# Implementation of the Monitoring System for HFSWR-based Maritime Surveillance Networks

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***Abstract*—Designing surveillance and monitoring applications for HFSWR (High Frequency Surface Wave Radar) networks faces with significant challenges, where it is mandatory to involve literally thousands of factors in order to create a comprehensive monitoring system, and respond to the needs of efficient maritime surveillance at the same time. All these factors make HFSWR network a complex system for distributed measurement and control. Described structure of sensor processing software and surveillance utility features allow system operators to make insight into specific surveillance situations, active protection of restricted naval areas and resolving missing vessel identifications, which represents huge problem in Exclusive Economic Zone (EEZ) monitoring of underdeveloped regions. Implemented solution for surveillance and monitoring system is presented through demonstration of its practical functionality, obtained from operational HFSWR network, installed in Gulf of Guinea, Africa.**

***Index Terms*—HFSWR network, Distributed sensor network, Integrated Maritime Surveillance, HF-OTH radar, Maritime security**

## I. Introduction

HFSWR is a sensor used for over the horizon surveillance in maritime applications, whose principles of operation are described in [1]. These sensors are often used in conjunction with AIS (Automated Identification System) [2] - [3], forming HFSWR networks, a well-known IMS (Integrated Maritime Surveillance) concept, based on HFSWR sensor (eventually supported with other low-range sensors) and described in [4] - [5]. One such network based on HFSWRs, presented in [6], has been installed in Gulf of Guinea.

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Since HFSWR based maritime network is a complex system, it consists of hundreds of subsystems, and thus equal number of possible monitoring and control probes. Just to name a few, there are: power amplifiers (PA), controllable power distribution units (PDU), ambient sensors, power measurement devices and many other sensor and controllable devices. Almost any of them could cause problems, that can jeopardize basic functionality of individual subsystems or even entire network. In [7] a typical topology of HFSWR networks is presented, from which certain design considerations about entire measurement / monitoring system can be deduced. First of all, access to measurement points could be organized from a single node and allow deployment of one aggregated monitoring module, which will ease the distribution and processing of monitoring data. Purpose of this paper is to give insight into HFSWR network, as a complex system for distributed measurement and control [8], to give insight into structure of data processing software and to give guidelines for the design of monitoring and surveillance applications on a practical example, by providing demonstration from working system.

In Section II an overview of HFSWR network sensors is made. Sensors, formats of their measurement data and equipment monitoring messages have been reviewed. After that, in Section III, monitoring and surveillance software structure has been described. Surveillance and monitoring applications design considerations and demonstration is presented in Section IV. The paper is concluded in Section V.

## II. HFSWR network sensors overview

In order to identify monitoring and control probes in the HFSWR network, a brief description of sensor outputs and format of both sensor and monitoring data is necessary. Since it is not possible to present every specific detail, an overview is made from the system level point of view.

### *A. HFSWR as a sensor in the HFSWR network*

The output result of the HFSWR as a sensor is, of course, its measurement data set. The HFSWR, after a scan period of approximately 33 seconds is completed, creates so-called Constant False Alarm Rate (CFAR) registration data, i.e. a file which contains data regarding potential target detections. Each data entry contains information such as distance from HFSWR, bearing relative to the true north position, radial velocity, corresponding standard deviations of measurement errors, CFAR Signal-to-Noise Ratio (SNR) and total cell SNR. It is important to note that this is textual file, which is backed up to a server on the remote HFSWR site. The file is transferred to the appropriate server on HFSWR data node in the C2 center via file transfer protocol or IP socket connection. An example of a listing of one such file is given in Fig. 1. In addition to its sensor function, the radar also performs regular calibration adjustments, which play a major role in the diagnosis of correct signal reception and transmission. Also, system possesses a notification mechanism concerning of critical events and hardware failures.

