Monitoring of Ecologic and Navigation Parameters

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Received: May 16, 2018 **Accepted: October 01, 2018**

Published: December 31, 2019

Abstract: *This work presents the approaches used in the process of design of a system with the purpose to transmit the measurements sampled at certain space coordinates along with the exact sampling position, biological data, provide information about certain events happening in the area of the interest. The aim is to obtain an optimal design solution in order to implement stable and reliable hardware platform based on the current design. This paper is the first of series of two papers that present the creation of a system from a conceptual design to working equipment.*

Keywords: *Autonomous measurement system, Design consideration, Positioning system, Communication system, Biological sensors, Communication.*

Introduction

The Framework Directive for Waters 2000/60/EC (FDW) [6, 8] is the fundamental document of the European Parliament and European Council in the field of water policies is a response to growing requirements for delivery of enough water of proper quality foe any purpose. The aim of the marine strategy framework directive Directive 2008/56/EO [8] is to achieve good environmental status (GES) of sea waters until 2020, continue its protection and conservation, as well as prevent any subsequent deterioration. The management and preservation of regional waters is regulated by international agreements on regional waters.

Regulation № 8 [2] is the basic document determining the quality of marine waters in the Republic of Bulgaria. This regulation should not be considered as valid for port aquatoria since it refers to the quality of marine waters in the regions of coastal resort waters and sanitary protection belts. As there are no other regulating documents, however, this Regulation was used as guidance for the comparison and estimation of the registered values. On the basis of the normative requirements to the marine waters in the zones mentioned above, conditions are provided for setting up automated monitoring systems measuring the required characteristics. The characteristics are summarized in Table 1.

To analyze the results obtained, it is necessary to develop automated and/or automatic monitoring systems. With them, it will be possible to register also the direct influence of the corresponding lake waters at the corresponding monitoring point. On this basis, deviations from the values measured at the comparatively inner monitoring points in the bay are formed.

The results obtained from the monitoring carried out of the marine waters in the aquatorium of the Port of Burgas, Bulgaria, should be processed with respect to the characteristics formulated in the Regulations mentioned above. Therefore, it is necessary to build and upgrade a system for automatic taking of samples and analysis of the characteristics of the marine waters at different points within the aquatorium of the Port of Burgas. The monitoring points at the monitoring points, sampling equipment and analyzers of the main biogenic elements are mounted – the three forms of nitrogen and general for phosphorus. While the probes measure instantaneous values by averaging them, the analyzers make measurements at specified times.

Table 1. Characteristics and standards for determination of coastal waters quality

No	Characteristic	Dimension	Region of usage	Sanitary protection belt
A. General physicochemical characteristics				
1	pH		6.5-9.0	6.5-9.0
2	Ammonium nitrogen	mg/dm^3	0.1	0.1
3	Nitrite nitrogen	mg/dm^3	0.03	0.03
4	Nitrate nitrogen	mg/dm^3	1.5	1.5
5	Phosphorus (total)	mg/dm^3	0.1	0.1
B. General characteristics for organic contaminants				
6	Dissolved oxygen	mg/dm^3	6.2 Not less than 80% of oxygen saturation	6.2
7	BPK5	mg/dm^3	6.0	6.0
8	Extractable substances	mg/dm^3	0.15	0.20
C. Characteristics for industry generated organic substances				
9	Phenols	mg/dm^3	0.005	0.005
10	Petroleum and petroleum products		No visible film on the water surface, no smell	No visible film on the water surface, no smell
D. Biologic characteristics				
11	Chlorophyll “A”	mg/dm^3	3.0	5.0

Each of these points characterizes a particular part of the port aquatorium. A feature of the separated aquatic areas is that some are more closed while others provide greater opportunities for influence by the bay waters and the streams formed around the interconnections of the Burgas bay with the coastal lakes. This requires taking into account the specifics of the external influences when selecting the individual zones and the monitoring points in them. At the same time, untreated household waters from city sewerage and from the Port of Burgas are discharged. Part of the aquatorium is characterized by as more widely open to the marine waters of the bay with opportunities for influence by the streams connecting the Burgas bay with the mouths of the coastal lakes Vaya and Mandra. This influence is accounted for by widening the monitoring studies. Table 1. characteristics and standards for determination of coastal waters quality.

