed up to 11000 min^{-1}, with 0.7 Nm precision planetary gearheads series 23/1 with 1 stage, reduction ratio 3,71:1 and 88% efficiency.
6. Quanser VoltPAQ-X1 single channel linear voltage-controlled power amplifier, providing the motor input voltage signal, capable of supplying around ± 24 V and 4 A continuous.
7. Quanser Q2-USB acquisition board, with a single-point I/O, two-channel data acquisition and USB interface for real-time performance. Low I/O conversion times, easy connectivity, and 2 kHz max closed-loop control make suitable this data acquisition device for Hardware-In-The-Loop development.

To drive the system towards a target position, a feedback loop with PID controller is implemented. LabView 2021 software is used for command, control, data acquisition and image processing, with Vision Development Module 2021 National Instruments toolkit.

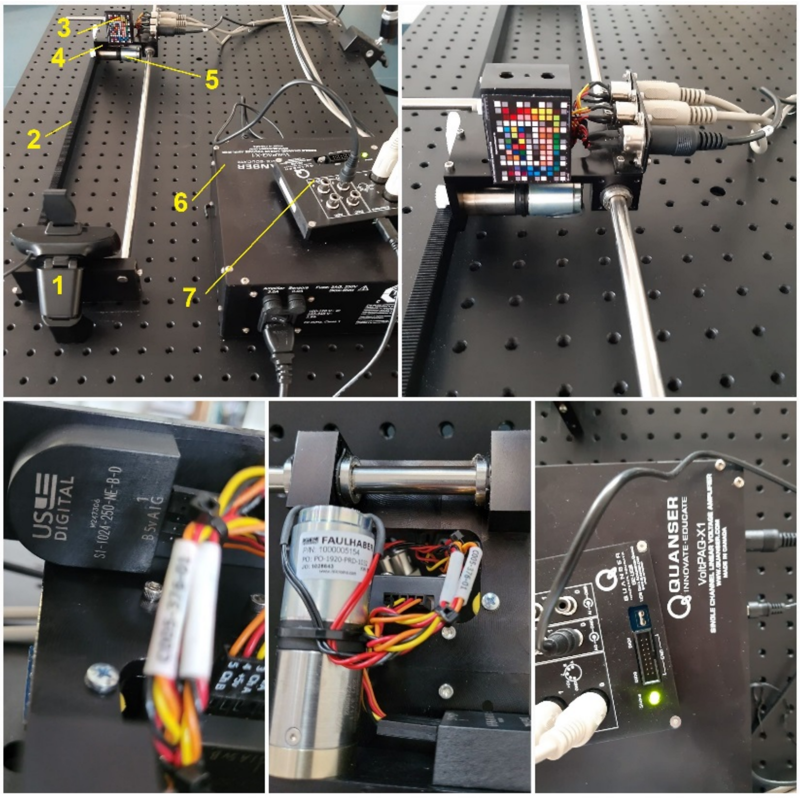

Fig. 1 – Overview of the video distance measurement system.

A calibration test was performed; the maximum clarity position was determined for a visual task placed at 80 mm from the camera, as shown in Fig. 2. In detail, the field in which maximum clarity is obtained, for each of the 16 lens positions, is specified in the adjacent table (Table 1).

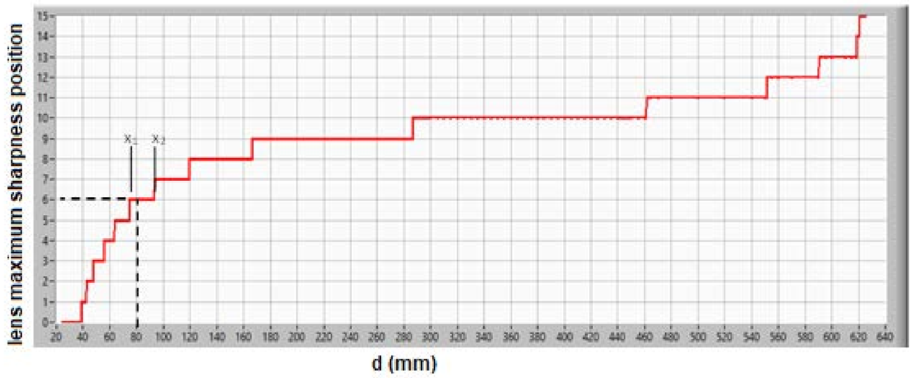

Fig. 2 – The sharpness variation with the lens' position, for a visual task at a specified distance.

