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Automatic measurement of precision and accuracy from the hit pattern of small arms using electronic target system

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Abstract. The basic parameters of the combat training and weapon practicing are the determination of the accuracy and precision. The automatic systems for acquiring of the hit pattern are very expensive and inaccessible. Modern automatic systems are designed as non-material target system for accurate spatial positioning of the projectile trajectory in one or more planes. In the paper will be described the design of the non-material high-resolution target acquisition system developed on the optoelectronics IR (infra-red) sensors. The frame of the multiple IR sensors coupled with the microcomputer platform is the optical frame. The complete target acquisition system is consisted of the two frames for positioning in vertical and horizontal direction. Additionally, in the target system is incorporated the algorithm for the determination of the appropriate statistical values from the group of shots, as accuracy and precision parameters. The assembly hardware components are commercially accessible. The designed algorithm is applied through simple software code. The main aim of the developed target system is for the measurement of the small arms shooting. The presented target system is open for enhancement and can be used for different weapon system.

1. Introduction
The quality of the small arms and ammunition is represented with accuracy and precision. The determination of the accuracy and precision depends on the reliability of methods and equipment. Despite the numerical, theoretical or semi-empirical methods for the determination of the precision parameters, experimental test and measurements of the hit parameters still represents the standard procedure and it is required by the armament and ammunition factories and especially customers.

The conventional experimental methods are consisted of the test fire from the small arms on the material target, on the proving test facilities. The results are the hits of the bullets on the target. The test material target is made of special type of paper with adequate dimensions. The distance of the test target from the test weapon depends on the caliber, muzzle velocity, type of the weapon and required test conditions (different standards as CIP, SAAMI, STANAG, etc.).

The test procedure is namely consisted of the required number of fire groups (usually three groups). The test group depends on the time that is required to fulfil the test conditions, and have to be less then several minutes. Every fire group is consisted of the required number of the hits, according to standard (usually ten hits). The determination of the precision begins from the measurement of the every hit.

The group of hits is represented as hit pattern and can be visually described as „image of shots" on the test target, [1].

The hit pattern enables the estimation of the precision parameters from the position of the every single hit in relation to the standard size and position of the test target, and in the specific relation to the other hits in the same fire group. The precision parameters depends on the standard and can be described through several types of measures as: hit pattern span („half-perimeter"), average radial derivation, best-half circle radius, probable derivation, core span, circular error probable, [1], etc. The specified precision measures are derived from the statistical parameters and probability distribution according to statistical methods.

The precision is defined as value of the precision parameters, i.e. better precision characteristics are represented as smaller size of the dimension of the hit pattern, and also as lower values of the precision measures. The one of the specific characteristic of the hit pattern is the average hit, and can be calculated or graphically determined, [1].

However, the term accuracy, in the paper and related references, represents the relation of the hit pattern characteristics to dimensions and characteristics of the specified target. In domestic military practices, the accuracy is described as the distance from the average hit to the centre of the specific target,(CT), Figure 1.

The goal of the research is the increasing of the reliability and the rate in the process of the hit detection, the decreasing of the processing time and the increasing of the safety and comfort during experimental research. The design of the device with performances of automatic hit detection and computing processing of detected results, according to implemented mathematical model, is the research proposition, in order to achieve the goal.

The performance of the hit detection coupled with programmable hardware interface, enables registration of the multiple results as data. The process of detection is automated and results are saved as array of data. Data of the group of detected hits is treated through mathematical, i.e. statistical methods due to determination of precision parameters.

2. Mathematical model

The detection of the single hit begins with registration of the particular sensors in frame, that are mounted in two opposite directions – vertical and horizontal. Every hit is saved as data from specific sensors, as following information: number (i.e. position) of the sensors in vertical and horizontal direction of mounted frames, in specific time. Different hits have different time tag.

In the research, the precision parameters have to be evaluated from the relation of the specific hit to the average hit. The average hit is the point, specific centre of the hit pattern, and doesn't represent any real hit, [1, 2].

The determination of the average hit can be done graphically or numerically, depends on the number of the hit. In the paper, as we have the information of the every hit, as numeric data, the determination of the average hit is numerical.

