Handheld Multi-Sensor System Design Dedicated to Mine Detection

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ABSTRACT

In this study, a general structure for hand-held multi-sensor mine detection system is proposed. Ideal sensor configuration for multi-sensor mine detection system, requirements of hardware structures, data transfer issues and operational restrictions are discussed. The properties of a sample system designed according to the proposed structure are explained and a new graphical user interface is presented.

Keywords: Metal Detector, Ground Penetrating Radar, Vapor Detector, Multi-Sensor Mine Detection

1. INTRODUCTION

Hand-held mine detection systems are widely used for path and road scanning operations. There are a few multi-sensor systems which can be operated in hard military conditions[1,2,3]. Candidate sensors for this type of application can be Metal Detector (MD), Ground Penetrating Radar (GPR), Vapor Detector (VD), etc.

The most popular sensor in mine detection is metal detector. But MD can only detect metallic objects, if an object is detected by MD, operator stops and inspects by eye or special apparatus' to understand what it is. In this case, if we obtain additional information about buried object, it would be very valuable for personal decision of the operator and automatically identification software. Use of GPR presents extra information about size, shape and burial depth of buried object.

On the other hand, VD would be superior if it could be used in real time mine detection operations, because the most discriminative feature of a mine is its explosive. If the air of buried object region is inspected by a molecular analyzer, mines signatures could be obtained. Unfortunately this process needs long computation time and it is not easy to analyze mine vapor in real time, for most systems. Moreover there are some problems in this kind of sensors, natural clutters and climatic conditions may change performance of the system. Vapor detection is realized in two main stages, synthesis of convenient chemical structure and creation of detection signal by means of an electronic circuit containing a convenient oscillator and required other complementary circuits.

Since military operational conditions are very hard, all possible sensors must be used to increase detection and identification probability of mines. In some scenarios one sensor can give consistent results but in another case another sensor is better than the others. For this reason use of multi-sensor is unavoidable. In this study we present a general structure dedicated for this purpose. Desired characteristics, requirements, restrictions, ergonomics of such a system will be given and a user interface dedicated to this purpose will be explained for dual sensor case.

2. GENERAL STRUCTURE

If a detection system contains only single sensor, there is no timing restrictions. When the number of sensors increases synchronization problems arises. In this situation, each sensor should be worked at separate time intervals. Thus aliasing among sensor data can be prevented. By this motivation the following structure is proposed.

Generic view of the proposed multi-sensor detection system is given in Figure-1. Main processing unit communicates with sensor controller unit and receives the acquired sensor data and then processes the data to perform detection, identification and data visualization if it is required.

Main processing unit performs all high level processes such as driving of user interface, running of detection and identification software. Since visual data has more information than audio, it is suggested to be used a visual user

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interface in multi-sensor detectors, additional to audio warnings. In this case all the gathered sensor data and its parameters can be shown in a display without any loss, as much as possible.

When the number of sensor is increased the considered data rate and communication load increase. For this purpose a slave processing hardware named as "sensor controller unit" can be used. In order to keep precision timings, each sensor should be controlled separately, in ideal case. Use of an FPGA is a solution for this situation. FPGA structure can be configured to work as parallel blocks for each sensor. At the same time the required data transfer between sensor controller unit and main processing unit can be performed in parallel. Thus, the modular multi-sensor control and processing structure is obtained while power is saved by means of low power FPGA usage.