Motivation and preliminary considerations

An implementation of a system for monitoring the parameters of marine waters can be combined with a system for monitoring of the Specialized Navigation Equipment (SNE). By the processing of the information, conditions for realization in real time should be obeyed. The algorithms of periodic planning are usually applied to the processing of homogeneous sets of tasks. The activities in a computer system can be periodic or aperiodic. Many applications in real-time systems, especially those related to monitoring, consist of processes of both types. A typical application of periodic task is connected with the processing of critical events which are strictly limited by time. The use of aperiodic processes is usually related to processing of events with strict, stable or loose requirements with respect to time.

When planning the processing of a hybrid sets of tasks, which means periodic and aperiodic ones, the main task of the real-time system is to guarantee schedulability of the treatment of all the tasks in the most severe situation possible. Simultaneously, acceptable average response time should be guaranteed for all the activities which are not strictly limited in time, as well as the real-time ones. By preliminary planning, guaranteeing the time limits by the processing of the events can be done using correct models of the environment. Here we can specify some parameters, e.g.:

- maximal speed by occurrence of critical events;
- minimal time between occurrences of individual events.

This suggests that the aperiodic tasks processing critical events have minimum time between the occurrences of the events. The minimal time characterizes the load during the processing of aperiodic events. Aperiodic tasks which have minimal interim times are called sporadic ones. With them, it is possible to guarantee maximum load assuming maximum frequency of their occurrences.

If the maximal frequency of occurrence of the aperiodic, and particularly sporadic events, cannot be guaranteed, then we cannot guarantee the preliminary planning of the processing of these tasks. In this case, it is necessary to implement on-line planning related to ensuring the processing of each of the individual instances of the tasks.

The modern implementations of monitoring systems are based on time synchronization between the host and the monitoring systems using the Network Time Protocol (NTP). The added time in this case is hard to predict due to the particularities in the implementation of the multitasking and the context switching between the tasks.

Theoretical background

The approach to the processing of aperiodic events in real time systems is usually very simple by realization of background planning. This approach suggests implementation of a linear data structure of the FIFO type (first in, first out) which is used for preservation of the task sequence. The aperiodic tasks are arranged by the order of their occurrence and are processed during periods when there are no tasks available for processing. The advantage of this approach is its simplicity but its efficiency is rather low.

The average response time for the background processing of aperiodic tasks can be substantially improved by implementation of planning server. In this respect, it will be a periodic task designed to treat all requests for aperiodic tasks for as short as possible time. Like all periodic tasks, the server will have its period T_{PS} and time for processing the requests C_{PS}. The treatment time is called capacity. Server planning is based on the same algorithm used for planning the periodic tasks. The requests for processing of aperiodic tasks do not depend on the type of algorithm for planning of the periodic tasks. Each aperiodic task has its time of occurrence, period necessary for its processing, deadline for its accomplishing and other parameters.

Definition: polling server is an algorithm allowing activation at certain time intervals T_{PS} and servicing the available aperiodic tasks within the limits of its capacity C_{PS} [10]. If no requests for aperiodic tasks are available, the polling server is deactivated until the beginning of the next period.

It should be noted that if a request for processing of aperiodic task occurs after the deactivation of the polling server, its treatment will start only in the next period of server activation.

Fig. 1 shows schematically a sample of the poling server operation. The planning of the task processing distribution is realized on the basis of RM (Rate Monotonic) [8]. The aperiodic requests are illustrated in the third row. It is assumed that server capacity is C_{PS} = 2. The processing by the separate instances of the server is realized at a priority lower than that for the periodic instances of task τ_1 and higher than that for task τ_2, as illustrated in lines 1 and 2. The processing of the instance of task τ_1 starts at moment t = 0 according to the RM algorithm [5, 10]. At moment t = 1, the processing of the instance of task τ_1 is accomplished. The period of the polling server is T = 2.5. There is no aperiodic request for processing at moment t = 1. With no requests, the server deactivates and its available capacity is used for processing of low priority periodic tasks. For this reason, he aperiodic request coming at moment t = 2 cannot be processed and must wait for the next period. At moment t = 5, there is an aperiodic request. Server capacity at this moment is again C_{PS} = 2. During the processing of aperiodic tasks, server capacity is not incremented. When all the server capacity is used then further requests cannot be serviced within the same period.