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118.669  177.020    5.714   1.433   2.486   0.864   35.654   35.772
290.665  177.499    9.754   1.293   2.271   1.768   13.506    8.249
108.271  181.191    5.577   1.281   2.438   0.879   37.794   33.468
252.134  182.024   -2.889   1.313   2.528   2.799    9.395    5.243
111.143  183.019   -6.013   1.344   2.514   1.210   20.761   18.098
275.041  183.905   17.544   1.195   2.019   2.116   11.294    7.080
102.843  184.115   -6.078   1.380   2.439   0.873   24.191   19.100
120.134  184.027   -5.932   1.115   2.500   1.191   21.648   16.687
136.795  183.966   -5.893   1.337   2.501   1.224   18.174   14.369
149.499  184.048    6.015   1.017   2.447   0.885   25.786   28.901
156.265  184.150    6.331   1.100   2.467   0.918   26.778   23.903
162.483  183.878   -5.216   1.427   2.348   1.057   19.663   13.704
234.151  184.476   27.184   1.102   2.322   1.662   13.158    7.822
 15.167  185.097    7.832   1.017   2.503   2.093   14.820   33.055
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Figure 1. Listing of a CFAR registration file with radar detection. Columns in the file represent range in km, bearing in degrees, radial velocity in m/s, standard error deviations of respective measurements, relative to resolution cell size, CFAR SNR in dB and total cell SNR in dB, respectively.

Calibration measurements are carried out every hour, during so-called Direct Path Test DPT) procedure [9]. These measurements are required to be stored for regular inspection, indication of interference and analysis of radar behavior. In order to do that, the amplitudes of the spectrum in a simple binary format are transferred to the HFSWR data node at the C2 center, where the DPT results are analyzed and alarms are generated as needed. This method allows not only on-site HFSWR self-calibration, but also provide possibility for network-aided, remotely controlled calibration scheme and better traceability of problems [10].

HFSWR has a notification mechanism, which is linked to the monitoring software with its own mechanisms for responding to notifications. The original notifications are textual with tab separated fields and the format is defined in Table 1. It specifies the remote HFSWR site ID that sent the message, the module that generated the message (message source), the message priority (values 1 to 4, with increasing priority), the destination to which the message is intended (binary coded two digits, the first describes the maintenance operator and the second describes supervisors of the entire network), the descriptive text of the error message and the message code. This mechanism transmits messages that are vital to the functioning of the equipment: temperature reports, voltage states on components (mains voltage and DC voltage references), failures in calibration tests on individual channels, states of individual components, etc. This is the reason why these messages are treated intensively in the software alarm system. It is convenient to transfer them from the site by file transfer or via socket connections to the servers in the C2 center. Due to their importance in radar diagnostics, they are backed up twice, both on the site server and on the server in the C2 center, and represent the basic diagnostic level of monitoring of HFSWR equipment.

TABLE 1.

NOTIFICATION MESSAGE FORMAT AND EXAMPLES

| Remote site ID | Message source | Prior. | Dest. | Message description |
|---|---|---|---|---|
| 1 | Remote Control-FCR | 1 | 10 | Frequency Control unit seems to be off, although it should be running. Resetting the unit... |
| 1 | Remote Control-PSR | 1 | 10 | All Voltages and all temperatures in Power Supply unit are wrong ! No status cable connected. |
| 20 | DPT_IQ_3 | 3 | 10 | I/Q-Balance of channel 3 out of range, according to DPT test. Check DPT results. |

### B. *AIS as a sensor in the HFSWR network*

AIS sensor data is available via terrestrial and satellite feed links (Land AIS and Satellite AIS feed), to which the corresponding client components can connect. These components are part of the fusion and integration nodes in the C2 center infrastructure. LAIS messages are most often transmitted by UDP or TCP/IP protocol to a specific destination - a collection endpoint, where a special software module - AIS concentration process, is installed, which has the role of filtering messages and eliminating duplicated and obsolete messages. The LAIS message format is a standard NMEA AIVDM [11], while the SAIS uses a slightly expanded, vendor specific format, which consists of concatenated header with fields separated usually by a semicolon character, in which the time of message reception, message specifics, and sender identification are specified. After the header, message continues with the original AIVDM message. The result of the AIS concentration process is a uniform stream of AIS messages, delivered to the connected clients with the knowledge of the access parameters (IP address, port) via IP socket communication.

## III. MONITORING AND SURVEILLANCE SOFTWARE STRUCTURE

The structure of surveillance and monitoring software is composed of one or more modules, dedicated to tracking, fusion and sensor integration tasks, and monitoring components. Basically, highest level of software structure can be represented with one central processing module, which contains definitions of alarms, within its monitoring rule-based engine. Short description of main software components follows in next subsections.

