Reprint

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IEEE Aerospace and Electronic Systems Magazine

VOL. 19, NO. 5, MAY 2004, pp. 26-30

Anti-Aircraft Artillery Simulator

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Air defense systems protect land and maritime resources from air attack. Depending on the regional characteristics and type of conflicting forces, air defense threats vary considerably. In regional conflicts, where forces with similar capabilities are involved and no air-superiority can be achieved, the role of air defense systems becomes critical. In combat terrains containing mountains (in mainland or in small islands), the man-operated or computer-controlled (using passive sensors) anti-aircraft artillery can be highly effective.

In many operations, aircrafts and helicopters used in ground forces support or in personnel and equipment airlift roles, typically operate in a low altitude regime, flying a few hundred or thousand feet above the ground. While the low-level portion of the flight exposes them to hazards from anti-aircraft artillery (AAA) fire and surface-to-air missiles (SAMs), it is the pass over the drop zone, or the time spent getting into and out of the assault strip that is probably the most dangerous for the aircraft and crew. Relatively high in the air and slow at that point, they are most vulnerable to ground fire. Therefore, anti-aircraft artillery systems can be used to improve air defense effectiveness in a given tactical environment, due to their lethality in short range and low altitude flying targets, in contrast with most guided missiles that have a minimum range within which they are not effective.

Anti-aircraft artillery is usually based on computerized search and fire control systems. Radar-guided weapons may become non-operational under conditions of deliberate emission of electromagnetic radiation. In this case and for low flying aircrafts and helicopters, man-controlled weapons may result in increased effectiveness if they operate in an environment that combines tricky weapons deployment with well-trained personnel.

The simulator presented in this work aims to exploit the capabilities provided by current Commercial-Off-The-Shelf (COTS) communication and multimedia technologies for providing a training environment that improves the personnel capability for effective use of man-controlled anti-aircraft weapons.

THE SIMULATOR'S FUNCTIONALITY

The developed AAA simulator consists of two types of computing devices: a Central Control Station (CCS); and a Weapon Terminal (WT), as shown in Figure 1. The Weapon Terminal is attached directly to the anti-aircraft weapon, utilizes its sensors, and presents realistic combat conditions to the trainee using high quality graphics. The Central Control Station is a multimedia terminal used by the instructor, where the trainee's actual behavior is presented, the exercise status is continuously updated, and statistics are collected. The communication between the computing devices is achieved by using a high-speed wireless link. The simulator uses powerful signal processors for calculating the projectile trajectory in real-time and for estimating the minimum distance between the projectile and the target.

The simulator supports pre-stored combat scenarios ranging from simple trajectories of a single aircraft up to evasive maneuvers and weapons delivery of multiple aircrafts. Since various factors affect the anti-aircraft artillery accuracy and effectiveness, the simulator employs a number of functional modules that result in realistic projectile flight simulation. Variations on projectile weight, initial velocity, elevation, and azimuth aiming, crosswind and range wind, as well as on air temperature and density that cause various miss distance distributions, are taken into account. For estimating the minimum distance between the projectile and the target with high accuracy, the simulator uses high precision analog sensors and intelligent signal processing algorithms that result in a resolution of 1 m at 4 km distance from the weapon.

Due to its centralized control, multiple anti-aircraft weapons can operate simultaneously using the same combat scenario under the supervision of a single instructor, having different views of combat conditions. Each weapon corresponds to a different location on the combat field and all weapons are synchronized to the timing evolution of the combat scenario. The anti-aircraft artillery simulator can also be extended to cooperate with aircraft flight simulators. In this case, the pre-stored flight scenarios will not be used, but real-time data generated by the flight simulator must be

