Conversion of Video Surveillance System into Measurement System Based on Video Camera

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Abstract*: *This work reviews measurement systems applied for static and dynamic detection of object coordinates as well as acquiring information of their position at various distances. The market of measurement systems based on video cameras has been analyzed. Their classification is presented, fields of application are described, advantages and disadvantages are summarized for each type of measurement systems. In addition, it has been revealed that the frequency and extent of measurement errors depend not only on the quality on system components but also on numerous other factors, such as light flare, microvibrations, thermal expansion, etc. The review of measurement systems is necessary for determination of the most efficient method of conversion of video surveillance system into measurement system.

Keywords* : *measurement systems, video camera, navigation, computer vision, images.

I. INTRODUCTION

At present operation of various specialized instruments and systems should be accompanied by detection of static and dynamic coordinates as well as acquiring information about their positions at various distances [1]. The market of measurement systems is continuously growing and developing. Appropriate products are proposed by numerous manufacturers. The available products can meet the requirements of high accuracy and expensive instruments as well as the demand for less accurate and inexpensive solutions. It covers all demands of any potential buyer of measurement system. Measurement systems based on video cameras are widely applied in such areas as navigation, failure detection, astronomy, microscopy, monitoring of fabrication process, military affairs, etc. Since the video surveillance systems are very popular, then it is possible to develop 3D measuring and surveillance arrays on their basis. Increased demands for video surveillance systems can be attributed to their properties, such as:

- convenient integration of video camera with any device of data processing and control system [2];
- high response rate of video surveillance systems capable to process signals from fixed and moving at various speed objects both in real and shifted time [3].

Application of video camera for high speed recording in measurement system can be justified for studying quick moving objects, in scientific research, upon monitoring of line production, and other tests.

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II. METHODS

A. Advantages and disadvantages of high-speed cameras were compared by empiric approach.

The results are summarized in Table 1.

Table 1. Advantages and disadvantages of high-speed cameras

Advantages	Disadvantages
High matrix sensitivity	High price
High frame rate and resolution	Export restrictions
Possibility to select extremely low exposure interval	High matrix heat emission
CMOS technology can increase frame rate upon decreasing resolution	High cost of embedded memory. Possibility to expand memory is restricted
	Specialized software is generally oriented at single operation system
	Unavailable detailed data on camera matrix, since this information of manufacturer know-how

Measurement systems with video camera as receiver are classified by ranking in terms of weight, wavelength, accuracy of measurements, etc. LED and laser systems are compared.

Survey errors from background noise were minimized by digital data processing.

B. Algorithm

The study was performed in the following stages:

At initial stage, advantages and disadvantages of high-speed cameras were compared aiming at detection of the optimum variant for application as receiver in measurement system. Then the measurement systems with video camera as receiver were classified aiming at detection of more accurate parameters of considered object. The classification was based on properties of measurement systems with and without radiation source. Laser and LED measurement systems with video camera as receiver were compared.

Numerous approaches to detection and separation of objects from background and noise are analyzed which provide information about object using several receivers, as well as solution of geometrical problems with comparison of reference points, planes, lines from different receivers and measurement systems with one receiver.

The obtained results are used for minimization of survey errors. Measurement system with video camera as well its type during operation will be performed by comparative analysis on the basis of operation conditions, purposes of measurements, required accuracy, etc.

C. Flow Chart

Let us present the algorithm of analysis as the flowchart in Fig. 1.

