COMBINED SENSOR FOR DETECTION OF EXPLOSIVES BASED ON TIMED NEUTRON SOURCE AND CONTINUOUS MICROWAVES[1]

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ABSTRACT

A portable version of a combined sensor for detection of explosive substances is described. The sensor is based on continuous electromagnetic UHF waves and timed neutron source. Combination of both methods allows one to quickly localize hidden object within large area and to identify it. It is expected that the sensor would be capable of detecting modern explosive substances weighting 100 grams with little or no metal content up to depths 20 cm.

I. INTRODUCTION

Research at Radium Institute (ISTC Project #1050) is centered on development of two methods of detection of explosive substances (ES):

- application of electromagnetic UHF waves for localization and preliminary identification of hidden objects by their dielectric properties ("microwave technique");
- irradiation of the localized object with neutrons and subsequent determination of its elemental composition by characteristic γ-rays ("nuclear technique").

The microwave technique is based on irradiation of the inspected area with low-power continuous microwave radiation and measurement of interference of the probing radiation with

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that scattered from objects located in the area. The on-line analysis yields both position of reflecting surfaces within the irradiated volume and dielectric properties of substances comprising the volume. The method is very fast and allows continuous scanning of large areas. It is capable of localization of suspicious objects within the area and their preliminary identification by their dielectric properties.

The main idea of the nuclear technique is to irradiate of the localized unknown object with neutrons from isotopic sources or portable neutron generator and to simultaneously measuring secondary γ-radiation induced by neutrons in the object and charged particles that accompany neutron emission from the source. The latter allows one to use "marked" neutrons and to carry out detection of secondary γ-radiation in narrow (nanosecond) time intervals, thus considerably reducing the identification time. By using position-sensitive detector of accompanying alpha particles one can obtain a 3D elemental image of the inspected volume and identify explosives hidden inside large volumes of metallic, organic or other material.

II. MICROWAVE SENSOR

To determine dielectric properties of hidden substances an automated experimental installation was created. The range of frequencies of the microwave radiation in this installation (5 – 25 GHz) were chosen to satisfy two conditions: high spatial resolution (1,2 – 6 cm) and acceptable penetrating ability of radiation in damp media. Unlike pulsed radars, in our method the inspected area is continuously irradiated by a probing wave with changing frequency.

The main advantages of such systems compared to pulsed radars are:

- It is easy to provide a wide range of frequencies equivalent to pulse length $\Delta t \sim 0.1$ ns, hence spatial resolution $\Delta L \sim c\Delta t \sim 3$ cm.

- Possibility of off-line correction of amplitude and frequency characteristics of the emitter and the receiver.

- Well-defined frequency boundaries of the signal, outside which it has zero energy.

- Less strict requirements to the quality of emitter and receiver, and to their decoupling.

It was experimentally shown that metals and dielectrics, including explosives, can be efficiently localized with continuous ultra-high frequency radiation. This technique allows one to carry out pre-identification of the hidden object. A procedure was developed to identify dielectric objects, including explosives in non-metallic cases. This procedure was applied to cases of high attenuation and dispersion (wet sand). A more detailed description of the technique was presented in [1].

The method will be further developed to achieve good results for media with higher humidity. This will be done by introducing a reference channel, increasing the sensitivity of the receiver, optimizing the antennae system, introducing 2-dimensional correlation and statistical analysis, and using a wider range of samples and ES imitators and more precise models.

At present a portable version of the microwave sensor is under construction (see Figure 1).

It will have the following characteristics:

- continuous microwaves in frequency range 2 – 8 GHz;

- number of frequency points per range – not less than 50;

- time of analysis of one scanning cycle – less than 0.1 second;
- the power of radiation – about 10 mW;
- sensitivity – 120 dB/W;
- dynamical sensitivity range – 40 dB with possibility of changing the range depending on the level of the reflected signal;
- spatial resolution: transversal – 4 cm, longitudinal – 3 cm;
- penetrating ability of radiation in medium with humidity 20% by weight – up to 10 cm; with humidity 5% by weight – up to 20 cm;
- time of continuous work without battery recharging – 8 hours.

III. NUCLEAR SENSOR

A. Existing Device Based on Timed Isotopic Neutron Source

The existing prototype of nuclear sensor is based on timed isotopic neutron source (^{252}Cf, 4×10^6 neutrons per second) enclosed in a miniature ionization chamber [2-6]. Gamma rays induced in the inspected object by neutrons from the source are detected by NaI(Tl) detector in coincidence (10ns-wide time window) and anti-coincidence with fission fragments of ^{252}Cf (see photos at Figure 2). The coincidence spectrum contains γ-rays from inelastic scattering of fast neutrons on nuclei of the object, while the anti-coincidence spectrum corresponds to capture of thermal neutrons. In the coincidence mode the background is suppressed by more that an order of magnitude, since only a small fraction of the background γ-rays fit into the 10 ns-wide measurement window.

The measured spectra of secondary γ-radiation allow one to determine relative concentration of the main chemical elements (carbon, oxygen, nitrogen, hydrogen and others) in the inspected object. Explosives and other dangerous substances are characterized by specific ratio of concentrations of chemical elements, that allows identifying them in the presence of other substances and household goods.

The prototype is serviced by a specialized block of electronics which contains battery power supplies, fast analogue electronics, ADCs and a programmable processor, which performs data collection, storage and transfer to the external PC for analysis.

The prototype has been tested in laboratory using phantoms of trinitrotoluene (TNT) and samples of common materials: iron, wood, water, etc. Samples were placed into media with different humidity (up to 20% by weight) at depths up to 5 cm.

