IMPULSE RADAR EMERGENCY SYSTEM TO PREVENT DAMAGE DUE TO HARMFUL OBJECTS IN VEGETATION

Anatoliy A. Boryssenko, Research Co. DIASCARB, Kyiv, Ukraine

Abstract – The paper presents the experimental radar-based sensor to operate in environment with vegetation cover for detection and discrimination there the small-sized invisible dielectric and metallic objects. This sensor constitutes a vehicle-housed emergency system for surveillance of area with vegetation ahead on the path of moving vehicle to prevent its contact with hidden objects. The emergency system functioning in basically implemented by real-time electromagnetic imaging of the scene of interest and its following image processing to enhance the target responses. The developed and tested experimental radar techniques are under consideration. The results of experimental examinations in field are presented and discussed.

Introduction

In this paper a potential of the UWB time-domain radar-based remote sensing system to detect and discriminate small-sized dielectric and metallic objects hidden in vegetation-covered media is treated for the vehicle emergency system design. Such system should provide surveillance of vegetation–covered area, i.e. a scene of interest, ahead on the path of a moving vehicle to prevent its possible damage caused by contact with the hidden harmful invisible objects in vegetation.

The detectable targets should be characterized by their spatial position, shape, dimensions, physical nature etc. to make a decision concerning its threat degree for vehicle. Reaching this goal the radar imaging of scene of interest is implemented in this study for automatic detection and recognition by special designed set of the DSP-based signal processing techniques.

Practical necessity of presented studies is originated from the natural phenomenon common for many agricultural regions of the East Europe. This phenomenon results from geological history of the moraine period and characterized by so-called "growth" of stones from the earth. For example, such moraine stones can be dispersed in the crop field on the path of harvest machinery, caught by its harvester and cause its damage. The buried ammunitions and unexploded ordnance objects of the times of the World War Two also demonstrate similar behavior.

Among other remote sensing techniques like optics, infrared, radiometric, millimeter-wave radar and others only ultra-wide band (UWB) radar with the effective 0.5-1.5 GHz frequency band has the potential to look trough vegetation, grass, foliage etc. This chosen frequency band is optimal one due to a common trade-off between minimum attended loss in vegetation propagation and maximum spatial resolution should be achieved in radar [1].

The designed emergency sensor is based on the UWB time-domain radar due to the author's early experience in design and applications of time-domain ground penetrating radar (GPR). Generally GPR systems are widely employed to obtain electromagnetic section of opaque media like soils, rocks, snow cover, ice etc. [2]. A modification of GPR-like system has been before examined for vegetation-covered environmental operation and this work is further development of the previous study [3].

The operation media for the designed system is a crop field. It is more statistically uniform site than the high-cluttered environments for the land-mine detection. The last problem is similar to that studied here [4]. So the automatic detection and recognition can be achieved for "stone-in-crop field" in more easy way than for land-mine detection. The more complex environmental scenarios can be also involved in study by introducing the adequate signal processing techniques similar to the developed in this study [5].

Basic Research Approaches

As a matter of fact the potential of radar-based sensing system is a function of the radar system performances and the features of the scene of interest including environmental conditions and target types. The radar performances are followed from properties of its antennas, transmitter, receiver, and all signal processing techniques implemented by electronics and software means. The operation environment is described by vegetation type like grass, crop etc. with the definite biometrics features such as architectonics, height, density, humidity and so on. All these environmental factors have real stochastic behavior demanding special care to estimate their influence on the registered electromagnetic scattering events and finally the achieved radar performances.

For the specified above problem a stone hidden under vegetation cover is a target should be detected. The RCS for energy-based detection and the signature for discrimination can characterize target in ordinary mode [6]. Both target features depends strongly on the contrast of electrical properties between target and background, which is formed by vegetation tip and terrain surface. The receiver-operation characteristic (ROC) can be employed for estimation of the overall radar system potential in the context of probabilistic problem nature [6]. The radar ROC should present detection and false alarm rates versus signal-to-noise ratio (SNR) and signal-to-background ratio (SBR).

Let consider the principal technical aspect of the radar-based emergency system implementation.

