

RIGA TECHNICAL UNIVERSITY

# Information Technologies and Tools for Space-Ground Monitoring of Natural and Technological Objects

Collective Monograph

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# Preface

Recent natural disasters and major technological incidents as well as intensification of human activities prove the strategic necessity for the effective use of results of natural and technological object monitoring and its integration within the national economic processes. This book presents main results achieved within the research project 2.1/ELRI-184/2011/14 “Integrated Intelligent Platform for Monitoring the Cross-Border Natural-Technological Systems” (INFROM) as part of “Estonia – Latvia – Russia Cross-Border Cooperation Programme within European Neighbourhood and Partnership Instrument 2007–2013”, from both theoretical and implementation perspectives. The project aims to improve the integrated monitoring and control of cross-border complex systems, which contain natural, technological and social elements, in normal and emergency situations based on heterogeneous data received from space and ground-based information sources.

Nowadays, monitoring and control methods are applicable only for specific Natural Technological Systems (NTSs). As a result, statistical information about existing systems is not well coordinated. This drawback becomes more evident in emergency situations, when effective decisions must be taken within a short period of time while different information flows have to be analysed.

Monitoring information regarding incidents and disasters is received typically from different facilities (e. g., biometric systems, aerospace systems, etc.), and, therefore, it is heterogeneous in nature (e. g., electrical signals, audio and video information, text, etc.). Since modern NTSs are very complex and multi-functional objects, their monitoring and control should be performed in conditions of large-scale heterogeneous datasets. Nowadays, the monitoring and control processes of NTSs are still not completely automated.

The INFROM project addresses the problem of integrated monitoring and control of cross-border natural-technological systems in normal and emergency situations, based on the analysis of heterogeneous data received from both space and ground-based facilities. The overall objective of the project is to develop a universal common intelligent platform for unifying efforts of specialists from Russia and Latvia to protect the environment and natural resources, based on the integrated space-ground monitoring. The project results achieved provide a unified approach to the integrated monitoring and control of complex systems based on the analysis of heterogeneous data received from space and ground-based facilities, by using different types of models (i. e., analytical, algorithmic, mixed) to model behaviour of these systems. In order to select and develop an appropriate model, techniques for estimation of the model quality and its adjustment to a real application are enrolled.

The book is recommended to the professionals responsible for monitoring of complex natural and technological objects and researchers working in this area.

The book contains a list of authors, a preface, four chapters as well as lists of abbreviations, figures and tables, and a summary. Each chapter is provided with references. The preface gives a short overview of the INFROM project objectives and briefly describes contents of the book.

Chapter 1 presents the state of the art in the development of computationally efficient and user-centred geospatial monitoring, analysis and modelling framework that allows processing and integration of remotely sensed data at different spatial and time scales, as well as modelling and simulation for assessment of possible future development scenarios of the monitored and analysed natural and technological objects.

Chapter 2 provides an insight into the advanced innovative information technologies for integrated space and ground-based monitoring of complex systems containing natural, technological and social elements.

Chapter 3 describes an integrated distributed network framework introduced in the project and the developed infrastructures. It also presents support tools for intelligent space and ground-based monitoring of river floods, integrated forest monitoring, including forest taxation and evaluating forest fire safety conditions and tools for information processing of water pollution.

Demonstration cases to prove functionality of the proposed technology platform, developed information processing and decision support tools are introduced in Chapter 4. These demonstration cases provide simulation-based Daugava River flood forecasting; integrated forest monitoring at Madona municipality and in Pskov region as well as monitoring of oil pollution in the Gulf of Finland and the overgrowing of Lubans Lake.

Finally, concluding remarks are provided in the summary.

We would like to express our gratitude to all project participants contributed to the preparation of this book as well as to representatives of the target groups actively participated in the implementation of the INFROM project. We are also pleased to acknowledge great support provided by colleagues from the institutions, involved into project implementation, in particular, project partners – Riga Technical University (Latvia) and St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (Russia), as well as project associate partners in Latvia (Latvian Transport Development and Education Association, and Diplomatic Economic Club) and Russia (Committee on IT and Communications, Government of the City of St. Petersburg). Our special thanks for the permanent support in searching for new approaches, developing new methods, algorithms and software tools in order to implement them, and finally for demonstrating efficiency of the developed methods and tools in particular demonstration cases go to the project Advisory Board and personally to its *Chair Dr. Jānis Lelis*.

We would also like to acknowledge the valuable and professional support of the Joint Technical Secretariat of Estonia – Latvia – Russia Cross-Border Cooperation Programme officers during the project implementation and preparation of this book.

*Yuri Merkuryev, Galina Merkuryeva, Boris Sokolov, Viacheslav Zelentsov*  
Riga, Latvia – St. Petersburg, Russia, May, 2014



# Chapter 1

## State of the Art in Space and Ground-based Monitoring of Natural and Technological Objects

### 1.1 Methodology and Trends for Monitoring and Control of Complex Systems

Monitoring of natural and technological systems and real objects focuses [1] on the issues of changing ecosystems, geo-systems, climate and providing services for sustainable economy, healthy environment and better human life by the following activities: early warning of natural and anthropogenic disasters; technological object security; land cover/land change, natural resource usage; human health and preservation of the environment.

#### 1.1.1 Overview of Models of Natural and Technological Object Monitoring and Control

Methods used to produce traditional cartography seem insufficient when dealing with an emergency response that requires a higher level of dynamism in creation and dissemination of maps. In order to be efficient in an emergency situation, those maps should contain real-time information and up-to-date data. Timeliness is crucial in the area of concern, and definitions of “trust” and “accuracy” significantly differ from those adopted in traditional cartography. In the case of an emergency response, also data of unknown quality and with a low level of accuracy can play an essential role, even higher than pre-qualified data and maps. Therefore, a new framework is necessary to be able to quickly and correctly integrate real-time observations, including ones received from automatic and human sensors.

Technical models for monitoring of natural and technological objects are structurally similar to conceptual models of these objects and are determined by monitoring objectives. Here, some models for most prioritised issues are considered.

The growth of complexity of natural and technological objects (NTOs) and their monitoring and control systems (MCSs) as well as the increasing importance of uncertainty factors at all monitoring and control stages necessitate new approaches to control system design [2].

The most perspective approach, namely, intellectual and intelligent control, has arisen within artificial intelligence investigations [2]. The intellectual control sys-

tems, contrary to the intelligent ones, are assumed to solve the problems of goal setting and model development. Hence, new intelligent information technologies (IITs) extend traditional analytical and simulation modelling of complex technical objects. IITs use data-driven non-algorithmic computing with intrinsic parallelism and non-determinism.

IITs include [3]: technologies of knowledge-based and expert systems; fuzzy-logic technologies; technologies of artificial neural networks; case-based reasoning (CBR technologies); technologies of natural language systems and ontology; technologies of content-addressable memory; technologies of cognitive mapping and operational coding; technologies of evolutionary modelling.

The technologies for monitoring of natural and technological systems (NTS) are based on the use of abstractions of the monitored objects in the form of conceptual, analytical or simulation models that can be categorised in three groups: ecological NTS models; technological NTS models; and natural disaster and industrial accident models.

The monitoring of natural and ecological processes requires the use of endpoints and target indicators that can be measured and clearly understood by scientists, environmental managers, and the public. An important role there is played by computer models that allow developing hypotheses about system behaviour and interpreting available data. There are a great variety of methodologies, models and systems in the area of natural and ecological NTSs. In this chapter, the most important monitoring, analysis and modelling systems in the project context are reviewed.

1. *Flood mapping systems.* Floods are the most frequent disaster types globally and often also the most costly ones [4]. Flood management can be considered a spatial problem. Flood mapping is tightly coupled with remote sensing and hydrochemistry, which combines the use of GPS and multispectral remote sensing for mapping the inundated area, chemical water sampling for distinguishing water sources and interpolation techniques, and geographic information systems for analysing spatial patterns. The main tasks of the flood mapping systems are the following:
  - Monitoring of a water surface;
  - Control of ice conditions in a given region;
  - Detection, monitoring and modelling of occurrence and dynamics of dusty storms.
2. *Wildfire monitoring systems.* Forest fires play a critical role in landscape transformation, vegetation succession, soil degradation and air quality [5]. Improvements in fire risk assessment are vital for reducing negative impacts of fire; either by less burn severity or intensity through fuel management, or by aiding the natural vegetation recovery using post-fire treatments. The monitoring of forest fires usually includes the detection of thermal anomaly and

the control of fire propagation. Fire sites can be therewith interpreted both visually and automatically (infrared spectrum) using radiance temperatures of thermal channels.

3. *Land use monitoring systems.* The use of Earth Science Data, models and geographic information systems in agricultural monitoring and assessment expands an ability to understand the impacts of climate variability, landscape change, and anthropogenic and economic forces on the global agricultural production. There are a large number of methodologies and models for land-use modelling and monitoring systems, for example, the CLUE land-use change model [6].

Geographically Weighted Regression (GWR) or multi-level models, which sometimes are used for tropical land-use and cover change, can also be applied. GWR is becoming a more commonly used technique in urban geographical and environmental studies. The GWR is stated as follows [7]:

$$y_i = \beta_{i0} + \sum_{k=1}^n \beta_{ik} x_{ik} + \varepsilon_i, \quad (1.1)$$

where  $\beta_{ik}$  is the value of parameter  $k$  at location  $i$ .

4. *Systems for automatic detection of coastline changes.* According to the International Geographic Data Committee (IGDC), the shoreline could be regarded as the most unique feature on the Earth's surface. The location and attributes of shorelines are highly valued by a diverse user community because they have never been stable in either their long-term or short-term positions. Consequently, shoreline change detection and mapping are critical for safe navigation, coastal resource management, coastal environmental protection and sustainable coastal development and planning. One of the most valuable models for coastline change detection is the Darss-Zingst peninsula adapted to a particular environment [8].
5. *Forest and land-cover change monitoring systems.* During the last decade, forest damage due to high wind speeds has caused significant economic losses in forestry, both in Central and Northern Europe. In certain countries, wind is the main abiotic risk factor in the forest. Therefore, different special tools that help managers to assess the risk of wind damage are necessary. Different models can be used for such systems, for example, the HWIND model is used to simulate data for the tree species specific regression models for predicting the critical wind speed [9].

The natural and technological objects and systems belong to the class of complex systems. By complex systems we mean systems that should be studied through polytypic models and combined methods. In some cases, investigations of complex systems require multiple methodological approaches and theories, as well as interdisciplinary research. Different aspects of complexity can be considered to distinguish between

a complex system and a simple one, for example: structure complexity, operational complexity, complexity of behaviour choice and complexity of development. Classic examples of complex NTS monitoring problems and models are the following: 1) monitoring cracks and bowing walls; 2) monitoring of soil undermining by burst water main; 3) calculation of the available hydropower for hydroelectric power stations; 4) calculation of the available power for wind farms; 5) road surface and wear monitoring.

Crisis situations in NTSs may be caused by natural disasters or industrial accidents.

A natural disaster is a major adverse event resulting from the Earth's natural hazards. A natural disaster can cause loss of life or property damage, injury, economic and environmental losses. The severity of the losses depends on the ability of the affected population to resist the hazard, also called resilience [10]. Natural disasters for the project area are floods, wildfires, earthquakes, thunderstorms, etc.

Industrial disasters or accidents are caused by industrial companies, either by an accident, negligence or incompetence [11], and may lead to a great damage, injury or loss of life. These accidents may also be caused by the products or industrial processes, e. g., chemical processes where loss incurred may be very high. Hazardous materials in various forms can cause death, serious injury as well as damage to buildings and other properties. The industrial process setup is under immediate threats. People working in that industry or residing in the neighbouring areas are usually affected by these threats. Main industrial disasters can be classified in the following industries: chemical industry and hazardous materials; construction industry; energy industry and power outage; manufacturing industry.

Detailed description of investigated models for natural and technological object monitoring and control is given in [12].

### 1.1.2 Integrated Conceptual Framework for Natural and Technological Object Monitoring and Control

The proposed integrated conceptual framework is based on the theory of structural dynamics control, system theory and system analysis, operation research and artificial intelligence techniques.

Development of knowledge-based models, methods and algorithms for the monitoring and control of natural and technological objects and for the reconfiguration of monitoring systems plays an important role in decision-making in the task of synthesis and intellectualisation of the monitoring technology and systems for complex technical objects under real-time dynamic conditions. This task includes the following subtasks [13]:

- Development of methodology for accumulation and use of ill-formalised knowledge about the states of complex technical objects under rigid constraints (e. g., real-time operation mode, recurrence of computational processes) applied to

- both knowledge accumulation and state estimation; as well as development of methodology for structural reconfiguration of objects and monitoring systems;
- Development of models and algorithms for the analysis and synthesis of re-configurable monitoring systems;
- Design of a new information technology for the development and maintenance of monitoring software and its approbation in typical application domains.

Each application for remote sensing-based monitoring of natural and technological objects has specific requirements for spectral (physical), spatial and temporal resolution (see also [2]). Spectral resolution refers to the width or range of each spectral band being recorded. For example, panchromatic imagery (sensing a broad range of all visible wavelengths) will not be as sensitive to vegetation stress as a narrow band in the red wavelengths, where chlorophyll strongly absorbs electromagnetic energy. Spatial resolution refers to the discernible details in the image. Detailed mapping of wetlands requires much finer spatial resolution than the regional mapping of physiographic areas does. Temporal resolution refers to the time interval between images. There are applications requiring data repeatedly and frequently, such as oil spill, forest fire, and sea ice motion monitoring. Some applications only require seasonal imaging (crop identification, forest insect infestation, and wetland monitoring), and some need imaging only once (geology structural mapping). Obviously, the most time-critical applications also demand fast turnaround for image processing and delivery – getting useful imagery quickly into the user’s hands.

For the monitoring of natural and technological systems, the following main functional capabilities of the technology framework are required [14]:

- Image filtration (edge detection; smooth filters; speckle noise filtering; morphological operations; texture feature calculation; noise removal; interpolation);
- Satellite data based thematic products (fire detection; cloud detection; snow and ice cover detection; land surface temperature calculation; possibility to set threshold values during calculation);
- Thematic processing of radar images (radar image segmentation using specific algorithms; oil spill detection; possibility to get statistical probability of assessing the pixel as oil spill; ship detection);
- Solar radiation balance calculation (capability to calculate short-wave and long-wave radiation; capability to calculate air and surface temperatures);
- Hydrological modelling (possibility to model hydrograph; flooding modelling; freshet and overflow modelling; acquisition of water distribution model on a specified date);
- 3D modelling and visualisation (cloudiness, fog, mist, smoke modelling; water surface modelling; tree modelling).

The proposed framework structure (Fig. 1.1) supports a high performance user-centred computational platform. At the lowest component level, the goal is to effectively

integrate all the available data with analytical capabilities from various geographically distributed data sources to enhance the reliability of the monitoring information and the speed at which it becomes available to decision-makers.

Another important aspect is to provide a user with the most accurate spatial and temporal resolution of data, model and tools according to a task to be solved. Consequently, the assessment at different geographic scales should take advantage of different data sources.

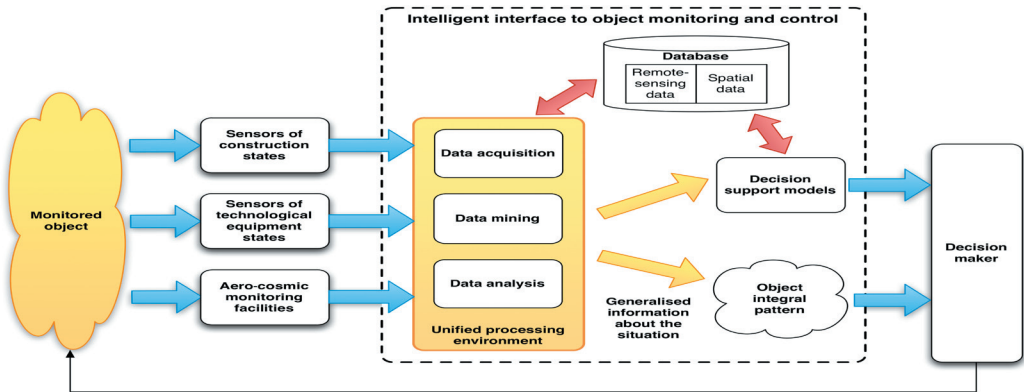


Fig. 1.1 General architecture of integrated remote sensing and monitoring system

This framework implements a unified approach to the integrated monitoring and control of complex systems that include natural, technological, economic and social elements and contain the following main components [15]:

- Integrated real-time monitoring and control based on the analysis of heterogeneous information from space and ground-based facilities;
- Unified processing environment for processing heterogeneous data from different sources and their integration;
- Distributed, real-time database embedded into the monitoring and control system for creating a common information space;
- Multi-models for behaviour analysis of complex objects in normal and emergency situations and decision support;
- Intelligent interface to object monitoring and control;
- Data-flow computing models for large-scale datasets executed in real-time and in territorially distributed computer networks.

A key component of the conceptual framework is a unified processing environment that provides data mining, processing and analysis functionality. The processed data are used by the decision support component for modelling, optimisation and visualisation of the monitored systems.

The main problem of analysis and synthesis of monitoring and control systems for natural and technological objects is making effective decisions. The proposed



framework structure allows combining analytical, simulation and knowledge-based approaches to the modelling, monitoring and control of natural and technological systems [16]. The inter-modal coordination scheme with multiple preference relations in the power grid is discussed below in Section 2.3.1.

The monitoring data can be produced by different sensor platforms (satellites, aircrafts, land or water based). Consequently, these data may vary in spatial and temporal resolution and internal structures. Integration of information received from numerous heterogeneous data sources provides possibilities to unify and simplify monitoring and control processes. Moreover, the proposed integrated framework and information technology will allow non-professional users to design and develop integrated real-time monitoring and control systems of natural and technological objects.

### 1.1.3 Intelligent Monitoring Technology Based on Integrated Ground and Space Data

An application of new intelligent information technologies to the monitoring and control of natural and technological systems includes three lines of investigations:

- Development of modelling algorithms and tools for knowledge representation and processing;
- Development of a new intelligent technology for system monitoring based on integrated data from ground and space information sources;
- Development of new applications for proposed models, algorithms and tools.

Within the first line of investigations, the change from automated processing of measured information to a computer-aided analysis involves semantic aspects of data representation. Thus, information about the control object should rather be regarded as a set of interrelated parameters that characterise its technical state than simple collection of measurements. In this case, the concept of a metric space typically used in simple monitoring problems is poor for our purposes; hence, more general representation constructions should be used.

It has been proved that parameters of the object technical states can be described by an open set system that forms a base for a topology. It has been assumed that a set of parameters has a topological structure. Thus, a system of neighbourhoods meeting the topological axioms has been established for each element. Here, the technical state means abstract collection of data, including information about the object attributes as well as about the state of computations within the monitoring process. This allowed optimising computations in order to receive monitoring results in real time.

The following statements have been proved: 1) the whole set of the state parameters constructed through the proposed model of knowledge representation is a lattice or a lattice ordered set; 2) if a set of technical states has the greatest element and the least element that define initial data and the results correspondingly, then a complete lattice can be formed via the construction of additive and multiplicative lattices; 3) ne-

cessary and sufficient conditions for the existence of a topology base are obtained for a set of technical state parameters; 4) the constructed topology can be used for the whole description of possible technical states and construction of a computational scheme to analyse these states.

Moreover, the following scientific and practical results have been obtained [17]:

- Formal description of all possible types of states adequate to actual actions and processes of the control object by using different mathematical apparatus for various functional objects. Multi-model formalisation is introduced for describing these actions and processes;
- New methods for the synthesis of programmes to perform the analysis of measured information that provides the interactive intellectual processing of data and knowledge about physical properties (i. e., functional, range, signal, code and integrated parameters) of states and for different formal descriptions without reference to their physical properties as well as the automatic generation of alternative programme schemes for measured data analysis taking into account the control objectives under a changing environment;
- New algorithms for the poly-model description of monitoring processes via attribute grammars, discrete dynamic systems and modified Petri nets that allow adapting these algorithms to different classes of control objects;
- A general procedure for the automatic synthesis of monitoring programmes that includes the following steps: 1) description of the problem conditions and constraints via a network model connecting input data with goals; 2) automatic analysis of the existence of the problem solution via a formal attribute grammar; 3) generation of the programme alternative schemes in a specific environment for the monitoring system.

The main advantages of the proposed procedure are simple modelling of the measured data sources that can be performed by a non-programmer in the shortest time and the real-time implementation of the intellectual methods and algorithms of data analysis and processing for an arbitrary measurement structure. The proposed methods for monitoring automation allow switching from the heuristic analysis of telemetry data to a sequence of well-grounded stages of monitoring programme construction and adaptation, from unique programming skills to unified technologies of software design. The consecutive specification of software functions is the ground of technologies to be used for the creation of monitoring systems.

Within the second line of investigations [17–20], the problem of structural dynamics of monitoring systems for the control of natural and technological objects under a changing environment has been analysed. Structural and functional control in monitoring systems involves a change in system objectives; reallocation of functions, tasks, and control algorithms between different levels of the monitoring system, control of reserves; and transposition of MS elements and subsystems. To solve the structural



dynamics and structural control problems, methodologies of system engineering and analysis, system dynamics, modern optimal control theory for the complex systems with reconfigurable structures, and artificial intelligence techniques are applied. Structural control problem solutions are based on well-known principles, such as programmed control, external complement, multi-scale variety, etc. The development of the programme for optimal structural dynamics and control in the monitoring systems includes two phases. At the first stage, a set of feasible multi-structural macro-states is generated, so the structural and functional synthesis of a new system is performed in accordance with an actual or forecasted state of the control object. At the second phase, a single macro-state is selected, and an adaptive plan that specifies the transition of the monitoring system to the selected macro-state as well as provides system stable operations in the intermediate macro-states is designed. The construction of the transition programme is formulated as a multi-level multi-stage optimisation problem.

The proposed method of the structural dynamics control programme construction allows obtaining the most preferable macro-state of the monitoring system at finite time. This state defines reliable operation of the monitoring system in the current or forecasted situation.

Within the third line of investigations, the pilot version of the computer-aided monitoring system for state supervision of the control object has been developed. It uses a special operational environment [21], [22], real-time database management system, multi-window man-machine interface, and programming language C/C++. Technical and operational characteristics of the developed monitoring software prototype are given in Table 1.1.

*Table 1.1*

Characteristics of the Monitoring Software Prototype

Characteristics	Value range
A number of parameters simultaneously analysed	up to $1.6 \cdot 10^7$
Integer parameters	from $-2147483648$ to $+2147483647$
Real type parameters	15 decimal digits with exponents from $-307$ to $+308$
A number of parameters analysed within one session	up to $6 \cdot 10^{10}$
Time accuracy for events	up to $10^{-3}$
Complexity of unified structures	– situation matrix (up to 512 situations); – finite-automaton models; – linear-bounded automata; – unique models of arbitrary strength; – universal applications
A number of versions	limited by ergonomic and hardware application aspects

## 1.2 Project Methodology: Concepts, Principles, Requirements, and Approaches

### 1.2.1 Conceptual Modelling of Monitoring and Control Systems for Natural and Technological Objects

Structural dynamics and control problems require innovative solutions and investigation of models to obtain them. The conceptual model represents concepts and relations between them. It is a descriptive model of a system based on qualitative assumptions about its elements and relations between them. The conceptual model is used to understand the system operation in a specific environment using natural language and naïve logic statements [24], [33]. Conceptual models play a key role in software application development. Moreover, the conceptual modelling is an important step in the simulation study.

With regard to NTO space-ground monitoring and control problems, conceptual modelling supposes the definition of a clearly formulated target set on various stages of object lifecycle under investigation; setting-up basic concepts in the area of concern and relations between these concepts; as well as definition borders between an investigated system and its environment.

The control system for natural and technological object monitoring may have a multi-level hierarchical structure. It may include control points, control stations, space and ground-based measurement equipment, and a telecommunication system. Each MCS subsystem can be considered a control subsystem with respect to its inferior elements, on the one hand, and a controlled element with respect to ranking all subsystems, on the other hand.

For further specification of the structural dynamics and control problems let us introduce a subclass of control objects that represents artificially created or virtual objects (e. g., a set of devices) that could be moved in a real or virtual space and interact with other objects by information, material or energy exchange.

The object structure allows a wide interpretation, so these objects can be used for the description of natural objects, e. g., a part of land, forest area, water basins as well as ground and space facilities. They can be interpreted as different users who want to implement results of space-ground monitoring for their own goals [27–29], [32]. In this case, interactions between objects could have the active or passive character.

The following basic concepts are used for the conceptual modelling of the structural dynamics of monitoring and control systems.

- a. “Operation” defines any action or a system of actions to accomplish a goal. Operations require resources, including information, material and energy exchange. Operation content is formulated by specifying parameters that define

the operation results (e. g., volume, quality, and operational time), required resources as well as information, energy and material flows.

- b. Concept “Resources” includes materials, energy, production means, technical equipment, transportation tools, and finances. The operational time and personnel involved are defined as resources as well.
- c. Concept “Task” is used to describe the desirable result of actions for a specified time period. Tasks are derived from the goals and are characterised by quantitative data or parameters of the desirable results.
- d. “Flow” is characterised by current volume (level), transmission intensity, velocity of flow level variations, etc. Different types and kinds of flows are determined in real systems [37], e. g., material, energy and information flows; single-commodity and multi-commodity flows; continuous and discrete flows; homogeneous and heterogeneous flows; synchronous and asynchronous ones.
- e. “Structure” characterises stable links and interactions between system elements. The structure defines the integrity and composition of the system, and its organisation framework. Here, the following basic forms of structures [23–25], [29], [30], [37] are defined: structure of goals, functions and tasks; organisational structure; technical structure; topological structure; information support, hardware and software structure; structure of system basic elements and its subsystems at various stages of its lifecycle. Additionally, for various classes of relations between basic elements of MPS, multiple constraints (i. e., space-time, technical, technological, energy, material and information) are specified for different application areas.

Furthermore, the main system function in any computer-aided control system belongs to the structure of the control subsystem that communicates with all other types of structures of other types, and each structure is related to MCS objectives.

### 1.2.2 Formalisation of Structural Dynamics and Control Problem for Monitoring Natural and Technological Objects

The structural dynamics and control problem for monitoring natural and technological objects includes the following main subgroups of tasks [32]: 1) control tasks of structural dynamics; 2) investigation tasks for structural dynamics under the condition of zero inputs (neither controlling nor perturbation inputs are considered); 3) investigation tasks for structural dynamics and structural control over nonzero inputs.

The problem is formulated as follows. The following data are assumed to be known: alternative system structures; an initial structural state; inputs affecting system elements and subsystems; space and time technical and technological constraints; a list of system measures to evaluate the quality of the control process, e. g., goal abilities, structural and spatial characteristics [29], and information technology abilities. Multiple criteria are introduced to evaluate structural dynamic states of the MCS.