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Manuscript received November 14, 2003.
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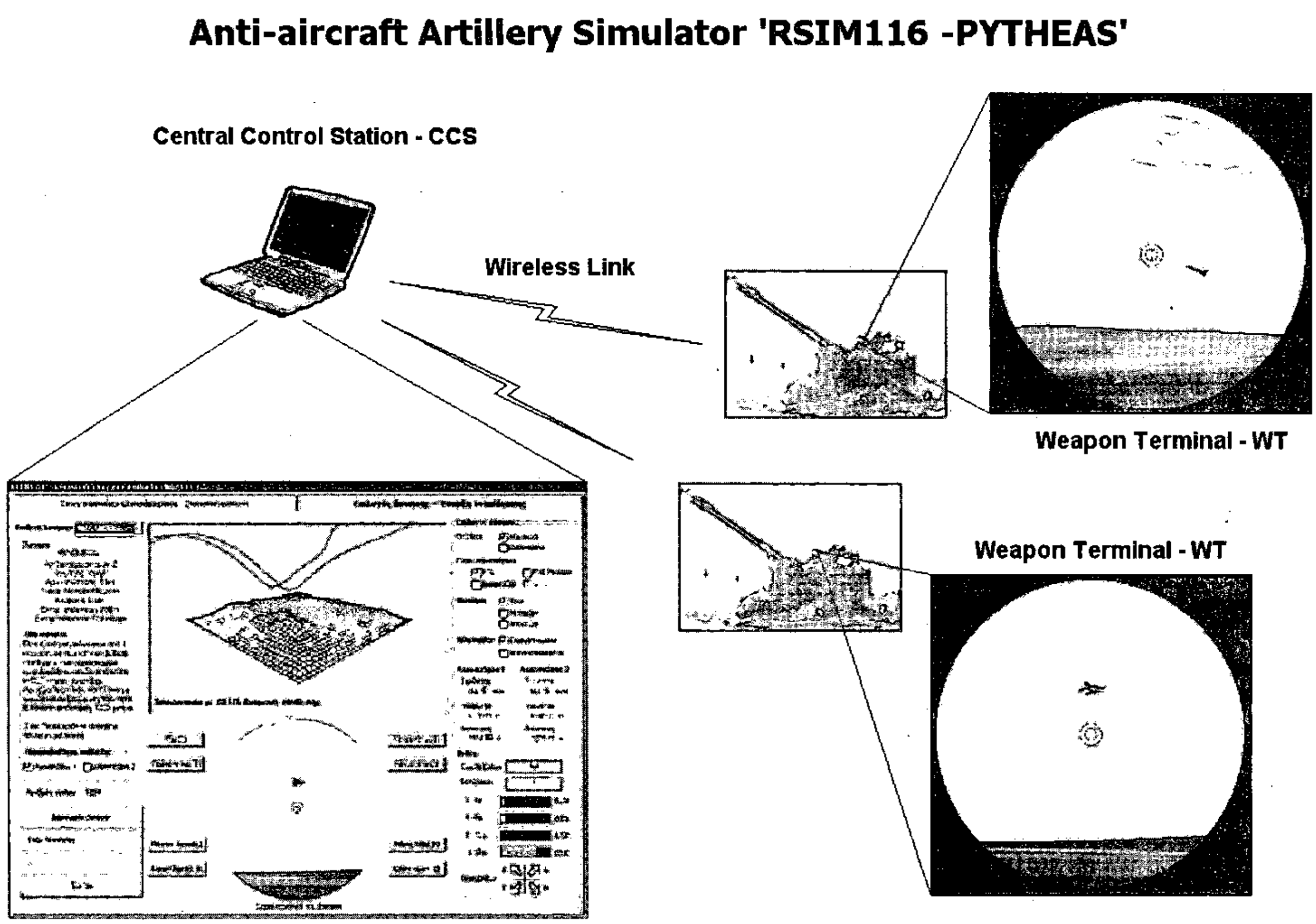

Fig. 1. The Anti-Aircraft Artillery Simulator

utilized for updating the weapon's terminal screen. Using this functionality, along with the capability to support multiple weapons simultaneously, a high-performance combat simulator can be developed.

THE WEAPON TERMINAL

The Weapon Terminal utilizes the anti-aircraft weapon's sensors and presents realistic combat conditions to the trainee. The WT uses a low-power, highly-integrated multimedia single board computer (SBC) as its main processing unit and a number of peripheral devices connected to a PC104 extension bus. The peripheral devices contain a high-speed wireless LAN modem, a board for digital signal processing, and a general purpose I/O card. Figure 2 shows the Weapon Terminal architecture. The SBC combines 3-D audio and video functions on a single Eurocard and provides support for advanced graphics manipulation, using a separate graphics controller with a 3-D accelerator and dedicated fast memory.