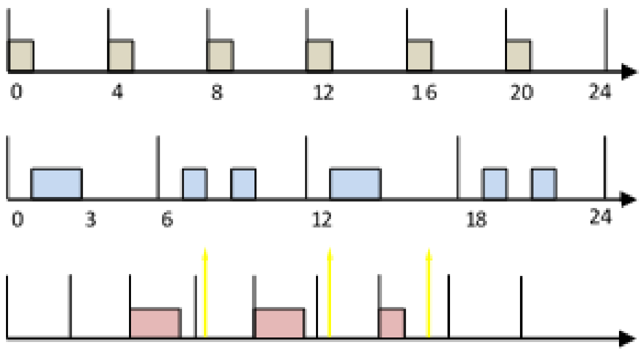

Fig. 1 Example of the operation of a polling server

Analysis of the schedulability

For the analysis of the schedulability, guaranteed conditions of strict real-time operation will be assumed, in presence of aperiodic tasks treated by means of polling server mechanism.

Periodic tasks schedulability can be ensured by an estimation of the interference during the polling server processing during its periodic activation. The heaviest case is when there is interference equivalent to that of a periodic task with period T_{PS}, i.e., the same as the period of activation of the server and processing time equal to server capacity C_{PS}. Regardless of the number of aperiodic tasks processed by the polling server, the maximum processing time remains C_{PS}. As a result, server utilization will be:

$$U_{PS} = \frac{C_{PS}}{T_{PS}}, \tag{1}$$

where T_{PS} is the period of activation of the polling. If n tasks are to be processed, the schedulability is guaranteed if the following condition is obeyed [10]:

$$U_P + U_{PS} \le U_{lub}\left(n+1\right). \tag{2}$$

If the periodic tasks, including the server, are planned on the basis of RM scheduling, then the schedulability check can be expressed as [6]:

$$\sum_{i=1}^{n} \frac{C_i}{T_i} + \frac{C_{PS}}{T_{PS}} \le \left(n+1\right)\left[2^{\frac{1}{(n+1)}} - 1\right]. \tag{3}$$

It is possible to create more than one polling server and activate then concurrently for processing of different aperiodic tasks. Depending on the priority, the activation of high priority servers will allow processing the higher priority tasks. Assuming that the number of parallel processed periodic tasks is a set of n elements and there are m polling servers processing aperiodic tasks, they are planned on the basis of RM and this can be expressed according to Eq. (1) and [9] as:

$$U_P + \sum_{j=1}^{m} U_{PS_j} \le U_{lub}\left(n+m\right). \tag{4}$$

More precise schedulability check can be derived using the adaptive thresholds method of Liu and Layland [7]. It should be noted at this point that the method suggested in the present paper is a modification of the methods used in [4, 10].

It is assumed that the polling server has the highest priority in the system. This is convenient for the realization of systems processing aperiodic events within the limit of strict real-time operation. The heaviest situation which might occur by the processing is characterized by the following parameters [1]:

$$\begin{cases} C_{PS} = T_1 - T_{PS} \\ C_1 = T_2 - T_1 \\ C_2 = T_3 - T_2 \\ \dots \\ C_{n-1} = T_n - T_{n-1} \\ C_n = T_{PS} - C_{PS} - \sum_{i=1}^{n-1} C_i = 2T_{PS} - T_n. \end{cases} \tag{5}$$

It should be noted here that the set of Eq. (5) are direct sequence form he conditions described in [1, 5, 10] for the heaviest case of asks processing. The resultant utilization can be written as:

$$U = \frac{C_{PS}}{T_{PS}} + \frac{C_i}{T_i} + \cdots + \frac{C_n}{T_n} = \\ = U_{PS} + \frac{T_2 - T_1}{\tau_1} + \cdots + \frac{T_n - T_{n-1}}{\tau_{n-1}} + \frac{2T_{PS} - T_n}{\tau_n} = \\ = U_{PS} + \frac{T_2}{T_1} + \cdots + \frac{T_n}{T_{n-1}} + \left(\frac{2T_{PS}}{T_1}\right)\frac{T_1}{T_n} - n. \tag{6}$$