There are two main modes, i.e. stand-over and stand-off, to employ the UWB high-resolution radar for target detection and discrimination in vegetation and subsurface like schematically shown in Figure 1. The stand-over mode is applied widely in GPR practice especially for a hand-held radar [2]. The stand-off mode is more preferable for the designed system due to opportunity to monitor large area at safe distance before moving vehicle with installed radar [7]. Also in this case stochastic medium does not disturb the radar antennas in contrast to the stand-over mode [5]. So in this case the radar has more stable operation behavior. Again from geometrical point of view there is some uncertainty of target position in Figure 2a in contrast to Figure 2b due to geometrical shape of equal double-travelling time traces of the antenna footprint.

The stand-off radar concept has static and dynamic implementations for its examination. For simplicity reasons the static experimental assembly, in Figure 2a, is firstly used. For this case testing assembly consists of the stationary mounted radar on the tripod and a set of movable test targets shown later in Figure 5 a,b. The dynamic experimental set-up, in Figure 2b, i.e. a prototype of developing radar emergency system, must operate being housed on movable platform or vehicle.

In order to reach high-resolution features in radar a short-pulse signal or equivalent wide band is above chosen on the competitive base. In the time-domain radar the pulse antennas with shock excitation enable such features. Antenna illumination forms a scene of interest covered by antenna footprint. The size of antenna footprint depends on height of antenna installation and its down-look angle. Note that energy pattern of pulse antenna with transient excitation is too wide resulted in large footprint [8]. The last has positive and negative aftereffects in radar. The negative aspect is strong background scattering and positive one is absence of special scanning to monitor the definite-sized area.

Signal Processing

The simple case of emergency system will be under examination, which is based on single-receiver monostatic radar. Nevertheless such simplicity the monostatic single-receiver UWB time-domain radar enables investigation all principal features on the discussed subject. The receiving antenna array will be next research step and is in progress now.

Due to used one-channel receiver in radar a 1-D dynamic presentation of scene of interest like shown conditionally in Figure 3 is employed here. The radar imaging of scene of interest is represented in Figure 2 in a form similar to common B-scan or radargram for GPR data [2]. But in this case the vertical axis of radargram presents the distance between the target and the radar that changes in time due to their mutual replacement. The horizontal axis is current or scan time.

For example, one can observe in Figure 3 two typical predictable cases of target-radar approach. If the target is directly spaced on the axis of mutual approach the trajectory as straight line is registered. If the target is shifted from this axis the curved trajectory line is obtained. Of course, there is some uncertainty in the last case: from whish side, left or right in accordance to the approach axis, is target located? However this can be resolved by using at list one additional receiver channel to implement a receiving array in radar.

The next important moment should be stressed is one that in order to overcome antenna pure directivity and its following consequences discussed above two principal radar techniques will be employed here:

1) ***the synthetic aperture technique*** to improve spatial resolution due to effect of mutual replacement radar and scene of interest with target on it when antennas with inherent low directivity are employed [1];
2) ***the moving-target-indication technique*** common for radar operating in air to overcome masking effect of strong background scattering [6].

The features both the synthetic-aperture technique and the moving-target indication are examined experimentally in this study. The final goal is development of the relevant signal-processing algorithm should be tractable for their real-time implementation by the DSP means. The simple detector schema with threshold criterion should be integral part of the overall system functioning algorithm. The target identification algorithms are not studied here. This aspect is not actual one for the treated uniform agricultural fields operation as mentioned before. Besides radar's antennas and electronics features the signal processing gains sufficiently the growth of the radar potential.

Experimental Technique

The UWB time-domain radar system under examination in Figure 3 is based on the adopted components of the own designed UWB radar used before as a GPR system. This radar system is characterized by utilization of the active pulse bow-tie antennas with backside reflector. Those antennas are directly terminated to the front-ends of transmitter and receiver. The transmitter has 50 Volt pick pulse to drive antenna with 100 kHz pulse repetition. The receiver has about 50-microvolt MRS with stroboscopic sampling and the following 10-digit ADC. The radar returns is processing by some radar electronics units like temporal AGC of 60-dB range and mainly by DSP computer card for real-time processing presented below. All radar data are stored on the hard disk of portable computer with real-time visualization of the scene of interest.

Two kinds of targets have been involved in the system field-testing program. The first target is a stone like shown in Figure 5a of about 10-cm^3 volume. For static examinations this stones is tug by a cord as seen in Figure 5a. The next target applied for calibration is a vertical dipole made from telescopic flagpole antenna mounted on foam plastic base in Figure 5b. This antenna is comfortable due to possibility to change its height in process of testing for radar performance estimation.