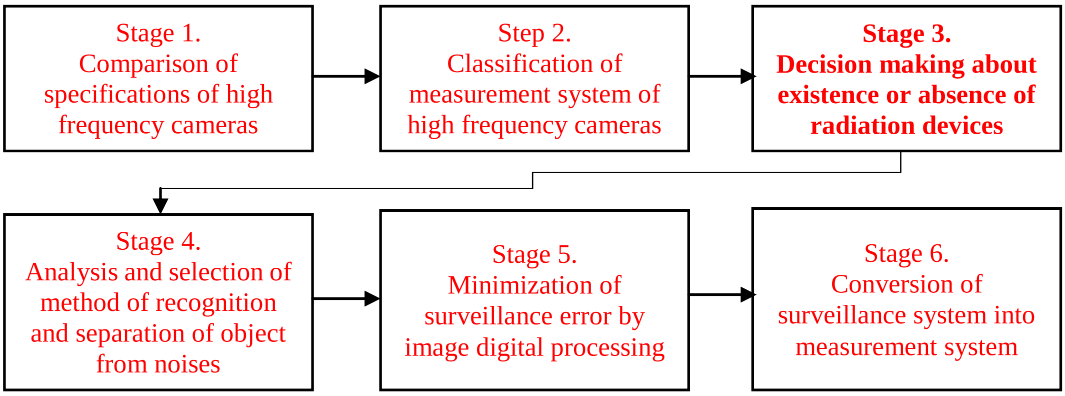

Fig. 1. Analysis of surveillance system based on video camera

III. RESULTS AND DISCUSSION

Embedded memory makes it possible to use video cameras only for video recording since the acquired data are recorded into camera memory and they cannot be used for computations before they are transmitted to processor. At such camera architecture it is impossible to perform data flow computations and to use them in computer vision systems and automatic monitoring. Nearly all problems, which are intended not only for data acquisition but also for computations, cannot be solved by such cameras.

Nearly any system requires for preliminary camera calibration in order to evaluate its internal and external parameters [4]. This process is characterized by its difficulties, it is individual for each variant of measurement system. Total approach to such calibration is as follows: camera detects a set of characteristic elements, such as points or lines with known position with regard to certain fixed external coordinates. Then optimization is performed when the difference between elements of observed image and their theoretical positions is minimized with regard to internal and external camera parameters.

Let us classify measurement systems with video camera as receiver. Measurement systems with radiation source are capable to acquire sufficiently accurate parameters of considered object. Such systems are equipped generally with only one camera as receiver. A system is comprised of numerous interconnected elements, each of them is connected directly or indirectly with any other element, herewith, any two subsets cannot be independent without violation of system integrity [5].

The sources used in laser measurement systems are distinctive that they operate in visible range with capturing nearest IR region (0.5…1.5 μm) [6]. The use of this illumination is stipulated by the fact that capabilities of video camera exceed capabilities of human eye since surveillance camera is characterized by sensitivity in sufficiently wider spectral range in comparison with human eye [7] as well as transmission spectrum of Earth atmosphere. General operation principle of triangulation scanners based on detection of object morphology according to previously known position of radiation source with respect to receiving video camera is illustrated in Fig. 2.

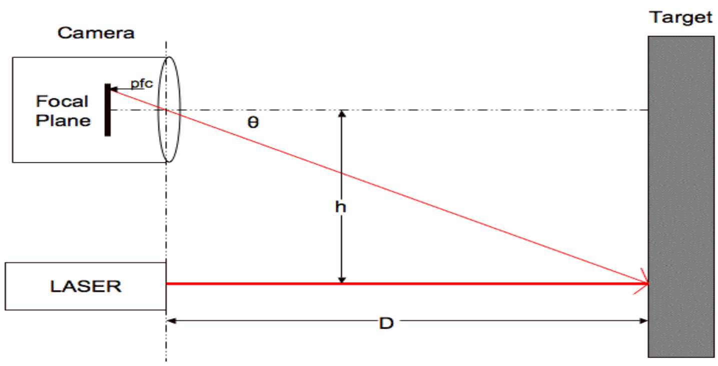

Fig. 2. Schematic view of laser ranging system with video camera as receiver.

The distance from source to object can be determined as follows:

$$D = \frac{h}{tg\theta}; \quad (1)$$

$$\theta = pfc * rp + ro \quad (2)$$

where ***h*** is the distance from source to camera, ***pfc*** is the number of pixel with respect to camera focus, ***rp*** is the amount of pixels in one radian, ***ro*** is the error compensator.

In the case of unknown θ , the system is calibrated when known **D** and **h** are used for calculation of actual angle $\boldsymbol{\theta_{actual}}$. On the basis of $\boldsymbol{\theta_{actual}}$, unknown $\boldsymbol{\theta}$ are determined at which the error of distance detection to object is minimum. This method is known as triangulation since the laser spot, camera, and laser emitter form triangle. In many cases data acquisition is performed using laser band, grid etc. which are used instead of laser spot.

Some commercial projects based on this technology are summarized below:

1) GapGun mobile measurement system [8] which is capable to measure nearly every gap, roughness, radii, scratches, scoring, seams, profiles, etc. It is applied mainly in car manufacturing.

GapGun is a manual tool with detachable sensors. The sensors are replaced according to size and distance of measured surface.

Direct line is projected from radiation source to measured area, the object relief is plotted on the basis of deviation from normal. The specifications are summarized in Table 2.

