Contactless Area Measurement (Contactless Planimeter)

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Abstract. *The paper describes the designed hardware and software systems (so-called planimeters) for contactless measurement of areas (eventually geometric distances between two selected points) of planar projections of various objects. These systems operate on the principle of processing the video signal scanned by a digital camera (or TV camera).*

Keywords

Measurement, area, dimension, video signal, camera, processing.

1. Introduction

The measuring systems described in this paper are capable of fast and simple contactless area measurement of various objects (more exactly - their perpendicular projections into the plane of the object-lens of the scanning system), eventually measurement of geometric distances between two selected points in a scanned scene. Contactless planimeters can be used in various applications in many branches. The measured area size can be arbitrary, because it is defined by the optical parameters of the scanning system only (especially the camera lens magnification). The measuring system must be calibrated to achieve absolute values of measured area. Therefore it is necessary to measure a reference area with a known size at first. Above all, the measurement accuracy depends on the resolution (number of picture elements) of the optoelectronic sensor used in the camera (CCD or CMOS), and on the ratio of the measured area and the size of the whole picture raster. Two variants of planimeters will be described in the following paragraphs.

2. Planimeter – Hardware Version

Fig.1 displays a block diagram of the hardware version of the planimeter with analog video signal processing. The measured data are processed by a microprocessor, which was designed and realized at the Department of Radio Electronics, BUT Brno. The input video signal (standard CCIR D) is generated by an analog TV camera which scans the measured object in this case.

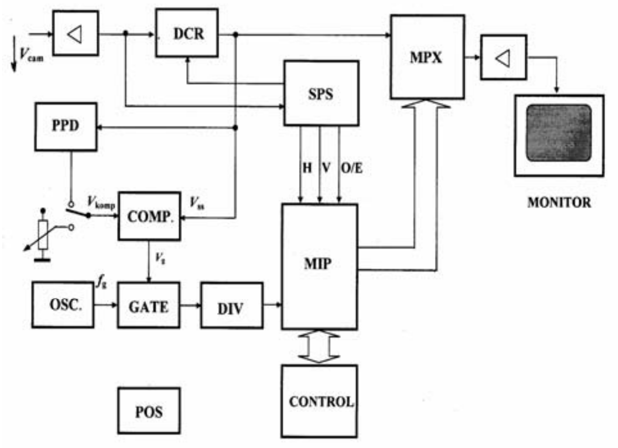

Fig. 1. Block diagram of the hardware planimeter version: **DCR** direct-current restorer (clamping circuit), **MUX** multiplexer of video signals, **PPD** peak-to-peak detector, **SPS** synchronization pulse separator, **OSC** clock pulse oscillator controlled by a crystal, **COMP** comparator, **GATE** electronic switch, **DIV** frequency divider, **MIP** microprocessor, **CONTROL** control circuits with control keyboard, **POS** power supply circuits.

The microprocessor MIP is a fundamental part of the planimeter. It is controlled by the synchronization pulses H, V and E-O that defines the even and odd fields of the picture. The microprocessor executes (using the signals of circuits CONTROL and control keyboard) especially the following functions:

- generation of an adjustable frame signal,
- numerical conversion of the measured data on the absolute value based on the comparison of the unknown and known reference areas measuring,
- averaging of the measurement results for a given time interval and numerical display control,
- insertion the rated results (including measuring unit) into defined positions in the picture,
- control of the multiplexer MUX and the display unit,
- co-operation with the measuring circuits in order to improve the application possibilities (e.g. option for

the measuring of dark areas on bright backgrounds and vice versa).

A detailed function description is beyond the scope of this paper.

3. Planimeter – Software Version

The software version of the planimeter represents a fundamental innovation in the branch of contactless area measurement. All functions and operations are provided in the digital form by a special program AD-EVAL. The principle of area measurement itself is well known, i.e. counting of pixels whose intensity value is compared with adjustable comparing level. The measured intensity value can be higher or lower than the comparing level or be at once higher than one comparing level and lower than another comparing level. The innovation lies in fast and comfortable setting of factors influencing the measurement, namely an adjustable and moveable frame, adjustable comparing level displayed simultaneously in an image histogram, and also highlighting of the measured area and real-time displaying of the measured result. The main innovation consists of reduction of equipments necessary for the measurement. Just a digital camera or camcorder and PC are enough for the real-time measurement. The program co-operates with a digital camera (several brands and models). An uncompressed picture file in the bmp format forms the PC input. A digital camera is connected to the computer through a USB interface. This connection can also be used when a digital TV camera (camcorder) with a digital output is used – with a DVI - USB reduction cable for instance. Theoretically, an analog television camera can be used, too. It is necessary to use a suitable video-card in this case (e.g. PC Pinnacle Movie Board Plus 700 PCI) with a relevant software (e.g. Virtual Dub) to capture and digitize a picture of scanned video-sequence.