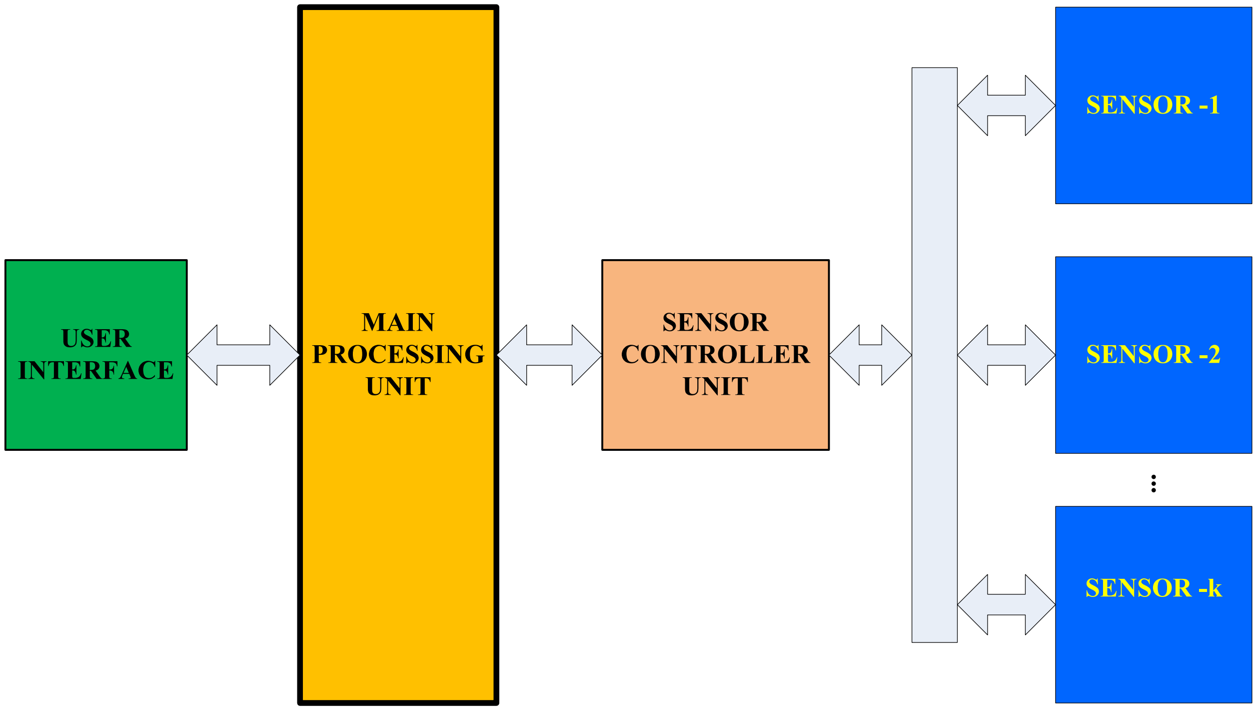

Figure-1 Generic view of multi-sensor detector

In the following chapter, the developed system named as SEZER is explained; this is based on the above explained structure. Main properties of SEZER, sensor suit, ergonomics and user interface are studied.

3. DUAL SENSOR HAND-HELD MINE DETECTOR (SEZER)

SEZER is a new generation hand–held mine detection system containing both MD and GPR sensors operating in challenging military conditions.

The operator can localize both metallic and non–metallic buried mines or IEDs through a scanning path and may identify the buried objects utilizing automatic classification software.

Audio–visual warnings are given to the operator by earphone/external speaker and on LCD display. Hence, user may create his own identification decision additionally by means of audio–visual information created by the system. SEZER is built on robust, ergonomics and lightweight structure.

The system may be used with both hands and electronic unit can be sloped to the shoulder or attached to the bandolier, ergonomically.

There is a BIT (Built In Test) at startup and during operation to supply reliability. Communication with sensors, system warnings and battery level are displayed on the screen for the operator. During operation, the processor internally checks whether desired functions of the detector are supplied or not. An acoustic alarm signal is produced when a fault is faced in these functions. These tests guarantee that the detector operates in reliable states.

The SEZER communicates with outer world by Ethernet interface if it is needed. The search head is designed optimally to obtain high antenna gain and high metal detection sensitivity. The system is compatible with military standards such as MIL STD 810G and MIL STD 461F. General view of SEZER is presented in Figure-2.

Figure-2 General view of dual sensor mine detection system (SEZER)

The control and data flow diagram of SEZER system is given in Figure-3. The Main Processing Unit (PowerPC module) meets high level computational requirements of the system. Linux Kernel based simple operating system runs over the module. The graphical user interface of the system was developed using embedded QT environment. In order to increase shifting speed of the displayed image and quality, graphical performance boosting methods were developed.

Sensor Control and Synchronization Unit (FPGA hardware) collects all data of sensors with proper timings. The collected sensor data is transferred to the Main Processing Unit by means of a special data bus. There is an Ethernet port to send out all the received data to the outer world if there is a connected device, is also helpful for real-time data transfer and software debug processes. Additionally, this utility can be used for online help to the operator during operation.