To solve the problem, first, the existence of the solution is analysed. Then controllability and stability of the MCS and sensitivity of optimal solutions are investigated. Finally, the analysis, classification and sorting of MCS multi-structural states are performed.

Let us introduce the following basic sets of objects and structures:

$\tilde{B} = B \cup \bar{B}$  is a set of objects, where  $B$  is a set of objects (subsystems, elements) of the MCS, and  $\bar{B}$  is a set of external objects interacting with the MCS through information, energy or material exchange.  $\tilde{C} = C \cup \bar{C}$  is a set of channels (hardware facilities) that are used by objects;  $D$ ,  $\Phi$  and  $P$  is a set of operations, resources and flows, correspondingly.

$G = \{G_\chi, \chi \in NS\}$  is a set of MCS structural types, where the main structures are topologic (spatial) structure, technology (functional) structure, technical structure, software structures and organisational structure. To interconnect these structures, the dynamic alternative multi-graph is introduced:

$$G_\chi^t = \langle X_\chi^t, F_\chi^t, Z_\chi^t \rangle \quad (1.2)$$

where  $\chi$  denotes a structure type,  $\chi \in NS = \{1, 2, 3, 4, 5, 6\}$ , where 1 indicates a topologic structure, 2 – a functional structure, 3 – a technical structure, 4 and 5 indicate math and software structures, and 6 indicates an organisational structure, time point  $t$  belongs to a given set  $T$ ;  $X_\chi^t = \{x_{\chi l}^t, l \in L_\chi\}$  is a set of elements of structure  $G_\chi^t$  that presents multi-graph vertices at time  $t$ ;  $F_\chi^t = \{f_{\langle \chi, l, l' \rangle}^t, l, l' \in L_\chi\}$  is a set of arcs of the multi-graph  $G_\chi^t$ ; the arcs represent relations between the multi-graph elements at time  $t$ ;  $Z_\chi^t = \{f_{\langle \chi, l, l' \rangle}^t, l, l' \in L_\chi\}$  is a set of parameters that numerically characterise these relations.

The graphs of different types are interdependent; thus, for the structural control of each particular task the following mapping should be constructed:

$$M_{\langle \chi, \chi' \rangle}^t : F_\chi^t \rightarrow F_{\chi'}^t \quad (1.3)$$

The compositions of the mappings can also be constructed at time  $t$ :

$$M_{\langle \chi, \chi' \rangle}^t = M_{\langle \chi, \chi_1 \rangle}^t \circ M_{\langle \chi, \chi_2 \rangle}^t \circ \dots \circ M_{\langle \chi'', \chi' \rangle}^t \quad (1.4)$$

A multi-structural state is defined as follows:

$$S_\delta \subseteq X_1^t \times X_2^t \times X_3^t \times X_4^t \times X_5^t \times X_6^t, \quad \delta = 1, \dots, K_\Delta \quad (1.5)$$

Thus, we obtain a set of MCS multi-structural states:

$$S = \{S_\delta\} = \{S_1, \dots, S_{K_\Delta}\} \quad (1.6)$$

Feasible transitions from one multi-structural state to another one can be expressed as:

$$\Pi_{\langle \delta, \delta' \rangle}^t : S_\delta \rightarrow S_{\delta'} \quad (1.7)$$

It is assumed that each multi-structural state at time  $t \in T$  is defined by a composition (1.4). Hence, the problem is defined as the selection of a multi-structural state  $S_{\delta}^* \in \{S_1, S_2, \dots, S_{K_{\Delta}}\}$  and transition sequence (composition)  $\Pi_{<\delta_1, \delta_2>}^{t_1} \circ \Pi_{<\delta_2, \delta_3>}^{t_2} \circ \Pi_{<\delta', \delta>}^{t_f}$  ( $t_1 < t_2 < \dots < t_f$ ). The results of the selection can be presented as an optimal programme for MCS transition from a given structural state to a specified one.

The interpretation of the object structural dynamics process is given in Fig. 1.2. 2 Multi-graphs  $G_{\chi}^{t_1}$  and  $G_{\chi_1}^{t_1}$  describe dynamics of functional and technical structures, where  $\Gamma_{\chi}^{t_1}$  and  $\Gamma_{\chi_1}^{t_1}$  present object functional and technical structures at the moment  $t_1$ .

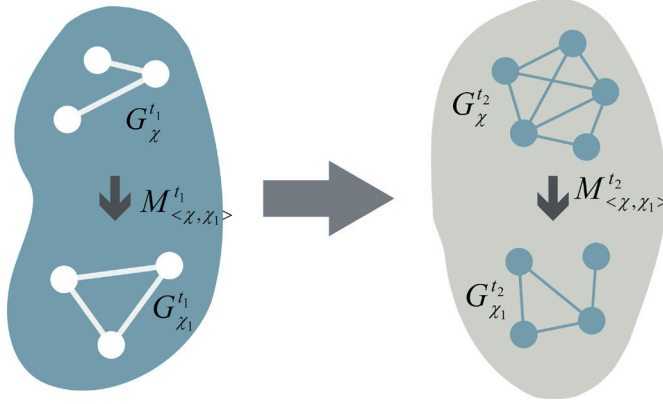


Fig. 1.2 Structural changes in the system

Well-known approaches to solving the problem are based on the PERT description of scheduling and control problems and the process dynamic interpretation. The implementation of these approaches results in algorithmic and computational difficulties caused by high dimension, non-linearity, non-stationarity and uncertainty of appropriate models.

### 1.2.3 Modern Optimal Control Theory Application in Monitoring and Control of Natural and Technological Objects

Let us introduce the following modification of dynamic interpretation of monitoring and control processes. The main idea of model simplification is to implement non-linear technological constraints in sets of feasible control inputs rather than in the right parts of differential equations. In this case, Lagrangian coefficients, keeping the information about technical and technological constraints, are defined via the local section method [27–29], [31–32]. Furthermore, interval constraints instead of relay ones can be used. Nevertheless, the control inputs take on Boolean values caused by the linearity of differential equations and convexity of a set of alternatives. The proposed substitution enables the use of fundamental scientific results of the modern control theory in various monitoring and control problems of natural and technological systems.

As provided by the concept of a multiple model description, the proposed general model includes the dynamic models of (see Fig. 1.3): system motion control ( $M_g$  model); channel control ( $M_k$  model); operation control ( $M_o$  model); flow control ( $M_n$  model); resource control ( $M_p$  model); operational parameter control ( $M_e$  model); structural dynamic control ( $M_c$  model); and auxiliary operation control ( $M_v$  model).

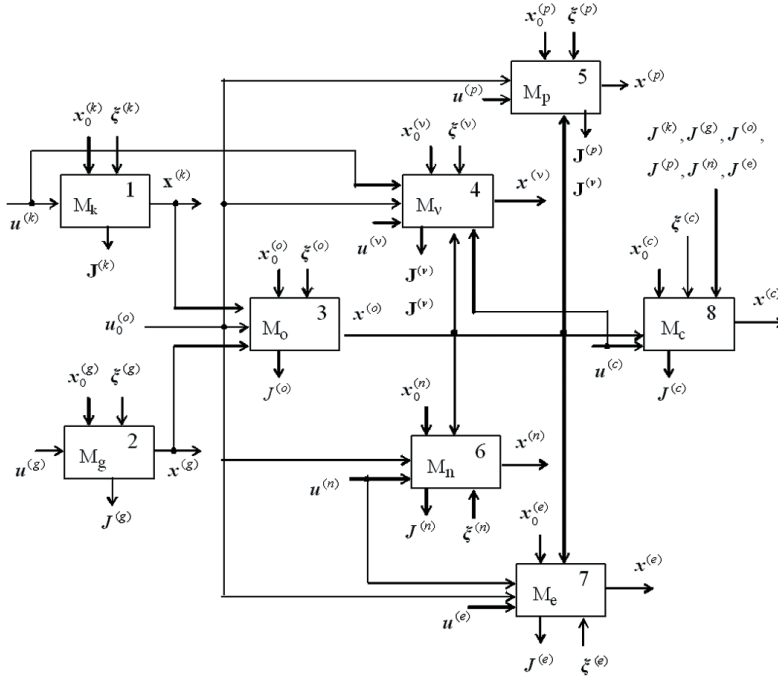


Fig. 1.3 The interconnection of the MCS models

Procedures of structural dynamics problem solving depend on the variants of transition and output function (operators) implementation. Various approaches, methods, algorithms and procedures of a coordinated choice through complexes of developed heterogeneous models have been developed by now.

The control problem of structural dynamics of monitoring and control systems has some specific features in comparison with classical optimal control problems. The first feature is that the right parts of the differential equations undergo discontinuity at the beginning of interaction zones. The considered problems can be regarded as control problems with intermediate conditions. The second feature is the multi-criteria nature of the problems. The third feature is concerned with the influence of uncertainty factors. The fourth feature is the form of time-spatial, technical, and technological non-linear conditions that are mainly considered in control constraints and boundary conditions. On the whole, the constructed model is a non-linear non-stationary finite-dimensional differential system with a re-configurable structure. Different variants of model aggregation have been studied. These variants are associated with the tasks

of the model quality selection and reduction of its complexity. Decision-makers can select an appropriate level of the model thoroughness in the interactive mode. The level of thoroughness depends on the input data, external conditions, and required level of solution validity.

The proposed interpretation of system structural dynamics and its control processes provides advantages of applying the modern optimal control theory for the analysis and synthesis of monitoring and control systems. During the performed investigations, the main classes of structural dynamics problems have been defined. They are as follows: the analysis of structural dynamics of mobile objects and its diagnosis; observation, multi-layer control problems; synthesis of generalised states of monitoring and control systems; generation of optimal transition programmes providing the transition from a given system structural state to feasible (or optimal) one.

Methodology for structural dynamics control developed in [23–26], [29–33] includes the methodology of general system analysis and modern optimal control theory for monitoring and control systems with re-configurable structures. As stated above, the solutions are based [23], [26], [32–38] on principles of goal-programmed control, external complement, multi-scale variety, multiple models and multi-criteria decision analysis: The dynamic interpretation of the structural control allows applying known results from the theory of dynamic systems (in particular, stability and sensitivity analysis in optimal control) to the analysis of monitoring and control systems of natural and technological objects (see Table 1.2).

*Table 1.2*

**Practical Use of Theoretical Results in the Analysis  
of Monitoring and Control Systems**

	<b>Qualitative analysis of space facility control processes</b>	<b>Practical implementation of the results</b>
1	The existence of the solution in a control problem	Adequacy analysis of the system process description in control models
2	Controllability and attainability conditions for a control system	Realisability analysis on the planning time interval (major factors of object goal setting and IT abilities)
3	Conditions for uniqueness of optimal controls in scheduling problems	Analysis of the possibility to obtain optimal schedules for MCS functioning
4	Necessary and sufficient optimality conditions for control problems	Preliminary analysis of an optimal control structure and scheduling algorithms
5	Conditions for solution reliability and sensitivity	Reliability and sensitivity analysis of control processes regarding perturbation effects and alterations in a system structure



## References

1. Romanovs, A., Sokolov, B., Lektauers, A., Petuhova, J. (2013). Crowdsourcing Supported Modelling and Analysis Infrastructure for Intelligent Monitoring of Natural-Technological Objects. In: *Proceedings of the 25<sup>th</sup> European Modelling & Simulation Symposium EMSS2013*, Greece, Athens, 25–27 September 2013. Rende: DIME Università di Genova, pp. 389–394.
2. Russell, S. and Norvig, P. (2010). *Artificial Intelligence: A Modern Approach*, 3<sup>rd</sup> ed. England: Prentice Hall, 1152 p.
3. IEEE (1996). *Intelligent Control Systems: Theory and Applications*. Piscataway, NJ: IEEE Press, 820 p.
4. CRED (2011). The International Disaster Database, 2011 Disasters in Numbers. Available at: <http://www.emdat.be>. Accessed: 29 April 2014.
5. Chuvieco, E., Aguado, I., Yebra, M. et al. (2010). Development of a Framework for Fire Risk Assessment Using Remote Sensing and Geographic Information System Technologies. *Ecological Modelling*, vol. 221, no. 1, pp. 46–58.
6. Verburg, P. H., Overmars, K. P. (2007). Dynamic Simulation of Land-Use Change Trajectories with the Clue-S Model. In: *Modelling Land-Use Change*, vol. 90, Koomen, E., Stillwell, J., Bakema, A., et al. (eds.) Netherlands: Springer, pp. 321–337.
7. Martin, P., Gómez, I., Chuvieco, E. (2005). Performance of a Burned-Area Index (BAIM) for Mapping Mediterranean Burned Scars from MODIS Data. In: *Proceedings of the 5<sup>th</sup> International Workshop on Remote Sensing and GIS Applications to Forest Fire Management: Fire Effects Assessment*, pp. 193–197.
8. Peltola, H., Kellomäki, S., Väisänen, H., Ikonen, V. P. (1999). A Mechanistic Model for Assessing the Risk of Wind and Snow Damage to Single Trees and Stands of Scots Pine, Norway Spruce, and Birch. *Canadian Journal of Forest Research*, vol. 29, no. 6, pp. 647–661.
9. Norenkov, I. P. (1998). The Approaches to Designing of Automation Systems. *Information Technology*, vol. 2, pp. 2–9.
10. Wisner, B., Blaikie, P., Cannon, T., et al. (2003). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. 2<sup>nd</sup> edition, New York: Routledge, 134 p.
11. Singh, M. (2011). *Presentation on Industrial Accidents*. p. 20.
12. Romanovs, A., Lektauers, A., Soshko, O., Zelentsov, V. (2013). Models of the Monitoring and Control of Natural and Technological Objects. *Information Technology and Management Science*. Vol. 16, pp.121–130.
13. Sokolov, B. V., Okhtilev, M. Y., Zelentsov, V. A., Maslova, M. A. (2012). The Intelligent Monitoring Technology Based on Integrated Ground and Aerospace Data. In: *Proceedings of the 14<sup>th</sup> International Conference on Harbour Maritime and Multimodal Logistics M&S, HMS 2012*. 19–21 September 2012, Vienna, Austria, pp. 112–117.



14. Petuhova, J., Lektauers, A., Zelentsov, V. (2012). Classification of Natural-Technogenic Objects in Remote Sensing Applications. In: *Proceedings of the 14<sup>th</sup> International Conference on Harbour Maritime and Multimodal Logistics M&S, HMS 2012*. 19–21 September 2012, Vienna, Austria, pp. 91–95.
15. Merkuryev, Y., Sokolov, B., Merkuryeva, G. (2012). Integrated Intelligent Platform for Monitoring the Cross-Border Natural-Technological Systems. In: *Proceedings of the 14<sup>th</sup> International Conference on Harbour Maritime and Multimodal Logistics M&S, HMS 2012*. 19–21 September 2012, Vienna, Austria, pp. 7–10.
16. Okhtilev, M. Y., Sokolov, B. V., Yusupov, R. M. (2006). Intellectual Technologies of Monitoring and Controlling the Dynamics of Complex Technical Objects. Moskva: Nauka, p. 409.
17. Okhtilev, M. Y., Sokolov, B. V., Yusupov, R. M. (2006). Intelligent Technologies of Complex Technical Objects Monitoring and Structure Dynamics Control. Moscow: Nauka.
18. Ivanov, D., Sokolov, B., Kaeschel, J. (2010). A Multi-structural Framework for Adaptive Supply Chain Planning and Operations with Structure Dynamics Considerations. *European Journal of Operational Research*. 200(2), pp. 409–420.
19. Ivanov, D. A., Sokolov, B. V. (2010). *Adaptive Supply Chain Management*. London: Springer, 269 p.
20. Sokolov, B., Ivanov, D., Fridman, A. (2010). Situational Modelling for Structural Dynamics Control of Industry-Business Processes and Supply Chains. In: *Intelligent Systems: From Theory to Practice*. Sgurev, V. Hadjiski, M., Kacprzyk, J. (eds.) London: Springer, pp. 279–308.
21. Sokolov, B., Yusupov, R., Okhtilev, M., Maydanovich, O. (2010). Influence Analysis of Information Technologies on Progress in Control Systems for Complex OBJECTS. In: *New Trends in Information Technologies. Proceedings of International Conference Information-Interaction-Intellect (iii2010)*, 23–27 June 2010, Varna (Bulgaria), pp.78–91.
22. Okhtilev, M. Y. (2004). The Data Flow and Distributed Calculations Intelligence Information Technology for Decision Support System in Real Time. In: *Proceedings of the 6<sup>th</sup> International Conference on Enterprise Information Systems ICEIS 2004*, Porto (Portugal), 2, pp.497–500.
23. Ackoff, R. L., (1978). *The Art of Problem Solving*. New York: Wiley-Interscience.
24. Aframchuk, E. F., Vavilov, A. A., Emel'yanov S. V., et al. (1998). *Technology of System Modelling*. Emel'yanov S. V. (ed.), Moscow: Mashinostroenie.
25. Casti, J. L., (1979). *Connectivity, Complexity and Catastrophe in Large-scale Systems*. New York, London: Wiley-Interscience, 203 p.

26. Gigch, J. (1978). *Applied General Systems Theory*. New York: Harper and Row.
27. Ivanov, D. A., Sokolov, B. V. (2010). *Adaptive Supply Chain Management*. London: Springer, 269 p.
28. Ivanov, D. A., Pavlov A. N., Sokolov B. V. (2012). Model-supported and Scenario-oriented Analysis of Optimal Distribution Plans in Supply Networks. In: *26 European Conference on Modelling and Simulation ECMS 2012*, 29 May – 1 June 2012, Germany, Koblenz, pp. 588–594.
29. Kalinin, V. N., Sokolov, B. V. (1995). Many-Model Approach to the Arrangement of Control Processes for Space Facilities. *Izv. Ross. Akad. Nauk, Teor. Sist. Upr.*, 1 (1995) [*Comp. Syst. Sci.* (1), 47 (1995)].
30. Merkur'yeva, G., Merkur'yev, Y., Vanmaele, H. (2011). Simulation-Based Planning and Optimization in Multi-Echelon Supply Chains. *Simulation: Transactions of the Society for Modelling and Simulation International*, 8(87), pp. 698–713.
31. Moiseev, N. N. (1974). *Element of the Optimal Systems Theory*. Moscow: Nauka.
32. Okhtilev, M. Y., Sokolov, B. V., Yusupov, R. M. (2006). *Intelligent Technologies of Complex Technical Objects Monitoring and Structure Dynamics Control*. Moscow: Nauka, p. 409.
33. Peregudov, F. I., Tarrasenko, F. P. (1989). *Introduction to Systems Analysis*. Moscow, Vysshaya Shkola.
34. Peschel, M. (1978). *Modellbildung für Signale und Systeme*. Berlin: Verlag Technik.
35. Shannon, R. E. (1975). *Systems Simulation*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 387 p.
36. Siliak, D. D. (1990). *Decentralized Control of Complex Systems*. New York: Academic Press.
37. Skurikhin, V. I., Zabrodskii, V. A., Kopeichenko, Yu. V. (1989). *Adaptive Control Systems for Manufacturing*. Moscow: Mashinostroenie.
38. Sokolov, B., Ohtilev, M., Potryasaev, S., Merkur'yev, Y. (2014). Multi-model Description of Monitoring and Control Systems of Natural and Technological Objects. *Information Technology and Management Science*, vol. 16, pp. 11–17. doi: 10.2478/itms-2013-0001.

# Chapter 2

## Innovative Information Technologies for Integrated Space and Ground-based Monitoring

### 2.1 Data Processing and Integration

The effective use of results of natural and technological object monitoring and its integration within the national economic processes to analyse preventive measures from natural and other disasters becomes an important strategic factor for sustainable development of any region in the world. To reduce the risk of potential dangerous situations, the global monitoring of critical areas and facilities as well as the creation of the common information space to provide actual information to all interested parties is required.

#### 2.1.1 Heterogeneous Information from Different Data Sources

Remote sensing from space provides a unique opportunity to obtain actual information about the objects and phenomena on a global scale with a high space-time resolution. The criteria for the appropriateness of space systems in the solution of a problem are the relevance of solutions, economic efficiency or the impossibility of solving by traditional technologies. For the majority of natural and technological objects, the most effective solution is the solution that integrates traditional and space monitoring tools.

The monitoring information regarding incidents and disasters is received typically from different data sources (e. g., biometric systems, aerospace systems, etc.), and, therefore, it is heterogeneous by nature (e. g., electrical signals, graphical, audio, video information, text, etc.). Since modern natural and technological objects are very complex and multifunctional ones, their monitoring should be performed under conditions of large-scale heterogeneous datasets. At present, the monitoring and control of natural and technological systems are still not fully automated.

The technology developed within the project [1] involves the creation of an intellectual platform for the processing and use of the results of both ground and space monitoring. The project ensures the development of a common information space to monitor natural and technological objects, providing the government and the public with topical environmental information to be used in education, science, business, and case management; moreover, the project also provides additional independent

sources of operational information on natural and technological hazard processes. Another important result is to attract people to the development of innovative technologies and the active use of space activities. The developed intellectual platform will also help to reduce the risk and minimise the impact of natural or technological disasters by means of timely notification of the population in the case of disaster and its forecasting. To achieve this goal, it is proposed to use crowdsourcing [2] as a social technology that has been widely spread in many areas of the economy.

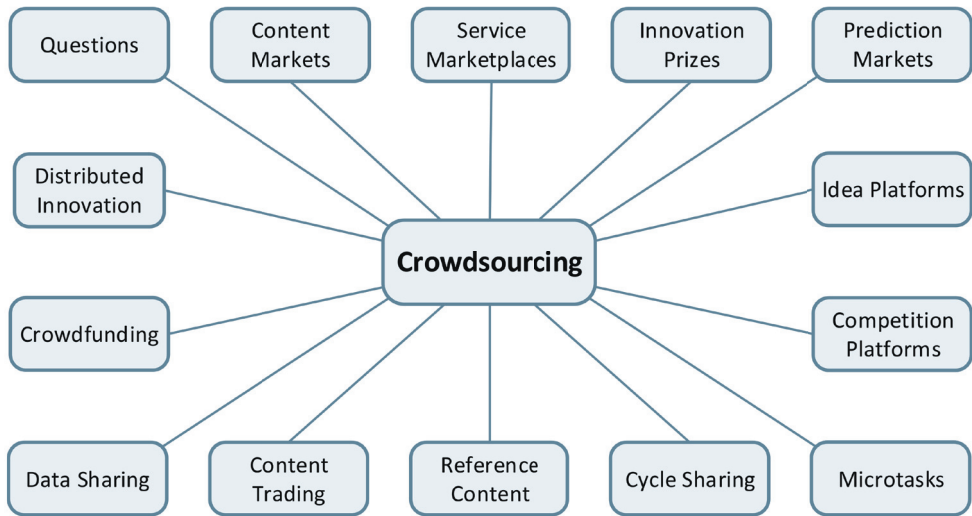
### 2.1.2 Review of Crowdsourcing Technology

The crowdsourcing is a conceptual part of the Human Computing that can assume a variety of forms (Participatory Sensing, Urban Sensing, Citizen Sensing), according to the scale at which humans are engaged, the tasks they are called to solve, and the incentive mechanisms that are designed to foster participation. Recent studies performed by a well-known Gartner Inc. company have shown [3] the need for choosing new business models (instruments and processes) primarily based on the social networks and media.

The term “crowdsourcing” is derived from the words “crowd” and “outsourcing”; this is a process required by people, who are not organised in any other system, to perform a specific job. Jeff Howe, the creator of the term, considered crowdsourcing to be a new social phenomenon that is beginning to emerge in certain areas [4], a phenomenon of bringing people together to solve the problem without any reimbursement, and the consequences of such groups/associations for business, solving similar tasks professionally. The method consists in the fact that the task is offered to an unlimited number of people, regardless of their professional status or age. Participants of a crowdsourcing project form the society that chooses by discussing the most successful solution of the given problem. For businesses, this method is an inexhaustible resource for finding solutions to their own problems, a powerful tool that allows adjusting the cost-effective development, including the development of the most customer-oriented products.

At present, a number of social tools are ranked as crowdsourcing; researchers from Crowdsourcingresults [5] proposed a comprehensive classification of crowdsourcing methods. The most popular methods of crowdsourcing are the following (see Fig. 2.1):

1. Reference Content, when everyone who knows more improves reference resource; Wikipedia is the most popular resource;
2. Content Markets, when visitors locating and evaluating some content, and site owners are allowed to produce their best examples;
3. Crowdfunding is the collaboration of people, who pool their resources (money) to support projects initiated by other people or organisations;



**Fig. 2.1 Methods of crowdsourcing**

4. Competition Platforms, when the customer announces a competition at an online platform; actors offer their solutions and evaluate the proposals of colleagues; as a result, the best work is chosen, which is usually rewarded; one of the most famous examples of such a resource is the site Zooppa.com;
5. Micro-tasks, when the customer announces the use of human intelligence to perform small tasks that cannot be formalised and solved by computers (Human Intelligence Tasks); the most famous site is the platform Amazon Mechanical Turk;
6. Crowdsourcing Aggregators, when the performers take on a client project, divide it down into individual tasks that are offered in the form of micro-projects for crowdsourcing workforce, and then aggregated. This approach allows solving large-scale, automated and hard tasks. The site CrowdFlower is the largest provider of this platform;
7. Cycle Sharing is the method of crowdsourcing that uses computers for volunteer distributed computing.

### 2.1.3 Crowdsourcing in the Tasks of Monitoring

Remote monitoring has a long history of use for collection of environmental measurements. Many sensor networks have been deployed to monitor the Earth's environment, and more sensor networks will follow in the future. Environmental sensors have improved continuously by becoming smaller, cheaper, and more intelligent. Due to the large number of sensor manufacturers and differing accompanying protocols, integrating diverse sensors into observation systems is not straightforward.

A coherent and integrated infrastructure is needed to treat sensors as an interoperable, platform-independent and uniform way. The concept of the sensor web reflects such a kind of infrastructure for sharing, finding, and accessing sensors and their data across different applications. It hides the heterogeneous sensor hardware and communication protocols from the applications built on top of it. The Sensor Web Enablement initiative started by Open Geospatial Consortium defines the term “sensor web” as “web accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and application programming interfaces”. Thus, the sensor web is to sensor resources what the WWW is to general information sources – an infrastructure allowing users to easily share their sensor sources in a well-defined way.

Environmental management and monitoring systems provide an important application of the crowdsourcing-based paradigm, particularly in the area of integrated planning and management. More specifically, crowdsourcing can be integrated in environmental planning, management and monitoring at three different levels:

1. Setting up a social network for a better comprehension of the underlying social system, i. e., network identification, interest characterisation, stakeholder clustering and representative selection, and social disambiguation of interests.
2. Putting humans in the loop in order to exploit human potential as sensors, task solvers and decision-makers, i. e., human sensing, human judgment for task solving, and co-deciding.
3. Eliciting collective knowledge on the environmental systems by exploiting distributed knowledge and expertise, i. e., the so-called social capital.

