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OPTIMIZED SYSTEM FOR COORDINATES DETERMINATION WITH ACCURACY FIRING AT GROUND TARGETS

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Abstract

The paper is devoted to an automated seismological system determining the target coordinates with bomb casting. The basic problems are formulated and the options for their resolution are discussed. Unique method and equipment for automatic determination of the coordinates of bomb- or bullet-hit target are proposed. A brief optimization analysis is made, based on which the optimal block diagram of the equipment implementing the proposed method is synthesized.

1. Problem

The enhanced requirements for intensification and quality improvement of fight training in aviation require to have objective data for the crews' results with firing at ground-based targets. Such data can be provided by high-performance methods and instrumentation for objective control of bomb casting and firing at ground-based targets, automatic express analysis, and result assessment.

2. Problem resolving options

The problem for automatic express identification of a bomb- or shell-hit target can be resolved using various methods: seismic, acoustic, location, infrared etc. [3,13,14]. All of them feature some advantages and shortcomings, but some of them might be implemented effectively at a later time, when the new type of components needed for the purpose will appear.

The idea for using a seismological system to identify explosion targets with various types of firing is boosted by its relative simplicity, high performance, and cost effectiveness. Such systems allow to identify automatically the position of earthquake epicentres. Ready-made elements and units for construction of such systems are already available, as well as the related software [7].

In [4], the optional methods for identification of earthquake epicentres are discussed, using directly the recorded times of the first arrived seismic waves. The most popular of them are the Successive Iterations Method [8] and the Hyperbole Method [1,6].

Since the task lies in determination of fire-hit with polygon fighting, we can assume the source of seismic waves as being located on the ground surface, accounting only for the propagation of voluminous longitudinal waves. This allows to consider the problem in plane coordinate system.

3. Proposed method

In [4], a copyright-protected [5] method and an equipment are proposed, providing to identify automatically the epicentre position of earthquakes, explosions, bomb- or shell-hits etc., for epicentres whose depth is negligibly small compared to the epicentre's distance. Here, t_1, t_2, t_3 , ...t_n are the recorded times of the first seismic waves arrived at recording sites P_1, P_2, P_3 ,....P_n.

In Fig.1, a plane coordinate system XOY is shown, with one exemplary arbitrary position of three recording stations, P_1, P_2 и P_3, with their respective coordinates, a_1b_1, a_2b_2 and a_3b_3, and the epicentre E (the bomb or shell's hit-position) with unknown coordinates, x and y. The arriving times of the first seismic waves, generated by the bomb or shell's hitting epicentre E at time t_o are t_1, t_2 и t_3 at the three recording sites, accordingly.

For basic geometric considerations, a system of 3 equations may be written, where v stands for seismic waves' propagation velocity throughout the earth's surface. Obviously, this velocity can be assumed constant within the firing-ground, where the surface ground layer is actually homogenous:

$$(1) \quad \left| \begin{array}{l} (x - a_1)^2 + (y - b_1)^2 = v^2(t_1 - t_o)^2 \\ (x - a_2)^2 + (y - b_2)^2 = v^2(t_2 - t_o)^2 \\ (x - a_3)^2 + (y - b_3)^2 = v^2(t_3 - t_o)^2 \end{array} \right.$$