When detection is occurred in one of the sensors, modulated sounds are created and detection functions are presented on display, which are proportional with detection strengths of each sensor.

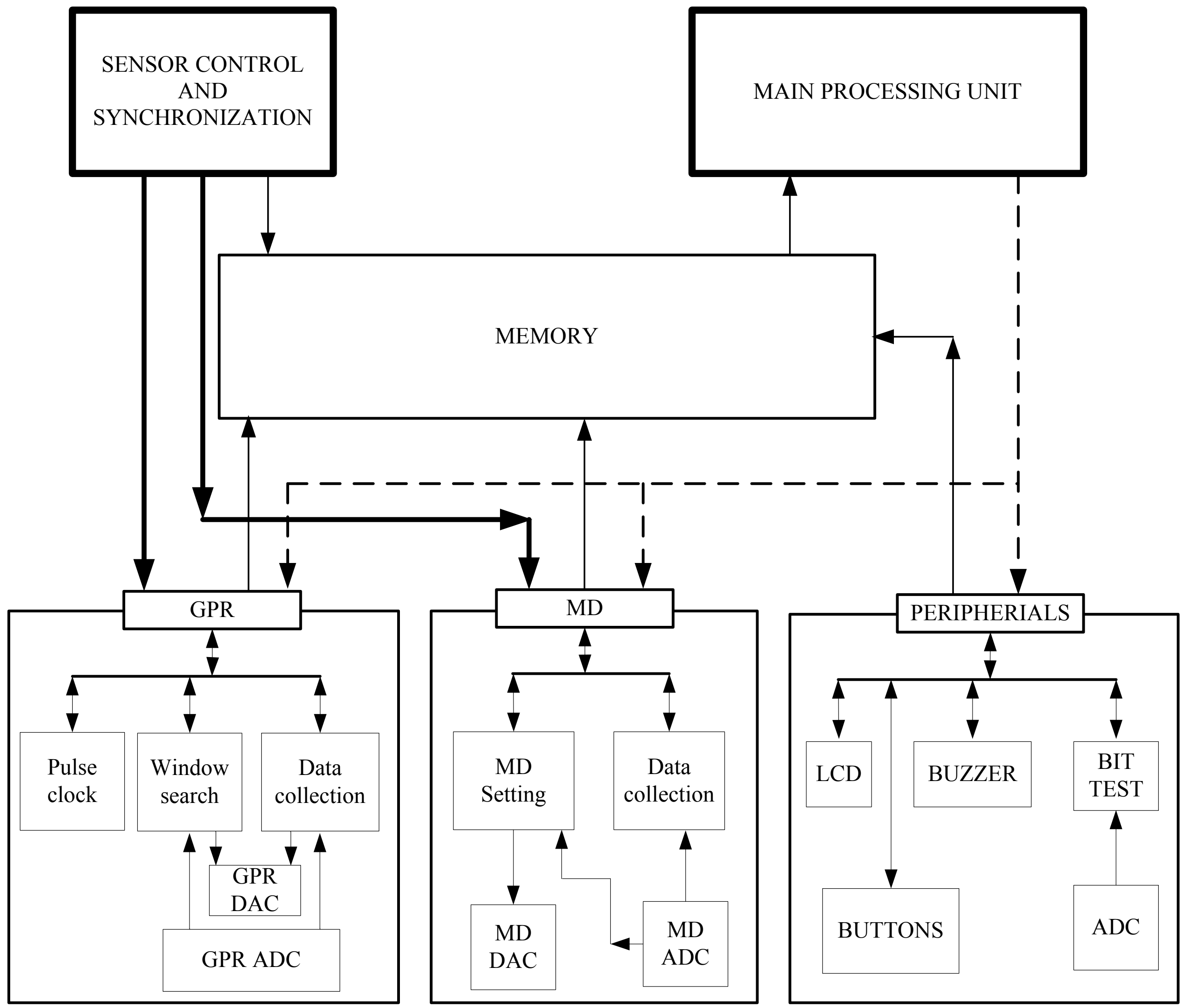

Figure-3 Control and data flow diagram of dual sensor mine detection system (SEZER)

3.1 Metal Detector

MDs are the simple, cheap and widely used sensors which can easily be procured. MDs can be categorized as continuous or impulsive types. In both types, transmitter coil emits a primary magnetic field and then it is aimed to detect secondary magnetic field originated from Eddy currents over the surface of metallic ferromagnetic objects. The information over the received target signal level depends on ferromagnetic properties of the target and metallic surface area of the buried object. Geometries and areas of coils have important effects on penetration depth of magnetic field and detectable minimum metal content.