Table 1
The sharpness ranges for each lens position

Lens maximum sharpness position		0	1	2	3	4	5	**6**	7	8	9	10	11	12	13	14	15
Measuring range	x_1 [mm]	25	38	42	47	55	63	**74**	93	119	166	286	461	551	590	618	620
	x_2 [mm]	38	42	47	55	63	74	**93**	119	166	286	461	551	590	618	620	625

Application of the method involves identifying the position with maximum sharpness of the lens (1), the minimum measuring range of the maximum sharpness position (2), the maximum measuring range of the maximum sharpness position (3), the difference between the maximum sharpness value and the value of the previous position (4) and of the difference between the maximum sharpness value and the value of the next position (5) – as render in Fig. 3. To focus on an object at a certain distance from the camera, the lens scrolls through the 16 positions, and for each position, the sharpness is calculated based on the contrast of the image. The image with the highest sharpness is selected from the set of 16 images. Next, its proper measurement range is identified (from x_1 to x_2). The set of clarities is normalized (simple value scaling by dividing each one to maximum, in order to reduce measurements to a "neutral" or "standard" scale, new values being in [0, 1]).

The differences between the maximum sharpness (1) and the sharpness of the adjacent positions (Fig. 3) are calculated, obtaining y_1 and y_2.

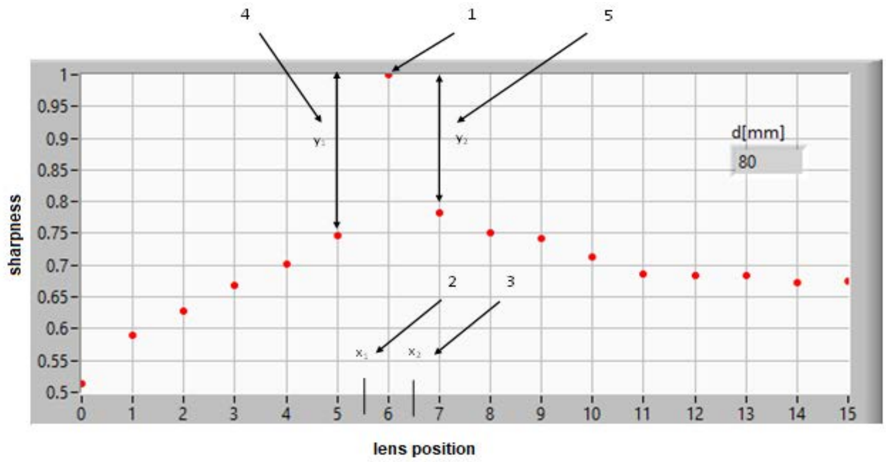

Fig. 3 – Establishing calculation points from sharpness variation by lens position.

Then, the distance d between the camera and the focused object (visual load) is determined by the relationship:

$$d = x_1 + (x_2 - x_1) \cdot \frac{y_1}{y_1 + y_2} \tag{1}$$

where x_1 is the lower range limit of the measuring interval of the maximum sharpness position, x_2 is the upper range limit of the measuring interval of the maximum sharpness position, y_1 is the difference between the maximum sharpness value and the value of the previous position, y_2 is the difference between the maximum sharpness value and the value of the next position. For the presented experiment, y_1 is the difference between clarity of index 6 and clarity of index 5, and y_2 is the difference between clarity of index 6 and clarity of index 7.