Static examination set-up is shown in Figure 5c. There is radar monostatic head with transmitter and receiver and their antennas in single case installed on the tripod. The active antennas terminated directly to transmitter and receiver units, which are connected via coaxial cable link with other radar electronics and computer. A target attached to towing lag is also seen in Figure 5c.

The dynamic examination set-up has been implemented on the base of car in Figure 5d. The height of antenna installation on the special chassis was about 3 meters that corresponds to the possible installation height on harvest machinery.

Preliminary experiments have been conducted with both the dynamic and the static testing assemblies. In such way the radar-based emergency system and its potential to solve the above formulated problems have been successfully examined.

Examination Results

The only "stone-in-meadow vegetation" scenario is considered below. The examination results are presented in the form of electromagnetic images of scene of interest. Those images are formed by conversion of bipolar radar responses into electromagnetic image like the B-scan for GPR system.

Next, let show and discuss typical experimental results obtained by implementation of above presented testing techniques. Firstly, the simplest experimental arrangement with the stationary radar and the movable target, the stone in Figure 5a, on the terrain surface without sufficient vegetation is demonstrated in Figures 2a and 5c. The radar-registered data are presented in Figure 6 as a screen copy of the computer window where the radar returns are displayed in real-time mode due-to the DSP technique used.

The left picture in this window shows the initial radar data presented in the format discussed before. In this case the distance coordinate is along the vertical axes and the current time coordinate along the horizontal axes. The distance along the vertical axis is ranged here up to 10 m and total examination time is about 6 s. Those figure corresponds to the target velocity of about 1.5 m/s that is a typical speed for harvest machinery movement in field operation.

As seen in Figure 6, the original image of the scene of interest is under powerful masking interference's signals due to strong background scattering. A trajectory of mutual approach of the target and the radar is slightly visible as a fuzzy line drawn from the below-left corner to the upper-right one. This line is observable very difficult for the original data and then it is better visible after processing. The aforementioned velocity value of mutual approach of the target and the radar is the inclination of the trajectory fuzzy line. A residual uncompensated noise is presence here too due to fluctuations of background scattering in the process of radar/target movement. Special signal processing techniques to enhance SNR figure should be employed and it is discussed later.

When the target is hidden in vegetation for static examination the situation is worse than previous case as seen in Figure 7. Due to target movement trough vegetation the last is swung makes more non-stationary background scattering. In turn, this unfavorable event increases non-compensated noise on the left part of the presented picture.

The next picture in Figure 8 illustrates the results of the dynamic examination to locate stone hidden in 20-30 cm meadow vegetation of sufficiently non-uniform density. The velocity of car movement is about 2 m/s (7 km/h) and slightly non-uniform. Such movement is expressed in Figure 8 as non-constant inclination of the trajectory. There are also some false targets, or clutters, formed by hillocks and separated fragments of vegetation of high density and height. It is possible to separate these scattering events by the resonance-based discrimination [4] due to different features of the registered waveforms for stone and clutter electromagnetic scattering. The vertical-to-vertical polarization is considered here but the full-polarimetric technique [4] is also very preferable in this case.

Further investigations have been conducted to implement the advanced signal processing approaches that enable improving the system performances like ROC. For illustration, Figure 9 shows four consecutive images of the scene of interest for the case of static examination with stone on the terrain surface without sufficient vegetation. The conditions of this experiment are same as shown in Figure 6. The corresponding radar echo-waveforms for various processing stages, which demonstrate transformation and discriminations of useful signal components masked initially by a background scattering, are also shown in Figure 9.

The first upper image is non-processing one with SBR magnitude equals about –15 dB. The next image after the moving-target filtration include a residual uncompensated noise. This noise with SNR figure $\leq -6 \ldots -8$ dB is produced due to unavoidable fluctuations of background scattering resulted from target-radar replacement. The third image in Figure 9 is resulted from the its upper neighbor after eliminating the residual noise by the corresponding filtration. On this stage SNR $\geq$ 10 dB that is enough for reliable threshold detector operation in the accordance to the standard ROC [6]. The results of one-sided threshold applied to previous stage processed data is shown in the last lower image in Figure 9.

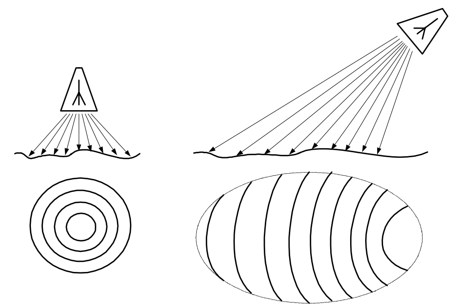
Discussions and Conclusions

Brief summary of the test results and the future directions of radar-based emergency system development are listed below.