In order to acquire the data from the weapon's sensors, a custom DSP-based board was developed. The on-board DSP gets the status of various position sensors (elevation and azimuth) along with information from the weapon's driving (motion, movement control) and firing subsystems.

Since the weapon introduces leads during target tracking and firing, the WT estimates the introduced leads and calculates the rotation of the telescopic sight, so the line of sight remains directed to the target. The on-board DSP contains a functional module that behaves like the weapon's fire control unit. Therefore, in the case of target engagement, it computes the azimuth and elevation angular velocities, the azimuth angular lead with respect to the pivot axis, and the total elevation angular lead with respect to the trunnion axis that includes the super-elevation angular lead.

The calculated values along with information from other sensors are transmitted to the SBC via a serial link protected with an additional error control mechanism. For that purpose, a proprietary serial communication protocol between the DSP-board and the SBC, incorporating data and control messages, was defined.

The data acquisition of the weapon sensors is performed using high-speed and high-resolution A/D converters. Due to the distortion inserted by the weapon's motor power unit, noise filtering of the sensors' data is performed using a combination

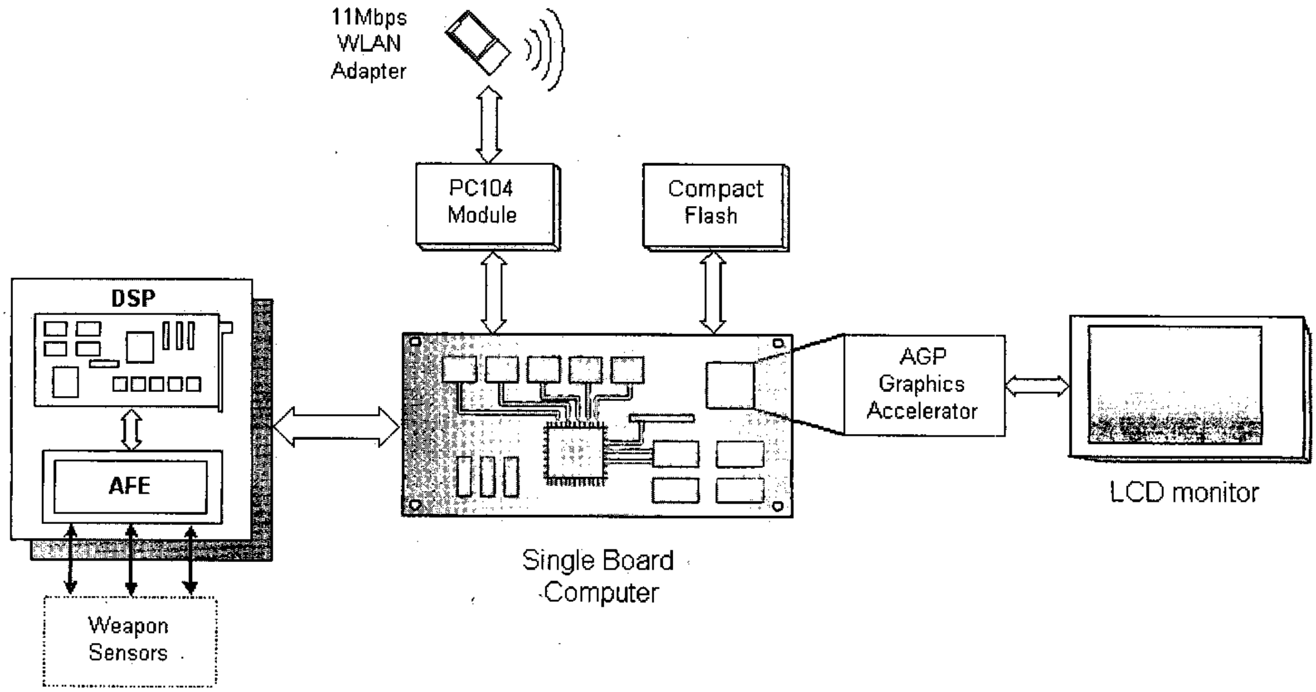

Fig. 2. The Architecture of the Weapon Terminal

of analog and digital domain techniques to support the high accuracy estimation of the projectile trajectory. Additionally, to perform self-calibration of each specific weapon, the on-board DSP contains a weapon calibration module based on a set of automated measurements taken during the WT's installation.