*A. Long Distance Integrator module*

The software module that will perform the functions of sensor fusion and integration in the network's corresponding nodes is called the Long Distance Integrator (LDI) module. It has a primary role of target integration over longer distances. The reason for this name lies in the fact that closer targets are usually subject to consideration by Microwave (MW) radars, provided that aforementioned radars exist in the IMS. The structural diagram of the module is shown in Fig. 2.

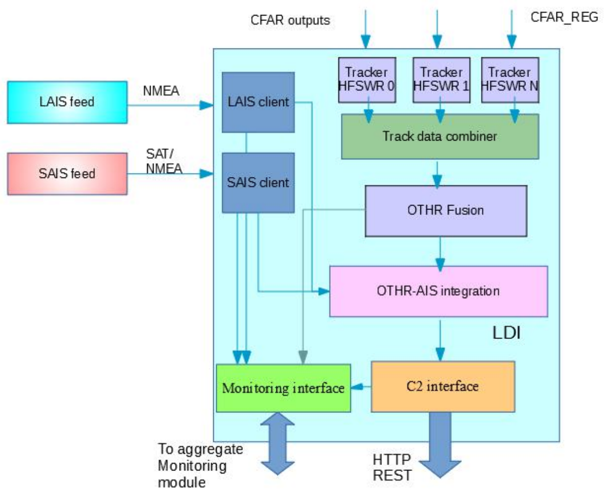


Figure 2. LDI module structure and input and output formats

The LDI module inputs are derived from HFSWR and AIS sensors, and handled by dedicated components, whose performance needs to be monitored in some way. First of all, it is necessary to describe the operation of each component individually, and define notifications and alarms which are suitable for monitoring tasks. The LDI module consists of the following components:

- **LAIS and SAIS clients**. The components connect to the LAIS or SAIS feed on the basis of predefined access parameters (IP address, port). Once the connection is established, the type of communication is one-way, in the direction of the client. The interface type is based on IP protocol and standard socket communication.

- **Tracker components**. One Tracker component is assigned to each particular input connection towards the HFSWR sensor. Its input interface accepts CFAR registrations from an associated sensor and executes an target tracking algorithm [12]. The component output product is a list of track registrations with a given time stamp, inherited from the received set of CFAR registrations.

- **Track Data Combiner**. This component accepts track registrations from Tracker components and performs time-pairing of the data from all HFSWR sensors. The data in this component arrives, in general case, marked by different timestamps, while being arbitrarily late, depending on the state of the communication channel and processing. The component pairs data from all Tracker components according to the specific time criteria.

- **OTHR Fusion component**. This component performs fusion of the combined information of the Track Data Combiner component [13]. It has its own time-stamping mechanism, relies on input reference information and provides an unified HFSWR picture (UHP), i.e. operating image for the associated set of HFSWR sensors.

- **OTHR - AIS Integration component**. The component fuses an UHP data and all AIS sensor data. This component provides a common operational picture (COP) [14] for a given set of associated HFSWR sensors.

-**C2 interface component**. This component is used to format the output. It transforms data into JSON format. Then the HTTP client, as its integral part, connects to the appropriate service in the C2 center and submits the data using HTTP REST methods.

- **The monitoring interface** serves to collect notifications and alarms from each individual component of the LDI module. This data is then conveniently presented in an internally used format and passed on to a higher level of processing.

*B. Central process*

Central process (CP) is a process that has a function analogous to the one given in [5] by a multi-sensor association processor (MSAP). CP associates HFSWR output detections to create multi-layer target associations and combines HFSWR and AIS sensor data to form a partial or complete operating images. The role of CP is to provide centralized treatment of sensor processing and monitoring of the entire HFSWR network, which is made possible due to the specific star-shaped topology of the HFSWR network [7]. In the general case of a widely distributed HFSWR network, it is possible to adopt the principle that individual LDI modules collect data from only those sets of HFSWR sensors whose coverage zones overlap, so fused image is required for these separated areas, since they can be viewed as separate network subsystems. Individual measurements from other sensors, calibration results, etc. can be delivered to a specific set of endpoints, different interfaces, suitable for the scenario and communication conditions in the field. The presented generalized approach is depicted on Fig. 3. The implementation of the CP is based on hosting the process on classic windows services, and the number of processes and separation by functionality (for example, LDI modules in one process, monitoring of sensors in a network in another) is a matter of preference. In the simplest case, the topology with fewer branches, the single-process version represents the optimal solution. In such implementations, it is possible to fully aggregate the monitoring information and create a unique reporting system, before the final, application layer.