Table 2. GapGun specifications

Weight w/o sensor	370 g
Sensor weight	170 g
Wavelength of radiation of sensor laser	670 nm
Accuracy of measurements	20 μm

2) Rausch laser profiler [9].

Morphological map of pipes is plotted by means of 360° rotating laser measurement system with video camera installed on mobile chassis. It makes possible to detect deviation of current radius from ideal one. This profiler is equipped with accelerometers, the acquired data compensate the influence of roughness on measurement results.

In addition to morphology, the acquired data can be used for plotting of full-color pipe model and to analyze it remotely. This profiler can operate in total darkness without additional illumination since it is equipped with embedded LEDs.

This profiler performs measurements using spot radiation source. The specifications are summarized in Table 3.

Table 3. Rausch specifications

Radius of analyzed pipe	0.2-1.8 m
Accuracy of measurements	0.5%
Minimum crack size or pipe deformation which can be detected automatically	0.25 mm
Operation wavelength	650 nm

3) SPI-200-3D Solder Paste Inspection Measurement System (Caltex Scientific) [10].

It is comprised of fault detector and microscope. Direct line is used as radiation source in this device. The specifications are summarized in Table 4.

Table 4. SPI-200-3D specifications

Height resolution	1 μm
Lens magnification	30× – 200×
Accuracy of measurements	5 μm for 30×
	1 μm for 200×

Operation range of triangulation laser scanners is restricted by several meters, however, the accuracy of measurements is high (4–10 μm).

Measurement systems with LED radiation source are characterized by higher radiation pattern and wider radiation range contrary to the systems with laser sources. These systems are safe for human eyes due to lower density of source energy which is insufficient for damaging live tissues.

Structured light scanning is a widely applied technology used for formation of 3D image [11]. This method is applied in industry, for instance, for monitoring of manufacturing processes and volume measurement, and is based on high-accuracy and expensive scanners. Operation principle of structured light scanners is based on projection of narrow light stripes or patterns of certain geometry. Performing observations from a point differing from the source forming the stripe, the scanners use information about deformation of this band on object surface. While projecting several light stripes, the receiver acquires simultaneously more information about morphology of the considered object.

Kinect (Microsoft) [12] can be mentioned among other commercial systems.

Kinect was initially developed as a gaming accessory for *XBox*, it became sufficiently popular and its price decreased significantly in comparison with analogs. The first *Kinect* was the most bestselling user device. Thus, taking into account open library of solutions with various possibilities, this device was considered in designing of robotized platforms.

The *Kinect* structured light system differs from commercially applied variant. Instead of projection of visible light stripes, the *Kinect* IR projector transmits encoded pattern of IR beams which after reflection from object are received by CMOS matrix, which makes it possible to receive 3D image by *Kinect* sensor under any natural illumination.

Depth map is a consequence of operations executed by PS1080 chip (*PrimeSense)* with IR image acquired by *Kinect* from IR CMOS. This VGA image has 11-bit resolution. It is comprised of 2,048 various gray shades from white (2,048) to black (0). The *Kinect* specifications are summarized in Table 5.

Table 5. Kinect specifications

View angles	Vertical: 43° Horizontal: 57°
Range of measured distances	1.2–3.5 m
IR CMOS resolution	320×240

Nearly any video camera can be converted into system comprised of IR filter and LED illumination which could detect approximate morphology of object on the basis of acquired image. If nonspecialized IR camera is used, then the preinstalled filters are removed from the camera.

A promising approach is application of this method in combination with smartphone cameras. Comparative analysis of LED and laser systems is shown in Table 6.

Table 6. Comparison of laser and LED measurement systems with video camera as receiver

Parameters	Laser systems	LED systems
Accuracy of measurements	~ 10 μm	~ 0.02 cm
Distance of measurements	Up to 5–6 m	Up to 10 m
Outdoor operation	Available	Unavailable or restricted
Necessity to add auxiliary components into existing system	Yes. Laser source and signal processing system	Yes. LED source and signal processing system

Now let us consider measurement systems without radiation source. It is known that visual perception by live organisms and possibility to approximately estimate properties of observed objects do not require any illumination except for natural [13]. This concept was widely applied in measurement systems, however, such systems mainly use digital processing of acquired images and are labor consuming.

Methods based on nonradiative measurements are used in the case of hidden observation in military or security facilities, when spectral selection of laser or LED radiation cannot be used due to external disturbances, as well as when the aim of processing of acquired signal is classification of separate objects and image recognition. Image from camera can be used for classification of object by comparison of combination of acquired data: shape, color, sizes, speed and type of motion. For instance, dog, child, adult, bicycle, car, lorry, etc.