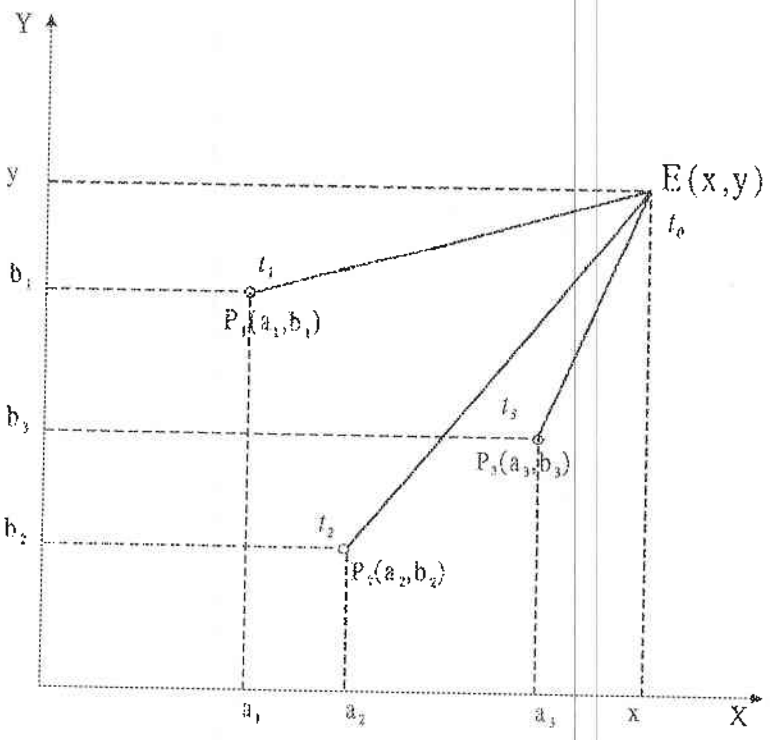

Fig. 1

Should the recording stations be positioned: one on the y axis ($a_1 = 0$), the other – in the origin of the coordinate system ($a_2 = 0$, $b_2 = 0$), and the third - on the x axis ($b_3 = 0$), then, the system of equations (1) can be simplified:

(2)

$$\begin{cases} x^2 + (y - b_1)^2 = v^2(t_1 - t_o)^2 \\ x^2 + y^2 = v^2(t_2 - t_o)^2 \\ (x - a_3)^2 - b_3^2 = v^2(t_1 - t_o)^2 \end{cases}$$

Since the distance from the epicentre to the recording stations is relatively small, a higher resolution is required for recording the times of the first arrived seismic waves, as well as for the system's overall speed of operation.

In Fig. 2, the position of the eight stations, P_1, P_2, P_3 ....P_8, along the firing ground's periphery and the central station *CP* are shown.

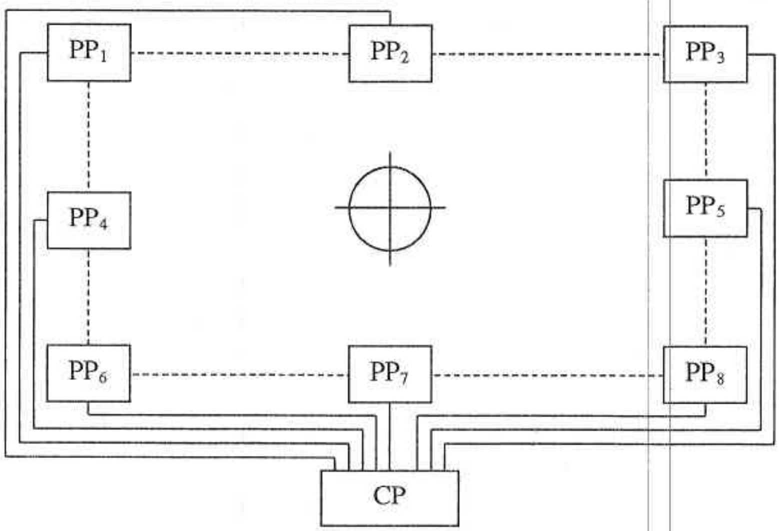

Fig. 2

4. Optimization analysis

A simple assessment reveals that, with assumed average velocity of seismic waves propagation of 3 km/s and acquired accuracy of hit target coordinates of the order of 10 m, the resolution at the time of recording the arrival of the first waves is of the order of 0,003 s. Though such time recording accuracy is no problem for modern chronometric systems, the possible differences in seismic waves propagation velocity and instrumentation errors in threshold blocks' activation at the recording stations might result in incorrect determination of the hit's position. This can be eliminated by software means and by increasing the number and optimizing the position of the recording stations [12]. The increased number of recording stations produces an overdetermined system of equations, thus eliminating the influence of local minimums with the minimization procedure and increasing significantly the accuracy in determining the unknown coordinates. Here, overdetermination of the system can be achieved by about 8 registration stations.