As it is known commonly, most of classical metal detectors have only audio channels. But profile of metal density channel gives valuable information to the user in the identification of buried object. For this reason presentation of both channels of MD over a visual display would be useful. The MD of the SEZER has two channels, sensitive detection channel and metal density channel. Both channels are presented on display with overlaying for interpretation of the user. Additionally acoustic warning is created to the user synchronously.

3.2 Ground Penetrating Radar

GPR systems may work in frequency domain or time domain. There are some advantages and disadvantages of the systems according to each other. Signal to noise ratio of frequency domain systems is better than time domain systems. Meanwhile the data is present in time domain system whilst frequency domain systems need inverse calculations of Fourier transform to obtain time domain signal.

One of the most important parts of GPR systems is antenna which radiates ultra wideband (UWB) signal to the soil. Antenna should have stable performance over different types of soil and transmit and receive short pulses of electromagnetic field with minimum distortion.

In the literature, a few types UWB antennas are used in GPR systems, such as resistively loaded dipole antenna, dielectric rod antennas, bow-tie antenna, TEM horn and Vivaldi antennas[4]. Each type has its own advantages and disadvantages and potentials of these antenna types are almost fully exploited.

Besides the antennas, cavity-backed UWB antennas can be used in impulse GPR systems. In SEZER, we use modified small sized cavity-backed antenna to obtain a near field subsurface detection system.

The cavity height is diminished using by resistive loading so that the antenna is suitable for such kind of portable systems. The cavity height of the antenna is 50 mm and the size of cavity is equal to size of substrate plane being 260 x 110 mm.

Although the antenna has a small cavity size according to center frequency that is in GHz region, it can operate lower frequency band too. The antenna 10 dB bandwidth is approximately 1.5 GHz. In the active region of antenna, the return loss performance of the antenna is lower than -10 dB (S_{11}<-10 dB) which produces low level ringing for the designed system. Radiation pattern of the antenna is directional and stable for the propagation direction in the frequency range. The coupling level between the transmitting and receiving antenna is lower than -30 dB. The corners of the cavity are rounded to reduce the SWR performance of the antenna.

The attenuation of GPR energy is important in the detection of buried targets. Moreover penetration of radar energy into the soil is limited by electromagnetic characteristics of soil. The GPR signals arriving at the receiving antenna are attenuated and changed because of the absorption of the ground. The electromagnetic characteristics of soil are determined by three parameters: dielectric permittivity, electrical conductivity, and magnetic permeability[5].

It is necessary to calculate value of attenuated GPR signal, which should be above noise level. The attenuation coefficient is important to determine how much power of the signal propagates into the medium. Figure-4Figure 4 shows attenuation coefficients which are depicted according to effective relative dielectric permittivity and electrical conductivity at 500 MHz and 1 GHz frequencies.