Thus, crowdsourcing can be applied not only to monitor the status of the selected object or area, but, at the same time, to increase the awareness of people about the behaviour of the monitoring object. The motivation for engaging the public in monitoring is two-fold [6]. On the one hand, crowdsourcing can complement modern assessment methods to achieve a high degree of spatial-temporal granularity at lower costs. On the other hand, the active involvement of citizens in the processes of decision-making control increases their self-awareness and sense of responsibility. Numerous international reports [7], [8] show the participation of all concerned citizens, at all levels for sustainable socio-economic development. For example, the introduction of smartphones as personal instrumentation reduces barriers to achieve the democratisation process monitoring.

The impact of emerging technologies on information security is clearly seen. As about 14 % of large organisations had a security breach relating to social networking sites and 9 % had a breach relating to smartphones or tablets [9], assuring security of industrial and private information assets is becoming an extremely sensitive issue. There are a lot of available freeware and paid methods for information protection from unauthorised access by unwanted individuals [10].



## 2.1.4 Integration of Traditional and Social Data

Mobile phones increasingly become multi-sensor devices, accumulating large volumes of data related to our daily lives. These trends obviously raise the potential of collaboratively analysing sensor and social data in mobile cloud computing [11]. At the same time, there is a growing fleet of various robotic sensors (e. g., robotic fishes) coupled with the emergence of new and affordable monitoring technology that exponentially increases the amount of data collected from the world's geo-spheres. This puts decision-makers and researchers who work with these data in a completely fresh situation.

The two popular data types, i. e., sensor and social data, are in fact mutually compensatory in various data processing and analysis. Participatory sensing [12], [13], for instance, allows collecting data via social network services (e. g., Twitter, Waze, Ushahidi) over the areas where physical sensors are unavailable. Simultaneously, sensor data (Fig. 2.2) are capable of offering precise context information, leading to the effective analysis of social data. Obviously, the potential of blending social and sensor data is high; nevertheless, they are typically processed separately, and the potential has not been investigated sufficiently. Therefore, there is an urgent need for fusing various types of data available from various data sources.

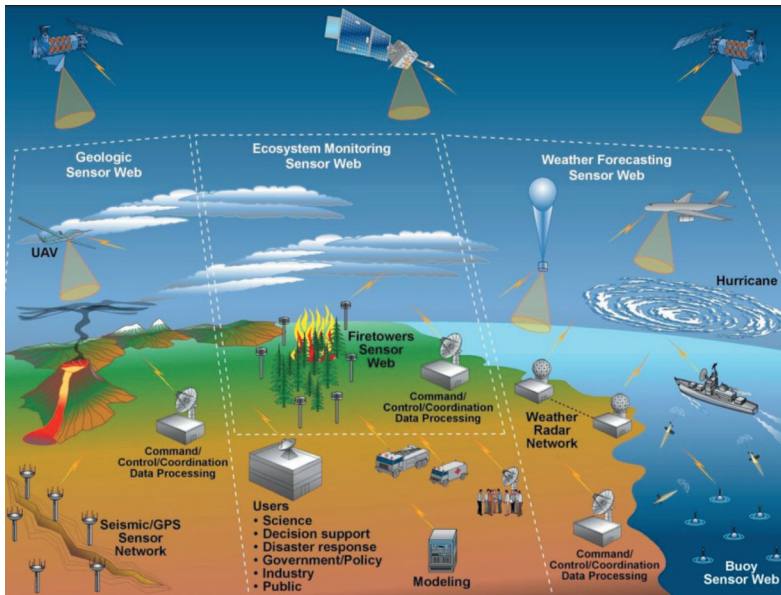


Fig. 2.2 Various sensor data sources [14] arranged in a sensor web [13]

Data fusion is the process of combing information from a number of different sources to provide a robust and complete description of an environment or process of interest [15]. Automated data fusion processes allow essential measurements and

information to be combined to provide knowledge of sufficient richness and integrity whose decisions may be formulated and executed autonomously.

The existing projects and platforms for data collection and processing, e. g., GOOS [16], Marinexplore [17], Social.Water [18], show that the bottleneck of the data market is not in collecting the data, but in processing the data. Most available data are disconnected, often archived, and sometimes never used again [17].

### 2.1.5 Crowdsourcing-based Information Processing Framework

The existing space-ground monitoring information processing platform can be without significant cost supplemented with an application that processes the data of social sensors. At a minimum, this social application could consist of two components: a mobile application and server public knowledge base. Mobile applications are downloaded free of charge and installed on smartphones to turn them into mobile monitoring system social sensors. Smartphones collect information from various sensors (microphone, GPS, descriptive or qualifying user-typed information), and in real time send to the server public knowledge base.

Public knowledge base (also called Web-based Community Memory) is defined as a resource of information and communication technologies that enables the public to record and archive information relating to the management of common property [19]. Thus, it is part of the software that operates on a central Web server, collects and processes all data received from mobile social sensors, supports a website that allows users to search, analyse and visualise data.

### System Architecture

The objective of the proposed crowdsourcing-supported software platform is to allow blending the heterogeneous social and sensor data for an integrated analysis, extracting and modelling environment-dependent information from social and sensor data streams.

The general system architecture consists of four coupled layers (Fig. 2.3):

1. *External data sources.* Environment monitoring is based on data gathered externally by sensors, from structured and unstructured data sources. Data and information providers include researchers, non-researchers, companies, universities, students and communities.
2. *High-performance computing layer.* High-performance computing layer includes the grid computing cluster, GPU-based computing cluster, environmental modelling subsystem.
3. *Storage layer.* Storage layer is intended for storing and managing high volumes of raw and aggregated data.



4. *Presentation/service layer*. The presentation/service layer of monitoring system architecture is designed as a set of extendable services. Services are flexible and configurable for various data sources (sensors, structured and unstructured data). Services can be multimodal having a capability to work in automatic, semiautomatic and manual modes.

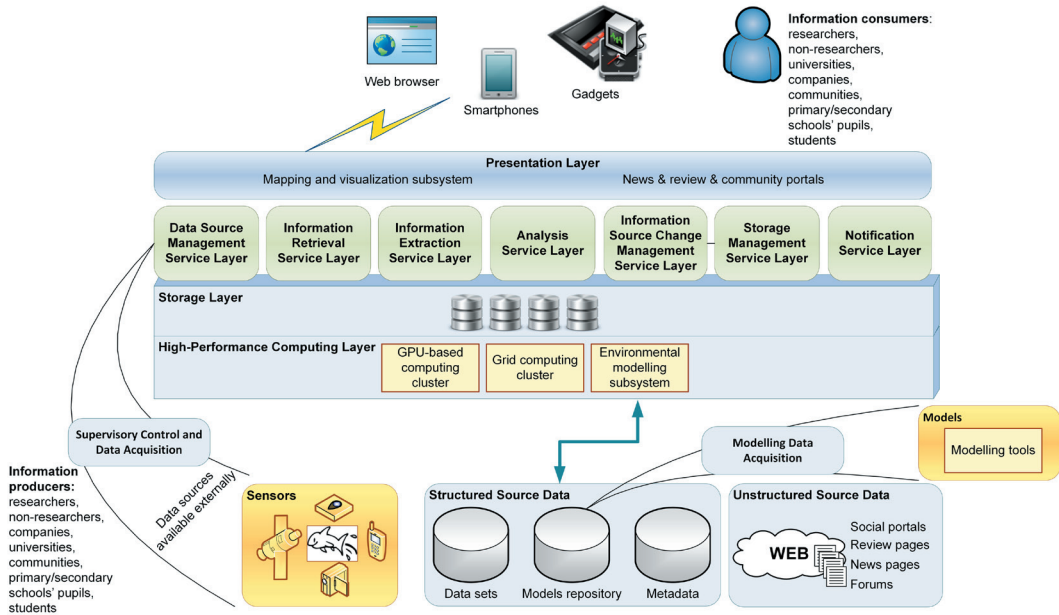


Fig. 2.3 General crowdsourcing-supported system architecture and its components

## Modelling Scenarios

The developed application has a wide range of use, mainly in the form of two scenarios. *First scenario*: citizen-led initiatives. Because of the low barrier, in terms of both cost and complexity, concerned individuals can use the platform to study noise pollution in their neighbourhood. The participants can be self-organised citizens with varying levels of organisational involvement: ranging from total strangers that happen to live in the same area; over loosely organised groups of neighbours facing a shared problem; to well-organised existing activist groups. The motivation for such initiatives can be diverse: from curiosity about one's daily environment to gathering of evidence on concrete local issues. These can be long-term issues (such as the problems faced by people living close to airports, highways, factories or nightclubs); short-term ones (such as roadwork or nearby construction sites); or accidental annoyances (such as manifestations).

*Second scenario:* authority-led initiatives. Social application can be used by the authorities and public institutions – usually at the municipal or regional levels – to collect data on the behaviour of natural and technological objects in their territory. These data can be used to support decision-making and policy-making in such areas as health and urban planning, environmental protection and mobility. When used alongside an existing monitoring system a participatory sensing platform could make up for missing data, help to estimate error margins of simulation models, add semantics (e. g., identification of pollution sources), etc.

In the most effective way, a social application can be used to control rapid dissemination of information on natural disasters, major accidents, etc. The prototype of the social application, developed within the project, allows effectively implementing both of the above-mentioned scenarios by the example of Daugavpils City (Fig. 2.4).



Fig. 2.4 Crowdsourcing for flood modelling: social application prototype

The integration of remote sensing data as well as data from other information sources with social information becomes a strategic issue in the context of the monitoring of natural and technological objects. This integration allows effectively resolving three major issues concerning managing the environment-related data:

- How to access the vast amounts of data that are available in different data formats and have different spatial and temporary resolution and quality, as well as that reside in isolated silos, segregated and disconnected from each other;
- How to make the time-consuming handling and processing of all these data more efficient;
- How to make the available data, modelling and analysis results publicly available in an efficient and user-friendly way to facilitate the social interest and responsibility in the environmental monitoring and research processes.

## 2.2 Geographic Information Systems and Simulation

In recent years, new simulation technologies have come into popular use in environmental research, supported by an array of interdisciplinary advances in many scientific areas, especially in the geographical and computer sciences [20]. These models are most commonly based on *Cellular Automata* (CA) and *Multi-Agent System* (MAS) formalisms and are often applied to the simulation of geographical systems in dynamic and high-resolution contexts [21].

### 2.2.1 Geographic Information Systems

Modelling system behaviour with explicit dependency of the geographic space requires geographic information support that is usually accomplished with *Geographic Information Systems* (GISs).

Despite their potential for urban simulation, CA and MAS are limited in their geographic functionality when considered in isolation. The limitations stem from the disjunction between the tools and the understanding of the spatial dynamics of the systems they are used to simulate. The existing research on multi-agent systems (agent-centric view) and geographic information systems (resource-centric view) reveals that actual platforms do not provide truly integrative modelling and simulation of both views [22].

A relatively new alternative for the research of urban systems is *geosimulation* [23] that is based on the concept of *Geographic Automata Systems* (GASs), which tightly couples spatial data and process models within a single, integrated system. Geosimulation is concerned with automata-based methodologies for simulating discrete, dynamic, and action-oriented spatial systems, combining cellular automata and multi-agent systems in a spatial context.

### 2.2.2 Simulation Modelling

Simulation modelling in environmental studies is used at two main levels of system description [24]. There are the following types of modelling:

- Macroscopic modelling – the processing of given geographic regions in an aggregated form based on the black-box principle where each region is specified by prescribed average statistical indicators, such as the land use, status of natural and technological objects, population, transport nets and services;
- Microscopic modelling – the depiction of the modelled system in a very detailed manner and execution of simulation activities with homogeneous spatial units.

Macroscopic models represent relatively large-scale units of analysis by using spatially and statistically aggregated information, and they tend to be static and determined. The small amount of the necessary data and a small number of computational

resources make macroscopic modelling one of the most widely used approaches in spatial planning [25].

Microscopic models contain small-scale analysis units, and models of such scale are gaining ever broader application area over the past twenty years due to the rapid development of information technologies. Microscopic models have stochastic behaviour and provide a more detailed behaviour specification of the real system.

The main criteria for choosing a system modelling level and simulation model type are identified in the context of the simulation study to be performed.

### 2.2.3 Geosimulation

The geosimulation concept is introduced in [26] where applications of the modern micro-simulation tools in solving complex spatial and regional problems are considered. These tools are mainly based on an integrated use of cellular automata and agent-based models. While cellular automata are inapplicable for processing mobile objects, multi-agent systems make cells mobile (Fig. 2.5).

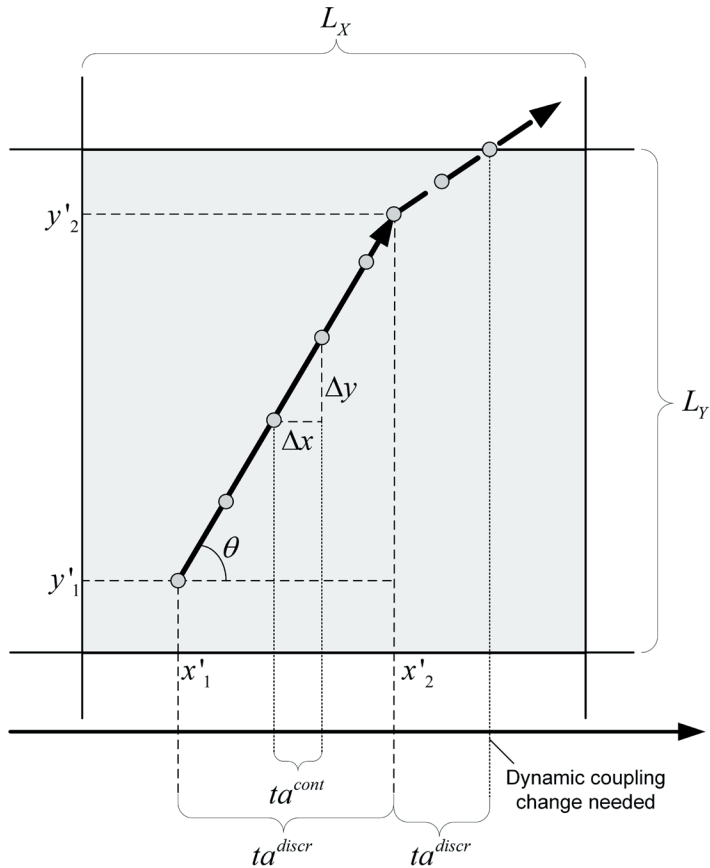


Fig. 2.5 Agent movement in a cellular space

Geosimulation models operate with objects – individuals or infrastructure entities, which are represented at spatially non-modifiable scales, for example, households, buildings or vehicles. For modelling and visualisation of object behaviour dynamics, different computer animation techniques and tools are used. Geosimulation models have four main specific features:

1. *Time representation* – geosimulation models are executed in real-time mode, where the simulation time is divided into discrete change intervals.
2. *Representation of scale* – geosimulation systems can provide a very detailed spatial scale of a simulation process.
3. *Entity-based simulation* that provides process simulation at an atomic level, where each simulation object has its specific attributes and behaviour.
4. *Interaction* that allows extending the interaction between a localised form of model entities, or vice versa – in a more general way.

## 2.3 Automation, Intellectualisation, and Reconfiguration in Natural and Technological Object Monitoring and Control Systems

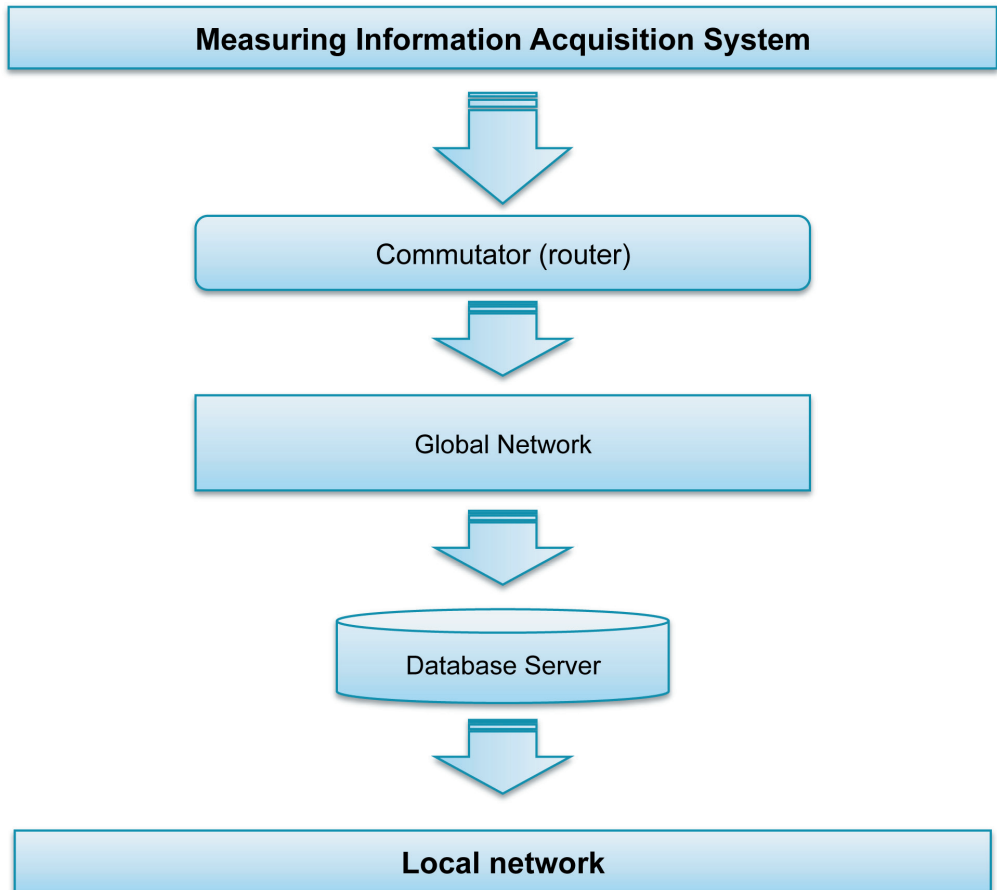
### 2.3.1 Modern Theories of NTO MCS Automation, Intellectualisation, and Reconfiguration

Modern monitoring and control systems of natural and technological objects are widespread in practice. The typical technical and organisational structure and technology of these monitoring systems are presented in Figs. 2.6–2.7.

Many natural and technological objects in practice are remotely controlled. Operators and decision-makers (DMP) usually receive information about the current state of the object in the form of telemetry (see Fig. 2.7) [27–33]. Complication of modern technical systems resulted in expansion of sets of their parameters to be measured and controlled. A number of such parameters can exceed hundreds or thousands for various types of technical systems that makes interpretation of their states very difficult.

The problem of real-time monitoring of NTO states is the most important problem in emergency situations when the NTO state differs from a predicted one as it is caused by different external and internal factors. Thus, to receive the desired level of safety, control quality and responsiveness of the control system, it is necessary to develop real-time procedures for interpretation of its state in different modes of NTO operations, including ones in emergency situations. Moreover, the NTO state monitoring is not usually completely automated. Operators receive semantic information about particular elements of NTOs rather than integrated information on their states.

To estimate the overall NTO state the operators should be able to analyse various context conditions on interactions between NTO elements and subsystems. There are no universal methods and technologies for solution of the above-mentioned problems. Existing software systems for gathering, processing and analysing telemetry data depend on characteristics of a particular control object and are not adaptable to undesired alteration of the object structure.



**Fig. 2.6** Typical technical and organisational structure

Nowadays, existing methods and tools for construction of monitoring algorithms and systems are very specific and can be used in narrow application domains. The problems of monitoring of natural and technological objects are investigated thoroughly enough in the world. However, semantic interpretation of the object integral states remains the prerogative of operators. On the other hand, significant scientific results have been received in the areas of complex object automation, intellectualisation of monitoring and control processes [31], [33–35].

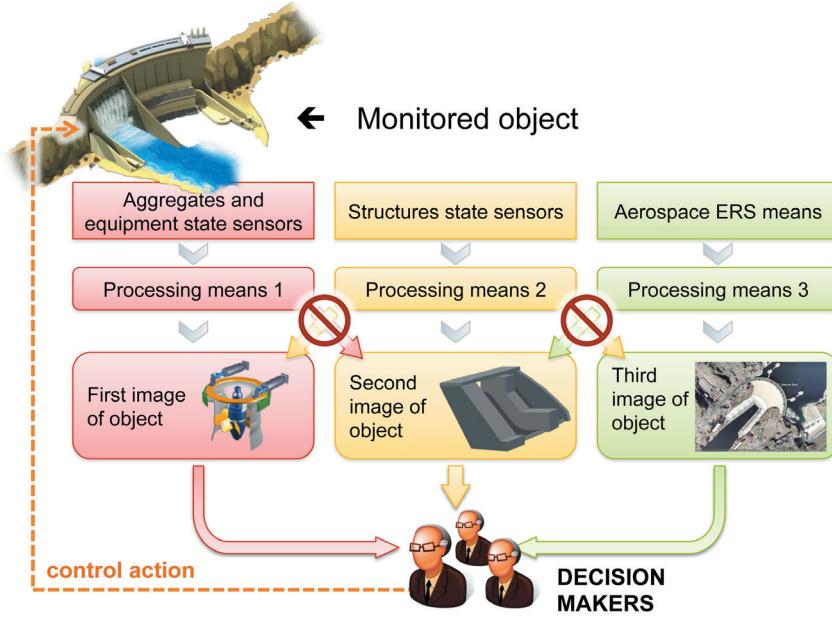


Fig. 2.7 Typical technology operation

Traditionally, NTO MCSs are investigated using analytical and simulation inter-related models. An example of multiple model coordination involving analytical and simulation models is shown in Table 2.1, where different types of the above-mentioned procedures are defined. The following notations are used: AOM (analytical optimisation model); AN [analysis (automatic or decision-maker-assisted) of received results]; C (correction of obtained solutions);  $\Delta^{(a)}$ ,  $\Delta^{(u)}$  are sets (subsets) of feasible alternatives, analytically ( $\Delta^{(a)}$ ) or algorithmically ( $\Delta^{(u)}$ ) described;  $f_0^{(a)}$ ,  $f_0^{(u)}$  are general effectiveness measures estimated by a multi-objective problem solving analytically ( $f_0^{(a)}$ ) or algorithmically ( $f_0^{(u)}$ ).

The coordination schemes for models and effectiveness measures can differ in:

- Methods of solution generation in the tasks;
- Rules for constraint (analytical, algorithmic) verification;
- Mechanisms of interactive elimination of feasible alternatives.

As mentioned above, new intelligent information technologies (IITs) extend the conventional analytical and simulation modelling of NTO [27], [36], [37]. IITs use data-driven non-algorithmic computing with intrinsic parallelism and non-determinism.

IITs include [31], [34]: technologies of knowledge-based and expert systems; fuzzy-logic technologies; technologies of artificial neural networks; case-based reasoning (CBR technologies); technologies of natural language systems and ontology; technologies of content-addressable memory; technologies of cognitive mapping and operational coding; technologies of evolutionary modelling.



Table 2.1

## Coordination Schemes for Analytical &amp; Simulation Models and Procedures

Models of CTS SDC Procedures of CTS SDC task solving	$f_0^{(a)} \rightarrow \text{extr}_{\Delta^{(a)}}$	$f_0^{(a)} \rightarrow \text{extr}_{\Delta^{(u)}}$	$f_0^{(a)} \rightarrow \text{extr}_{\Delta^{(a)} \cap \Delta^{(u)}}$	$f_0^{(u)} \rightarrow \text{extr}_{\Delta^{(a)}}$	$f_0^{(u)} \rightarrow \text{extr}_{\Delta^{(u)}}$	$f_0^{(u)} \rightarrow \text{extr}_{\Delta^{(a)} \cap \Delta^{(u)}}$
$\text{AOM} \rightarrow \text{AN} \rightarrow \text{C}$	+					
$\text{SOM} \rightarrow \text{AN} \rightarrow \text{C}$				+	+	+
$\text{AOM} \rightarrow \text{SOM} \rightarrow \text{AN} \rightarrow \text{C}$		+	+			
$(\text{AOM} \subset \text{SOM}) \rightarrow \text{AN} \rightarrow \text{C}$			+			
$(\text{SOM} \subset \text{AOM}) \rightarrow \text{AN} \rightarrow \text{C}$			+		+	+
$\left( \begin{array}{c} \text{AOM}_1 \\ \cup \\ \text{SOM} \\ \cup \\ \text{AOM}_2 \end{array} \right) \rightarrow \text{AN} \rightarrow \text{C}$				+	+	+

SDC – Structure Dynamics Control

An application of IITs to the monitoring and control of NTOs induces three lines of investigations [38]:

- Development of modelling, algorithmic, and informational tools for knowledge representation and processing;
- Development of knowledge representation models in the interests of new intelligent information technologies;
- Construction of new applications accumulating results of two previous items.

A recent classification of knowledge representation models is shown in Fig. 2.8. It is quite reasonable to arrange the models in three groups, namely, declarative, procedural, and special (combined) ones (see Fig. 2.9).

Semantic networks, frames and production systems constitute the basis of generic knowledge representation tools. A rapid progress of new constructions, such as multi-agent asynchronous decentralised systems and underdetermined models, can be currently detected.

These constructions are efficient for both computational and logical problems and gradually replace production languages.

There are the following tendencies under the influence of new knowledge representation models upon the IIT.