A major problem here is the choice of seismoreceivers. Depending on operation conditions, the problem can be solved using seismoreceivers with magnetoelectric transducer, capacity transducer, or piesoelectric transducer [4]. The analysis criteria are sensitivity, frequency bandwidth, damping, and calibration options. Magnetoelectric transducers feature highest sensitivity and best damping potential, but they are relatively largesized, require adjustment at the time of assembly and current maintenance, and are relatively expensive. Here, high sensitivity is not decisive. The most important criteria are sameness of amplitude-frequency characteristics, maximal increment velocity of the electric signal at the sensor's output, maximal high-frequency bandwidth, and own resonance frequency outside the frequency band of the processed seismoreceiver electric signals.

Accounting for the above, and minding besides the cost and operation conditions (temperature and moisture in the first place), a seismoreceiver with piesoelectric transducer is suggested.

Since the sensors are positioned at some depth under the earth's surface, the disturbing influences should be eliminated, such as acoustic waves, generated by various sources, the bomb-casting airplane including. The influence of climatic factors (temperature, wind, moisture etc.) is also reduced.

The manner of discriminating (comparing) the arrival times of the first seismic waves at each sensor is essential. The available options are two – discrimination at each station or discrimination at the central station. The first option requires taking measures to preserve the front of the electric pulse, which in its turn necessitates coordination and using cables with precise wave resistance. The second option means transmitting the amplified actual analogue signal from the seismoreceivers along a shielded audio-instrumentation cable to the central station, whereas comparing takes place at the input of a dedicated analogue interface module, where data from all sensors is collected. Upon comparing, by the lag times of pulse fronts, time intervals are transformed into lag-equivalent digits, which are supplied through a standard interface to the computer inputs. In the dedicated interface module, the electric signals from the sensors are received, filtered, amplified, and discriminated. The first seismic wave front, propagating in the firing ground's surface layer, activates the sensors in a succession, depending on their distance from the hit point. As illustrated in Fig.3, the seismic wave arrives with time lags of $+\Delta t_1$, $+\Delta t_2$ etc., accordingly), which are function of propagation velocity and the relevant distance S_i. Equal time lags may be observed with several sensors positioned at equal distances away from the hit point (as with the case in Fig.2), as well as with pairs of sensors etc. Thus, for instance, with 8 seismosensors, the system measures 7 relative time lags with respect to the first activated, which is assumed to be "0".

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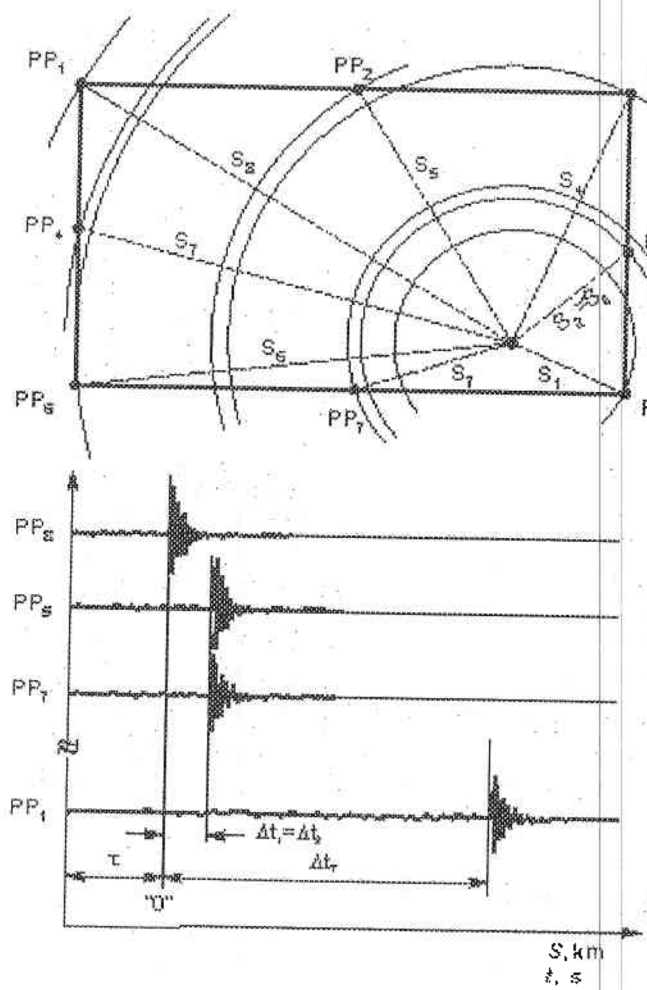