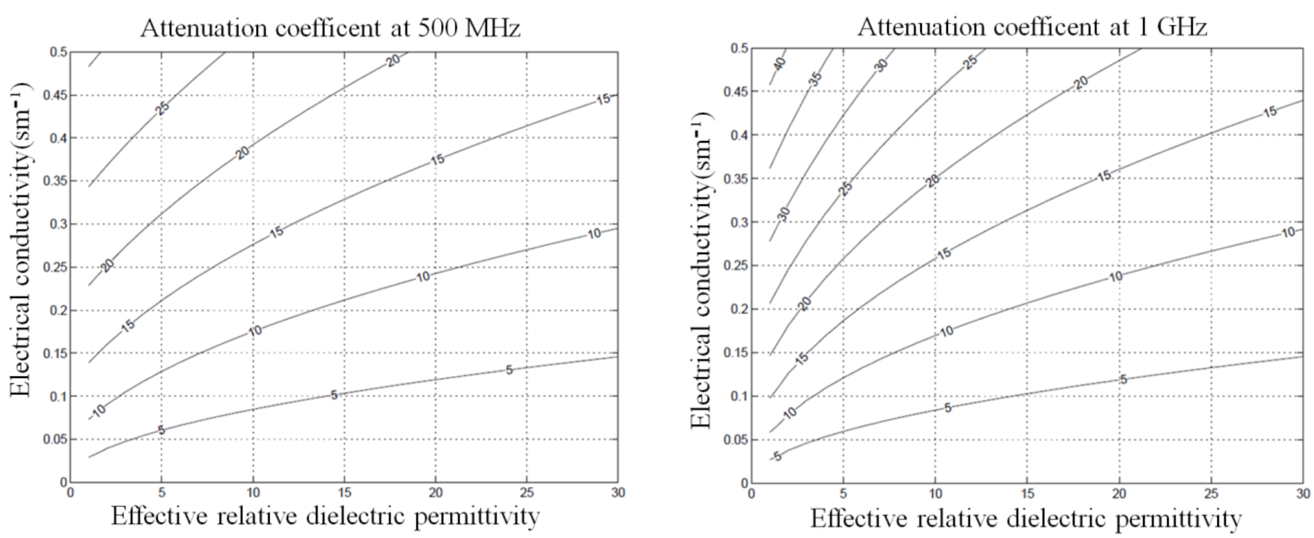

Figure-4 Attenuation coefficients as a function of effective relative electric permittivity and electrical conductivity at 500 MHz and 1 GHz.

It is expressed in[6] that the total path loss may reach up to 100 dB in problematic soil types at reasonable burial depths of landmines. For this reason loop gain of GPR system should be in the order of 120dB.

3.3 Spatial resolution and data transfer rate

While passing over the buried object, each sensor collects the data in its own sampling rate. Generally MD works in a few hundred Hz Pulse Repetition Frequency (PRF), transmitted signal and its power, shape and area of the coils determines performance of the MD.

On the other hand GPR signal should be in Ultra Wide Band characteristic to obtain discriminative information. It should be noted that soil suppresses high frequencies more than low frequencies. PRF of GPR systems may change from several hundred kHz to MHz region.

A typical scanning scenario of a hand-held detector is given by Figure-5 and relevant parameters are defined in the following.

V_s : scanning velocity of search head [m/s]

X : scanning length [m]

dx : sampling distance in scanning direction [m]

Minimum radius of the target R_T is in the range of 4-6cm in landmine detection applications. Hence, we need high enough bandwidth as high as possible to detect the smallest target. Meanwhile we should gather at least k_{min}=10 A-scan data over the smallest mine to be able to detect it easily.

If we choose V_s=0.2m/s and dx=0.004m we obtain approximately k=10 A-scan signal over the minimum sized target. On the other hand, N=X/dx=250 GPR A-scan signals are collected from GPR sensors in 1meter length. This corresponds to 20 ms time interval between consecutive A-scan signals.

When PRF=100 KHz is selected and L=256 samples are grabbed for each A-scan signal, we obtain the calculation time of one A-scan signal is 256/100 x 10^{-3}=2.56 ms. If sample averaging is used to filter high frequency noise with 4 samples, 10.25 ms time intervals are obtained. In the next step MD should be run according to this time plan.

If the overall data transfer rate is considered between main processing unit and Sensor Control & Synchronization Unit we see that approximately 5 kbit/s transfer rate is enough.