The aggregation monitoring module provides a complete monitoring image of the HFSWR network in the case described above. The only exception is the system monitoring of the central process itself, which is either the task of a special component or can be left to, for example, the Windows management interface. The information accepted by the CP through its monitor endpoints is generally one-way in nature and of different types, from simple ambient sensor temperature measurements, hard disk drive occupancy on site servers to signal calibration measurements on each of the HFSWR receiving antenna arrays. The notifications created by the HFSWR are received in central process and its event handler triggers certain alarms. Temperature events, events related to failed DPT calibrations on individual channels, as well as all those with higher priority, without referring to the normalization of the condition, raise the level of maintenance alarms for the HFSWR.

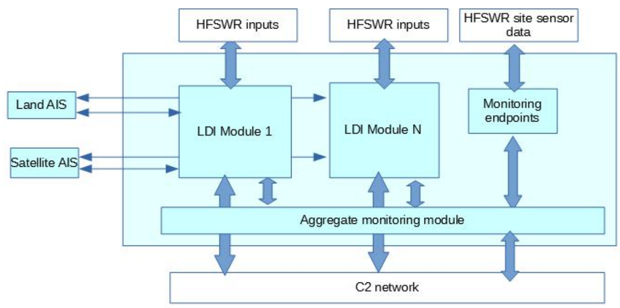


Figure 3. Structure of the central processing and monitoring process - single-process realization

### C. Measurement/control summary and alarm system build-up

All measurements and controls within the HFSWR network, for monitoring purposes, can be classified into 9 groups, see Table 2.

TABLE 2.

MEASUREMENT AND CONTROL GROUPS IN HFSWR NETWORK

| Group | Description |
|---|---|
| 1 | Ambient measurements |
| 2 | PDU Control and measurement of power consumption |
| 3 | Measurements of reflected and radiated power |
| 4 | Rx input validation (DPT) tests |
| 5 | Multi-server cluster info and fail-overs |
| 6 | Control and status of Power amplifiers |
| 7 | Control, notifications and monitoring in C2 center |
| 8 | Monitoring/control of servers/PC machines |
| 9 | HFSWR acquisition status |

In the system, besides the sensors described that perform the main function in the HFSWR network, there are a number of others, whose role is also important, only in other aspects. Monitoring system owns an alarm mechanism to invoke user reaction on certain critical failures. The nature of alarms is predominantly related to sensors, but there are also operational surveillance alarms, related to zones of special interest, maritime rules of engagement and rules of surveillance. Not every alarm in the system produces the same response from both software and maintenance operators. There is a need to define different levels of severity of alarms, i.e. the states they produce within the system. Because of this, alarms are often followed with a new feature, which characterizes them as two-static, three-static or multi-static.

## IV. SURVEILLANCE AND MONITORING SYSTEM DEMONSTRATION

Surveillance and monitoring system will be demonstrated with application layer utility screen-shots from operational HFSWR network, installed in Golf of Guinea, Africa. Purpose of this demonstration is to present functionality of surveillance application, that reflects actions of different software blocks in LDI, and monitoring application, that should provide insight into main monitoring features and alarm mechanism. In Fig. 4, surveillance application elements are presented, alongside with all-layer views. Protected maritime areas (1), including the polygon of HFSWR exclusions in territorial waters, reserved for MW radar operations (2), and interference alarm zones (3) are marked, to indicate zones with special rules of operator and alarming engagement.