The following substitutions will be made to simplify the calculations:

$$\begin{cases} R_{PS} = \dfrac{T_1}{T_{PS}} \\ R_i = \dfrac{T_{i+1}}{T_i} \\ K = \dfrac{2T_{PS}}{T_1} = \dfrac{2}{R_{PS}} \end{cases} \tag{7}$$

At this moment we shall use the approach described in [10] for determination of the utilization by RM, so we can write:

$$U = U_{PS} + \sum_{i=1}^{n-1} R_i + \frac{K}{R_1 R_2 \cdots R_{n-1}} - n. \tag{8}$$

After some mathematical transformations associated with finding extrema of functions of more than one variable, the following relationships can be written for R for the case of minimal utilization:

$$R_1 = R_2 = \cdots = R_{n-1} = K^{\frac{1}{n}}. \tag{9}$$

The analysis of the schedulability is always based on the least upper bound value of the utilization U_{lub} which, in the case discussed, is the minimum of U. Substituting the values calculated for the variables R_i, the least upper bound value U_{lub} can be expressed as:

$$U_{lub} = U_{PS} + n\left(K^{\frac{1}{n}} - 1\right). \tag{10}$$

We can write also the following equations:

$$U_{PS} = \frac{C_{PS}}{T_{PS}} = \frac{T_1 - T_{PS}}{T_{PS}} = R_S - 1. \tag{11}$$

Thus, taking into account (11) the parameter K can be rewritten as follows:

$$K = \frac{2}{R_{PS}} = \frac{2}{U_{PS}+1}. \qquad (12)$$

Using relationship (12), the least upper bound value of utilization can be determined as:

$$U_{lub} = U_{PS} + n\left[\left(\frac{2}{U_{PS}+1}\right)^{\frac{1}{n}} - 1\right]. \qquad (13)$$

The heaviest processing conditions can be found if the limit of the function (13) is calculated for n approaching zero. The equation will be of the type [1, 4, 9]:

$$\lim_{n\to\infty} U_{lub} = U_{PS} + \ln\left(\frac{2}{U_{PS}+1}\right). \qquad (14)$$

Eq. (14) shows the relationship between U_{lub} as function of U_{PS}. The latter dependencies allow summarizing that if a set of n independent aperiodic tasks with common utilization U_P and polling server with utilization of U_{PS}, the schedulability is guaranteed by the RM algorithm if:

$$U_{PS} + U_P \leq U_{PS} + n\left(K^{\frac{1}{n}} - 1\right), \qquad (15)$$

or

$$U_p \leq n\left[\left(\frac{2}{U_{PS}+1}\right)^{\frac{1}{n}} - 1\right]. \qquad (16)$$

It can be concluded now that the schedulability test expressed by Eq. (16) is valid by realization of all kinds of servers the instances of which are processed as periodic tasks.

Design and implementation

The system consists of the following modules:

- A module for analysis of the state of the current parameters of navigation buoy-voltage, state of accumulators, occurrence of impact by a marine vessel, dynamic positioning of the navigation buoy, state of the maritime channel, light functioning, modular probe unit for measuring parameter complexes;
- A module for dynamic positioning and determination of coordinates and floating navigation buoys;
- A module for exchanging data about the state of every navigation buoy in the aquatorium of Burgas – from Obzor to Rezovo;
- GIS (Geographic information system) containg dynamically updated map of the region, of the aquatorium of the Port of Burgas, dynamic updating of the navigation devices and interface to the international Automatic identification system (AIS);
- A system of tools allowing fast navigation and on-click operation with the individual units of the navigation equipment;

- Server module ensuring the security of the data exchanged;
- Data base which allows for taking decisions and generating motoring messages.

A generalized model of a communication node

A generalized scheme of a communication node is presented in Fig. 2 the system realized is with heterogeneous system architecture. It is characterized by strong restrictions with respect to the available hardware resources. The optimization of the system was made by taking into account of number of conceptual considerations [11, 12]. By the development of the general schematic of the communication node, special attention was paid to both local characteristics of the individual subsystems and the global characteristics of the wireless network. The quantitative and qualitative analyses showed the necessity to use different concepts and methods which can be summarized as follows:

- Transition to asynchronous communication paradigm based on the principle of event management;
- Integration of Wake-Up-Strategies;
- Interconnection and aggregation of data.