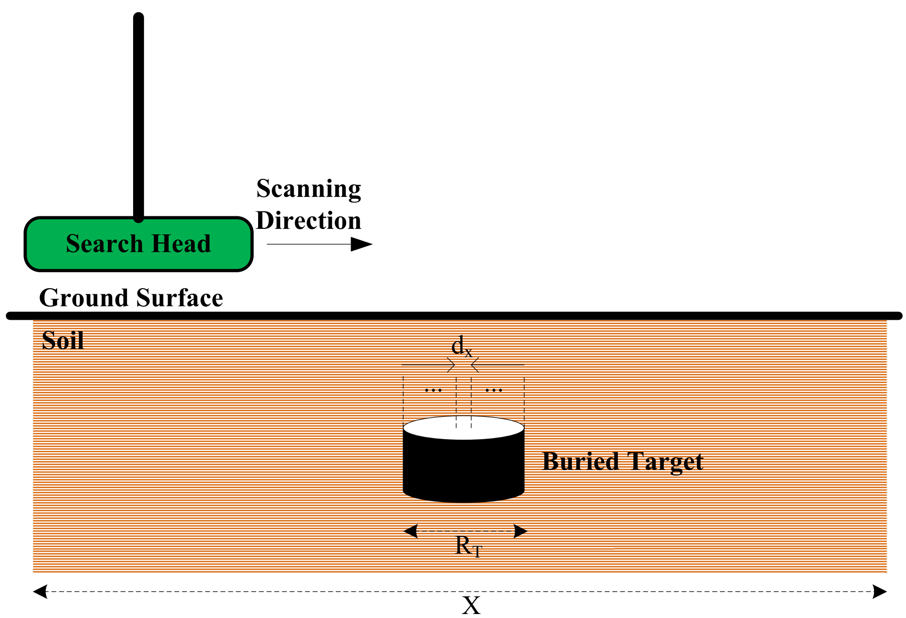

Figure 5 Data collection scheme

3.4 Mechanical Properties

The most essential needs for military products are ergonomics and robustness in terms of usage. Moreover, if the product is carried by an operator during the operation, weight of the product becomes significant restriction for the designer. On the other hand, robustness must be conserved while decreasing the weight of the product. In order to design an optimal system, proper material must be selected. Composite materials and aluminum alloys generally provides these requirements.

If the overall detection system is considered physically, it can be divided into two main parts: electronic unit and hand unit. The main design parameters of electronic unit are electromagnetic compatibility, accurate heat transfer, corrosion and water resistance. When the weight, corrosion resistance, electromagnetic compatibility, manufacturing parameters and production costs are considered all together, the most appropriate material for the electronic unit is aluminum alloys. On the other hand each electronic card should be placed separate rooms inside of the electronic unit, in order to prevent interference between each other

Search head is critical part of hand held mine detection systems. Since its furthest part from the supporting point creates high moments to the arm of the operator, it may cause trauma in the arm. Thus it should be light as much as possible. To the best of our knowledge, raw-material of the search head should keep exceptional mechanical, thermal, and electrical properties. Hence, it is proposed to use thermo-plastic materials in design of the search head.

The next step of hand-held mine detector design is to form the scanning-arm which is the frame of the system. The robustness must be primary requirement for this part since it holds all components of hand unit. In order to obtain maximum strength in the minimum volume, its geometry is defined tubular. This also implements easiness for manufacturing. The fittest material for this part is glass reinforced fiber because of its strength and electrical properties.

In order to finalize the concept design of the arm, the functional parameters must be supplied. The main functionality of the arm is being adjustable for the different operators' heights. This is also fundamental requirement for ergonomics design. In order to supply this function, the arm of the product is designed as telescopic structure. Hence, the hand unit length can be set from 80 cm to 170 cm.

One of the distinctive properties of the developed product is to have a visual interface unit. This brings beside sophisticated problems such as electromagnetic compatibility, ergonomics and extra cable problems. The ergonomics issue is solved by designing a joint supplying two axes rotation. The electromagnetic compatibility and reflection problem is solved by using special filtering panel in front of the display.

3.5 User Interface

It is known that real time buried object detection is very important issue for hand-held detector search applications[7], especially for mine detection operations. In case of multi-sensor usage, interface between man and machine would have paramount importance. In order to obtain maximum user interface efficiency for each sensor, a visual interface unit should be used in addition to voice alerts. Because, when the number of sensor is increased, audio warnings would not be enough for easy interpretation.

On the other hand, creation of individual audio warnings may cause discomfort for the operator in case of false alarms, thus operator cannot feel himself in safe. It is also known that visual data has more useful information than audio in the learning of human brain. For these reasons presentation of data visually on a display would be useful. At the same time operator would feel comfortable himself during scanning process while observing the inspected region data visually, when it is needed.