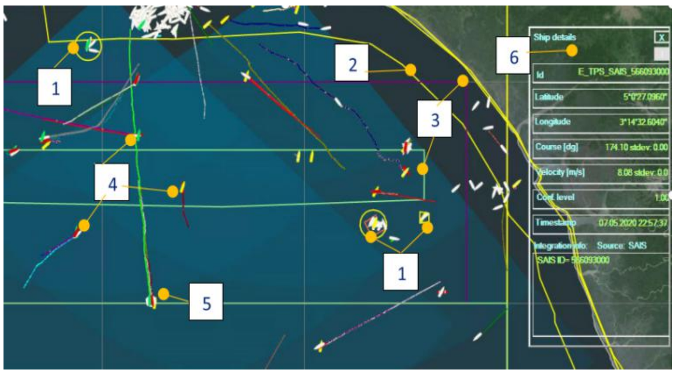


Figure 4. Surveillance screen elements overview

Note that in protected areas, UHP picture elements are excluded from surveillance. The reason for this rule lies in the fact that HFSWR is used to detect vessels entering or leaving such zones, while zones within MW range are better covered with aforementioned sensors due to its better resolution. Individual targets (4) are represented with ship markers of different colors. Green and red markers are reserved for particular HFSWR targets. Red markers represent UHP, while white markers are reserved for AIS targets. Details of the selected target, white hexagon (5), are presented on target details view, on the right (6). Another important aspect of surveillance application is its layered view. It has proven useful to have the ability to distinguish target origin in COP view and to visualize its tracking data by different sensor sources, which will be demonstrated in an example, later in the text. On Fig. 4, an all-layer view is shown, which means that multiple markers exist for the same target, originating from different sources, both sensors and intermediate processing layers. There are 4 types of basic view layers: tracking, UHP, AIS and COP view layer and each corresponds to one processing stage in LDI components or sensor source.

Primary, lower tracking layer view is the result of Tracker components in LDI, associated with every HFSWR, see Fig. 5.

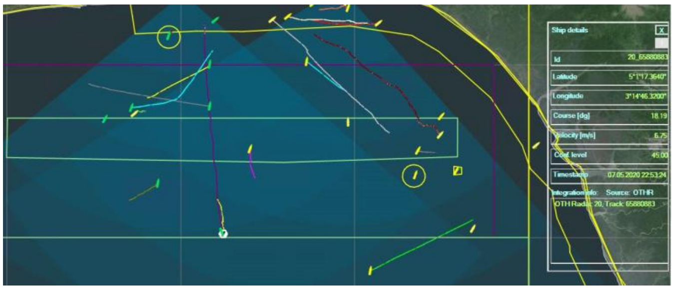

Figure 5. Lower tracking layer view.

After the fusion process, UHP is formed in the fusion component of LDI. This result is shown on Fig. 6, where UHP targets are presented with red markers. Comparing the picture from Fig. 6 with the one on Fig. 5, proper grouping of targets can be easily noted.

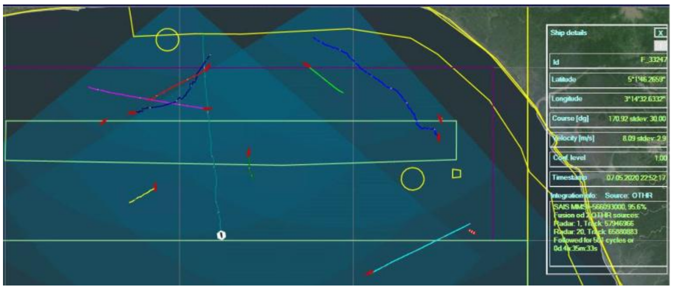

Figure 6. UHP layer view

Fig. 7 displays combined UHP and AIS view, where AIS targets are displayed with white markers. This figure is shown only to be compared with COP layer view, on Fig. 8. At this point, all particular UHP and AIS targets are completely integrated, forming a reliable operational view. Color of markers indicates origin of the target, giving advantage to HFSWR (red markers), even if target has multiple origins. As an example, a selected target on Fig. 7 has multiple sensor origins. It is tracked by 2 HFSWRs, out of which one UHP target is formed, then by AIS, and, at the end, on COP layer, a single target is formed. On Fig 7, one AIS target, marked with red circle, stopped emitting its AIS positions. On the other hand, it was clearly followed with HFSWR, which was marked with white circle. If we switch to COP view on Fig. 8, it can be noted that AIS target from previous view is missing. Reason for that lies in HFSWR-AIS integration rules [14], where integration link remains active for up to 6 hours after last emitted AIS position report. This example not only emphasizes the importance of layered view in surveillance applications, but also indicates huge problems for surveillance operators on the field [14].