1. The presented idea of the radar-based emergency system is functional for its implementation due to UWB radar high-resolution features with the corresponding signal processing techniques.
2. Additional efforts should be directed to optimize system components like antennas, radar electronics and its general behavior (system algorithms of operation).
3. In general, the sufficient improvement of the system performances (high probability of detection, low and stable false alarm rate etc.) can be achieved by development of the optimized detection strategies and improved target recognition.
4. The theoretical target signatures can be employed to build the advanced matched-like detector schemas [4]
5. Sufficient improvement of radar receiver operation characteristic can be achieved by application special 2-D signal processing and detecting techniques.
6. 2-D presentation of scene of interest requires application of two and more channels receiving array with additional opportunities for target recognition.
7. Full-polarimetric technique is also preferable here due to advanced opportunities to discriminate and recognize target by processing its response with estimation the target 3-D geometrical features.
8. It was estimated that registered by radar background scattering depends on biometrics features of vegetation and can be useful for setting of operation modes of harvest machinery.

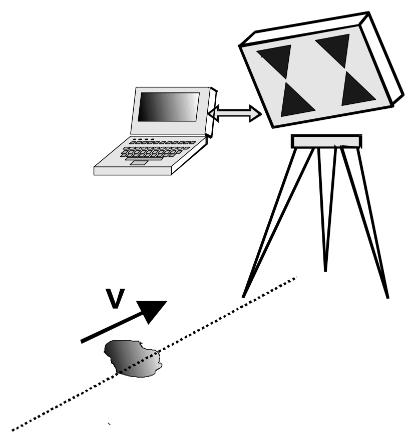
References

1. *Subsurface Radar* (1994), Ed. by M.I. Finkelstein, Radio i Svjaz, Moscow. (In Russian).
2. *Proceedings of the international conference on ground-penetrating radar*" (1998), Lawrence, Kansas.
3. A. Boryssenko (1999), "Active microwave imaging in opaque media", *Book of Abstracts of the XXVIth URSI General Assembly*, Toronto, Canada, p. 119.
4. L. Carin, N. Geng, M. McClure, J. Sicina, L. Nguyen (1999), "Ultra-wide-band synthetic aperture radar for mine-field detection", *IEEE AP magazine*, **41**, No. 1, pp. 18-33.
5. A. Boryssenko (1999), "Ultra-Wide Band Impulse Radar for Stand-off and Stand-over Searching of Land Mines and UXOs in Subsurface Regions and Vegetation", *Proceedings of Euromine Conference*, Florence, Italy, pp. 111-116.
6. *Radar Handbook* (1970), Ed. by M.I. Skolnik, McGraw-Hill Book Company.
7. *Jaycor stand-off mine detection radar system*, http://www.jaycor.com/eme/smdr.html
8. A. Boryssenko, V. Tarasuk (1999), "Ultra-Wide Band Antennas for Subsurface Radar Applications", *Proceedings of Antenna Application Symposium*, Monticello, IL, pp. 478-504.

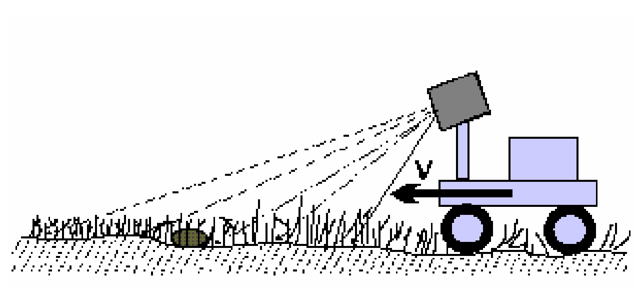


a) b)

Figure 1. Radar's antenna position in accordance to the scene of interest: a) stand-over, b) stand-off.



a)



b)

Figure 2. Experimental implementation of radar emergency system for two kinds of operation: a) static and b) dynamic.