The WT SBC is primarily responsible for the accurate representation of the flight and combat scenarios, and, therefore, the WT should maintain direct communication and synchronization with the CCS. The high-quality graphics used in the WT are based on a high performance 64-bit 3-D engine, which allows accurate reproduction of the area surroundings and ground morphology, as well as realistic emulation of combat conditions. The movement of the telescopic sight in 3-D space is specified in real-time by the elevation and azimuth values provided by the DSP board.

When the trainee performs rounds, the embedded processor calculates the trajectory of each projectile, estimates the minimum distance between the projectile and the flying target, and produces statistics regarding the shots' accuracy and space-orientation. At the same time, tracer-shells are used to indicate the projectiles trajectory, while special sound effects simulate combat conditions and inform the trainee about his performance.

All information related to the weapon's movement and the rounds performed is gathered during runtime and sent to the CCS via wireless link. Therefore, an accurate reproduction of the trainee's behavior is achieved in the CCS application environment and performance results are stored for further evaluation while the instructor maintains total control over the progress of the training course. The installation of a prototype WT on a Flak 20mm Zw weapon is shown in Figure 3.

THE CENTRAL CONTROL STATION

The Central Control Station (CCS) is a multimedia terminal that provides to the instructor the capability to define the combat scenario, to monitor and control the trainee's behavior as the exercise is performed, and to statistically process the collected data. The CCS communicates with the WT by using a high-speed wireless link with a proprietary data exchange and synchronization protocol in order to continuously update the data required for immediate presentation of the trainee's behavior and performance.

The CCS contains a set of flight scenarios with ranged difficulty. During a flight simulation, statistics concerning the accuracy of the rounds that the trainee performs are collected. These statistics are stored in a local database and can be used for generating several reports, which may present the progress of each individual trainee per combat scenario, or the relative progress of the trainees of a group.

The CCS provides a graphical user interface where the instructor can choose the combat scenario to be executed, the type and the number of the aircrafts, as well as the environmental conditions. The difficulty of the same scenario increases when the exercise is taking place at night or in cloudy weather conditions. A ground morphology grid is supplied for each scenario to allow the instructor to observe the aircraft's course over the area of interest the weapon is defending. Figure 4 shows the main CCS screen.