Hardware design

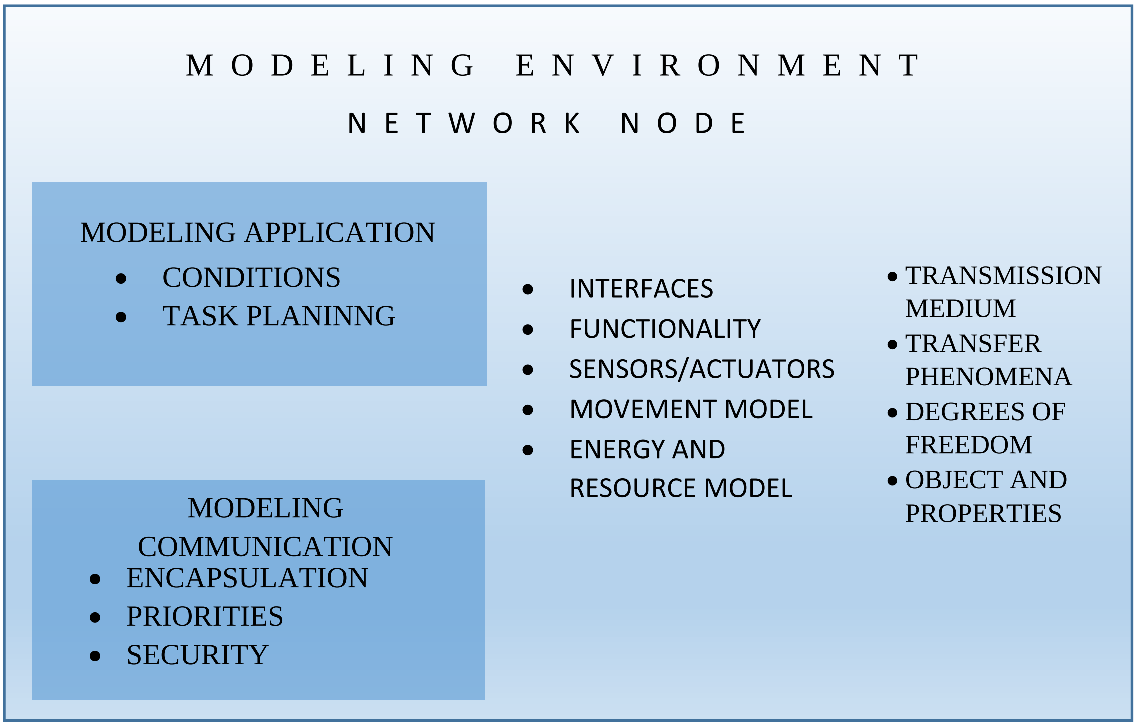

Fig. 2 Model of the sensor communication node

It is based on the analysis performed along with the resulted schematics. Based on that schematic, a working PCB will be created. The software used to design the schematics, software and PCB is called Proteus. It is a powerful tool for implementation and testing of electric and electronic circuits and prepare the PCB original using variety of component libraries that aid the designer. In order to provide good product, a number of considerations in the design process were taken into account:

- Develop minimalistic PCB;
- Design communication and RF circuit tracks as short as possible;

- Use single sided PCB;
- Implement components with DIP footprints;
- Use standard 0.25 inches raster network.

The modules used in the present implementation are the ones specified by the previous paper. The design is module based with respect to greater system flexibility and minimalistic design in term of size. This is the reason for all connections to be built with connectors of type rake. A base for the modular structure is the main board containing the main computation module- the microcontroller is designed to interconnect the peripheral modules. Other hardware components used in the design are several resistors used for the voltage divider, MCLR pin, GPS module LED indicator, two capacitors and a quartz resonator. It is possible to compress the design further up by using SMD components and multi-layer PCB. This improvement is not relevant to the system performance, but might increase the price.