Measurement systems with one signal receiver. If a measurement system is equipped with the only radiation receiver, estimation of geometrical parameters using only one frame becomes more difficult. One of the approaches to obtain approximate sizes of object by one frame is the comparison with the a priori known geometrical parameters of another object. Another approach is based on previously known marking of surveyed objects. Detection of approximate geometrical parameters of object by one frame can be exemplified by an early video recording of vehicle traffic. The operation principle is simple: a camera is located above restricted speed road. The camera lens is oriented perpendicularly downwards. Current frame of video stream is stored only when a vehicle crosses conventional zone. Vehicle sizes in the acquired image are determined by special points (brightness drops). One frame can be used for detection of physical parameters of object using the principles of texture and pattern imposition. However, these principles are completely related to image digital processing.

While processing frame sequence, the observed objects are interrelated with their physical properties. After digital separation of various objects, it becomes possible to compare variations of motion of each specific object. This can be exemplified by a system analyzing optical stream.

Optical stream is the image of visible motion of objects, surface, of scene edges acquired as a result of camera motion with respect to scene [14]. Algorithms based on processing of optical stream operate with motion of objects, surfaces, and edges. Detection methods of optical stream are based on brightness jumps, spectra, estimated smoothness of drops of pixel displacement vectors, etc.

Some systems analyze pixel displacement in several frames of video stream [15]. The essence of tracking of point features is as follows: for a certain point in one frame it is necessary to determine its position in the next frame using data from two or more frames of the sequence. Point feature is such point of image the vicinity of which can be distinguished from vicinity of any other point of image.

Procedure of recognition and separation of each object from background and noise is sufficiently complicated and based on numerous various approaches.

Assembly of signal receivers. Systems of stereo TV are known to be comprised of two [16] or more video cameras spaced apart by certain basic distance. The distance accuracy of stereo systems is proportional to the base length which can increase the sizes of the system. Correctly calibrated stereo system provides sufficiently accurate (~1 mm) image depth by computer processing of acquired signals.

The methods of data acquisition using several signal receivers provide solution of geometrical problems by comparison of reference points, planes, lines from various receivers. Let us consider SIVER DATA measurement system [11]. This system detects with sufficient accuracy deformations of damaged vehicle bodyshell which cannot be estimated visually. The model of considered vehicle is provided by the software database, operator performs measurements by reference points using pointer, and the system provides information about existence or absence of bodyshell deformations. The specifications of the system are summarized in Table 7.

Table 7. SIVER DATA specifications

Accuracy of measurements	2 mm
Operation distance from video cameras to pointer	0.9–3.3 m
Pointer-to-computer connection	wireless
Maximum number of measured points in one project	100
Size of measuring unit	1.2×0.1×0.1 m
Manipulator size (pointer)	30×8×4 cm
Weight of measuring unit	3 kg
Manipulator weight (pointer)	0.5 kg

Embodiment of measurement system with video camera as well as the number of signal receivers depend on specific targets of designer of measurement facilities. The accuracy of nonradiative systems is worse than those of systems with LED illumination, however, the distance of measurements is restricted only by sizes of measurement system.

If less expensive measurement equipment is used, the accuracy of measurements drops much quicker than in the systems with radiation source since such systems are less susceptive to impact of noise and the interfaces of brightness jumps between radiation source and image are more contrast.

IV. CONCLUSION

Therefore, it can be concluded that type of measurement system should be selected on the basis of operation conditions, targets of the measurements, required accuracy, etc. Illuminated systems would provide unsatisfactory results outdoors in bright daylight, whereas non-illuminated systems would operate with nearly the same accuracy. When high measurement rate is not required but accuracy and compact sizes are necessary, then measurement systems with laser source demonstrate the best results.

While reviewing specifications of commercial models, it is obvious that recovery of surveillance parameters is always characterized by errors. The lower is the measurement error, the higher is the accuracy of recovery of initial data. Hence, any measurement system is oriented at minimization of such errors. Peculiar importance of further research is that the frequency and extent of errors occurring during measurements depend not only on quality of system components but also on other numerous factors, such as light flare, microvibrations, thermal expansion, etc.

On the basis of the performed analysis, it was decided to use the least expensive conversion of video surveillance system into measurement system, i.e. a system without emitters and with one signal receiver based on image digital processing.

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