3.1 Flowchart of the Computer Program AD - EVAL

The computer program AD-EVAL in its first version allows to measure an area in the selected parts of planar objects, which are scanned with a digital camera or a digital television camera. It is able to measure the geometric distance between two selected points in the scanned scene, too. The development system Builder C++ was chosen for the design of a user friendly program. The flowchart of this program is presented in Fig. 2.

3.2 Functions of the AD - EVAL Program

a) Open picture (Scan object)

In the program AD-EVAL it is possible to open a picture file saved in the PC. The supported file format is grey scale .bmp. If the AD-EVAL co-operates directly with a digital TV camera, the data are obtained through the API (Application Programming Interface) functions implemented in the DLL or LIB libraries. These libraries are part of drivers or the SDK (Software Developer Kit) provided with the particular device. Using these API functions, the program communicates with the TV camera and thus it is able to save the scene into a file or in the PC memory. Once the scene is displayed, the required action is chosen - area measurement or geometric distance between two selected points in a scanned scene measurement.

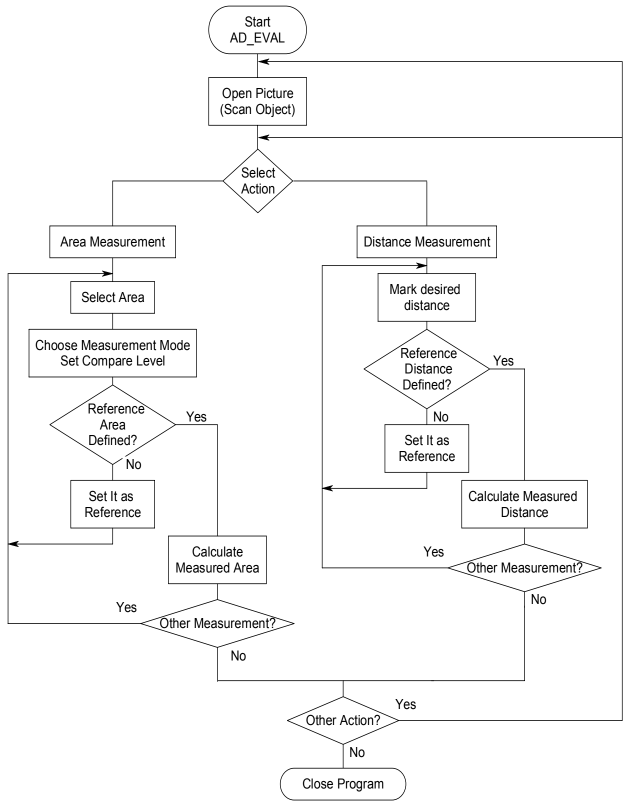

Fig.2. The flowchart of the program AD-EVAL.

b) Area measurement

As written above, the measuring system must be calibrated. Therefore a selected area with a known size should be measured first and set as reference. The selection is done by an adjustable frame. The measurement mode and the comparing level are taken into account (see Section 3.3). This setting influence the number of picture elements (pixels) in the selected frame. The possible measurement modes are also mentioned above in Section 3. The comparing level can be set by a user at any level within the range of image color depth. Similarly, an unknown area is selected and its size is calculated with respect to the reference area.

c) Distance measurement

The measurement of the distance between two points is based on a relative measurement as well. The known distance is marked with two points and set as a reference one (in pixels). The unknown distance is pointed again and its value is calculated and displayed as a ratio of the measured and the reference distance.

3.3 The Main Control Window of the AD-EVAL Program

The main control window of the AD-EVAL program is presented in Fig. 3. Three parts can be distinguished in this window. The first and the biggest part belongs to the scanned picture display. This is where a user can define a measuring location with a mouse. The measured area in this location is automatically highlighted (see Fig. 3). At the bottom of the window, the measuring mode switch for selector level (white, black, manual user's setting) and scroll bars for the decision level of the comparing operation can be found. A histogram of the scanned picture is located in the bottom-right part of the window. The right part of the window is reserved for measurement results (test data) – number of pixels belonging to the measured and reference areas and the resulting relative ratio (in %) of the measured and the reference area.

Fig. 3. The main control windows of the program AD-EVAL 1.

4. Attainable Measurement Accuracy

There is a number of factors having impact on the relative measurement error ε_m of the **hardware** version with analog video signal processing (see Fig.1); especially:

- resolution and aperture distortion of the sensor used in the camera,
- geometrical distortions of the sensor and the lens (this impact is low in monolithic optoelectronic sensors CCD and CMOS),
- frequency drift Δf_g of the clock pulse oscillator OSC,
- voltage drift ΔV_{comp} of the comparison voltage,
- voltage drift ΔV_{dc} of the video signal direct current component,
- rise and fall times t_r, t_f corresponding to the effective amplifier bandwidth,
- time delay of the signal in the comparator COMP and electronic switch GATE.

A detailed analysis and derivation of these factors is introduced in [2].