It is noticeable in the PCB original that the circuit tracks are slightly wider than usual along with the components pads. This increase in the size of pads and tracks is also taken into account due to the fact that the board is etched and manufactured at the embedded systems lab in "Prof. D-r Asen Zlatarov" University – Burgas, but it can also be prepared elsewhere. An attention must be paid to the conductive bridges placed on the components side of the board. This solution has been taken in order to simplify the PCB and reduce the time for preparation.

Software design

An important aspect of the implementation is the management software for the device. The main concept of this system is to acquire some data in terms of measurement and positioning coordinates, verify the obtained values and send some information to a centralized system by using a data channel [3] to the packed switched GSM network. The measured data currently consists of data for the level of supply voltage, the backup voltage level, light intensity, ambient light threshold, presence of a collision with another object, three level alarm states including theft, drop and impact, and case opening. Next in order is the spatial coordinates from the GPS module.

By the start of the algorithm, there are definitions of the main variables used by the algorithm. Next step is the initialization of all GPIO and communication ports, memory allocation and start of the sampling of all measurement interfaces along with the positioning GPS module. When all of devices are polled, the next step is to structure the data in an information packet. The packet is structured as shown in Fig. 3.

Preamble	**Start bit**	**Address**	**Length**	**Delimiter**	**Alarm**	**Delimiter**	**Data**	**CRC**	**End of frame**
2B	1B	2B	1B	1B	10B	1B	94B	2B	1B

Fig. 3 Data packet format

As can be noticed in Fig. 3, the packet structure is actually a communication protocol encapsulated in the serial transmission. In the beginning, there is a preamble which is used to synchronize the transmitter and receiver, the next is frame start to flag the beginning of protocol data followed by the unique address of the device in order to specify the sender and recipient, message length – it is a number of bytes according to the message length. Usually the frame must be 116 bytes long, but in case of an error or short noise burst some part of the message may be lost. The frame continues with a delimiter in order to separate the alarm state from the frame header, next is the measurement data followed by delimiter and the data. To verify the transmission, a Cyclic Redundancy Checksum (CRC) is used. The frame is terminated by end of frame delimiter.

After the frame is structured, next part of the algorithm is to switch on and configure the communication module, transmit the data and shutdown. The GSM module is switched off to save energy as it is switched on every 30 minutes to transmit the data. In case of alarm event, an interrupt is generated to immediately start the transmission of the alarm data. In case of lack of response from the centralized station SMS message is generated to notify the authorized personnel about the failure or an alarm event. At the end, the algorithm returns to the initial state.

The algorithm is realized using C programming language. The routine shown in Fig.4 is simplified to achieve continuous execution of the algorithm. To improve system efficiency, the algorithm contains instructions which put the system in low power (sleep) mode to save power. Another option provided is that if standard interfaces are used they can be plugged in any slot of the computational module. The algorithm has been tested and debugged in simulation mode before uploading it in the system. This is useful and time saving procedure. This algorithm is illustrated in Fig. 4.