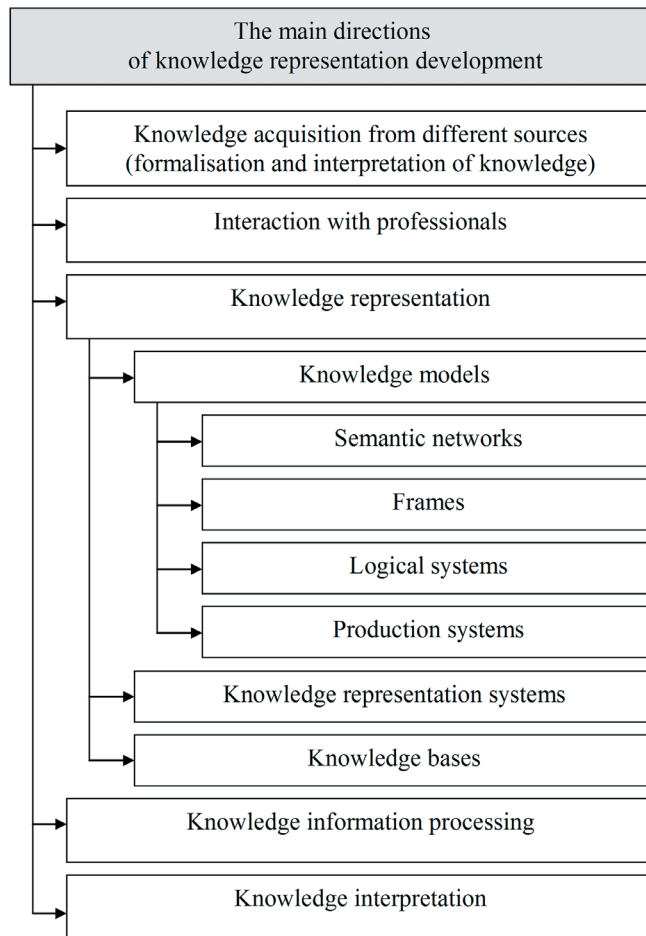


Fig. 2.8 Classification of knowledge representation models

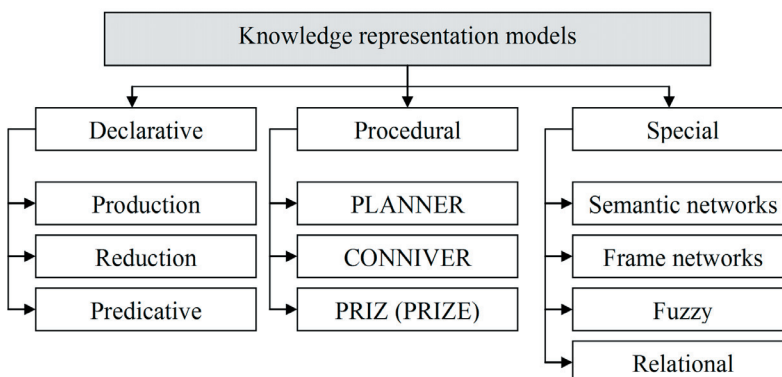


Fig. 2.9 Groups of knowledge representation models

1. A transition from classical calculations to a decentralised asynchronous parallel data-driven computational process.
2. Active object technologies. These technologies extend the object-oriented programming to a development framework for the construction of autonomous interacting active objects.
3. The priority of models rather than of algorithms. Some predictions foretell that in 10–15 years algorithms will go the way of assemblers and object coding.
4. Parallelism. The complexity of imperative programme multi-sequencing up to now reduces the development of multi-processor architectures. Within the IIT, the parallelism is not a problem but a natural feature.
5. Complexity management. The problem of complexity has various applications and aspects, such as structural complexity, functional complexity, complexity in decision-making, etc. To solve this problem, a new class of control and management systems has to be developed. The so-called neo-cybernetic systems can provide the following features: proactive controls; self-actualisation, self-reconfiguration, self-perfection, self-optimisation, self-treatment, and self-preservation abilities; as well as public behaviour; kindness; honesty [31], [34], [39], [40].

The above-mentioned tendencies confirm the significance of new knowledge representation models. Possible ways of inter-model integration for intelligent information technologies are summarised in Table 2.2 (see [31]).

The results of the investigations have shown that NTO MCS description should be based on a multiple model approach. Integrated modelling involves a poly-model multi-criteria description and analysis of the data domain. Various internal and external uncertainty factors are taken into account. Heterogeneous models, such as simulation and analytical models, logical-and-algebraic models, logical-and-linguistic models, are involved.

The main problem of the analysis and synthesis of a monitoring and control system for natural and technological objects is the effectiveness and efficiency of decision-making processes. Thus, we propose the generalised inter-model coordination scheme via choice structures with multiple preference relations [31]. These choice structures allow combining analytical, simulation and knowledge-based approaches to modelling, monitoring and control in the power grids:

$$\left\{ Q^{(\xi)}(s, (\Omega, F, \lambda_\mu), \{\Delta_\rho^{(\xi)}\}_{\rho \in \Xi_2}, \{\Delta_\eta^{0(\xi)}\}_{\eta \in \Xi_3}, \{r_{i_1}^{\alpha(\xi)}(\omega)\}_{i_1 \in \Gamma}, \{r_{i_2}^{\beta(\xi)}(\omega)\}_{i_2 \in \Gamma_1}, \right. \\ \left. \{W_e\}_{e \in \Phi_1}, \{W_k\}_{k \in \Phi_2}, \{F^{k(\xi)}(\omega)\}_{k \in \Gamma_2} \right\}_{\xi \in \Xi_1}, \quad (2.1)$$

where each mathematical structure  $\left\{ Q^{(\xi)}(s, (\Omega, F, \lambda_\mu)) \right\}_{\xi \in \Xi_1}$  defines a class of choice models (mathematical, logic-and-algebraic, deterministic or uncertain, etc.);  $\Omega$  is a space of events (a set of uncertainty);  $F$  is a sigma-algebra over the space  $\Omega$ ;  $\lambda_\mu$  is a

measure over  $(\Omega, F)$ ;  $\{\Delta_p^{(\xi)}\}_{p \in \Xi_2}$  is a collection of the basic sets of alternatives, and each basic set corresponds to some mathematical structure  $\{Q^{(\xi)}(s, (\Omega, F, \lambda_\mu))\}_{\xi \in \Xi_1}$ ;  $\{\Delta_\eta^{0(\xi)}\}_{\eta \in \Xi_3}$  is a set of auxiliary alternatives in coordination choice tasks;  $\{r_{i_1}^{\alpha(\xi)}(\omega)\}_{i_1 \in \Gamma}$  is a set of preference relations for selection of the best alternative via structures  $\{Q^{(\xi)}\}_{\xi \in \Xi_1}$ ;  $\{r_{i_2}^{\beta(\xi)}(\omega)\}_{i_2 \in \Gamma_1}$  is a set of the relations that define constraints to be satisfied when an alternative is selected;  $\{W_e\}_{e \in \Phi_1}, \{W_k\}_{k \in \Phi_2}$  are constructions formed of basic sets via Cartesian products and generation of subsets; the first construction corresponds to the input scale of the choice and the second one to the output scale;  $\{F^{k(\xi)}(\omega)\}_{k \in \Gamma_2}$  is a set of rules for construction of choice functions and preference relations.

Table 2.2

### Hybrid Model Systems

The method of computational intelligence and its applications	Combination		
	two methods	three methods	four methods
Fuzzy-deduction systems. Fzelips 6.04 Matlab	Fuzzy neural networks	Fuzzy probabilistic neural networks	Fuzzy probabilistic neural networks with a genetic algorithm (*)
Neural networks. Neurosolution 3.0	Fuzzy-and-probabilistic deduction systems Guru	Probabilistic neural networks with a genetic algorithm (*)	—
Probabilistic reasoning. Expert system Prospector	Fuzzy-deduction system with a genetic algorithm	Fuzzy neural networks with a genetic algorithm. Fungen 1.2	—
Genetic algorithms. Professional Version 1.2	Probabilistic neural networks Trajan 2.1 Matlab	Fuzzy-and-probabilistic deduction systems with a genetic algorithm (*)	—
NeuroGenetic Optimiser	Neural networks with a genetic algorithm	—	—
	Probabilistic deduction systems with a genetic algorithm	—	—

(\*) A hybrid model is not constructed or described

The proposed coordination scheme for multiple models needs detailed elaboration of main classes of dynamic models such as system dynamics, Petri nets, and operation dynamic models.

Dynamically reconfigurable graphs that allow directly modelling systems that change their structure dynamically provide a common scheme for integration of the

above-mentioned models. The general structure of an alternative reconfigurable graph is described in Chapter 1. Let us consider a simplified example of a discrete dynamic system (DDS) used for interpretation of a Petri net based on the dynamic graph.

Let us denote the state of the system by a vector  $\mathbf{x}[l] = \|x_1[l], x_2[l], \dots, x_n[l]\|^T$ ,  $l = 1, \dots, N$ , where  $l$  is a number of steps (or time points);  $x_i[l]$  is a number of markers in position  $p_i$ . The components of a control vector represent transitions in a Petri net. The control  $u_j[l] \in \{0, 1\}$  is assigned to transition  $t_j$  and equal to 1 if transition  $t_j$  is performed at step  $l$  and 0 otherwise.

We describe the dynamic state by the following recurrence equation:

$$x_i[l] = x_i[l-1] + \sum_{\beta \in \Gamma_i^-} k_\beta u_\beta[l] - \sum_{\alpha \in \Gamma_i^+} k_\alpha u_\alpha[l], \quad (2.2)$$

where  $k_\alpha, k_\beta$  are repetition factors of arcs connected to transitions  $t_\alpha$  and  $t_\beta$  in position  $p_i$ ;  $\Gamma_i^- (\Gamma_i^+)$  is a set of subscripts of the input (output) transitions in the position  $p_i$ .

The structure of the Petri net and rules for transitions to be activated are defined by the following constraints:

$$u_\alpha[l] \sum_{i \in I_\alpha} \prod_{\xi=k_i}^{s_i} (\xi - x_i[l-1]) = 0, \quad (2.3)$$

$$\sum_{\alpha \in \Gamma_i^+} k_\alpha u_\alpha[l] \leq x_i[l-1], \quad (2.4)$$

$$u_\alpha[l] \sum_{v \in J_\alpha} x_v[l-1] = 0, \quad (2.5)$$

where the number  $s_i$  is the maximal valid number of markers for the position  $p_i$ ;  $I_\alpha (J_\alpha)$  is a set of subscripts of input positions with inhibitory arcs for transition  $t_\alpha$ .

The constraints (2.3)–(2.5) must be satisfied under the initial state  $c$ , final state  $x(N)$

and the performance index  $F = \sum_{l=1}^N g_l(\mathbf{x}[l-1], \mathbf{u}[l])$ , where  $g_l(\cdot, \cdot)$  are given functions.

The suggested model allows coordinating heterogeneous decision-making models, such as computational models, for the control of natural and technological objects; knowledge-based models for MCS personnel support and semantic models for a system man-machine interface. We propose the model-based approach to the control system reconfiguration.

Typical technology of MCS reconfiguration under the condition of a single-resource failure includes the following main tasks:

1. Fixing and analysing the time and place of a resource failure, interruption of the task that used the defective resource, passing the task to another resource with or without retention of intermediate results;

2. Removal of the defective resources from the MCS configuration, making an attempt to use the reserve resource of the same type or another type with similar functionality;
3. Removal of connections with the faulty resource, prohibition on its use, as for the faulty resource itself making an attempt of its recovery.

If a task of a high priority uses the faulty resource, it can conflict with the tasks of the resource it is passed to, so it can be needed to pre-empt or to abort tasks of lower priority according to the service procedure.

The described technology is usually implemented in modern control systems at a micro-level, which is the level of system elements and blocks. Special hardware and software modules are used. This reconfiguration is sometimes called blind reconfiguration as far as the following operations are not fulfilled:

- Accounting and analysis of tasks, their characteristics, and functions;
- Analysis and estimation of the current state of the system as a whole;
- Real-time calculation, estimation and analysis of system abilities for reasonable reallocation of system functions among its elements and subsystems.

In a real situation, a single-resource failure can cause failures of some other resources or reduce their efficiency. Therefore, substitution of the faulty resource may require completely new efficient configurations of the system.

The following intermediate conclusions can be considered: 1) besides failure compensation, reconfiguration can be used to improve the operating efficiency of modern MCS; 2) to implement the proposed model it is necessary to construct such formal tools that can integrate processes of the MCS reconfiguration and the processes in NTOs at different phases of a system life cycle.

The main phases and steps of a programme construction procedure for optimal structure dynamics reconfiguration of NTO MCS are proposed in [31], [41].

*In the first phase*, feasible multi-structural macro-states are generated. The structural and functional synthesis of a new monitoring and control system is performed taking into account actual and forecasted situations.

The proposed algorithm of the structure-functional synthesis includes the following main steps.

**Step 1.1.** Collection and analysis of input data; identifying suitable models for structural and functional synthesis of a new monitoring and control system.

**Step 1.2.** Estimation of time and other resources required.

**Step 1.3.** Construction and approximation of the attainability set that describes different multi-structural macro-states of the system.

**Step 1.4.** The orthogonal projection of a set of macro-state requirements onto the attainability set.

**Step 1.5.** Interpretation of output results and their transformation into suitable formats for future use (e. g., construction of adaptive programmes for system development).

*In the second phase*, a single multi-structural macro-state is selected; adaptive programmes for MCS transition to the selected macro-state are constructed. These programmes should also specify the stable operation of the system in the intermediate multi-structural macro-states. The programme construction is formulated as a multi-level multi-stage optimisation problem. The general algorithm of problem solving includes the following steps.

**Step 2.1.** Collection and analysis of input data in an interactive mode; the structural and parametric adaptation of models, algorithms and special simulation tools (see Chapter 1) to the former and current state of the object, environment and control subsystems of NTO MCS. For missed data, simulation experiments are performed or expert knowledge is used.

**Step 2.2.** Planning of comprehensive modelling for adaptive control of NTOs and MCS development (selection of methods, models and algorithms for particular problems, estimation of time required).

**Step 2.3.** Generating feasible variants of NTO MCS operations in initial, intermediate and desired macro-states; as well as a preliminary structure-functional analysis of the modelling results is performed.

**Step 2.4.** Automatic putting into operation feasible variants of NTO MCS; analysis of constraints; final selection of an aggregation level for NTO MCS structure dynamics control models and computational experiments aimed at developing NTO MCS structure dynamics control programmes.

**Step 2.5.** Search for optimal structure dynamics control programmes that enable transition from a given multi-structural macro-state to a desired one and stable system operation in the intermediate macro-states.

**Step 2.6.** Simulation of programme execution under perturbation effects for different variants of compensation control inputs received via methods and algorithms of real-time control.

**Step 2.7.** Structural and parametric adaptation of the programme to the forecasted one through simulation states of the control object, control system and environment. Structural redundancy of the control system provides its robustness against perturbation impacts. After reiterative computational experiments, the stability of constructed programme is estimated.

**Step 2.8.** Interpretation and expert evaluation of control system structure dynamics programmes and comprehensive adaptive planning results are performed.

Finally, we receive an optimal control vector as well as the most preferable multi-structural macro-state of the control system that provides its reliable operations in the current (or forecasted) situation.

### 2.3.2 Implementation of Proposed Automation, Intellectualisation Procedures

Analysis of commercial automation software for monitoring of complex technological processes shows that the existing software has a narrow application scope specified by controlled objects and a limited capacity to adapt to environmental disturbances. This is why this software has contiguous functionality and differs in organisational methods of computational processes and the operational environment. Particularly, the following practical implementations of monitoring applicable software could be mentioned [28–31], [33], [35]:

1. Real-time dynamic expert systems, e. g., G2 (Gensym, USA), RT Works (Talarian, USA), COMDALE/C (Comdale Techn., Canada), COGSYS (SC, USA) and ILOG Rules (ILOG, France) that are widely used.
2. Constrained programming software packages and intelligent multi-agent systems, e. g., integrated software package SPRUT (OCTORUS) and the UniCalc solver demonstrate their advantages.
3. Data fusion and control systems like SCADA-systems (Supervisory Control and Data Acquisition); the most powerful software packages are Genesis software for structural analysis and optimisation, the SoftLogic package ISaGRAF and an integrated development environment TraceMode.

The results of investigations show that there are a large number of publications in the area of measuring information processing and analysis. On the other hand, an automated design of monitoring software as well as measuring information parallel processing and analysis in computing environments with changing structures are not sufficiently presented in literature [27–32], [37]. Moreover, the impacts of different types and structures of information to be processed on the composition and structure of monitoring software are not investigated enough. The above-mentioned aspects become even more important taking into account that software implementation for state monitoring of complex technological processes is based upon solutions of structural, functional and organisational problems, which deal with programme synthesis. In practice, successful software implementation depends on intuition and experience of software developers and requires time-consuming, labour-intensive experiments. Moreover, the existing methodology and software do not meet certain requirements in embedded software development for geographically distributed real-time complex technological systems with variable structures [31].



Transition from automated processing of measuring information to a computer-aided analysis involves semantic aspects of data representation. Thus, information about control objects should be interpreted as a set of interrelated parameters describing an object technical state rather than a simple collection of measurements. This allows concluding that metric space concepts typically used in simple monitoring problems are weak and not suitable for our purposes; hence, more general constructions should be introduced. It has been proved that the object parameters can be described by a system of open sets that form a base for their topological structure. Thus, a system of neighbourhoods meeting the axioms of topological spaces has been established for each element. The notion of a technical state is defined as an abstract collection of data, including information about the object attributes and computations in the monitoring process. This allows optimising computations in order to receive real time monitoring results.

As mentioned in Chapter 1, the following statements have been proved: a set of technical state parameters constructed through the proposed model of knowledge representation is a lattice or a lattice ordered set; if a set of technical states has elements that define the initial data and final results, then a complete lattice can be formed via the construction of additive and multiplicative lattices; necessary and sufficient conditions for the existence of a base for a topology are obtained for a set of technical parameters. The constructed topology is used for comprehensive description of possible technical states and construction of a computational scheme [34], [42].

The methodology and problem formalisation techniques for the synthesis and intellectualisation of NTO monitoring and control processes under dynamic conditions via multiple model sets as well as a multi-criteria approach to problem solving are shown in Figs. 2.10–2.12.

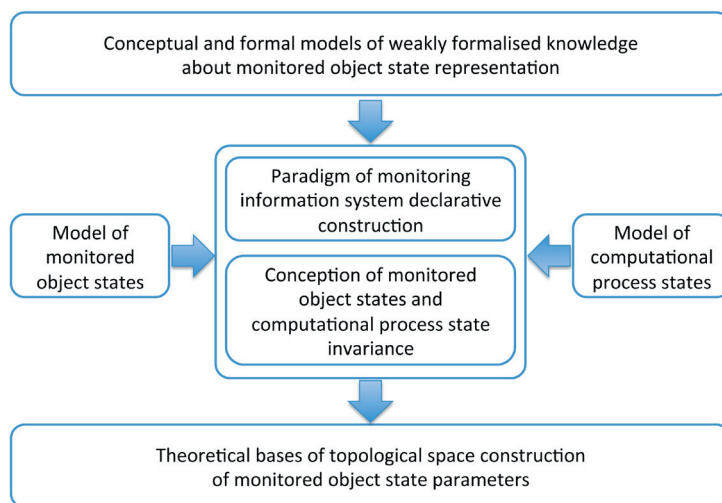


Fig. 2.10 Theoretical foundations of intelligent information technology

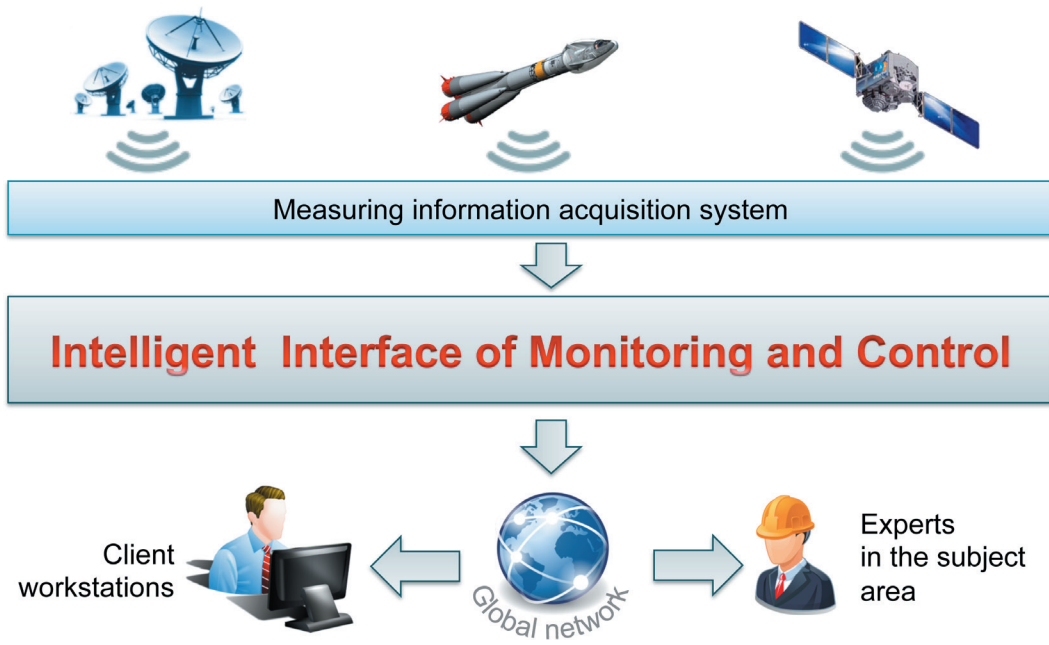


Fig. 2.11 Intelligent monitoring interface structure

The obtained results provide:

- Formal description of different types of controlled states (the assessed situation) using different mathematical apparatus for various functional objects; the intelligent interface for monitoring and control based on a multi-model formalisation approach that allows describing various actions and processes with regard to controlled objects (see Figs. 2.12, 2.13);
- Models and algorithms for automated synthesis of optimal programmes for target setting and monitoring in a given control session under specific implementation conditions;
- Models and algorithms for state estimation using *measuring information fusion* models (parallelism, data flow, weakly predictable intensity, doubtful measurements, etc.).

The pilot version of computer-aided space and ground-based monitoring system (CMS) for NTO states operates in a network of IBM/PC compatible computers. It uses a specific operational environment, real-time database management system, multi-window interface and programming language C/C++. The structure of the operational environment is shown in Fig. 2.13. The CMS prototype belongs to the MMI/CACSD/SCADA/MAIS class (man-machine interface/computer-aided control system design/supervisory control and data acquisition/multi-agent intellectual system).

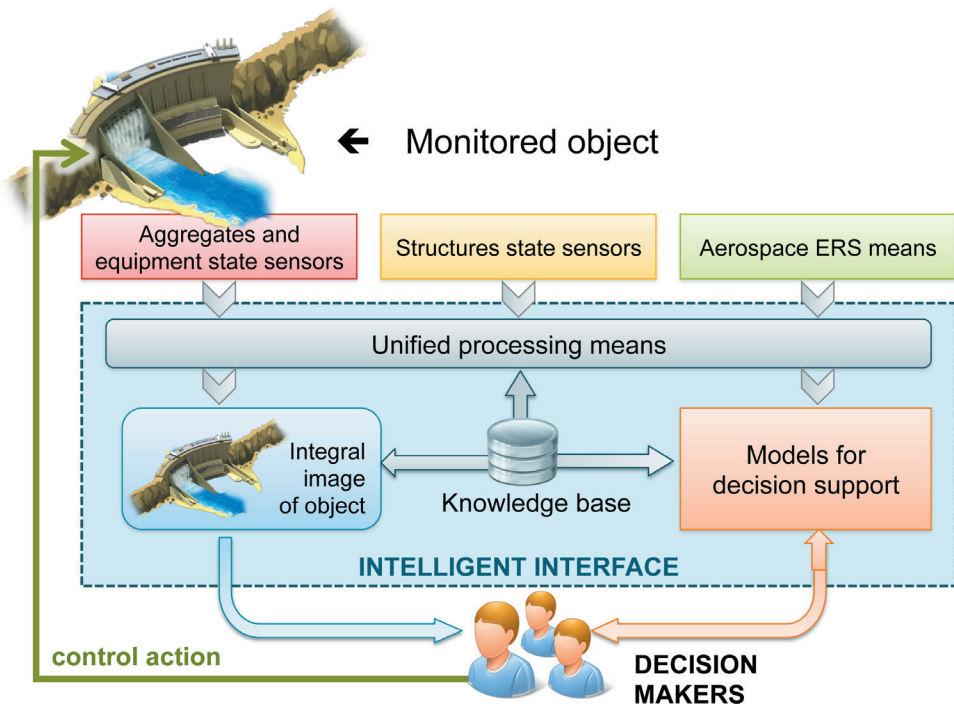


Fig. 2.12 Intelligent integrated monitoring system

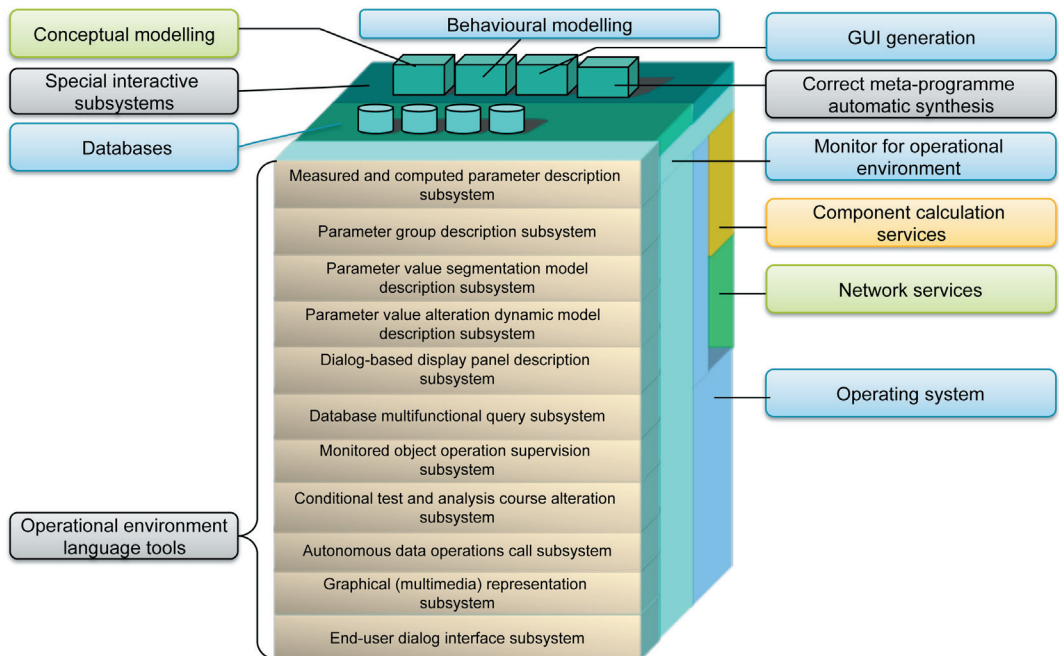


Fig. 2.13 Structure of operational environment

Figures 2.14 and 2.15 illustrate the main elements of suggested intelligent information technology and its implementation phases. IIT reduces the cost of the complex process underlying the development of a system for monitoring and control of complex natural and technological object states.