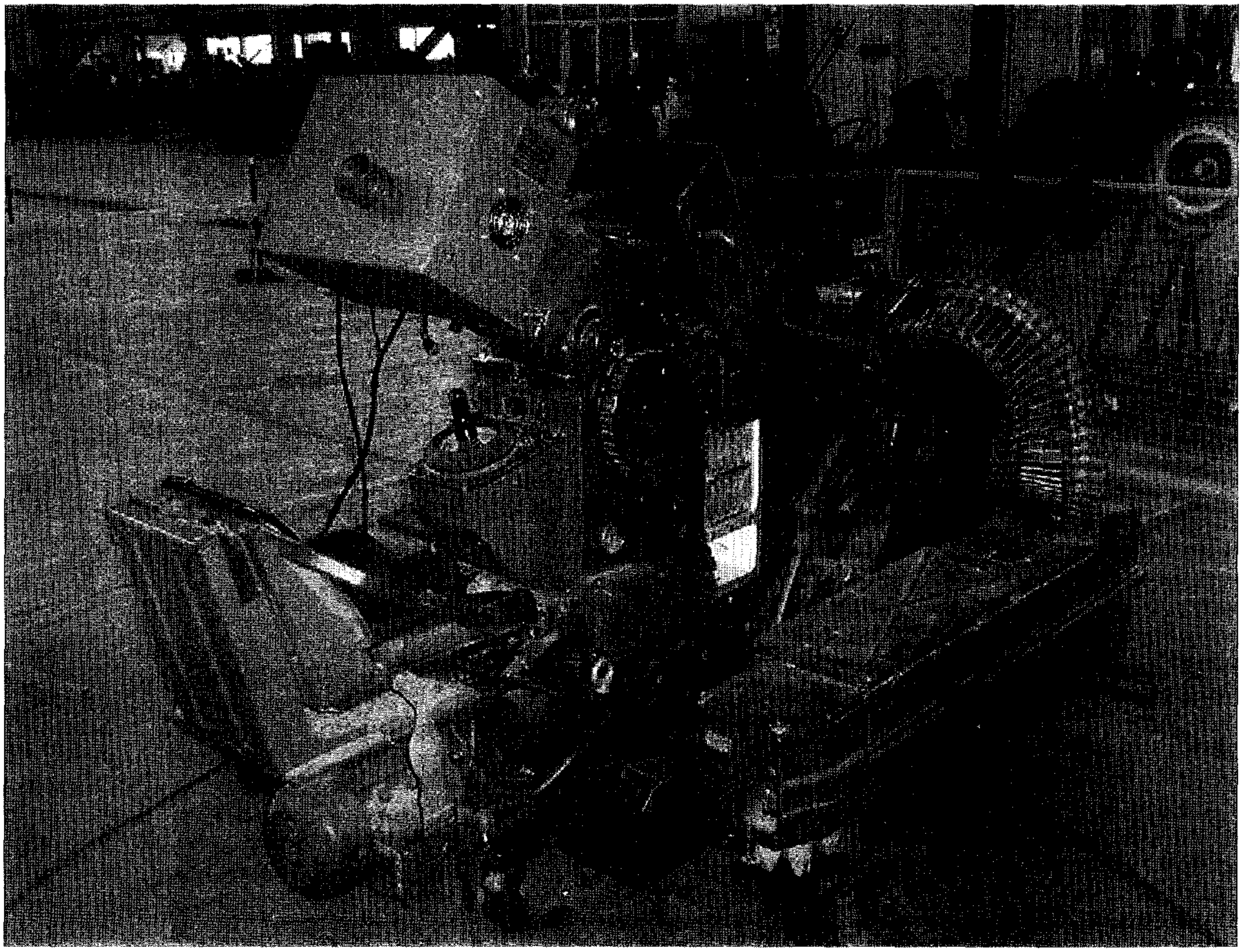

Fig. 3. The Simulator's Prototype on a Flak 20 mm Zw Weapon

The CCS main screen also contains an area that displays the same scene as the WT screen. When an exercise is performed, at this display area the instructor can observe with negligible delay, how the trainee maneuvers the weapon, whether lead has been added and statistics about the shots made so far. At the same time, he is able to send instructions to his trainee to improve his performance. When an exercise ends, the collected data are stored in the CCS database for further statistical processing, along with information about the trainee and the scenario executed.

COMMUNICATION ASPECTS

The presented simulator uses Direct Sequence Spread Spectrum (DSSS) transmission technology at 11 Mbps for real-time communication between the WT and the CCS.

Although the wireless communication is based on the IEEE802.11 medium access protocol, an application-specific protocol was also developed in order to achieve accurate synchronization between the CCS and the WT. Using this custom protocol, the two terminals exchange information regarding connection establishment and status, exercise parameters, weapon movement, and round statistics.

While an exercise is taking place, data regarding the weapon status are collected every 100 ms, round statistics are calculated and special packets are formed. These packets are transmitted to the CCS using an additional error protection mechanism. That procedure has, as a result, the introduction of an unnoticeable 200 ms time delay. The used protocol can support up to four weapon terminals simultaneously, without affecting the aforementioned time delay.

CONCLUSION

This paper has demonstrated a new type of anti-aircraft artillery simulator that uses commercially-available technologies for providing an improved and realistic training environment.