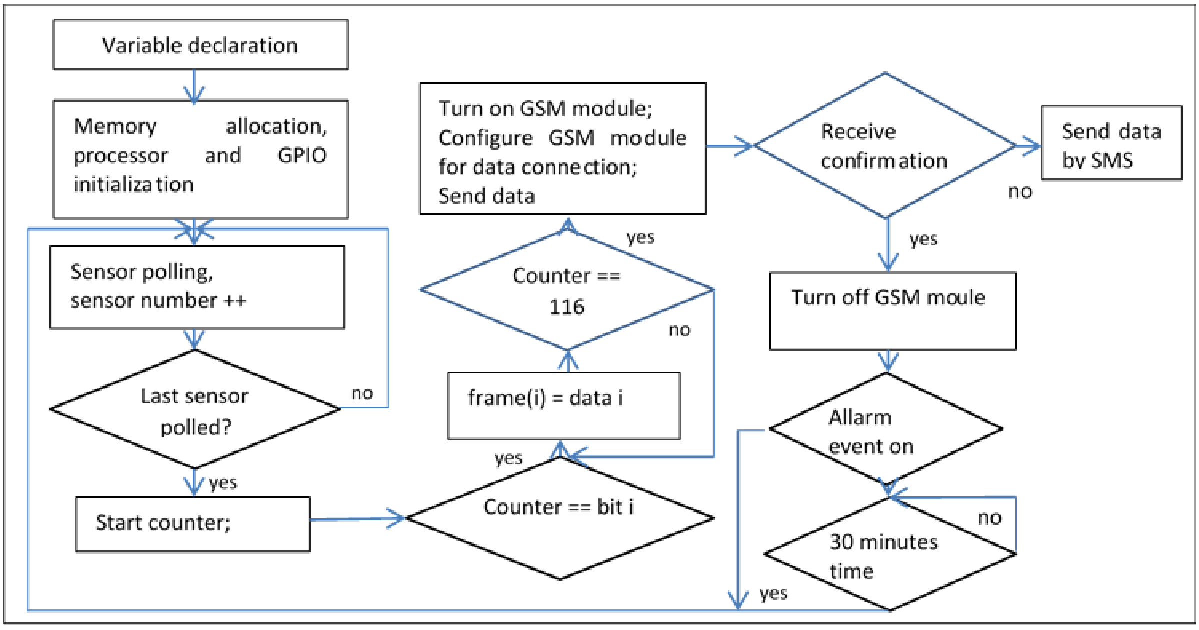

Fig. 4 Main routine of the node system

Fig. 5 shows the geographic system realizing a visualization of the parameters of the individual points. GIS realization is modular which allows attachment of additional information.

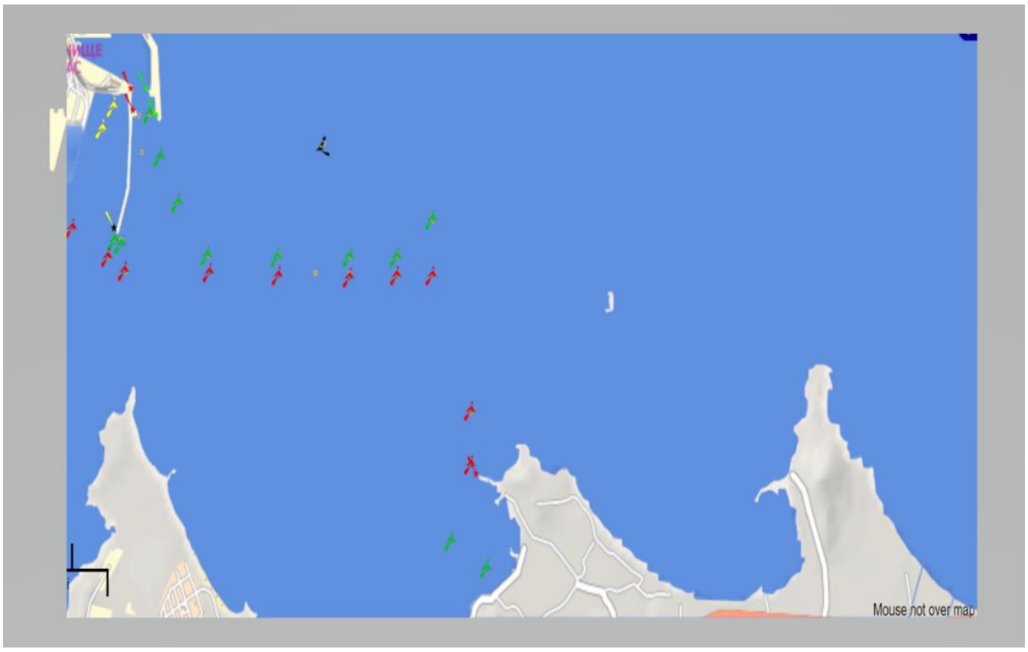

Fig. 5 General appearance of GIS

Conclusion and further studies

It can be concluded that the system in its current state provides possibility for reliable performance at low operational costs, features which filly comply with the problems it must solve. The low energy consumption and small size of the hardware makes it suitable for implementation in many kinds of objects, as it has been opted for as early as the stage of system design. The preparation of the full documentation and detailed description of the source code of the application and the system provides possibilities for further development or implementation of new decisions without incurring high costs. There is still work to be done on the formalization and expansion of the interface and its adaptation to link it to international information systems, e.g., AIS and data provision, the regional and national information monitoring systems.

Acknowledgments

The development work was done in the framework of GRANT № OUF-NI-09/2016 and project DNTS Germany 01/11.2014.

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