Fig. 3

The options for transmitting an electric signal from the peripheral stations are also two: along a wireless (radiochannel) or along a cable link. Undoubtedly, the lags over a radiochannel will be greater and of various size, and their compensation will be more difficult. Thus, a maximal cable length difference ΔL = 1200 m between the closest and the farthest station,

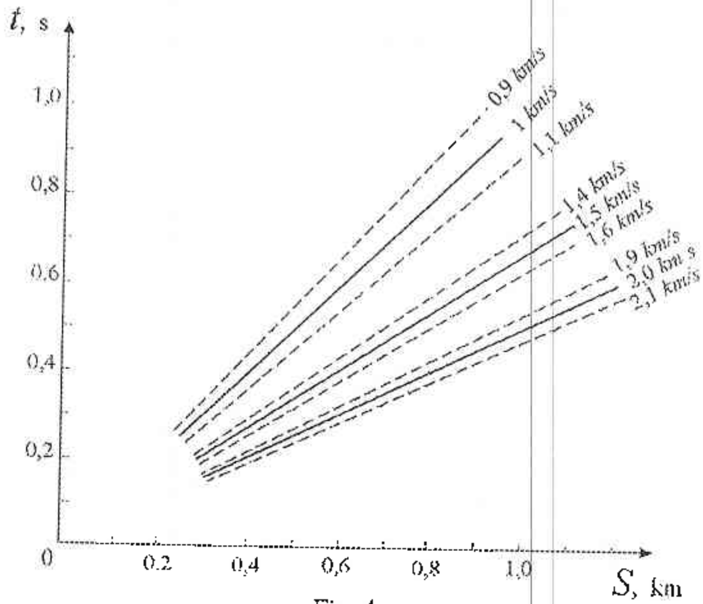

Fig. 4

will produce a time difference in passing this ΔL of the order of 3.10^{-6} s, i.e. within the microsecond range. Cables should be accordingly compensated for or harmonized, accounting for the time lags of the various peripheral stations.

With an assumed maximal difference of $\Delta v = \pm$ 0,1 km/s in surface seismic waves' propagation velocities within the firing ground, for distances of the order of 0,5 km, time error will be of the order of Δt = 0,03 s. With respect to overall time, this amounts to about 6 %. The relationship $t = f(S)$ for three different velocities v is shown in Fig. 4.

5. Technical implementation

In Fig. 5, the overall block diagram of the SDS-2 is shown, synthesized based on optimization analysis. The major considerations in its synthesizing were that in IBM PC, the internal time signals cannot be used directly because they feature but a short-time accuracy and time resolution. Their appearance, irrespective of the operation system, varies from a couple of to dozens of milliseconds. To provide for accurate measurement of the times Δt_i with sufficient resolution, another accurate supporting generator is needed, with sufficiently high frequency. For the purpose, some supporting frequencies of the bus of the IBM PC may be also used. Under a relatively simple work algorithm (used in frequency-meters), the time intervals Δt_i are filled by the frequency f_b, whereas the number of these pulses may be processed by the computer, using adequate software under the algorithm already proposed. For such purposes INTEL and some other producers propose the integrated circuit 8254 (3 timers), which can process time intervals; it is a part of the hardware set and it is compatible with the office signals of all IBM PCs.