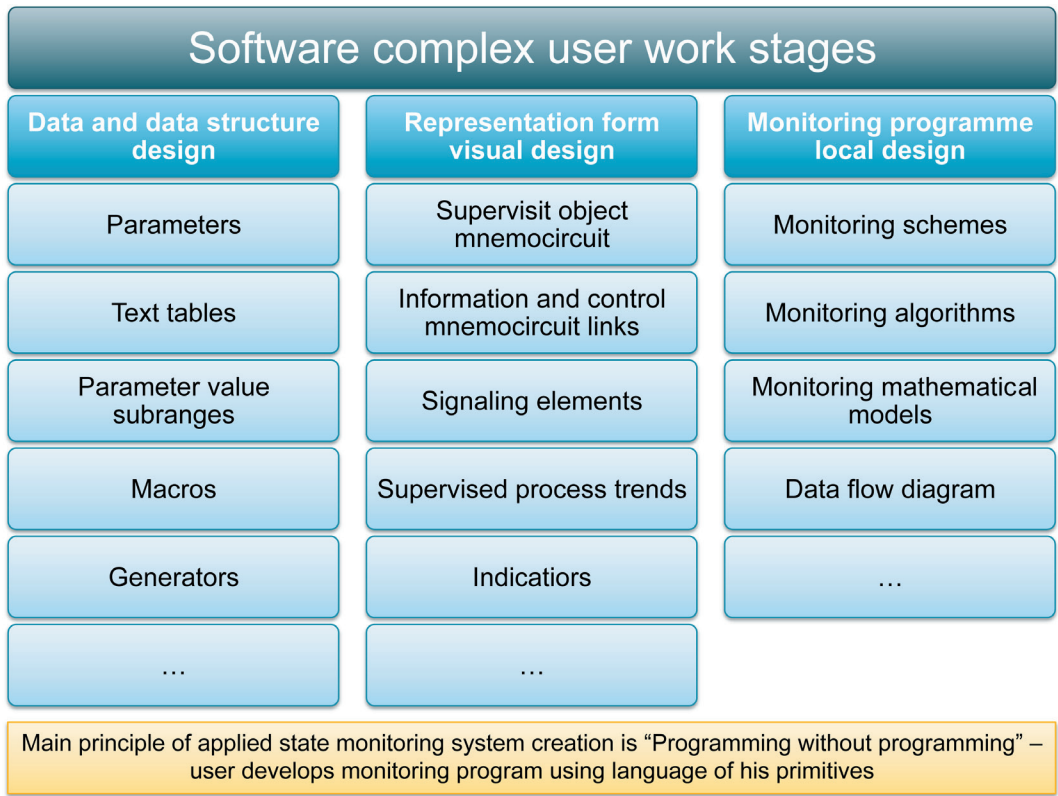


Fig. 2.14 Main elements of intelligent information technology

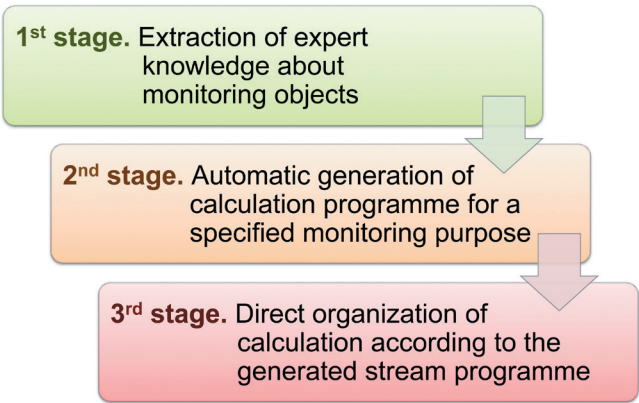


Fig. 2.15 Main stages of intelligent information technology implementation

The main principle of the proposed IIT is automatic programming (or “programming without programming”). Particularly, this intelligent information technology allows controlling the states of a complex technological process in real time taking into account a large number of measured parameters and reconfiguration ability of controlled object structures. The IIT advances an automation level for control of complex technological processes, extends control possibilities for objects at degradation of their structures, increases reliability and efficiency of control processes, enables early detection of various technical faults as well as provides timely prediction of catastrophes by making the right decision and taking appropriate preventive measures. Moreover, the proposed information technology can substitute most of operating software in the application when used for the design of embedded and scalable software. Implementation of specialised software based on the suggested intelligent information technology looks prospective for many emergency applications.

Figure 2.16 shows an example of an intelligent monitoring interface of the developed software prototype. The proposed models, methods and software for monitoring and automation, intellectualisation and modelling allow switching from a heuristic analysis of the NTO telemetry to a sequence of well-grounded stages of the monitoring programme construction and adoption, from unique skills to unified technologies of software design. These models, methods and software are based on a conclusion that a functional description of monitoring process is much less complicated than a detailed examination of software implementation.

- Text tables
- Sub ranges parameters values
- Parameters
- Groups of parameters
- Macros
- Generators

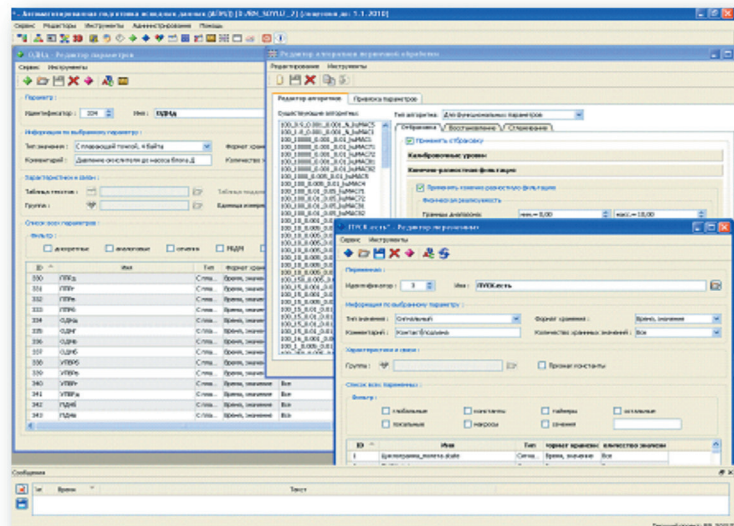


Fig. 2.16 IIT interface screenshot



The consecutive specification of software functions is the ground and technology for construction of new monitoring and control systems. It will enable essential reduction of terms and expenses for creating or modifying monitoring systems; possibility of carrying out monitoring and real-time management with a considerable number of measured parameters; decision support for prevention of disasters or accidents; significant reduction in a number of errors when creating software for monitoring and management systems; as well as integration of existing specialised monitoring and management systems in a unified information platform.

## References

1. Merkuryev, Y., Sokolov, B., Merkuryeva, G. (2012). Integrated Intelligent Platform for Monitoring the Cross-Border Natural-Technological Systems. In: Bruzzzone, A. G., Gronalt, M., Merkuryev, Y., Piera, M. A. (eds.) *Proc. 14<sup>th</sup> Int. Conf. Harb. Marit. Multimodal Logist. M&S, HMS 2012*. 19–21 September 2012, Vienna, Austria. Wayne Talley, Rende (CS), Italy, pp. 7–10.
2. Romanovs, A., Sokolov, B., Lektuers, A., Petuhova, J. (2013). Crowdsourcing Supported Modelling and Analysis Infrastructure for Intelligent Monitoring of Natural-Technological Objects. In: *Proceedings of the 25<sup>th</sup> European Modeling & Simulation Symposium EMSS2013*, Greece, Athens, 25–27 September 2013. Rende: DIME Università di Genova, pp. 389–394.
3. Bradley, A. J., McDonald, M. P. (2011). *The Social Organization: How to Use Social Media to Tap the Collective Genius of Your Customers and Employees*. USA: Harvard Business Review Press, 272 p.
4. Howe, J. (2006). The Rise of Crowdsourcing. *Wired*, 14(6), pp. 1–4.
5. Dawson, R. (2010). Crowdsourcing Landscape – Discussion. Available at: <http://crowdsourcingresults.com/competition-platforms/crowdsourcing-landscape-discussion>. Accessed: 29 April 2014.
6. Stevens, M., D'Hondt, E. (2010). Crowdsourcing of Pollution Data Using Smartphones. In: Workshop on Ubiquitous Crowdsourcing (UbiComp2010), Denmark, Copenhagen. Available at <http://www.brussense.be/Pubs/files/crowdsourcing-of-pollution-data-using-smartphones.pdf>. Accessed: 29 April 2014.
7. European Parliament and Council (EPC). (2002). Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise. Off. J. Eur. Communities, pp. 12–26.

8. United Nations Environment Programme (UNEP). (1992). Rio Declaration on Environment and Development. United Nations Conf. Environ. Development. Available at: <http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163>. Accessed: 29 April 2014.
9. PWC. (2013). Information Security Breaches Survey. Available at: <http://www.pwc.co.uk/audit-assurance/publications/2014-information-security-breaches-survey.jhtml>. Accessed: 29 April 2014.
10. Dorogovs, P., Romanovs, A. (2012). Modelling and Evaluation of IDS Capabilities for Prevention of Possible Information Security Breaches in a Web-based Application. In: *Proc. 14<sup>th</sup> Int. Conf. Harb. Marit. Multimodal Logist. M&S, HMS 2012*. Vienna, Austria, pp. 165–170.
11. Yerva, S. R., Jeung, H., Aberer, K. (2012). Cloud based Social and Sensor Data Fusion. In: *15<sup>th</sup> Int. Conf. Inf. Fusion*, pp. 2494–2501.
12. Boulos, K. N. M., Resch, B., Crowley, D. N., et al. (2011). Crowdsourcing, Citizen Sensing and Sensor Web Technologies for Public and Environmental Health Surveillance and Crisis Management: Trends, OGC Standards and Application Examples. *Int. J. Health Geogr.* 10:67. doi: 10.1186/1476-072X-10-67.
13. Fraternali, P., Castelletti, A., Soncini-Sessa, R., et al. (2012). Putting Humans in the Loop: Social Computing for Water Resources Management. *Environ Model Softw* 37:68–77. doi: 10.1016/j.envsoft.2012.03.002.
14. NASA. (2008). 2008 Report from the Earth Science Technology Office (ESTO). Advanced Information Systems Technology (AIST). Sensor Web Technology Meeting. 311 p.
15. Durrant-Whyte, H., Henderson, T. C. (2008). Multisensor Data Fusion. In: Siciliano, B., Oussama, K. (eds.) *Springer Handb. Robot.* Springer, 1611 p.
16. GOOS. (2013). The Global Ocean Observing System. Available at: <http://www.ioc-goos.org>. Accessed: 29 April 2014.
17. Marinexplore. (2012). Marinexplore: Cutting Ocean Data Processing Time Fivefold. *Mar. Technol. Report.*, pp. 30–35.
18. Fienen, M. N., Lowry, C.S. (2012). Social.Water – A Crowdsourcing Tool for Environmental Data Acquisition. *Comput. Geosci* 49:164–169. doi: 10.1016/j.cageo.2012.06.015.
19. Steels, L., Tisseli, E. (2008). Social Tagging in Community Memories. *Soc. Inf. Process.* – Pap. from 2008 AAAI Spring Symposium. AAAI Press, Menlo Park, California, USA, pp. 98–103.
20. Heppenstall, A. J., Crooks, A. T., See, L. M., Batty, M. (eds.) (2012). *Agent-based Models of Geographical Systems*. Netherlands: Springer, 760 p.
21. Ferber, J. (1999). *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*. The J. Artif. Soc. Soc. Simul. 528 p.



22. Gonçalves, A., Correira, L., Rodrigues, A. (2006). DEVS-based Simulations of GeoAgent-based Models with Decentralised Dynamic Properties. Spring. Simul. Multiconference DEVS Integr. M&S Symp.
23. Benenson, I., Torrens, P. M. (2004). *Geosimulation: Automata-based Modelling of Urban Phenomena*. London: John Wiley & Sons, 312 p.
24. Benenson, I., Kharbash, V. (2005). Geographic Automata Systems: From the Paradigm to the Urban Modelling Software. Agil. 2005, GISPlanet 2005.
25. Waddell, P., Ulfarsson, G. F. (2004). Introduction to Urban Simulation: Design and Development of Operational Models. In: Stopher, P., Button, K., Haynes, K., Hensher, D. (eds.) *Handb. Transp. Geogr. Spacial Syst.* Emerald Group Publishing, pp. 203–236.
26. Benenson, I., Torrens, P. (2004). *Geosimulation: Automata-based Modelling of Urban Phenomena*. London: John Wiley & Sons, 312 p.
27. Лаборатория информационных технологий в системном анализе и моделировании. Available at: <http://litsam.ru>. Accessed: 1 May 2014.
28. Okhtilev, M. Y. (2001). Construction of Programs for Real-time Processing and Analysis of Measuring Information. Program. Comput. Softw.
29. Okhtilev, M. Y. (2001). Specifics of Technology for Development of Special Computer-aided Systems Canalizing Information Measured in Real-time. Autom. Control Comput. Sci. 39.
30. Okhtilev, M. Y. (2000). Topological Approach to Construction of Computation Algorithms in Real-time Estimation of Complex Technical Objects. Autom Control Comput Sci 34:8–16.
31. Okhtilev, M. Y., Sokolov, B. V., Yusupov, R. M. (2006). *Intelligent Technologies of Complex Technical Objects Monitoring and Structure Dynamics Control*. Moscow: Nauka.
32. Sokolov, B. V., Okhtilev, M. Y., Zelentsov, V. A., Maslova, M. A. (2012). The Intelligent Monitoring Technology Based on Integrated Ground and Aerospace Data. In: *Proceedings of the 14<sup>th</sup> International Conference on Harbour Maritime and Multimodal Logistics M&S, HMS 2012*, September 19–21, 2012, Vienna, Austria, pp. 112–117.
33. Steinburg, A. N., Bowman, C. L., White, F. E. (1998). Revisions to the JDL Data Fusion Model. Present. Jt. NATO/IRIS Conf.
34. Maruyama, M. (1963). The Second Cybernetics. Deviation Amplifying Mutual Causal Process. *Am. Sci.*, vol. 51, pp. 164–179.
35. Norenkov, I. P. (1998). The Approaches to Designing of Automation Systems. *Information Technology*, vol. 2, pp. 2–9.
36. Casti, J. L. (1979). *Connectivity, Complexity and Catastrophe in Large-scale Systems*. New York, London: Wiley-Interscience, 203 p.

37. Ivanov, D. A., Sokolov, B. V. (2010). *Adaptive Supply Chain Mmanagement*. London: Springer, 269 p.
38. Sokolov, B., Okhtilev, M., Potryasaev, S., Merkuriev, Y. (2014). Multi-model Description of Monitoring and Control Systems of Natural and Technological Objects. *Information Technology and Management Science*, vol. 16(1), pp. 11-17. doi:10.2478/itms-2013-0001.
39. Foerster, H. (1974). *Cybernetics of Cybernetics*. Pap. Deliv. 1970 Annu. Meet. Am. Soc. Cybern.
40. Hyötyniemi, H. (2006). *Neocybernetics in Biological Systems*. Tech. Rep. 151, Helsinki University of Technology, Control Engineering Laboratory, 273 p.
41. Sokolov, B. V., Yusupov, R. M. (2002). Complex Simulation of Automated Control System of Navigation Spacecraft. *Probl Informatics Control*, pp. 103–117.
42. Okhtilev, M. Y., Sokolov, B. V., Yusupov, R. M. (2006). *Intellectual Technologies of Monitoring and Controlling the Dynamics of Complex Technical Objects*. Moscow: Nauka, 409 p.

# Chapter 3

## Integrated Distributed Information Network and Support Tools for Intelligent Space and Ground-based Monitoring

### 3.1 Integrated Distributed Network Framework and Infrastructure

The Intelligent Information Technology functionality discussed in 2.3 and its main elements provide an integrated technological framework that includes: 1) integrated real-time monitoring and control based on the analysis of heterogeneous information from space and ground-based facilities; 2) unified processing environment for processing heterogeneous data from different sources and their integration; 3) distributed, real-time database embedded into the monitoring and control system for creating a common information space; 4) multi-models for the behaviour analysis of complex objects in normal and emergency situations and decision support; 6) intelligent interface to object monitoring and control; and 7) data-flow computing models for large-scale datasets executed in real-time and in territorially distributed computer networks.

The novelty of the developed technological framework is cross-functional application of combined models and methods to support decision-making in various monitoring problems, including modelling, forecasting and safety control of complex natural and technological objects. This technological framework provides the following advantages:

1. Real-time processing of a large number of diverse parameters;
2. Simultaneous processing of heterogeneous data and knowledge;
3. Measuring information from different nature information source processing and its analysis;
4. Visualisation of data processed in 2D and 3D formats;
5. Interfacing with geographic information systems and information transfer;
6. The ability to create application-oriented monitoring systems for non-professional users (non-programmers).

To implement the proposed technological framework, an integrated distributed information network, IT support tools and modelling scenarios for specific application use cases are developed. The network framework focuses on supporting a high per-

formance user-centred computational platform (Fig. 3.1). Its main hardware segments are remote sensing and monitoring computer infrastructures created at both project partners' institutions (Figs. 3.2, 3.3). For example, in the segment of RTU, 2 servers, 12 desktops, 8 laptops, and 2 tablet computers have been installed.

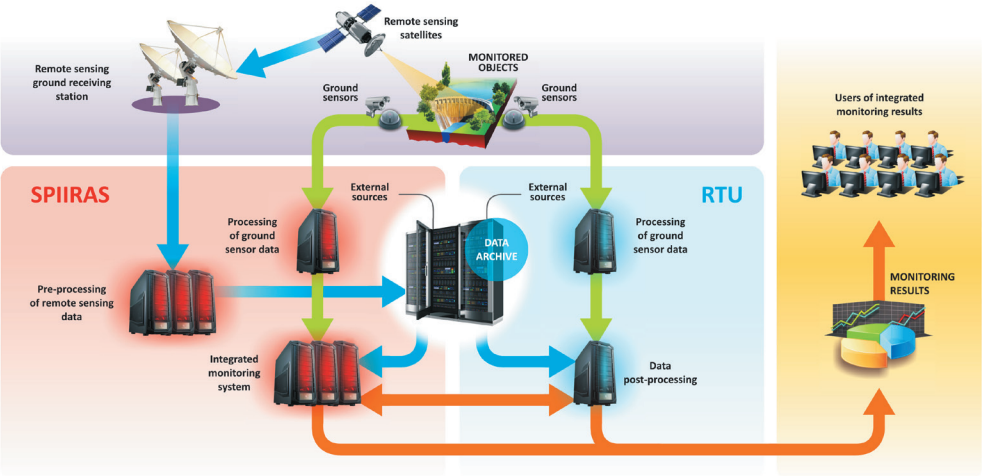


Fig. 3.1 Intelligent distribution network framework

INTEGRATED DISTRIBUTED INFORMATION NETWORK OF WORKSTATIONS

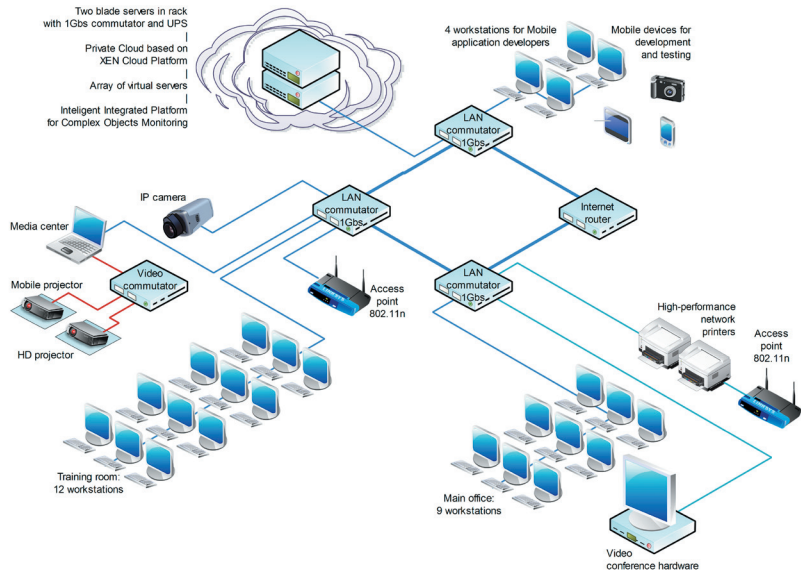


Fig. 3.2 Computer infrastructure (SPIIRAS segment)

The technological framework implements a unified approach to the integrated monitoring and control of complex systems, including natural, technological, economic and social elements, and is based on various innovative information technologies and software. The software infrastructure for remote sensing and monitoring of these systems is shown in Fig. 3.4.

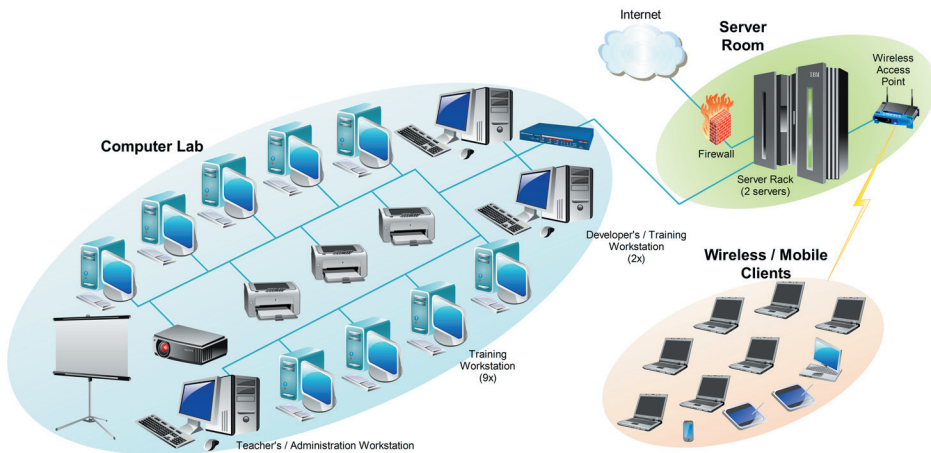


Fig. 3.3 Computer infrastructure (RTU segment)

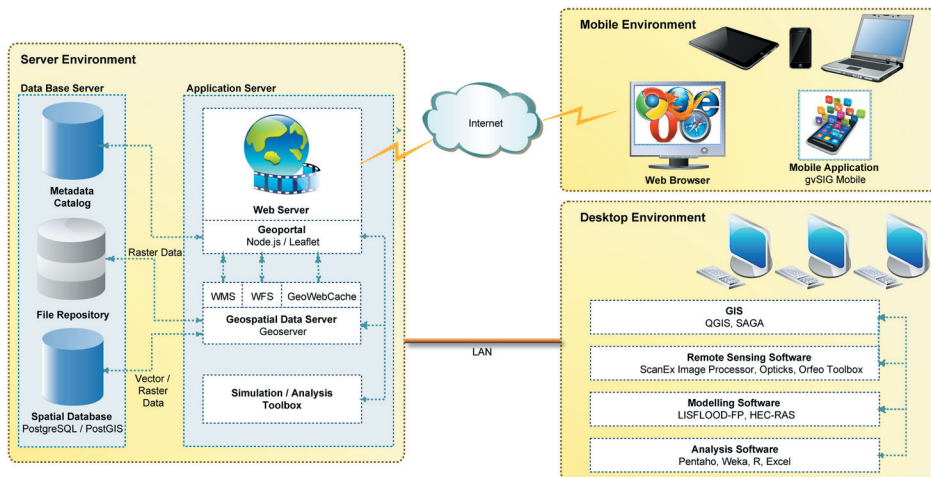


Fig. 3.4 Software infrastructure

The prototypes of support tools for information processing, process modelling, an experimental analysis of monitoring scenarios and decision-making for specific application areas are developed based on the above-mentioned computer and software infrastructures.

## 3.2 Support Tools for Intelligent Space and Ground-based Monitoring of River Floods

Flooding is one of natural disasters, which often causes significant economic losses, human and social tragedies. Therefore, flood forecasting and its effective control are always huge challenges for governments and local authorities [1]. Forecasts of river flow may be developed in the short term, over periods of a few hours or a few days, in the medium term, for several weeks, and in the long term, up to nine months [2]. An efficient flood alarm system based on a short-term flow forecasting may significantly improve public safety, mitigate social damages and reduce economic losses associated with floods.

### 3.2.1 Advanced Approach to River Flood Modelling and Monitoring

The traditional flood model-based forecasting approach based on modelling river physical processes is advanced by integrating different models and technologies for improving flood risk output prediction such as input data clustering and filtering; digital maps of a relief and river terrain; data crowdsourcing; forecasting models; different hydrological models for the timescale modelling of water flows; computer simulation for the modelling of river behaviour; visualisation tools; geographic information systems (GISs); and techniques for flooding scenario generation and comparison.

Real-time flood monitoring is based on the integration of heterogeneous data from both space and ground-based information sources (Fig. 3.5). Taking into consideration the floodplain width and the speed of flooding processes, satellite and aerospace monitoring allows regularly overlooking large areas and providing high-efficiency information on the research object. Additionally, to get a holistic view of the current situation, remote sensing is supplemented by data obtained from ground-based monitoring devices.

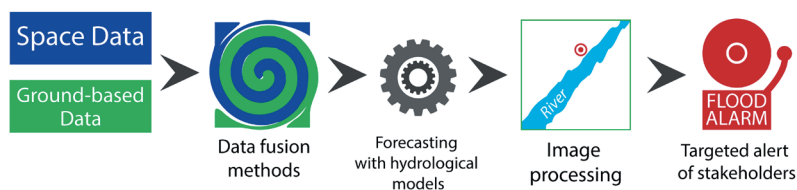


Fig. 3.5 Short-term forecasting based integration of space and ground-based data

Hydrological models are advanced by realistic physical models that are derived from topological maps and represent geo-information of the river and its neighbouring areas.



Data crowdsourcing is used for the calibration of a hydrological model based on comparison of the actual situation with the forecasted one. GIS and technology present the most powerful tools emerged in the hydrological field, which allow for the collection and analysis of environmental data as well as provide a platform for the integration of space and ground-based data for flood monitoring and modelling. Observed data support the creation of information through modelling, and the information evolves into knowledge through the visualisation and analysis of digital elevation pictures and finally supports the analysis of flooded geographic areas.