The average hit is the point determined as the cross of the vertical and horizontal axes of the average values of the coordinate of hits in the group. The vertical coordinate of the average hit is average value of the all hits, measured in the vertical direction – height. The horizontal coordinate of the average hit is average value of the all hits, measured in the horizontal direction – width. Every detected hit have the particular value of the derivation from the average hit.

The procedure of the determination of the average hit, on the material test target is:
- placement the horizontal line through the centre of the lowest hit on the test target (horizontal axe);
- placement the vertical line through the centre of the top left hit on the test target (vertical axe), as all hit positions can be perpendicular projected on the axe;
- measurement of the vertical coordinate of all hits from horizontal line to the centre of the hit;
- measurement of the horizontal coordinate of all hits from vertical line to the centre of the hit;

The coordinates of the average hit (AH) are calculated as average value as following, [1,2], and represent the values of horizontal and vertical coordinates in Cartesian coordinate frame of test target fram, Fig. 1,

$$\overline{x} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} \; , \; i = 1, 2, \ldots, \mathrm{n} \tag{1}$$

$$\overline{y} = \frac{y_1 + y_2 + y_3 + \ldots + y_n}{n} = \frac{\sum_{i=1}^{n} y_i}{n} \; , \; i = 1, 2, \ldots, \mathrm{n} \tag{2}$$
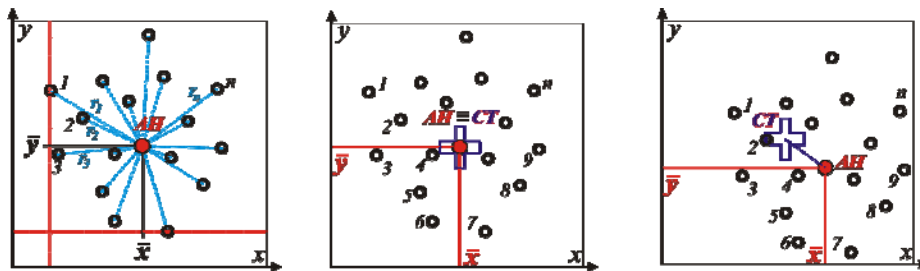

Figure 1. The hit pattern and precision parameters.

The precision parameters can be described, in relation to the average hit, with precision measure of average radial derivation. The average radial derivation (R_D), represents the arithmetic mean of the radial distances of the centre of every hit from the average hit, (r_i),

$$R_D = \frac{r_1 + r_2 + \ldots + r_n}{n} = \frac{\sum_{i=1}^{n} r_i}{n} \; , \; i = 1, 2, \ldots, \mathrm{n} \tag{3}$$

The single radial derivation is represented as,

$$r_i = \sqrt{\left(\overline{x} - x_i\right)^2 + \left(\overline{y} - y_i\right)^2} \; , \; i = 1, 2, \ldots, \mathrm{n} \tag{4}$$

In the Figure 1 is presented scheme of the hit pattern with ten hits with radial derivations (r_1, r_2, …, r_{10}) in the relation to the average hit ($\overline{x}$, $\overline{y}$) in Cartesian coordinate frame.

The estimation of the precision can be described, according to the presented relations (1) to (4), as better precision characteristics as lower value of the average radial derivation, i.e. as the hits are placed in lower radial distances.

The estimation of the accuracy is defined as matching, or lower distances between average hit (*AH*) and the center of the target (*CT*). In the Figure 1 are shown the differences between high and low accuracy.

The estimation of the precision and accuracy of the weapon can be described through four characteristic states, in relation to the value of the precision parameters (3) and the position of the average hit on the target:

- high accuracy and precision – average hit matches the target centre and low value of the average radial derivation;
- high accuracy and low precision – average hit matches the target centre and high value of the average radial derivation;
- low accuracy and high precision – average hit does not matches the target centre and low value of the average radial derivation;
- low accuracy and precision – average hit does not matches the target centre and high value of the average radial derivation;

As the quality of the small arms depends on the estimation of the presented characteristics of the accuracy and precision, the reliability and processing time are the key reason to made automated system. In the further part of the paper will be described the conceptual design of the virtual target system for automatic detection and determination of the precision and accuracy parameters. The proposed system is based on the signal communication of the infra-red sensor (IR diode) and photo transistor.