Most of these factors can be neglected in the **software** version of the planimeter with the all digital video signal processing. Aperture distortion of the used camera (non-zero value of the video signal rise and fall times before digitizing in the camera) can be eliminated by the relative character of measurement. This distortion is identical at the measuring of an unknown and reference known area. Pursuant to the quantitative analysis it holds on simplified conditions, that only one main factor has the **dominant** impact on the resulting systematic measurement error ε_m - **resolution of the sensor used in the camera**. Computation error of the used computer is insignificant. The minimal value of the systematic relative measurement error ε_v depends on the number n_v of picture elements (lines) in **vertical** direction and is expressed by the formula

$$\varepsilon_V = \frac{\Delta V}{V} = n_V^{-1} \tag{1}$$

The minimal value of the systematic relative error ε_H depends on the number m_H of picture elements in horizontal direction and can be expressed by a similar formula

$$\varepsilon_H = \frac{\Delta H}{H} = m_H^{-1} \tag{2}$$

where V, H are the maximum scanned picture (scene) sizes in the vertical and horizontal direction (the height and the width of scanned picture). Equations (1) and (2) are valid provided the vertical and horizontal proportions of the measured object are near the maximum sizes (V, H) of the scanned scene.

The resulting systematic errors ε_V and ε_H are independent. Therefore the minimal relative systematic error ε_{Smin} for measurement of the **greatest measurable rectangular** area $S_{max} \approx V \cdot H$ can be expressed by the formula

$$\varepsilon_{Smin} = \frac{\Delta S}{S_{max}} = \frac{\Delta S}{V \cdot H} \cong \sqrt{\left(\frac{1}{m_H}\right)^2 + \left(\frac{1}{n_V}\right)^2} = \frac{\sqrt{n_v^2 + m_H^2}}{m_H \cdot n_v} . \tag{3}$$

The resulting area measurement error ε_S depends on the shape and the orientation of the measured area towards the scanning raster. Its value can be significantly increased for the measurement of smaller areas $S < S_{max}$. Then the real resulting area measurement error ε_S is expressed as

$$\varepsilon_S = \varepsilon_{Smin} \left(\frac{S_{max}}{S}\right) = \varepsilon_{S\,min} \frac{(V \cdot H)}{S} . \tag{4}$$

Example: A digital camera with resolution $n_V \cdot m_H = 6.10^6$ pixels and aspect ratio $m_H / n_V = 1.5$ is used. Then numbers of pixels in the horizontal and vertical direction can be computed as $m_H = 3 \cdot 10^3$ pixels and $n_V = 2 \cdot 10^3$ pixels.

After substitution into equation (3)

$$\varepsilon_{Smin} = \frac{\Delta S}{S_{max}} \cong \frac{\sqrt{(2 \cdot 10^3)^2 + (3 \cdot 10^3)^2}}{3 \cdot 10^3 \cdot 2 \cdot 10^3} = 0.37 \cdot 10^{-3} .$$

If a measured area is smaller,e.g. $S \approx 0.1 \cdot S_{max}$ it holds

$$\varepsilon_S = \varepsilon_{Smin} (S_{max}/S) = 0.37 \cdot 10^{-3} \cdot 10 = 3.7 \cdot 10^{-3}.$$

This value is acceptable for most practical applications.

A measured area has, of course, a various form in a practical measurement. Theoretical values of a measurement attainable accuracy (or contrariwise – a measured error - see relation (3) and (4)) was experimentally verified by pictures with a various measured areas rate S/S_{max} from cameras with a different resolution. The rectangular area forms were measured at first. However – measurement error deviations were small (under 10 %) for the diverse area forms. The size of the measured area to the total picture area rate (S/S_{max}) has a fundamental influence on the measurement accuracy, which is apparent. The constant comparing level (mean between the maximal and minimal brightness level in the picture) was adjusted in the program for all experiments. Experimentally measured error values were just about around 15% greater in comparison with theoretical values corresponding to relations (3) and (4). This fact acknowledges answers to the mentioned presumption, that an influence of other factors (optical and electrical – see paragraph 4) is considerably smaller.

5. Conclusion

Hardware and software systems (so-called planimeters) for contactless area measurement are described in this article. Planimeters measure areas of perpendicular projections of arbitrary objects that are scanned by a camera or TV camera. The object size does not matter (measurement is suitable for macroscopic and microscopic pictures as well), because the measuring range can be adapted by an appropriate lens. The measuring system must be calibrated to achieve the absolute value of the measured area. Therefore it is necessary to measure a reference area of a known size first. Both measuring systems described in this paper were designed at the Department of Radio Electronics of the Brno University of Technology. The software planimeter represents a significantly better variant in terms of the measurement accuracy and user's comfort. These facts were confirmed in theoretical analyses and practical testing. Attainable accuracy of the described software planimeter was experimentally verified by the pictures with various measured area sizes and forms from cameras with a different resolution. The first simplified version of the program AD-EVAL is shown in this article.

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