It has been established that the current prototype can distinguish between TNT and non-explosive substances weighting not less than 400 grams in 5 minutes. At present tests are under way to try detection of various explosive substances hidden in soil, walls, hand luggage. However use of an isotopic neutron source limits application of the existing device.

B. Portable Sensor with Timed Neutron Generator

At present Radium Institute and All-Russia Research Institute of Automatics are working on the portable device, in which a portable neutron generator with built-in system of detection of accompanying particles is used as a source of neutrons [7]. The neutron generator is a small accelerator, which does not create any radiation when it is switched off. The sectioned detector of accompanying α-particles allows one to determine the location of the hidden object within the inspected area. The portable device consists of the neutron generator, γ-detector, detector shielding, block of electronics with battery power supply and is controlled from a pocket computer (see drawing on Figure 3).

Its expected characteristic are:

1. Detection and identification of explosives weighting 100 grams in 10 seconds.

2. Simultaneously surveyed area 30 cm × 30 __ (12 in × 12 in) up to depth 20 cm with position resolution 10 cm × 10 cm × 10 cm.

3. Total weight – not more than 30 kg.

4. Ability to work in the range of temperatures -25^{o} – +50^{o}C, independent power supply (8 hours of continuous work without recharging or replacing of batteries).

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LIST OF FIGURES

Figure 1. Drawing of the portable version of the microwave sensor. 1 – antennae block; 2 – block of electronics; 3 – indication and control board; 4 – headphones for sound alarm; 5 – power supply; 6 – object.

Figure 2. Existing prototype of the mobile device for detection of explosive substances during the laboratory tests.

Figure 3. Portable device for detection of explosive substances. 1 - neutron generator with built-in sectioned detector of accompanying α-particles, 2 – γ-ray detector, 3 - target, 4 - segmented detector of the accompanying particles, 5 - specialized block of electronics, 6 - pocket computer (control panel), 7 – the inspected area, 8 - hidden object.

Figure 1

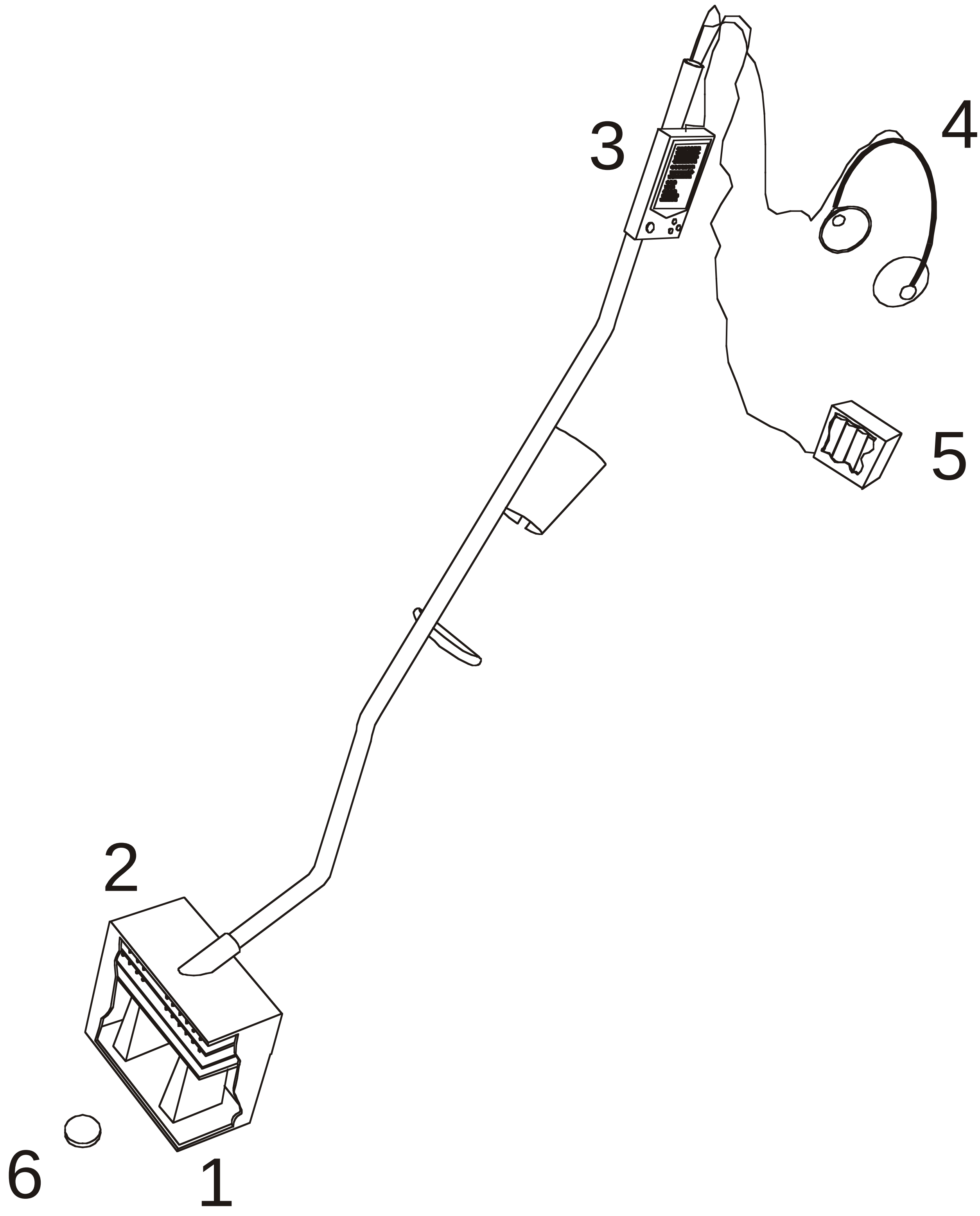

Figure 2

Figure 3