The structure and work algorithm of the SDS-2 according to the proposed structural diagram is as follows:

1. Filtration and amplification of the sensor-supplied signal for correct discrimination. This takes place in blocks HPF (very-high-frequency filter), Y (amplifier), and LPF (low-frequency filter). HPF is included to eliminate the possible direct-current level (which bears no data) originating from the sensors' amplifiers. HPF eliminates the noises outside the sensors' useful frequency bandwidth and is conjugated with them.

2. Because of the fact that the initial phase of the analogue signals supplied by the sensors is unclear, the provided comparers (K) are of the window type, with symmetrical comparing threshold with respect to the zero line, comparing above the noise level of the input signals. A great variety of such integrated elements is available.

3. An essential element in the operation of such a system is the comparing threshold. Depending on its level, false activation is possible with low threshold and missed activation - with high threshold. One possible solution is the floating activation threshold, which adapts itself to the input signal. For the purpose, the circuit is supplied with detectors of the mean and peak value of the signals obtained at the output of LPF; these detectors control the activation threshold of comparers K_I. The adequate control of the activation threshold makes the system adaptable to the input signals, prevents false activation, and may enhance measurements accuracy.

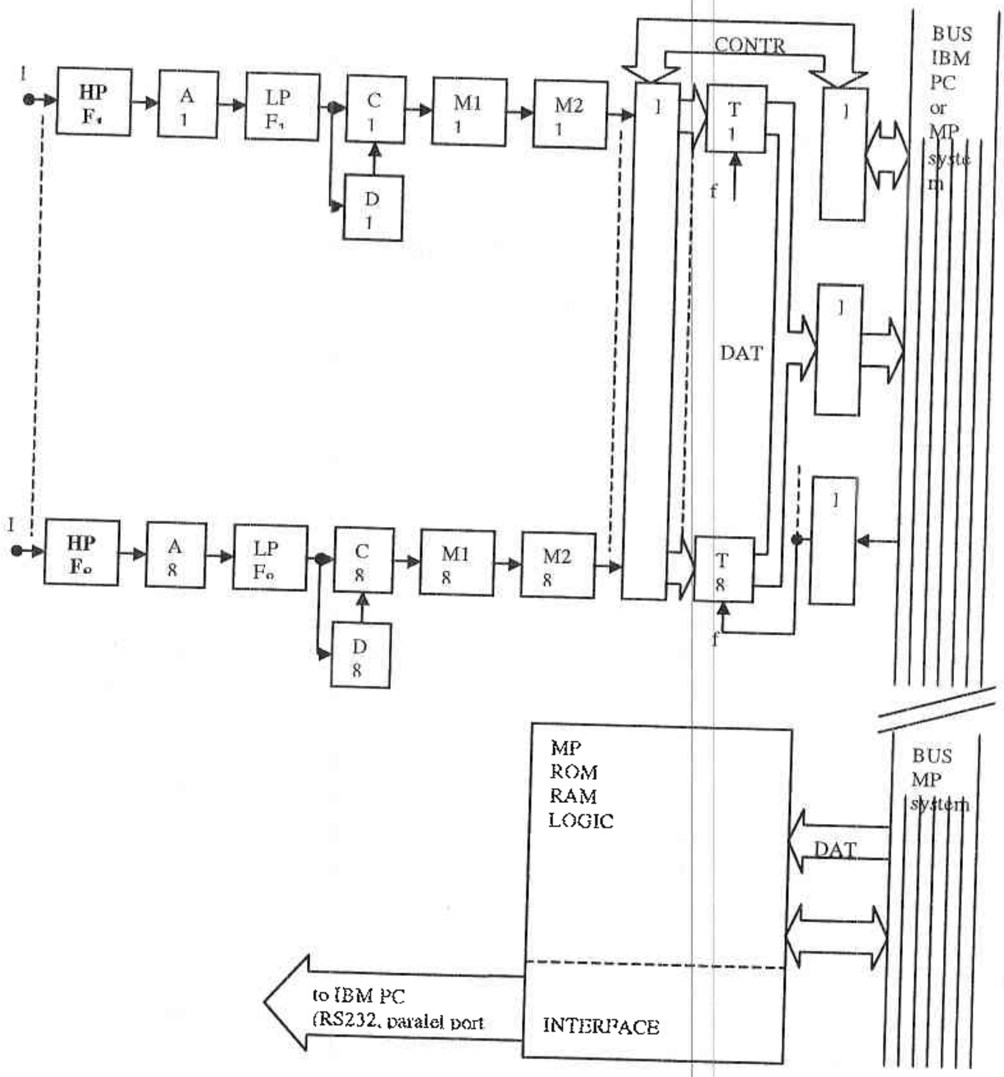

Fig. 5

4. The useful information is contained in the forefront of the first pulse at the output of comparers K_i for each individual channel. To simplify the operation of the next logic *L*, the pulse sequence should be transformed into one, wider pulse, preserving the forefront. This is carried out in blocks M_{1i} , which are, in fact, monovibrators.

5. To eliminate the error resulting from the different cable length from the sensors to the module's input, blocks M_{2i} are introduced, compensating for the different time lags of the signals along the cables.

6. The pulses obtained at the outputs of M_{2i} (in particular, their forefront) contain the whole data needed for accurate calculation of the hit coordinates. By the control logic *L*, the forefront of the first arrived pulse activates counting at all timers T_i, whereas the arrival of the forefront of each subsequent pulse at whichever channel stops the counting at this channel's timer. Each timer counts one number, whereas in the timer having started the counting this number is 0.