### 3.2.2 Flood Model-based Forecasting System and Support Tools

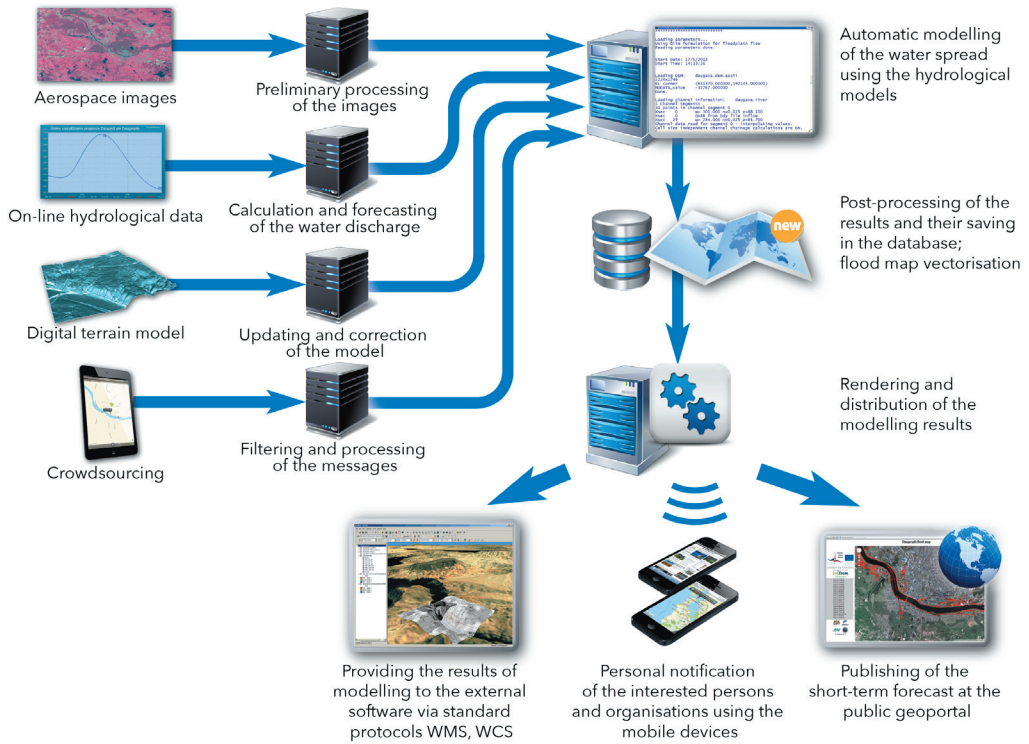
The real-time flood monitoring and forecasting system is developed within the approach described above and based on the integrated use of ground-based and aerospace data. The system allows operational forecasting of the river water levels, discharges and inundation areas, and provides prior notification of citizens on emergency situations at a geoportal and/or by using mobile devices. The system contains the following main components (Fig. 3.6):

1. ***Input Data Collection and Pre-processing*** component provides input data collection (e. g., aerospace images, on-line hydrological data from a meteorological station; a digital terrain model obtained by the airborne Lidar technology) and pre-processing (i. e., primarily image processing, information filtering and information fusion).
2. ***Modelling and Forecasting*** component allows the forecasting of water level, calculation and forecasting of the water discharge as well as automatic modelling of the water spread using hydrological models.
3. ***Post-processing and Visualisation*** component provides post-processing of modelling results, output data storage in a database, flood map vectorisation and visualisation of inundation areas.
4. ***Information Distribution*** component provides distribution of the modelling results to the external software, publishing short-term forecasts at a public geoportal, and automatic notification of local citizens and organisations (e. g., emergency rescue services, local municipalities) using a web service and mobile applications.

The proposed system operates automatically, provides flood forecasts over 48 hours ahead with hourly outlines of the potential flooded zones and objects and a water depth map, both available via standard protocols WMS, WCS. A high-resolution digital elevation model is required to provide a high accuracy of flood forecasts. Visualisation of the modelling results in 2D and 3D modes is performed. The flood forecasting results are provided as a web service on a remote basis. The modelling and forecasting results are automatically presented at a geoportal where data and information are con-



tinuously updated and available on-line for the end users. The users of the system are not required specific knowledge in modelling and simulation or programming skills.



**Fig. 3.6** Flood monitoring and forecasting system

Here, the LISFLOOD-FP [3] hydrological model that is capable of simulating dynamic flooding and floodplain inundation in a computationally efficient manner over complex topography has been built. The model takes an advantage of new sources of terrain information from remote sensing techniques. It is applicable for short-term forecasting and requires a minimum amount of input data to produce an acceptable result.

### 3.2.3 Short-term Forecasting Algorithm

A short-term flood forecasting algorithm includes the following main steps (Fig. 3.7):

1. On-line hydrological data on the river water levels are obtained from a hydrological station;
2. Observed data are processed by their smoothing with trend extraction in order to predict the river water levels in the short term;

3. A symbolic regression-based forecasting model is built, which provides water flow discharge forecasts;
4. Water flow discharge data, accompanied by the river terrain information, are processed by an adaptive hydrological model, which simulates water floating routes and, thus, provides forecasts on water covered territories in the river basin;
5. Visualisation software is used for geo-presentation of the river simulation results on water flows and inundation areas;
6. Archival data and images, satellite images of the current situation and data crowdsourcing through a geoportal are used to validate and calibrate the hydrological model.

The description of three main models, i. e., a water level forecasting model, a water discharge estimation model and the LISFLOOD-FP-based hydrological model, is provided in Chapter 4.

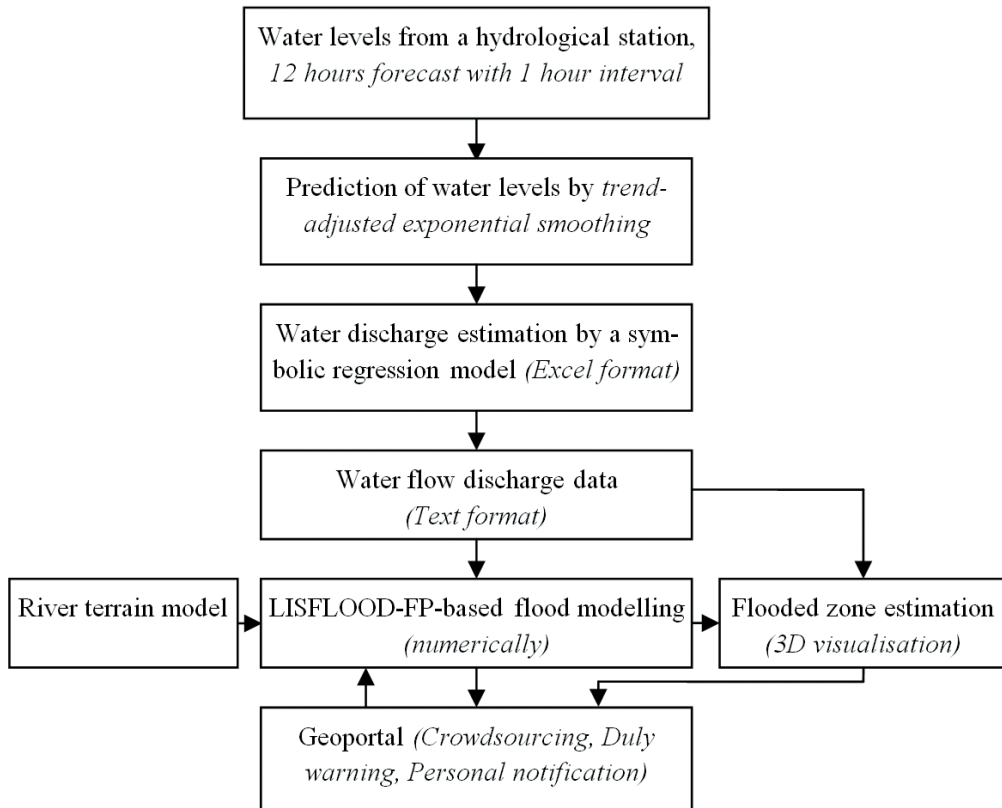


Fig. 3.7 Short-term flood forecasting algorithm

### 3.3 Support Tools for Integrated Forest Monitoring

Processing of the earth remote sensing (ERS) survey materials applied to evaluation of the conditions of the forest tracts is discussed. The importance and relevance of this application in the project are due to the fact that forests cover over the half of the territory of Latvia and adjacent regions of Russia. Two directions of thematic processing of the ERS data are discussed – updating the taxation description of the forest and evaluating the forest fire safety condition.

At present, the description of taxation of the significant part of forest tracts is outdated and requires further updating. Based on the processing of the ERS survey materials, the costs and frequency of updating the taxation description may be significantly reduced. The trustworthiness and visibility of information presented to a customer will be enhanced. In addition, controlling the forest fire safety conditions is an important task to be solved. Evaluation of the effectiveness of practical measures aimed at prevention of forest fires and their propagation is considered.

#### 3.3.1 General Approach to Evaluating the State of Forest Tracts

The evaluation of the state of forest tracts includes the sequence of operations [4–6]:

1. Regulatory document-based requirements analysis and generation of a list of controlled parameters;
2. Analysis of the forest management materials and generation of requirements to forest survey materials;
3. Analysis of historic survey materials and generation of requirements to the prospective SPG survey materials;
4. Planning and performance of survey works and test surface measurements;
5. Thematic processing of survey materials, creating thematic layers of the digital maps, and determination of numerical values for the controlled parameters.

The following initial data are required for evaluating the forest state:

- Survey materials and results of the test surface measurements;
- Forest management materials, such as plot boards and taxation description;
- Digital locality maps;
- Regulatory documents on compliance with the fire safety rules.

The following software and tools are employed to support the evaluation of forest tracts:

1. Data system with reflectance characteristics of typical landscape elements for the thematic processing of survey materials, identification and recognition of the controlled objects;
2. Software for detecting and estimating numerical values of the controlled parameters;

3. Geo-information system for presenting the results of thematic processing of survey materials and evaluating the fire safety condition of forest objects as well as simulating possible unfavourable processes;
4. Software for record generating, evaluating particular indices of the forest fire safety conditions and generalised state estimation of forest tracts.

The following data records are processed or generated by the above-mentioned software:

- A thematic layer of the digital locality map, which contains updated parameters of the taxation description;
- Thematic layers of the digital locality map, which reflect the fire safety conditions of forest tracts;
- Results of the thematic processing of survey materials;
- Numerical values of specific indices of the forest fire safety and assessment of the generalised state of the fire safety condition;
- Action plans for improvement of the fire safety condition and elimination of the detected drawbacks.

Requirements to the survey materials are given in Table 3.1.

*Table 3.1*

Requirements to Survey Materials

Task	Spectral ranges, mcm	Linear ground resolution, not below, m	Survey frequency
Updating a taxation description	0.4–0.7 0.7–1.0	0.6 2.0	Once every 5 years
Windfall control	0.4–0.7 0.7–1.0	0.6 2.0	After a hurricane
Cutting site maintenance control	0.4–0.7	0.6	Upon occurrence
Fire barrier and fire line control	0.4–0.7	0.6	Once a year
Fire-safe road control	0.4–0.7	1	Once a year
Control of approach ways to fire water body	0.4–0.7	1	Once a year

### 3.3.2 Numerical Characteristics for Updating the Forest Taxation Description

The taxation description of a forest plot is updated using the results of aviation and satellite data processing. In this case, the following numerical characteristics of forest stands are obtained: height of trees, height of standing timber, and width of crowns of standing timber, plant species composition, prevailing species, upper storey stand density, forest capacity, and growing stock of trunk timber.

**The height of standing timber** is determined in metres by the height (3.1) of felled standing timber (3.1) or by the length of shadows of standing timber (3.2) represented in the photograph:

$$H_{cp} = L \cdot LGR, \quad (3.1)$$

$$H_{cp} = \operatorname{tg} \alpha \cdot L_{shadow}, \quad (3.2)$$

where  $L$  is the height of felled trees in the photograph,  $LGR$  is a linear ground resolution,  $L_{shadow}$  is the shadow length in the photograph,  $\alpha$  is the angle of elevation of the sun.

**Plant species composition** is determined by the automated classification and visual deciphering of signs (i. e., crown shape, trunk tone). When determining the species composition, a share of species in the forest formula is expressed in scores from 1 to 10. The total volume of all crowns is defined by 10, and a share of each individual species is estimated.

**The trunk diameter** and the forest capacity are determined by the prevailing species and the height value from the age table.

Crown diameter is calculated by the formula:

$$D = d \cdot LGR', \quad (3.3)$$

where  $D$  is the crown diameter in metres;  $d$  is the crown diameter in pixels measured in the photograph;  $LGR'$  is the actual linear ground resolution.

**Growing stock of trunk timber** per hectare in  $\text{m}^3$  is calculated from the prevailing species by the formula:

$$M = K \cdot (3 + H) \cdot G, \quad (3.4)$$

where  $M$  is the stock;  $K$  is a coefficient equal to 0.4 for the pine, larch, birch, oak, hornbeam, aspen and alder, and 0.44 for the rest of the standing timber;  $G$  is the number of trunks per 1 ha,  $G = ((\text{Trunk diameter, m}) \cdot (\text{Fullness}) \cdot 100 \text{ m})^2$ ;  $H$  is the standing timber storey height.

Numerical values of the obtained characteristics are entered into the attributive table of the thematic layer for the taxation description of the forest plot.

The test surface measurements are made to validate the output results received from thematic aviation and/or space data or to adjust the taxation values of standing timber.

### 3.3.3 Numerical Characteristics for Evaluating Forest Fire Safety Conditions

An integrated approach allows analysing fire safety and preventive measures, and evaluating the forest fire safety conditions. Here, infringements that facilitate the occurrence and propagation of fires are identified, and a class of forest tracks with a fire hazard is defined.

The prerequisites for the occurrence of a forest fire are existing cuttings, windfalls, dead trees, landfills, and debris and oil pollution sites. Existing natural fire barriers

(such as lakes, rivers with a wide floodway, and forest sites with prevailing hardwoods), artificial fire barriers (such as motor roads, railroads, power transmission lines, and pipelines) and fire break lines reduce the probability of fires. Moreover, remote forest monitoring allows controlling the effectiveness of these measures. To evaluate readiness of the fire services, the existing fire-fighting roads, water areas and the ways to approach them as well as the estimated time of arrival to a potential fire location are taken into account.

The structural scheme of software and support tools for the evaluation of the forest fire safety condition is given in Fig. 3.8. As inputs to an analytical module, survey materials, surface measurements, reference images, spectral and textural signs are used. Based on the automated deciphering of remote monitoring data, the fire safety conditions for the forest area are evaluated, and recommendations for eliminating identified drawbacks in the forest are made.

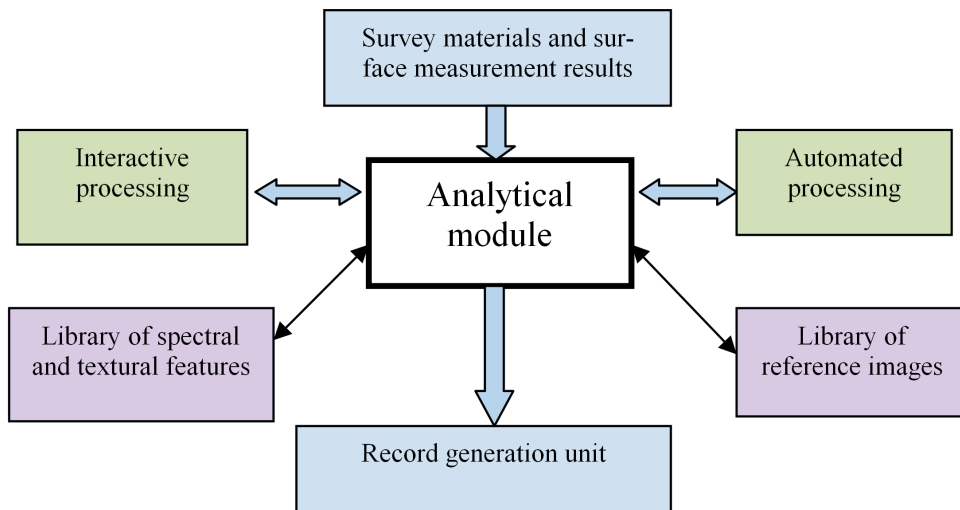


Fig. 3.8 Software and support tools

Remote monitoring of the forest state and evaluation of its fire safety condition allow solving a wide range of practical tasks, based on the thematic processing of materials of space survey and surface measurements with a high quality, i. e., to:

- Update the taxation characteristics of a forest plot;
- Estimate forest fire indices and evaluate the forest fire safety condition;
- Present the results of processing materials of remote monitoring and test surface measurements in a user-friendly manner, by thematic layers of digital locality maps;
- Compile records on the results of thematic processing of survey materials;
- Generate recommendations for fire service improvement and action plans for the elimination of identified drawbacks.

### 3.4 Monitoring Facilities and Support Tools for Information Processing of Water Pollution

Pollution monitoring in the water areas is one of the ways to control the condition of natural objects, e. g., water area, coast, and oil showings, and technogenic ones such as ships, oil rigs, and oil terminals. In the project, the analysis of oil pollution as well as the investigation of lake overgrowing is considered.

#### 3.4.1 Oil Pollution Monitoring

At present, the technology using the ERS data for monitoring of oil pollution of the sea areas has reached a commercial exploitation level and is widely used in many countries. The most efficient approach to water pollution monitoring [7–9] is based on the joint use of space and land data within GIS (Fig. 3.9). Satellite information is integrated with the data delivered by other observation facilities (air, sea, coastal), providing control of the vast water areas in a detailed overview and shooting modes. Thus, the data are obtained from ERS supplement information from land-based sources: information on the anthropogenic activities, which is the potential source of pollution, as well as information about natural phenomena and processes that affect pollution. The information about the natural (native) oil showings should also be used.

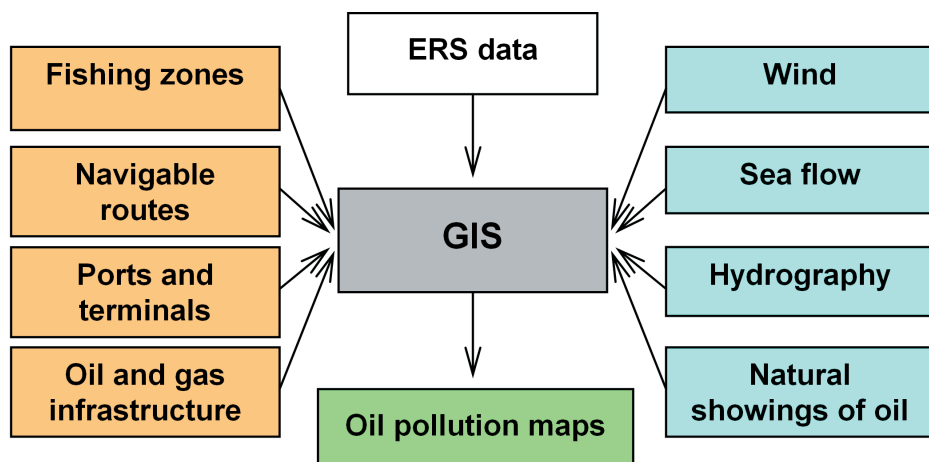


Fig. 3.9 Facilities of oil pollution monitoring in water areas

The traditional technology of oil pollution monitoring in water areas based on ERS data includes the preliminary and thematic processing of ERS data, and generating the map of oil spills.

There are various software tools for the preliminary and thematic processing of the ERS data. In the project, the ScanEx Image Processor software tool has been



selected as it allows performing all operations required at the stages of preliminary and thematic processing of the ERS data as well as generation of the map of oil spills. The automated identification of oil pollution by using several methods also allows increasing the awareness of research results.

Delivery of the results to a customer by the most expeditious method shall be the use of web services and geological portals. The geoportal <http://ocean.kosmosnimki.ru> can be considered a prototype. In this case, the obligatory information layers should be the following:

1. Geospatial base – the map containing the most significant landmarks; the base is formed only for the region of concern;
2. Outlining of the oil pollution areas, ranked by the dates of detection; for each contour, the attributive information such as date, size, additional data should be determined;
3. Converting to the format suitable for use in a geoportal; the ERS data used in monitoring; remote sensing data should also be ranked according to the date of their receipt.

### 3.4.2 State Monitoring of the Overgrown Lake

A flow diagram that presents an operation algorithm of the software prototype to analyse oil pollution in the water areas is given in Fig. 3.10.

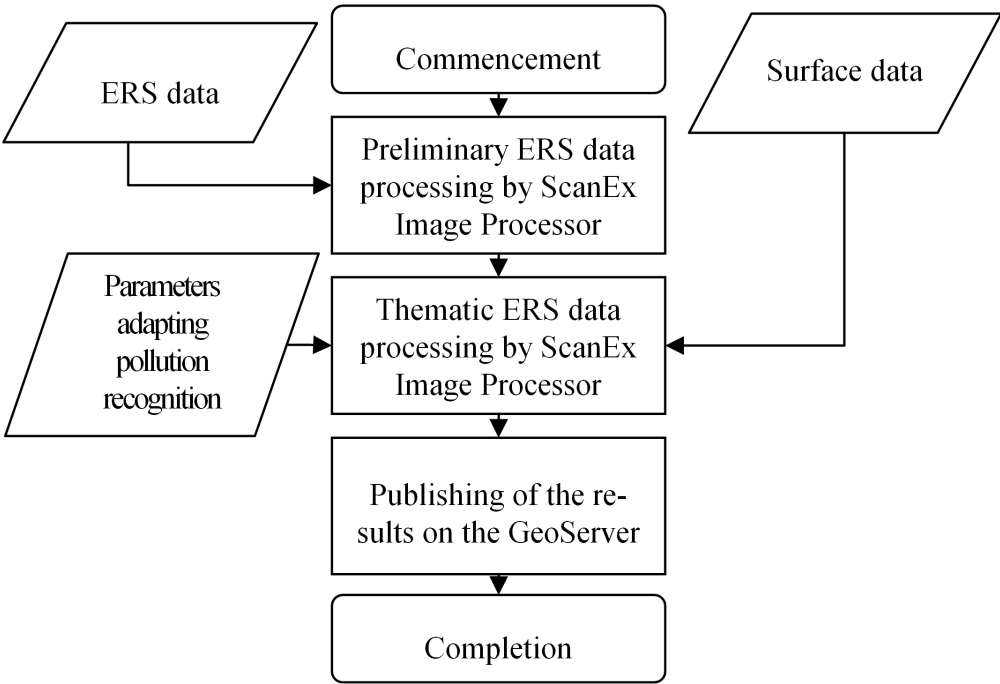
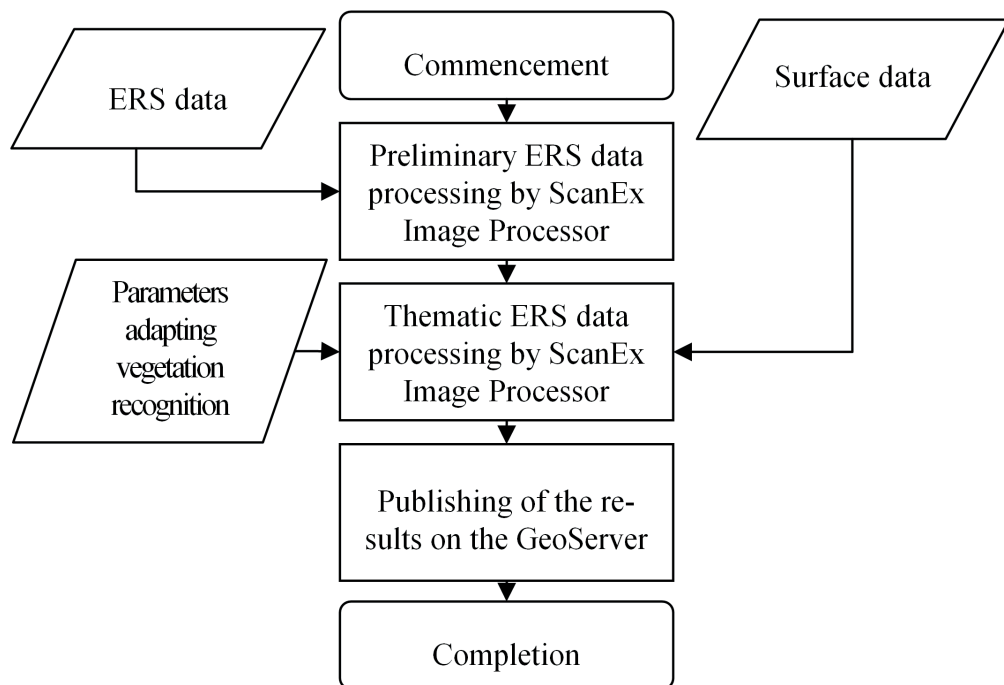


Fig. 3.10 An operation algorithm of the software prototype to analyse oil pollution

The monitoring of the state of the water body addresses the problem of overgrowing of lakes, particularly, Lubans Lake in Latvia. The flow diagram that provides an understanding of total operation of the software prototype adapted to analyse the overgrowing of lakes is given in Fig. 3.11.



**Fig. 3.11** An operation algorithm of the software prototype to analyse the overgrowing of lakes

The use of the software prototype for the analysis of overgrowing of lakes allows solving the following subtasks:

1. Determining the dynamics of overgrowing of Lubans Lake during one vegetation period and identifying the peak vegetation;
2. Determining the dynamics of overgrowing of the lake at the vegetation peak over many years;
3. Determining potential vegetation types in Lubans Lake.

As initial data for solving these subtasks, ERS data in the optical range can be used.

ERS data in the optical range have been captured over many years, and researchers have produced and accumulated a large amount of empirical knowledge. It is well known that the brightness ratio in various spectral areas corresponds to vegetation, naked soil, water surfaces, urbanised territories and other widely distributed landscape types. By expressing these brightness ratios as linear combinations of various areas, spectral vegetation indices can be obtained.

Thus, having the channels of the visible red ( $R$ ) and near-infrared part of spectrum ( $IR$ ), a normalised difference vegetation index ( $NDVI$ ) can be received that shows the existence of vegetation and “state of its health”. For each pixel of a space photograph, it is necessary to take the relation of the difference between these values in the areas to their sum:  $NDVI = (IR - R) / (IR + R)$ .

Thus, to solve the above-mentioned first and second subtasks, it is expedient to use the  $NDVI$  index, and, respectively, the ERS data that contain the channels of the visible red and near-infrared spectrum are required.

Furthermore, to solve the third subtask, the ERS data that contain the channels of the entire visible and near-infrared spectrum are required. For the territory corresponding to the mirror of the lake, it is necessary to perform a procedure of object-oriented image classification based on expert data and high spatial resolution ERS data.

Calculation of  $NDVI$  and the object-oriented classification can be made using the ScanEx Image Processor software tool.

As in the case of oil pollution monitoring, to ensure the customer awareness of the results of the lake overgrowing analysis, these results are delivered to a customer using web services and geoportals.

## References

1. Potryasaev, S., Zelentsov, V., Petuhova, J., Merkuryev, Y., Rogachev, S. (2013). Integrated Space-Ground Flood Monitoring. In: Longo, F., De Bonis, F., Merkuryev, Y., Gronat M. (eds.), *Proceedings of the 1<sup>st</sup> International Workshop on Innovation for Logistics, WIN-LOG 2013*. 14–15 November 2013, Campora S. Giovanni, Italy, pp. 1–5.
2. Merkuryeva, G. V., Merkuryev, Y. A., Lektuers, A., Sokolov, B. V., Potryasaev, S., Zelentsov, V. A. (2014). Advanced River Flood Monitoring, Modelling and Forecasting. *Journal of Computational Science* (in press).
3. LISPFLOOD-FP, University of Bristol, School of Geographical Sciences, Hydrology Group. Available at: <http://www.bris.ac.uk/geography/research/hydrology/models/lisflood/>. Accessed: 29 April 2014.
4. Ivanov, D., Sokolov, B. V., Potryasaev, S. A., Zelentsov, V. A., Brovkina, O. V. (2013). Structure Adaptation of Models Describing Scheduling Processes in Complex Technical-Organizational System (CTOS). In: *European Conference on Modelling and Simulation*, 27–30 May 2013, Aalesund University College, Norway.