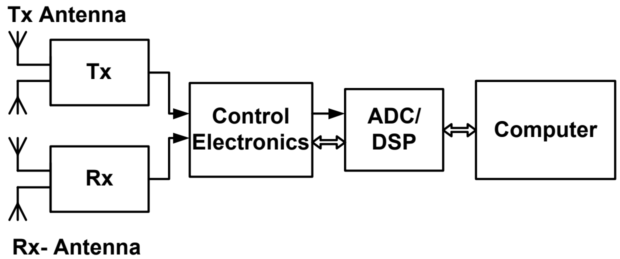
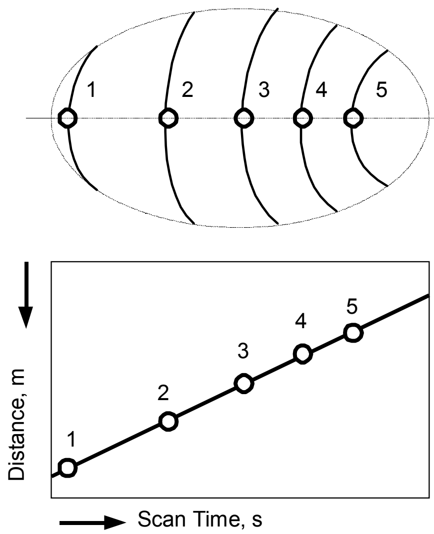
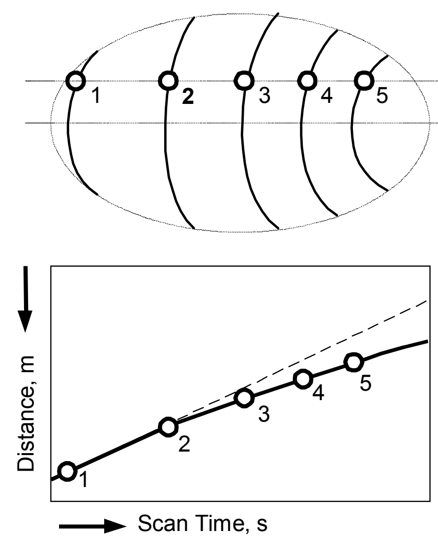


Figure 3. The UWB experimental radar structure.



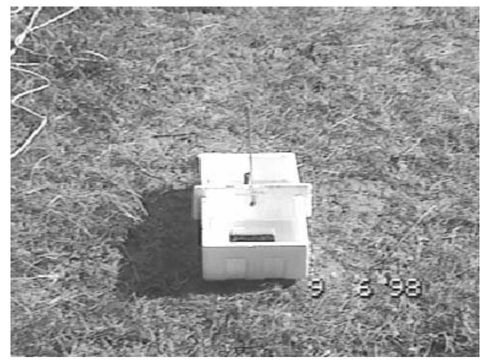
a)



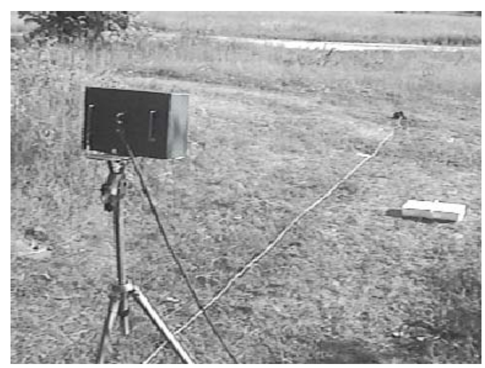
b)

Figure 4. Radar imaging of scene of interest by processing radar data for target (a) on the axis of radar movement and (b) outside it.

a)



b)



c)

d)

Figure 5. Outward appearance of testing assemblies elements.

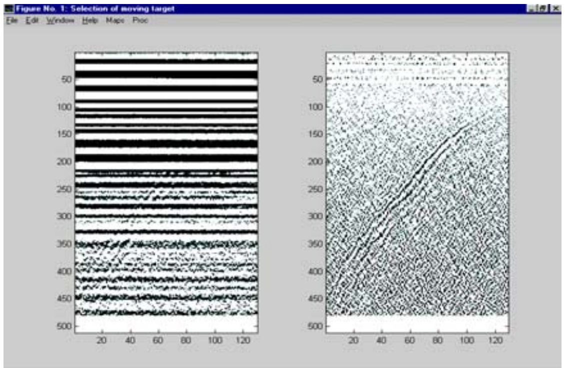


Figure 6. Results of static examination when target is located on area w/o sufficient vegetation.