3. The design conception

The idea of the design of the device for automatic detection of the hits is based on the interruption of the established signal between transmitting sensor (IR diode) and receiving sensor (Phototransistor). The transmitter is IR sensor, source of the IR light, and the receiver is the detector of the transmitted light as phototransistor. The scheme of the conceptual design is presented in Figure 2.
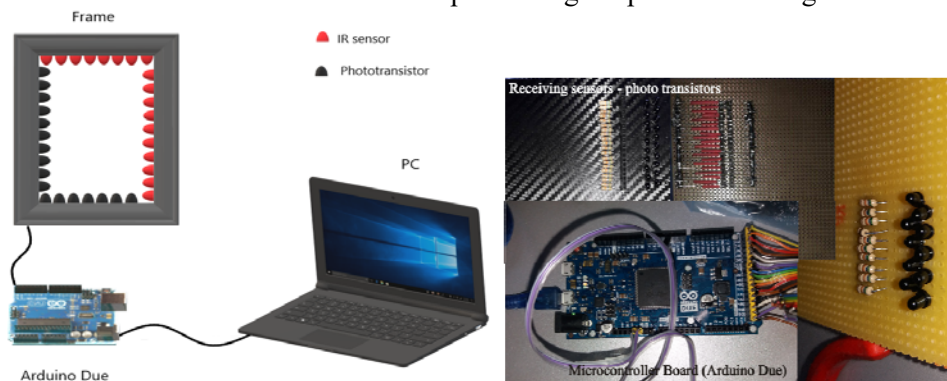

Figure 2. The conceptual design of the target system.

The figure shows two groups of the coupled transmitter and receiver in two perpendicular directions. The receiver is placed opposite to transmitter, in one plane, for one direction. Second group of transmitter and receiver is the same, except that is mounted in perpendicular direction, in the plane slightly translated from first test plane. The group of transmitter is consisted of the number of the single IR diodes, that are mounted in equal, small and required distance. According to the distribution of the IR diodes, in the opposite side of the frame are mounted coupled pairs of the phototransistor, in direct communication with diode separated from other diodes. Two frames are represented as optical net of the high resolution (distances between sensors are 2,54 mm i.e. 0.1") for detection the motion of small rigid body, as bullet (diameter of pellet is 4,5 mm, rifle bullet diameter is 5,56 or 7,62 mm).

The result of the detection is the position (h_i, v_i) of the bullet in the moment of interrupting of the signal between each pair of transmitter and receiver in two frames, horizontal (h) and vertical (v) frame. The prototype of the receiving sensors and microcontroller board are shown in Figure 2.

The data of interrupting signals are detected and saved using hardware device as microcontroller board Arduino Due, [4], connected to PC. The software code processes the received data, and according to the presented mathematical model, determines the values of the precision parameters.

3.1. Transmitting Sensors

The transmitting sensor is infrared diode, and represents the light source. The purpose of the IR diode is transmission of the infrared light to the receiver. The receiving sensor detects the IR light until interruption, as IR diode is connected to the supply voltage. The voltage supply of the diode is provided by microcontroller board Arduino Due, [4], Figure 3.
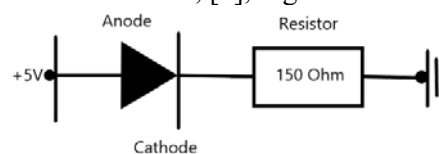

Figure 3. Scheme of IR diode.

The single IR diode transmits non-polarized light. Every phototransistor detects the light source from any direction. The light polarization is included in the research, in order to provide that one receiver sensor detects the light from just one transmitter. In the paper, polarizing filter is made, by the Malus's law, Figure 4 [3].
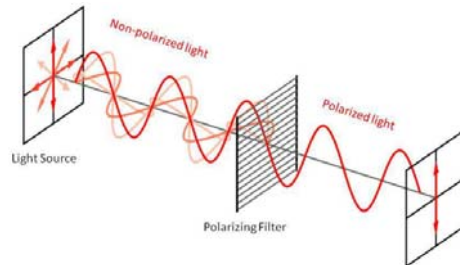

Figure 4. Scheme of polarizing filter.