5. Sokolov, B. V., Okhtilev, M. Yu., Zelentsov, V. A., Potryasaev, S. A. (2013). New Information intelligent Monitoring Technology for Complex Technical Objects under Dynamic Conditions in Real Time. In: *5<sup>th</sup> European Conference for Aerospace Sciences (EUCASS)*, 1–5 July 2013, Munich, Germany [CD].
6. Sokolov, B. V., Zelentsov, V. A., Mochalov, V. F., Potryasaev, S. A., Brovkina, O. V. (2013). Complex Objects Remote Sensing Monitoring and Modelling: Methodology, Technology and Practice. In: *8<sup>th</sup> EUROSIM Congress on Modeling and Simulation*, 10–13 September 2013, Cardiff, Wales, United Kingdom.
7. Бровкина, В. А., Григорьева, О. В., Мочалов, В. Ф., Матьяш, В. А., Саидов, А. Г. (2013). Автоматизированные методы оценки состояния окружающей среды по данным авиационной и космической гиперспектральной съемки. В: *Сборник докладов XIV Международного Форума «Формирование современного информационного общества – проблемы, перспективы, инновационные подходы»*, том 2, 2–6 июня 2013, Санкт-Петербург, Россия, с. 17–20.
8. Жуков, Д. В., Матьяш, В. А., Мочалов, В. Ф., Труфанов, А. В. (2013). Системный анализ актуальных задач, решаемых на основе интегрированной обработки аэрокосмических и наземных данных. В: *Сборник докладов XIV Международного Форума «Формирование современного информационного общества – проблемы, перспективы, инновационные подходы»*, том 2, 2–6 июня 2013, Санкт-Петербург, Россия, с. 37–39.
9. Matiash, V. (2013). Monitoring Facilities and Information Processing of Water Pollution, In: *Information Technology and Management Science*, 2013/16, RTU Press, p. 33–36.

# Chapter 4

## Demonstration Cases and Real-time Experiments

### 4.1 Simulation-based Daugava River Flood Forecasting

#### 4.1.1 The Flooding Problem

Floods may be caused by different reasons, such as snow and ice melting in rivers in the spring causing freshet; heavy raining in the neighbouring areas; and wind-generated waves in the areas along the coast and river estuaries. In Latvia, spring-time ice drifting and congestion can cause a rapid rise in water levels of the Daugava, Gauja, Venta, Dubna and Lielupe rivers. The risk of flooding along the Daugava River is relatively high, and in most flood sensitive areas (e. g., in Daugavpils district) it may occur even twice a year. Floods in Riga and Jurmala districts located in the deltas of the Daugava and Lielupe rivers and in the Gulf of Riga may be caused by the west wind during 2–3 days at a speed greater than 20 m/s following by winds in the north-west direction. As a result, the reverse water flow from the Gulf of Riga into the Daugava and Lielupe rivers may significantly rise to flood levels in these areas.

The EU Directive 2007/60/EC on the assessment and management of flood risks states that it is feasible and desirable to reduce the risk of adverse impacts of floods, especially for human health and life ([http://ec.europa.eu/environment/water/flood\\_risk/](http://ec.europa.eu/environment/water/flood_risk/)). Flood risk management involves flood monitoring, risk assessment and forecasting of the flood inundation areas. Flood monitoring can be performed by using satellite images, which allow detecting river overflows and provide data for flood damage modelling and assessment.

Flood forecasting is a challenging field of an operational hydrology, and a considerable amount of literature has been written in that area in recent years [2]. A water flow forecast presents an asset for flood risk management to reduce damage and protect an environment [3]. Reliable flow forecasting may present an important basis for efficient real-time flood management, including flood monitoring, control and warning. The integration of monitoring, modelling and forecasting becomes important in the construction of alert systems.

A new approach to integrated river flow monitoring, modelling and forecasting has been developed [4] and advanced by integrating different models and technologies for improving flood risk forecasting, based on the analysis of heterogeneous data received

from different information sources. Development of the flood monitoring and forecasting system is based on the recent progress in the sphere of spatial modelling and simulation, modern geo-information systems and earth remote sensing technologies.

#### 4.1.2 River Flood Modelling Software

There are several major river modelling software tools, such as HEC-RAS, LISFLOOD-FP and TELEMAC-2D. The HEC River Analysis System (HEC-RAS) allows performing one-dimensional steady flow, unsteady flow, and water temperature modelling and solves the full 1D Saint-Venant equations for an unsteady open channel flow. Implementation of HEC-RAS models requires large datasets. LISFLOOD-FP is a raster-based inundation model specifically developed to take an advantage of high resolution topographic datasets [2] and adopted to a 2D approach. TELEMAC-2D is a powerful and open environment used to simulate free-surface flows in two dimensions of a horizontal space [6]. At each point of the mesh, the programme calculates the depth of water and the two velocity components. The model solves 2D shallow water (also known as Saint-Venant equations or depth average) equations for a free surface flow using the finite-element or finite-volume method and a computation mesh of triangular elements (see also <http://www.opentelemac.org>).

The predictive performance of three models, i. e., HEC-RAS, LISFLOOD and TELEMAC, is analysed in [7]. The different model predictive performances stem from their different responses to changes in friction parameterisation. Performance of 1D HEC-RAS model gives good results, which are comparable with the ones received from more sophisticated 2D approaches adopted by LISFLOOD-FP and TELEMAC-2D. In addition, HEC-RAS models allow building long-term flood forecasts, but require large input datasets and need substantial time and expenditure for collecting them. These models reflect moving in recent years from a 1D approach (represented by the US Army Corps of Engineers HEC-RAS model) towards 2D finite element (TELEMAC-2D developed by Electricite' de France) and raster-based (LISFLOOD-FP) models.

LISFLOOD-FP [8] is a coupled 1D/2D hydraulic model based on a raster grid and capable of simulation dynamic flooding and floodplain inundation in a computationally efficient manner over complex topography. Flooding is treated using an intelligent volume-filling process based on hydraulic principles and embodying the key physical notions of mass conservation and hydraulic connectivity. The model is capable of simulating grids up to 106 cells for dynamic flood events and model large areas at fine special resolution of 10–100m cell size. It can also take an advantage of new sources of terrain information from remote sensing techniques. LISFLOOD-FP models are applicable for short-term forecasting and require a minimum amount of input data to produce an acceptable result. LISFLOOD-FP software has been used in several European research projects and successfully approbated.

The proposed real-time flood monitoring and forecasting system that provides input data collection and pre-processing, model-based river flood forecasting, modelling output post-processing and visualisation, and publishing of the short-term forecasts at a geoportal is described in Section 3.2.2. The short-term forecasting algorithm implemented in the system and given in Section 3.2.3 involves three main models described below.

#### 4.1.3 Water Level Forecasting, Flow Discharge Estimation, and Raster-based Modelling

Trend-adjusted exponential smoothing is applied to predict water levels. The model is appropriate when data vary around average data and have gradual changes and often used for flood forecasting [9].

The trend-adjusted forecast  $F_{t+1}$  is composed of two elements – a smoothed error and a trend factor, i. e.:

$$F_{t+1} = S_t + T_t, \quad (4.1)$$

where  $S_t$  denotes a previous forecast plus a smoothed error,  $T_t$  presents current trend estimate. These elements are calculated as follows:

$$S_t = \alpha F_t + (1 - \alpha)(S_{t-1} + T_{t-1}), \quad (4.2)$$

$$T_t = \beta(S_t - S_{t-1}) + (1 - \beta)T_{t-1}, \quad (4.3)$$

where  $\alpha$  and  $\beta$  denote smoothing constants for an average and for a trend, respectively. Here, values of these constants are defined as follows:  $\alpha = 0.2$ ,  $\beta = 0.05$ . A trend adjusted forecast value for water levels is calculated in MS Excel [8].

To predict water flow discharge values based on the dataset of the water level in the river, a symbolic regression model is used [10].

The initial dataset includes data on the following explanatory variables: the current water level  $h0$  in the river at time when the water flow is measured; water levels  $h3$ ,  $h6$ ,  $h12$ ,  $h18$  in the river that are measured 3, 6, 12 and 18 hours before the flow is measured, and water levels  $d1$ ,  $d2$ ,  $d3$  and  $d7$  are measured 24 hours, 2 and 3 days, and 1 week before the current flow is measured.

To find symbolic expressions for a flow value that fit the dataset on the water levels, genetic programming-based symbolic regression in HeuristicLab optimisation [4, 11] is used. The following model for the flow discharge estimation is found:

$$\text{flow} \approx 216.678 - 0.202 \cdot (0.645 \cdot h0 - 0.666 \cdot h12 + 0.361 \cdot h18 - 0.066 \cdot d3) \cdot (-0.361 \cdot h18 + 0.290 \cdot h12 - 24.078), \quad (4.4)$$

where  $\text{flow}$  defines the river water discharge in  $\text{m}^3/\text{s}$ . The main factors that affect the water flow discharge are attributes  $h12$  and  $h18$  that define the water levels 12 hours



and 18 hours before the flow is measured, respectively. Additionally,  $d1$  denotes the water level measured 24 hours before the flow is measured.

The model fitted data with coefficient  $R^2 = 0.963$  for the training set and with  $R^2 = 0.953$  for the test set. In case when the current water level  $h0$  in the river is not known, then the following model is used:

$$\begin{aligned} \text{flow} \approx & 208.214 - 0.011 \cdot h12 + 0.014 \cdot (-0.415 \cdot h3 + 1.123 \cdot h6 - \\ & - 1.262 \cdot h12 + 1.503 \cdot h18) \cdot (1.123 \cdot h6 - 0.814 \cdot h12 + 98.845). \end{aligned} \quad (4.5)$$

Details on the water discharge estimation model, parameters of a genetic algorithm applied to find this model and software used are given in [1].

The model structure includes two main components [5], [8]: a 1D model for simulating a channel flow by capturing the downstream propagation of a flood wave and the response of flow to free surface slope; and a 2D floodplain model that represents 2D dynamic flows on the floodplain or water transfer from the channel to the overlying floodplain grid when bank full depth is exceeded.

Both models are described in terms of continuity and momentum equations and discretised using finite differences.

A case study in flood forecasting for the Daugava River in Latvia that demonstrates the applicability of the proposed forecasting algorithm and models is described below.

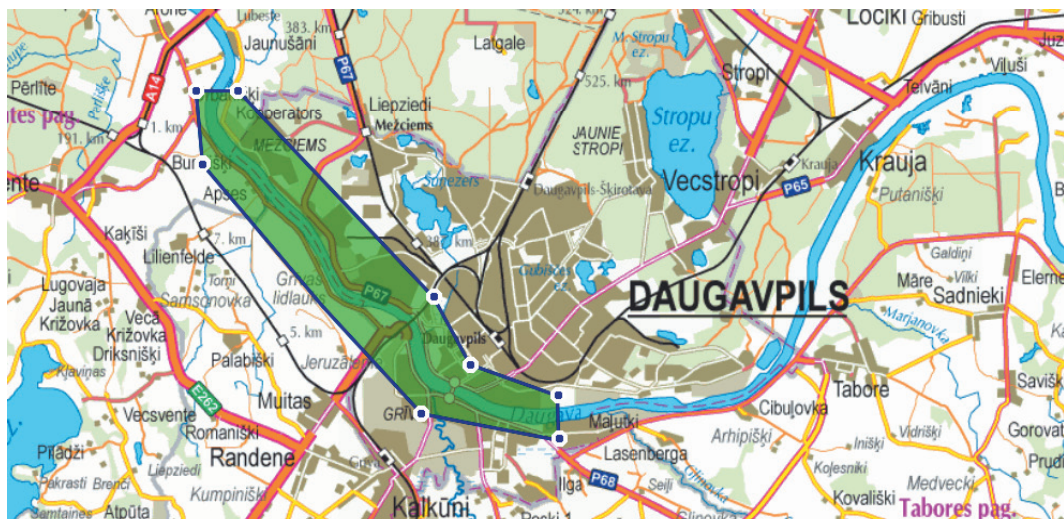
#### 4.1.4 A Short-term Flooding Forecast for the Daugava River

A case study was developed for a short-term flooding forecast for the Daugava River near the city of Daugavpils in Latvia, in spring 2013 when unexpected intensive flooding was observed, exceeding the previous highest water level in spring 2010 – 7.7 m. The main reasons for spring floods in Daugavpils are considered river ice jams arising from ice melting and rapid rise in the river water level.

##### 4.1.4.1 Input Data Collection and Pre-processing

The research area covers the territory along the river at a length of about 20 km (Fig. 4.1). It is specified based on historical data from flood risk assessments for the period April 1–26, 2010 with an increase in the probability of floods by 10 %. The critical water level in the Daugava River near Daugavpils city is 7.5 metres.

A digital elevation model of the research area has been obtained by means of airborne laser scanning performed by a specialised company with a horizontal resolution of 5 metres and a vertical resolution of 0.25 metres. To define hydrological characteristics of the river required for modelling water flows of the river channel network, a simplified model of the river channel on the selected section of the river has been built. The width data of the river channel have been determined based on the archival optical range space image for the period of low water levels in the river (Fig. 4.2). Absolute heights of the river bottom channel have been calculated using a digital elevation model.



 research area

Fig. 4.1 Flooding research area

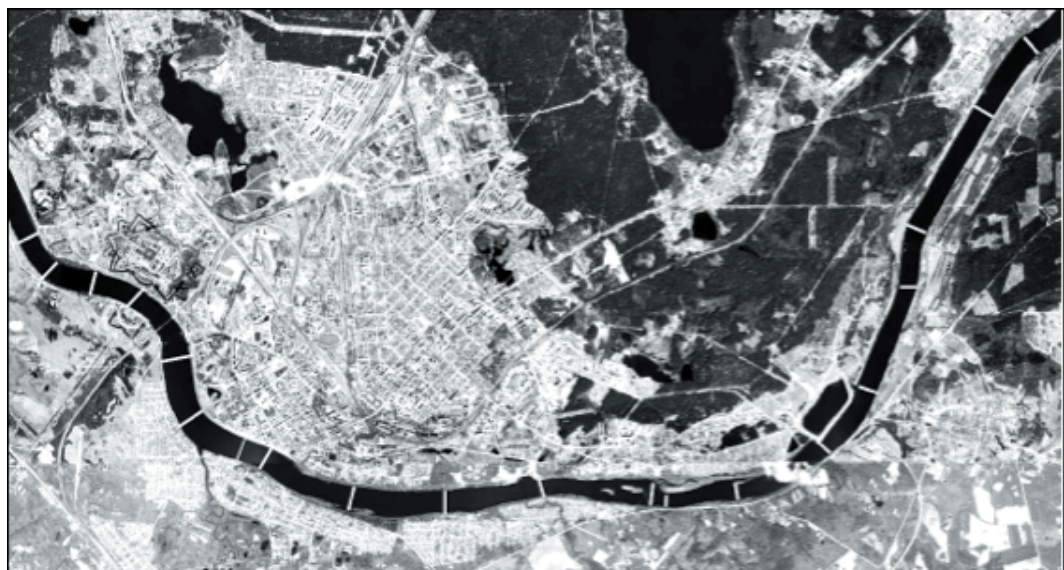


Fig. 4.2 Estimation of the river hydrological characteristics

The flood forecast horizon is defined by a period up to 12 hours, with 1 hour interval. There is only one hydrological station in the selected section of the Daugava River, which can provide hydrological data on water levels, heights of waves, a flow direction, etc. These data become available on a web site of the Meteorological Centre with a 10-hour delay. Moreover, for hydrological modelling the water flow data are

required, which actually are measured only twice a month. Thus, to obtain operational data on the water levels in the river on-line web service has been created. The resulting dataset included time series of water hourly levels observed in the river (Fig. 4.3).

<b>Hourly max water level in Daugavpils (cm)</b>	
<b>Date and time</b>	<b>Water level in Daugavpils</b>
<b>16.04.2013 08:00 -09:00</b>	<b>490</b>
<b>16.04.2013 09:00 -10:00</b>	<b>479</b>
<b>16.04.2013 10:00 -11:00</b>	<b>478</b>
<b>16.04.2013 11:00 -12:00</b>	<b>461</b>
<b>16.04.2013 12:00 -13:00</b>	<b>462</b>
<b>16.04.2013 13:00 -14:00</b>	<b>547</b>
<b>16.04.2013 14:00 -15:00</b>	<b>572</b>

Fig. 4.3 Operational data from a hydrological station

#### 4.1.4.2 Flood Forecasting and Modelling

To predict the river water levels for the upcoming period of 12 hours on a daily basis, a trend-adjusted exponential smoothing model is applied to the observed water hourly level time series. By application of a symbolic regression method, a model for converting the water level into the water flow discharge in  $\text{m}^3/\text{s}$  has been created.

To determine the functional dependency between the water flow discharge in the river and its water level within the forecasting horizon, several modelling scenarios, such as linear, nonlinear regression models and symbolic regression, have been experimentally tested [10]. Finally, a symbolic regression-based method implemented in HeuristicLab optimisation framework [4] has been selected. In order to train the model, historical data on water level forecasts have been used for the previous intensive flooding period in March – April 2010. A web service for recalculation of the river water level into the water flow discharge has been created providing hourly receipt of the water discharge in the river. In fact, forecasts of the water levels are transformed into forecasts for the water discharge values. The forecasting accuracy of the river water flow discharge has been within 95 % confidence interval (Fig. 4.4).

A LISFLOOD hydrological model has been developed to simulate water flows in the Daugava River bed and within the channel network by integrating the digital map of the relief of the specified area and obtained hydrological characteristics of the river. To increase the accuracy of flood forecasts, 3D elevation model data with low vertical resolution that does not exceed 1 metre have been used. Consequently, based on the water flow discharge data and a digital elevation model, LISFLOOD-based hydrological model has been built, which allows forecasting inundation territories along the river basin.

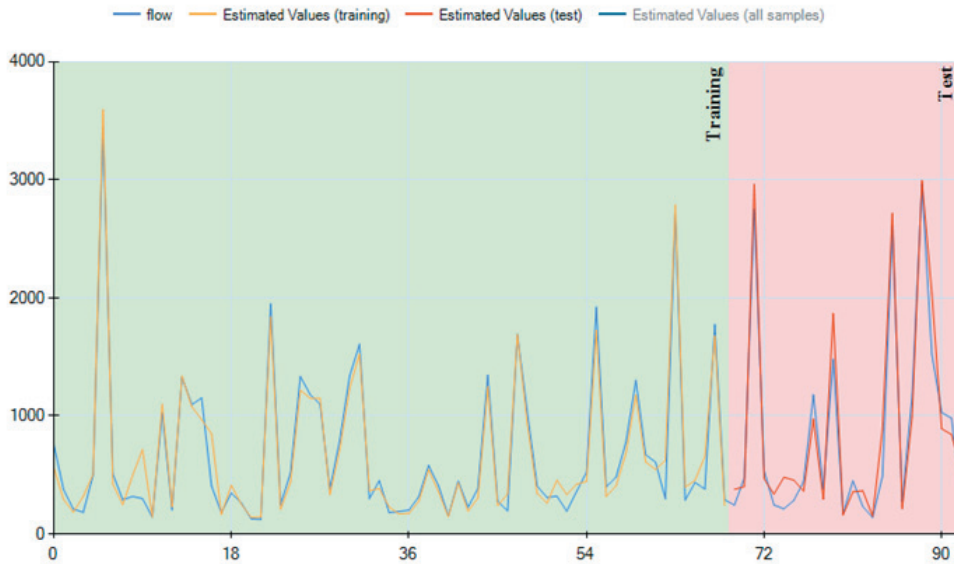


Fig. 4.4 Empirical data versus model-based forecasting results [10]

To test and validate the model, the flood simulation results have been compared with available historical data on the flooded zones in the research area for the period of March – April, 2010 (Fig. 4.5). The bounds of the inundation area from simulation experiments are close to historical data, and a forecast error is less than 10 %.

Then calibration of the model has been performed in two steps: by using the image received from the satellite RADARSAT-1 to precise the current state of the river channel; and by using data crowdsourcing technology – photos and video materials downloaded by socially active residents of Daugavpils district through a created web service <http://daugava.crowdmap.com> on an open-source platform *Ushahidi*.

Performed real-time experiments with the developed model have allowed achieving about 90 % confidence in flood forecasts regarding significant objects, which have been actually inundated later on (Fig. 4.6). The high forecast precision has been achieved through continuous updating of input parameters and arising short-term forecasts.



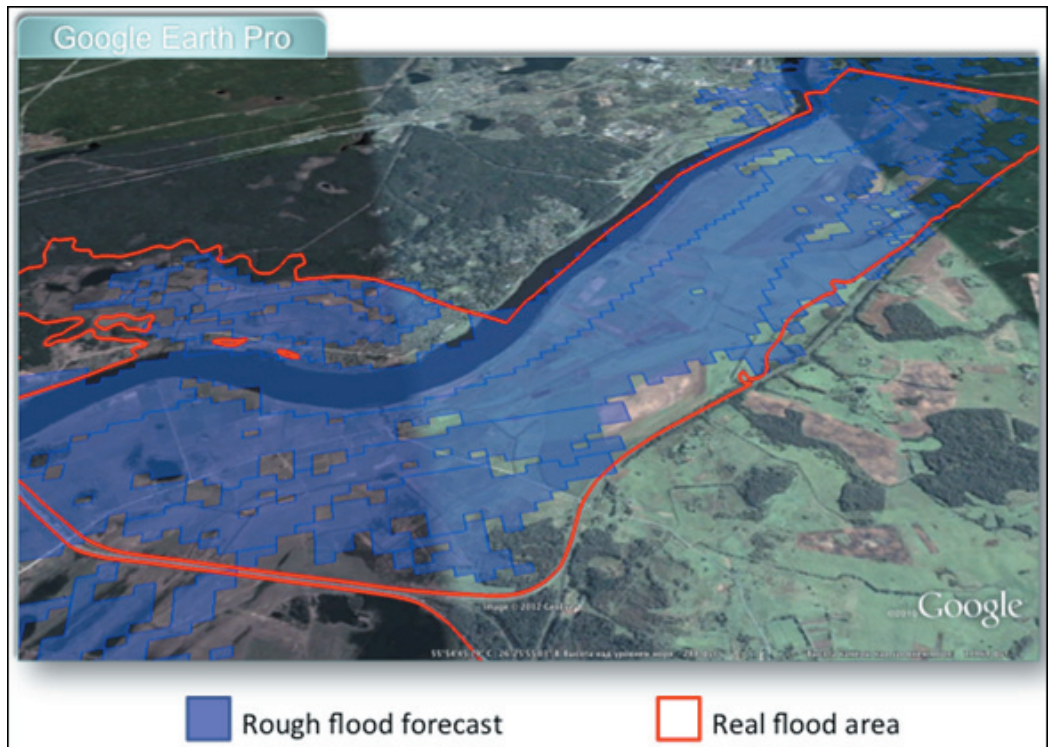


Fig. 4.5 Matching between simulation results and historical data as of 2010

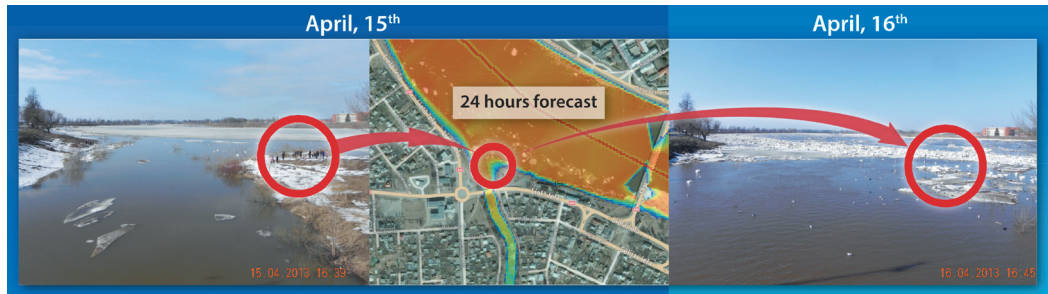


Fig. 4.6 Crowdsourcing: sample experimental results

#### 4.1.4.3 Post-processing and Visualisation of Modelling Results

The LISFLOOD-HP hydrological model generates 12-hour forecasts of inundation zones hourly (Fig. 4.7). The results of flood simulation are presented as a raster map (Fig. 4.8) with information about the depth of water in the flooded territory. These data have been automatically vectorised to provide their compatibility with the external GIS software and store them in the database as archival information about flood dynamics.

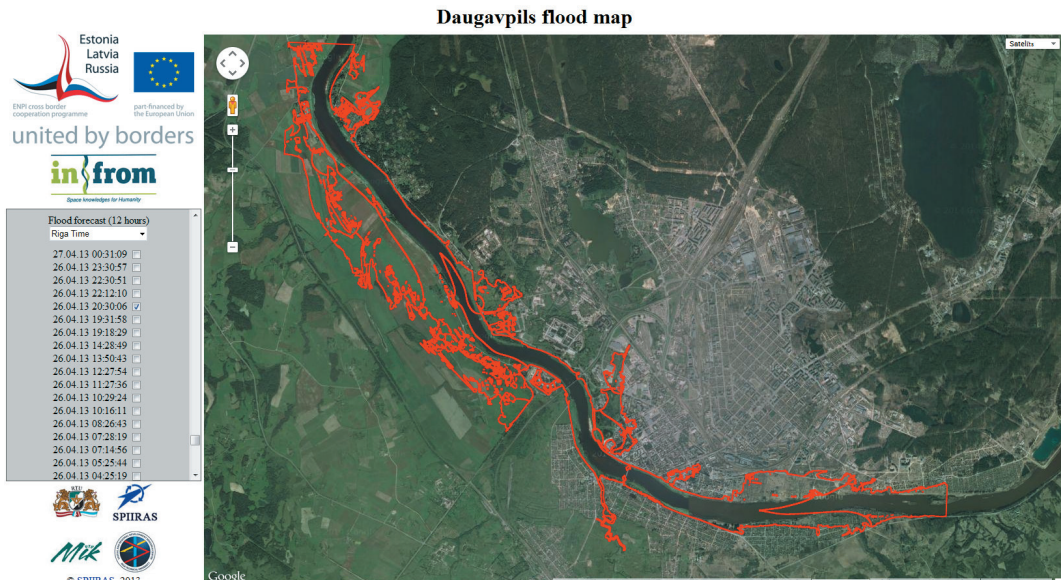


Fig. 4.7 Sample flooding forecast in Daugavpils: 26 April 2013, 20:30

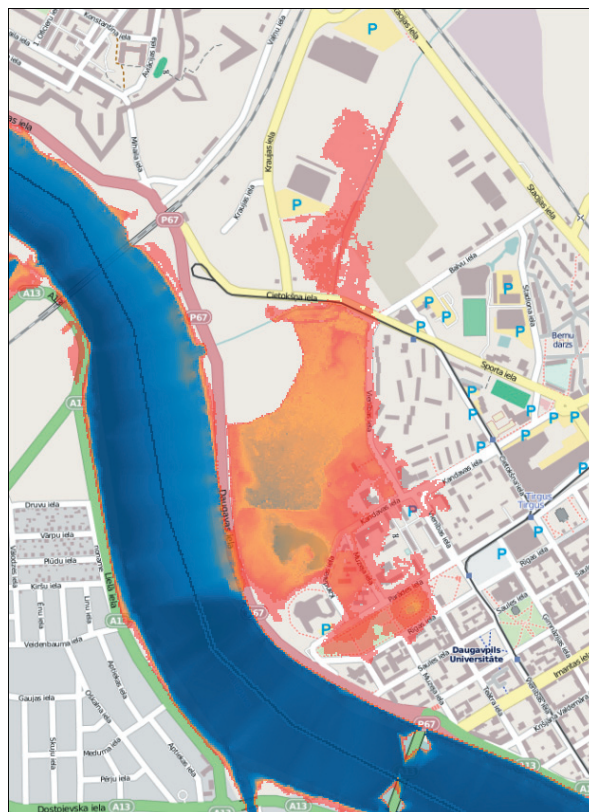


Fig. 4.8 Raster map of the flooded territory

Flood forecasting results are automatically published at the Google maps-based geoportal for prior notification about emergency situations. The web service provides possibilities of viewing layers with flood contours from the beginning of the modeling process up to a 12-hour forecast.