7. The digital data containing the channel's number and the result of counting is sufficient to calculate the hit coordinates. It is only this data that is transmitted by buffers (B) to the bus of the PC.

Another version is also possible, where the whole above-described module is part of a PC-independent microprocessor system. In it, the whole data, instead of being fed to the bus of the PC, is fed to the bus of the microprocessor system, consisting of microprocessor (μP), ROM, RAM and communication interface, say RS232, parallel port or USB. This option requires additional power-supply, a box, and own software.

On the structural diagram, both options are shown. In the first option, the module is positioned in the PC slot, provided with adequate software, while in the second option the microprocessor system communicates with the PC through standard interface.

A hit-matrix may be created, containing the relative actual time differences for each sensor and corresponding to each point of the firing-ground. Discretization depends on the needed recording accuracy of the hit. Here, no cable compensation or coordination is needed. The matrix also accounts for and eliminates the errors resulting from possible differences in the seismic waves' propagation velocities at different points of the firing ground.Knowing these different velocities at different points of the firing ground, the following algorithm may be adopted. After the initial identification of the hit position, the computer recalculates the coordinates, this time correcting velocity, and accordingly, the time for the seismic wave's arrival from the hit target to each PP.

The synthesized block diagram of the radioelectronic section of the COK-2, jointly with the determined basic technical-operation parameters, provides grounds for the system's technical design. Experiments in the field will verify the operability, accuracy, and applicability of the proposed system.

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ОПТИМИЗИРАНА СИСТЕМА ЗА ОПРЕДЕЛЯНЕ НА КООРДИНАТИТЕ ПРИ ТОЧНА СТРЕЛБА ПО НАЗЕМНИ ЦЕЛИ

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Резюме

В статията е описана автоматизирана сеизмологична система за определяне на координатите на целите при бомбомятане. Формулирани са основните проблеми и са разгледани възможностите за тяхното решаване. Предложени са оригинален метод и апаратура за автоматично определяне на координатите при бомбомятане и хвърляне на снаряди. Направен е кратък оптимизационен анализ, въз основа на който е синтезирана оптималната блок схема на апаратурата, реализираща предложения метод.