3.2. Receiving Sensors

The receiving sensor is phototransistor. Phototransistor is an electronic switching and current amplification component, which relies on exposure to light to operate. It is capable of converting light energy into electric energy. Along the detection function, phototransistor has the function of amplifier. The rate of detection on the light is very high, as the reason for the research. Every phototransistor is connected to microcontroller board, in order to detected signal interruption be captured and saveed for further data acquisition. The scheme of phototransistor is presented in Figure 5.
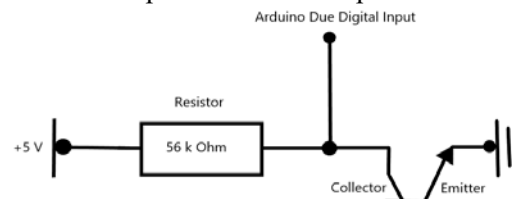

Figure 5. Scheme of phototransistor connection.

3.3. Microcontroller Board

In the research, four microcontroller board Arduino Due was implemented in the target system. The capabilities and availability of the board enables the design of the target system. The microcontroller is AT91SAM3X8E with technical specification in the Table 1, [4].

Table 1. Technical specifications of Arduino Due Microcontroller Board.

Operating Voltage	3.3V
Input Voltage (recommended / limits)	7-12V / 6-16 V
Digital I/O Pins	54 (of which 12 provide PWM output)
Analog Input Pins	12
Analog Output Pins	2 (DAC)
Total DC Output Current on all I/O lines	130 mA
DC Current for 3.3V Pin / 5 V Pin	800 mA / 800 mA
Flash Memory	512 KB all available for the user applications
SRAM	96 KB (two banks: 64KB and 32KB)
Clock Speed	84 MHz

The purpose of the microcontroller board in the research is to provide the voltage supply to the IR diode, to detect the signals from phototransistors, provide the detected signal to PC and enables data processing. The graphic user interface of the Arduino Due enables communication with connected sensors and components. The software code is made for the research, in Arduino Environment, [4], for monitoring of the signal interruption between IR diode and phototransistor, according to the specific frame and position of the pair of transmitter and receiver. The interruption signal as information of the hit position in target plane is displayed to user and recorded.

4. The Model of the Hit Pattern Determination

The model of the determination of the hit pattern is based on the automatic calculation of the detected signals of position of the hit on the test target plane. The detected values of the position and calculation of the precision parameters is provided by microprocessor acquisition system, as early described.

According to the described equipment, the design of the automatic electronic target system is consisted of two frames. The detection frame is initially designed for detection of sixty signals along the one direction. The detections of the every hit are results of interruption detection of both frames in the same time (i.e. predefined short period). The software receives signals, compiles and records as array of the data. According to the described mathematical model, automatic target system calculates the precision parameters and displays the results.

The determination process is consisted of the calculation the position of the every hit in the group, calculation of the average hit, and estimation of the precision parameter, as average radial derivation. The precision estimation software can be improved, by implementation of calculation of the other precision measures, [1].

The initial phase of the research, described in the paper, the accuracy parameter will not be estimated, because of the current technical limitations. The scheduled target frame is made of 60 connected sensors (30 sensors per 1 microcontroller board). The dimension of the active part of the frame is approximately 150 mm.

5. Conclusion

The paper deals with the research of the start-up design of the electronic target system for automatic detection of the bullet hits and determination of the precision and accuracy parameters from the group of the hits, as didactical resoure. The initial design of the system is made from available commercial electronic and IT components and custom made support mountings. The initial tests shows that designed system have improved performances in regard to the standard procedure with material test targets. Improved characteristics are the decreased time of test, automatic generation the results of the precision parameters, relatively simple and low-cost design and production, the possibility of perpetual usage. The automatic target system is designed and applicable for the different didactical purposes, fire practicing facilities, as sport fire practicing, military fire training, fire proving ground test for the research and development of the small arms and quality management of the ammunition.

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