EMI sensor gives a detection warning signal for metallic objects while creating a metal density function proportional with metallic content of the target in the scanned line. Sometimes waveform of this function would have discriminative features about buried object. For this reason presentation of this information on a display would be useful for the operator.

GPR sensor is used to detect nonmetallic and metallic mines or other objects. At the same time GPR sensor offers low resolution imaging capability of the scanned line, compared to light. Visual data of GPR sensor can be more useful than detection voice alerts for operator’s interpretation and decision.

For the reasons described above, a TFT LCD is added to our dual sensor handheld mine detector and the sensor data is also shown on a screen. The vertical synchronous visual graphical user interface for SEZER system is designed to display:

- Metal density of EMI sensor
- Detection information of EMI sensor
- Reflected target energy of GPR sensor
- Detection information of GPR sensor
- Buried target region spatial cross-section GPR image (in depth).

The data is organized in a manner that they are aligned in vertical axis and they shift from right to left simultaneously. General view of the user interface is given in Figure-6.

User is informed by means of display and detection warnings are depicted for both sensors. Additionally, self training becomes possible to understand the scene by the user.

Since commonly used sensor is MD the data of this sensor is displayed on top section of the data window. Operator can observe the metal detection information and metal density function in a shifting fashion depending on scanning speed. Detection region is marked with blue color and maximum value of metal density and sensitivity parameter are presented on the left side.

GPR target energy function is drawn on the middle section. Detection function's color changes to red when buried object is detected.

GPR cross-section image is presented in the bottom section of the window which shows information about the spatial cross-section image of buried object region and depth of buried object can be the estimated by the operator, depends on soil properties.

With these features, vertical synchronous visual graphical user interface for dual-sensor mine detection system has introduced new features which are unique in use[8].

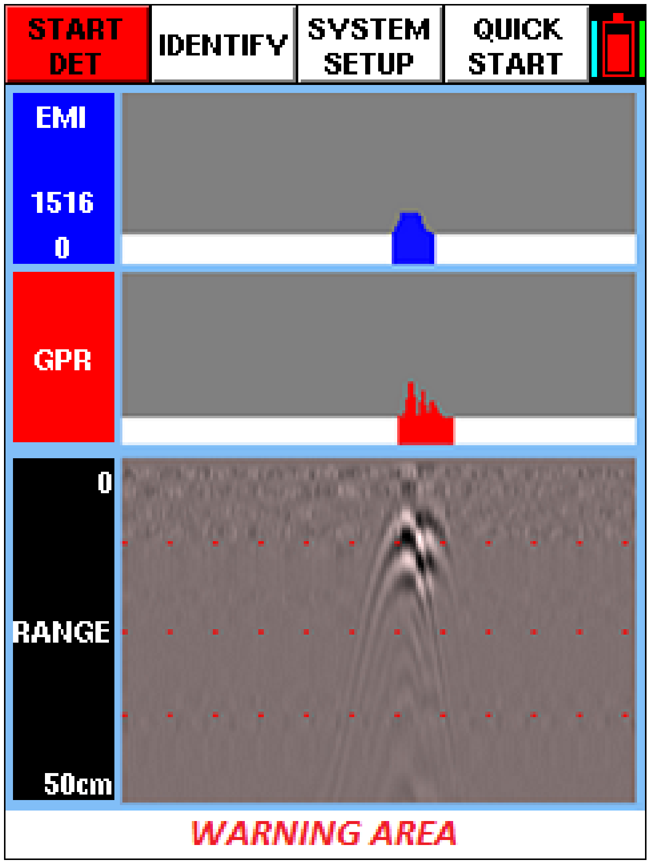

Figure 6 User interface of the developed system (SEZER)

4. CONCLUSIONS

In this study a modular hardware structure for multi-sensor hand held detector is proposed and a sample system developed according to this structure has been presented. Different aspects of design are addressed and a new user interface is given enabling interpretation of the sensor data personally in the identification stage. Complementary sensors can easily be added and their signals be processed in the proposed structure (e.g. vapor detector etc).

5. ACKNOWLEDGMENTS

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