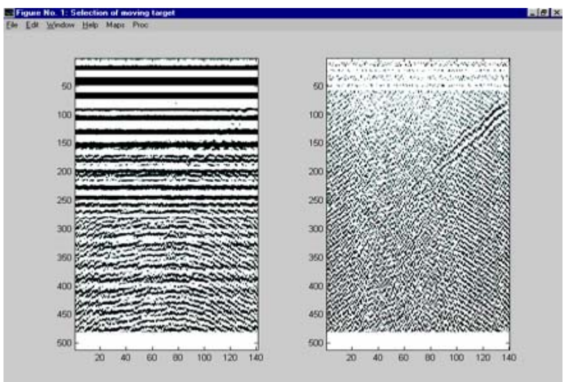


Figure 7. Results of static examination with target hidden under sufficient vegetation cover.

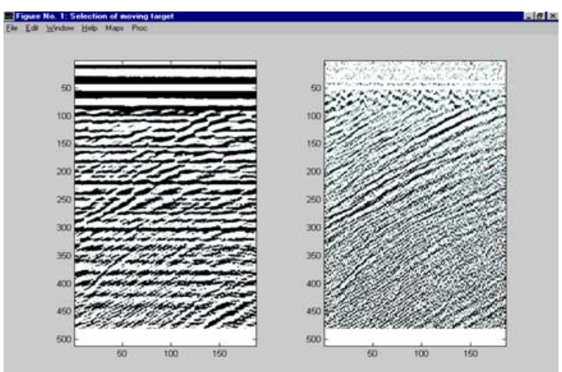


Figure 8. Results of dynamic examination when target covered by moderate vegetation.

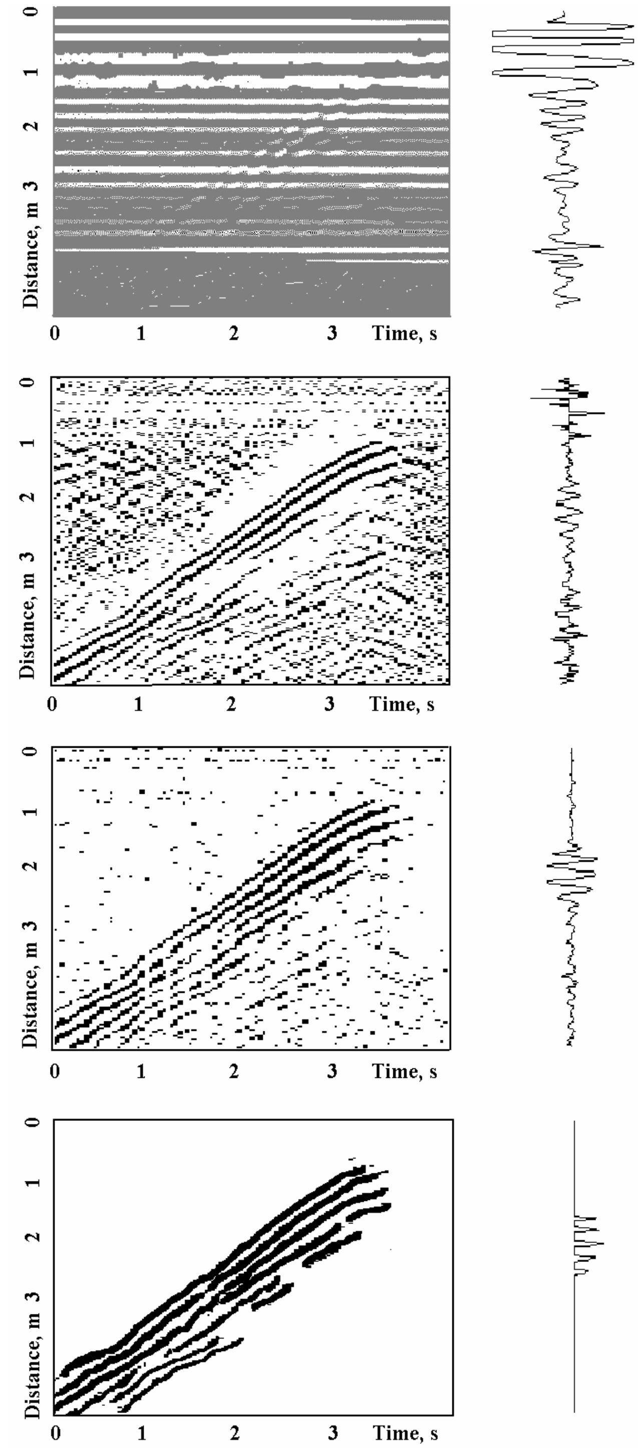


Figure 9. Signal processing flow-chart and typical scene images and waveforms.