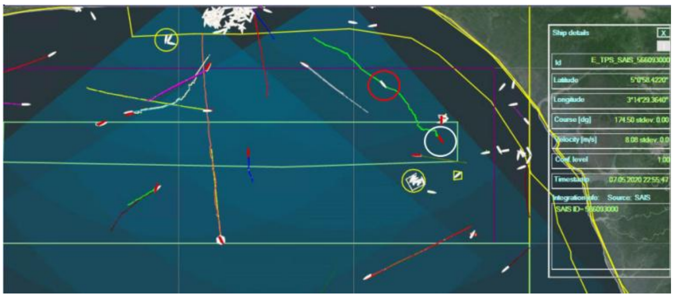

Figure 7. Combined AIS and UHP layers view

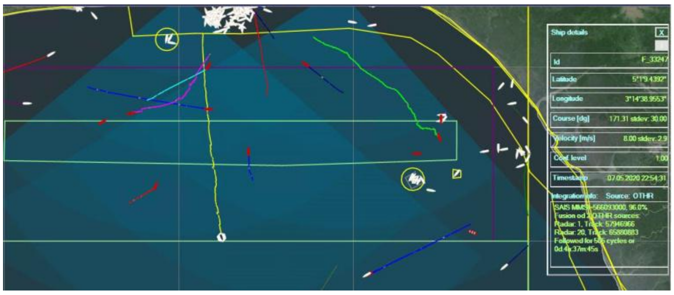

Figure 8. COP layer view

Monitoring diagnostics starts with a alarm overview panel, Fig. 9, where main monitoring groups are labeled. Overall HFSWR network alarms group (1) provides quick information about the health of the network. This group of alarms, combined with overall remote site states, is usually placed on graphical user interfaces of surveillance operators, for informational purposes. LDI connection alarms (2) inform about general state of LDI components. Interference zonal alarms (3) inform the users about possibility of very high ionospheric interference in defined zones. Alarms in these areas usually lead to lower detection probabilities, tracking problems and higher false alarm rate.

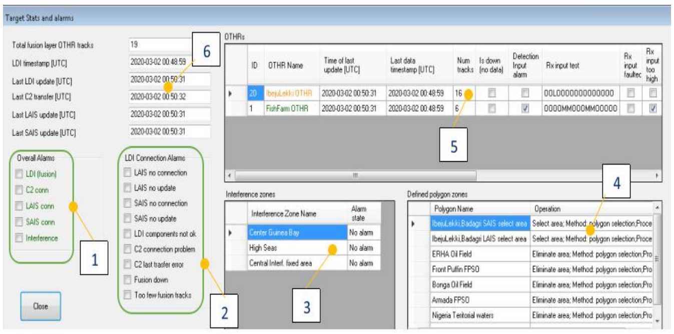

Figure 9. Main alarm and monitoring panel

Special polygonal areas (4) include protected areas, e.g. oil rigs and HFSWR exclusion zones. Protected areas, if configured, provide intrusion alarms, when unidentified vessels approach or leave such zones, based on defined surveillance rules. Group of remote sites (5) provides general state and overview of the most important equipment and measurement alarms and notifications, e.g. quick overview of HFSWR calibration (DPT) tests, active maintenance alarms etc. Main notifications group (6) provides timing information inside network's CP. By clicking certain fields, e.g. one of the remote site rows, another panel opens with lower level alarms, related to that feature and possibilities to control and monitor other components and sensors. On this way, monitoring of the HFSWR network allows maintenance operators easy and fast diagnostics of possible problems.

## V. Conclusion

In this paper a comprehensive network's alarm system has been presented, through which operators can achieve fast and descriptive insight into the entire HFSWR network parameters and ongoing surveillance operation state. Described solution was made feasible through aggregate monitoring principle, where practically all monitoring data is accessed or gathered from one node in C2 center, due to specific star-shaped topology of HFSWR network's IoT infrastructure. Specific sensor data processing structure and surveillance client utility implementation allows layered view of surveillance coverage area, which helps operators resolving critical situations, missing vessel identifications and special area protection. Along with detailed explanation of the adopted structure for implementation, its practical application was presented as well, through various examples of real – life data obtained from one operational IMS based on HFSWR network. Engagement in both surveillance functionality and main network parameters monitoring was presented from the perspective of the end user, in order to demonstrate achieved functionality at the top – level of application at its current version. While solutions of this kind are commonly tailor – made for particular system and the user, general flexibility of proposed structures makes it quite adaptable and thus convenient for easy reshaping in data representation at the top – level stage. For the future work, further optimization of network's alarm system and development of more functionally reach application utilities is planned, in order to further alleviate monitoring of this complex system for distributed measurement and control.

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