3. Experimental results and discussion

To focus on a visual task at a certain distance from the camera, the lens traverses a set of positions (stacks, as in Fig. 3). For each position, the sharpness value is calculated based on the contrast of the image. From the obtained set of clarities, is determined the image with maximum clarity and implicitly the lens' position where the sharpness is maximum. The maximum sharpness for a lens position is maintained for a certain depth of field in which the object can be located.

As rendered in Fig. 4, the relative error of measuring the distance is large in the transition zone of the intervals with maximum clarity specific to the lens positions. This is due to the uncertainty of determining the position of the lens in the vicinity of two intervals.

It can be seen that the relative error is dependent on the number of focus states, i.e. the number of positions of the focus lens. In the application presented in the paper, a video camera with 16 theoretical positions was used, of which only 12 are active, the last 4 having similar clarity values. It is obvious that using cameras with a large number of focus positions will lead to a relatively small error. Moreover, the use of a clarity dependency that takes into account multiple lens positions (3 in this case) may lead to lower relative error values.

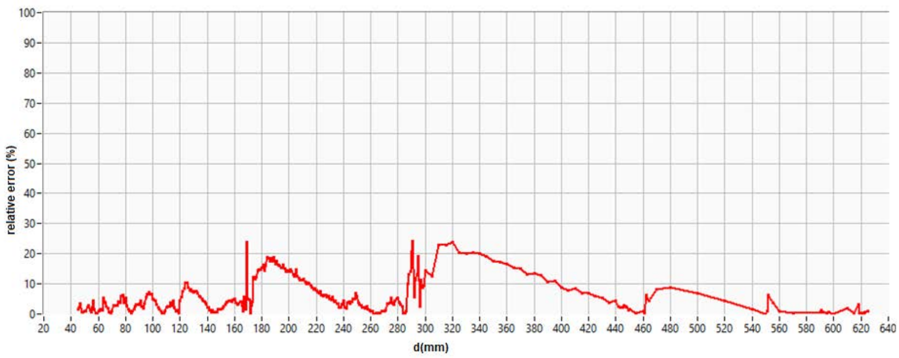

Fig. 4 – Video distance measurement relative error.

4. Conclusions

The single-camera video distance measurement method introduced in this paper can enhance the performance of specific systems. It particularity consists in evaluating the distance between a targeted object and the camera, by using the maximum sharpness position of the lens and the correlation with the sharpness values of the side-lines positions. The technical problem solved by the presented method is the improvement of the measurement's accuracy for cameras with focusing lens. Further, at industrial level, the method can be used for Human-Computer Interaction (HCI) applications, at non-contact measurement systems, in automotive industry or for intelligent transportation system at traffic surveillance.

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METODĂ DE MĂSURARE VIDEO A DISTANȚEI BAZATĂ PE TREI POZIȚII DE FOCALIZARE

(Rezumat)

Articolul prezintă o metodă nouă de măsurare a distanței cu o singură cameră video destinată evaluării distanţei la care se află sarcina vizuală față de cameră. Metoda cuprinde o etapă de calibrare și o etapă de măsurare. Calibrarea se realizează o singură dată pentru un tip de cameră și presupune stabilirea domeniului de măsurare corespunzător fiecărei poziții a lentilei de focus pentru care se obține claritatea maximă. Măsurarea distanţei presupune utilizarea poziției de claritate maximă a lentilei şi corelarea cu valorile de claritate ale pozițiilor alăturate poziției de claritate maximă. Pentru aceasta se identifică poziția cu claritate maximă a lentilei și se calculează patru parametri pe baza cărora se determină distanța dintre cameră și obiectul focalizat: minimul domeniului de măsurare al poziției de claritate maximă și maximul domeniului de măsurare al poziției de claritate maximă, diferența dintre valoarea de claritate maximă și valoarea poziției anterioare, diferența dintre valoarea de claritate maximă și valoarea poziției următoare.