The simulator has been tested on a Flak 20 mm Zw weapon, but it can be easily adapted to other anti-aircraft weapons, by

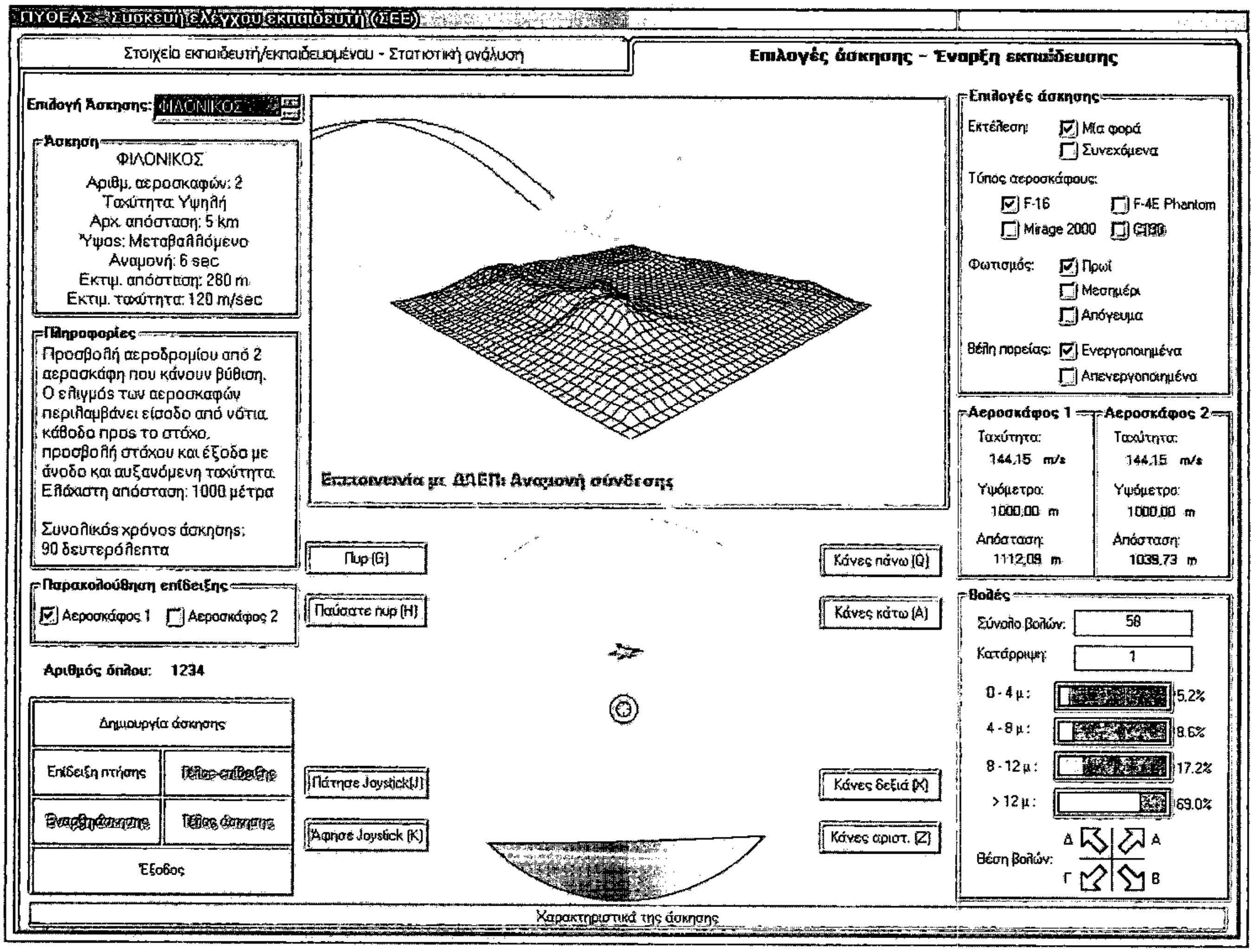

Fig. 4. The main screen of the Central Control Station

customizing its signal processing algorithms and the sensors' interface module.

ACKNOWLEDGMENT

This work was financially supported by the Greek Department of Defense, under the contract RSIM116PYTHEAS.

The authors thank Airforce Major (Air Defense) Ioannis Giannakopoulos of the 116 AFB "Araxos" and Group Captain (Aeron. Eng.) Nikolaos Fanis of the "Araxos Maintenance Plant" for their valuable comments and support during the definition and the development of the simulator's prototype.

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