The experimental results have shown a high forecasting accuracy. Additionally, the flood monitoring and forecasting system allows significantly improving the social security and decreasing an economic damage caused by floods.

More details on the models and software used in this demonstration case can be found in [12], [13].

## 4.2 Integrated Forest Monitoring at Madona Municipality and in Pskov Region

The use of techniques and software for the thematic processing of space survey data has allowed solving forest monitoring tasks at Madona municipality (Latvia) and in Pskov region (Russia). This has also allowed demonstrating technology applicability without lowering qualitative indices when time periods are reduced and the cost is lowered.

In Madona district, specific attention is given to the stock-taking of the forest and specifying its taxation characteristics. The results received from the project have been coordinated with interested parties, and the efficiency of the technology applied has been discussed on the site.

Space survey data from Pleiades – 1A, 1B space system controlled by the French National Centre for Space Studies (CNES) have been used in the demonstration cases.

Table 4.1 presents general data on the photographs used.

Table 4.1

Characteristics of the Survey Data

Frame title	Survey date and time	Boundaries of spectral channels, mcm	Spatial resolution in nadir, m
F CGC600076067	18.09.2013 12:51:50	0.48–0.83 (panchromatic)	0.7 (panchromatic)
F CGC600076067_itog	18.09.2013	0.43–0.55 (blue)	2.8 (multispectral)
F CGC600076068	18.09.2013 12:58:39	0.49–0.61 (green)	
F CGC600076068_itog	18.09.2013	0.60–0.72 (red)	
		0.79–0.95 (near IR)	

The space survey parameters taken into account during thematic data processing are given in Table 4.2.



Table 4.2

Survey Parameters

Incidences and orientation	start	middle	end
Orientation	179.9364723309823	180.0699673533825	180.2640914926995
Global incidence	18.8764685149678	18.99100175034564	19.10461606507689
Across/along the track Incidence	-18.75275448646029/ 2.320551421637669	-18.86743491057165/ 2.32834424619373	-18.97892850676142/ 2.35730918899994
Solar azimuth	173.6647009334129	173.6614046848564	173.6578724582616
Solar elevation	36.84929376248018	36.88901075218527	36.9287455720966

The adjustment factors have been set up to adjust the power of spectral channels, survey time periods, the angular position of the sun, and the parameters of the geographical reference system.

Figure 4.9 presents a detailed map of Madona and near places, in which the space survey frame and the forest area under analysis are marked.

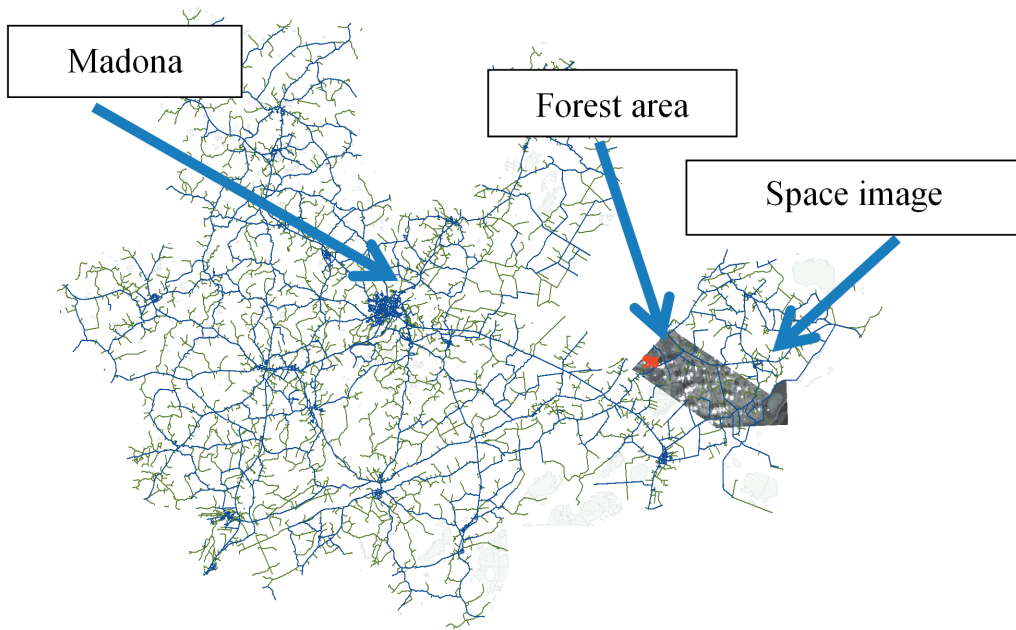


Fig. 4.9 Diagram of Madona district

In the taxation description task, data on the forest tract, tree species, and age are inputs, and their qualitative characteristics are determined. These data are presented as a taxation card and diagram. Examples of a taxation description card and a forest site diagram are given in Table 4.3 and Fig. 4.10, respectively.

Table 4.3

Fragment of a Taxation Description Card

Plot No.	Area, ha	Plot characteristic	Soil type	Composition by tree species	Prevailing species				Characteristic			Actual year of renewal	Year of stock-taking	Year of last cutting, cutting method
					Capacity	Height	Diameter	Age	Density	Number of trees	m <sup>3</sup> · 1 ha			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2.8	Forest	Gr	9Ba58 2B70 1G70 1Vi70 1A70	2	19	21	50	6	43	195		2003	
2	2.8	Forest	Gr	9Ba1 B60	1	21	22	60	8		227		2003	
3		Forest	Ap	8B2Ba60 K	1	24	23	60	9		312		2003	2005 22
K – partial cutting														
C – total cutting														

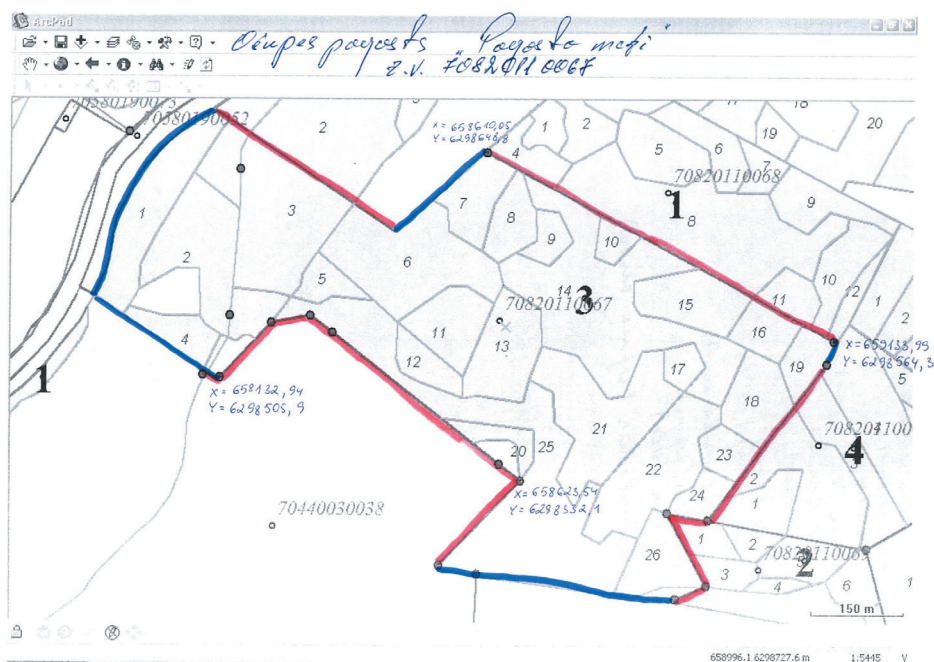


Fig. 4.10 Diagram of forest plots

The following subtasks have been performed by using the developed software and methodology:

- a. Activating the programme ArcGIS for working with maps and geographic knowledge;
- b. Creating a thematic layer presenting the digital base material of Madona municipality;
- c. Creating a layer that represents space survey data in a panchromatic channel;
- d. Creating a layer that presents a diagram of a forest area and plots;
- e. Delineating boundaries of plots onto a layer with space survey data;
- f. Preliminary analysis of coincident boundaries of the forest site being updated;
- g. Determining numerical indices to characterise plot conditions;
- h. Analysing coincident data presented in the taxation description table with the results of thematic processing of space survey data;
- i. Developing proposals for performing test surface measurements;
- j. Developing proposals for specifying the boundaries of forest plots;
- k. Analysing temporary and economic costs of performing the work;
- l. Performing (when necessary) test surface measurements within coordinated periods with participation of representatives of Madona municipality;
- m. Analysing the results of updating a taxation description, evaluating trustworthiness, the cost and rate of work being performed;
- n. Developing further action plans.

The subtasks specified in clauses *a...h* have been performed at the autonomous workplace with the installed specific software. The subtasks specified in clauses *i...k* have been performed jointly with representatives of the municipality administration at their workplaces. The test surface measurements specified in clause *l* have been performed directly at the forest site by employing necessary measuring and recording (photographing) tools. The results received from the above-mentioned subtasks performed as well as further action plans and measures have been coordinated with representatives of Madona municipality administration.

The fragments of images that demonstrate information capacities of space survey materials are given in Figs. 4.11, 4.12. Here, the red lines represent the boundaries of forest plots. Taking into account a high accuracy of coincidence of the exterior boundaries of the forest, attention can be drawn to individual deviations of the boundaries of individual plots.

Figure 4.13 presents the diagram of forest plots, in which red spots specify identified significant deviations between the data of the taxation description and the results of thematic processing of space survey data.



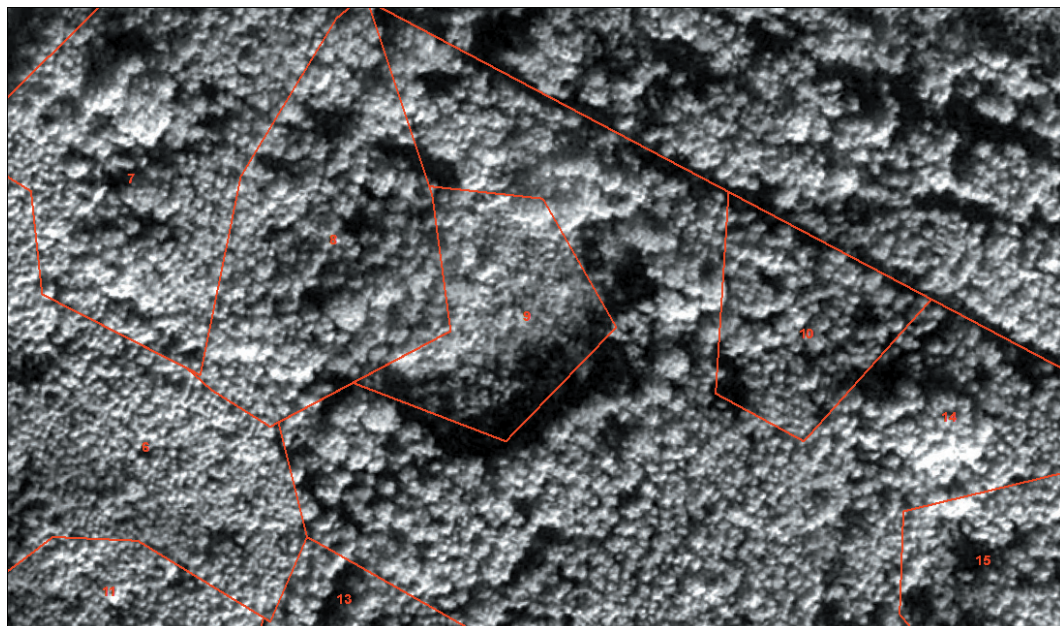


Fig. 4.11 Fragment of the central part of the forest site

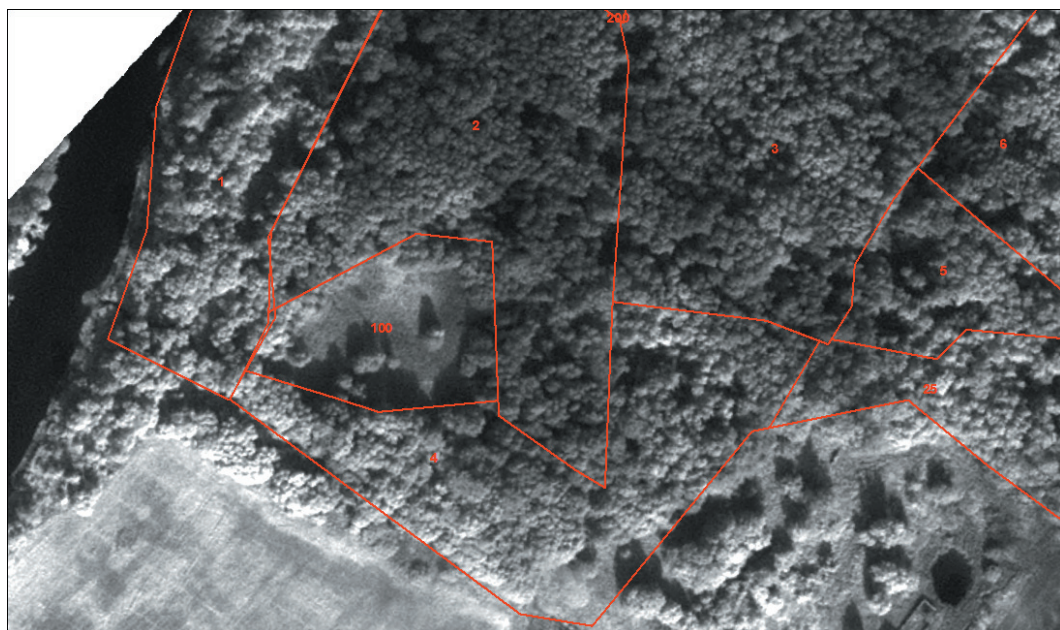


Fig. 4.12 Fragment of the north-west part of the forest site



Table 4.5

## Basic Discrepancies

Plot No.	Note
1	Forest of 4.175 sq. metres not taken into account
2	Cutting of 995 sq. metres not taken into account
7	Cutting of 729 sq. metres not taken into account
7	Cutting of 14.121 sq. metres not taken into account

The results of the applied coincidence analysis of data obtained from the thematic processing of space survey data and data presented in a taxation description card are illustrated in Fig. 4.14. Here, coinciding data are marked in green, deviations are marked in pink, and non-coinciding data – in red and purple.

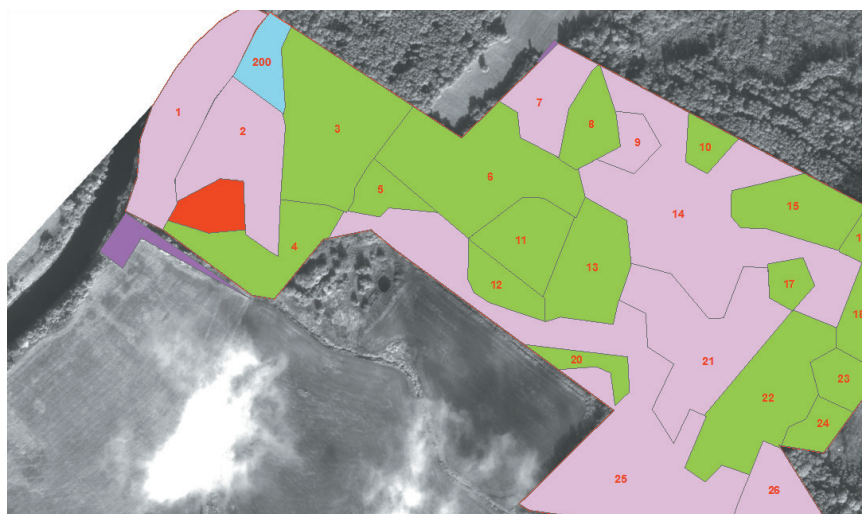
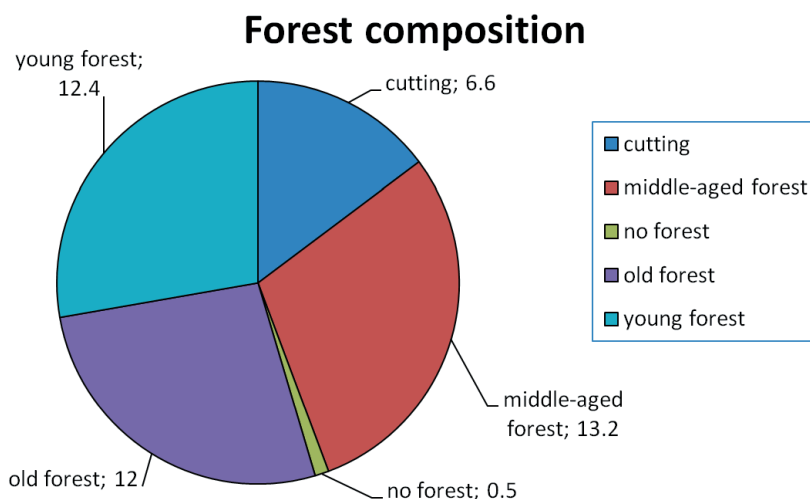


Fig. 4.14 Coincidence diagram

The trustworthiness of data obtained from the thematic processing of space survey data has been validated by experts through discussing the received results with the self-governing administration of Madona municipality. Figure 4.15 represents the forest composition and age structure diagram that reflects a harmonious structure with the uniform forest age distribution. This is evidence of the proper measures taken to assure the efficient use of the forest and its reserves.

To analyse the economic efficiency of the performed tasks, an equipped workplace was made available in the municipality administration with the software installed and widely-used for the forest land analysis. Two experts were involved, with the personnel cost of 85 EUR per day. The cost of observation materials was 1,000 EUR. On the average, information about 20 forest sites would be provided. Correspondingly, we obtained the cost of the space observation data for one survey equal to 50 EUR.



**Fig. 4.15** Forest composition and age structure

In practice, traditional ways of collecting data take 10 days for one survey on the average, and then another 10 days are required for data processing and integration (see Table 4.6). The application of a new technology requires only a day for data collection and 5 days for processing these data. Thus, the economic efficiency of implementing a new technology is about 30 %.

*Table 4.6*

The Economic Efficiency of a New Technology

	Traditional approach	Use of space survey data
Cost of equipment (GPS, Compass, Computer, ArcGIS, Digital Photogrammetric Station PHOTOMOD), EUR	6,500	6,500
Data collection, carrying out surface measurements, days	10	1
Processing, updating a taxation description, days	10	5
Total work duration, days	20	6
Personnel cost, EUR	1,700	1,510

Moreover, the cost of implementing the proposed technology can be decreased by:

1. Purchasing historical data rather than new data. As a rule, the cost of survey carried out over a year ago is reduced several times.





The objective of oil pollution monitoring has been the detection of an oil stain in the Gulf of Finland as of 30 June 2011 based on the historical data received from the satellite RADARSAT-1 using the ScanEx Image Processor software (see Fig. 4.17).

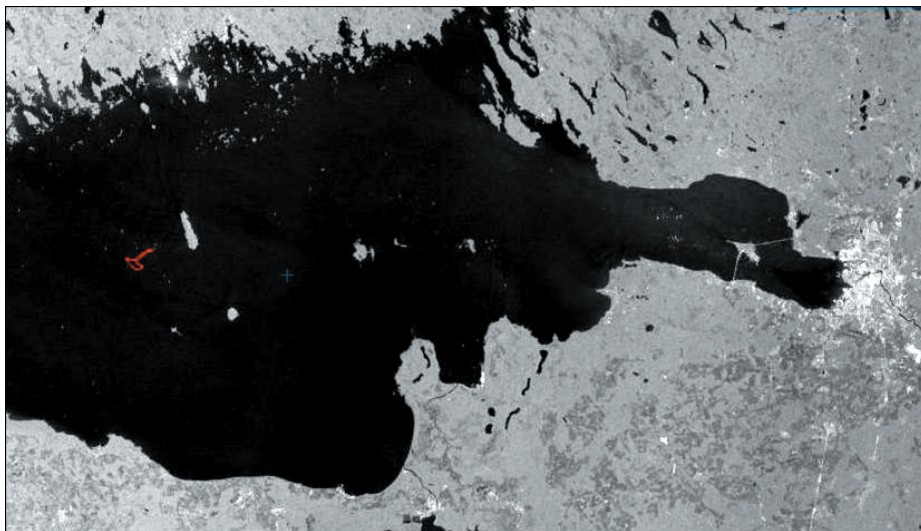


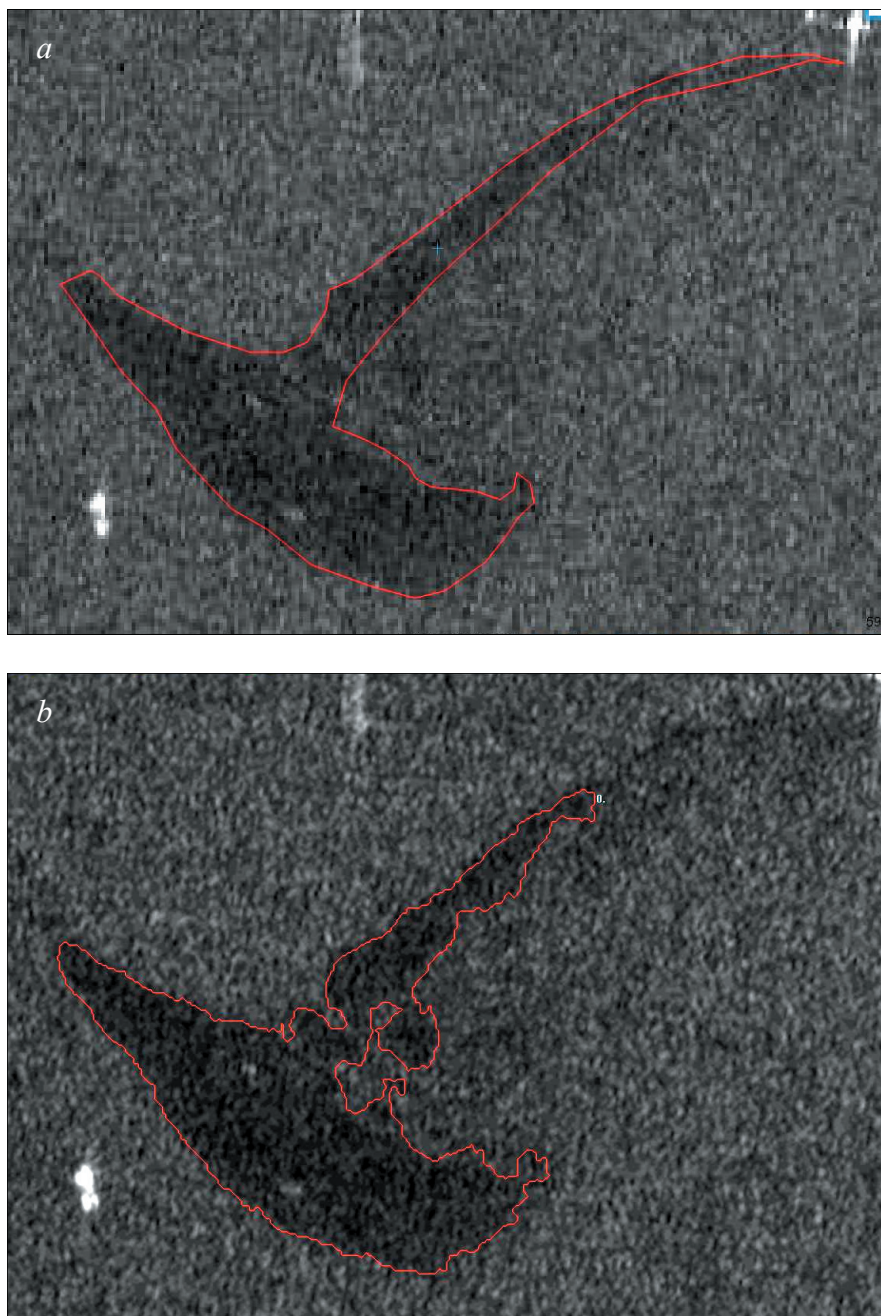
Fig. 4.17 A fragment of the photograph of the Gulf of Finland with an oil stain received from RADARSAT-1 (30 June 2011)

Moreover, a benchmark result of detecting this oil stain was available (marked by the red outline in Fig. 4.17). Detection has been performed using the technology described above, and the obtained result has been compared with the benchmark. The comparison has shown high coincidence of the result and its benchmark as seen in Fig. 4.18.

In this figure, the effect of “smoothing” of oil pollution of the sea surface can be observed. This effect is clearly detected on the ERS radar as an area whose texture characteristics are significantly different – visually it is perceived as more than one-ton stain dark tint on the background of the most variegated surface.

However, the same effect is given by natural phenomena, such as calm, wind shading, clusters of surface-active agents (surfactants) or algae. This can be seen as a factor interfering with oil pollution detection, which reduces the reliability of the results. To improve the reliability, it is necessary to use information from additional data sources, as discussed in Section 3.3. Besides, oil pollution has a characteristic shape.

The solution to this problem is of great importance for the environmental sustainability. Timely detection of oil pollution allows taking measures to quickly eliminate and minimise environmental damage. Moreover, it allows identifying the potential source of pollution or narrowing the range of such sources, as well as estimating early targeted interventions whose results can be used to impose penalties for environmental damage.



**Fig. 4.18** Detection of oil pollution from the ERS radar data:  
a) – the benchmarking data; b) – the obtained result

The results of the second demonstration case on studying the overgrowth dynamics of Lubans Lake during one vegetation period are presented in Figs. 4.19, 4.20 and in Table 4.7.



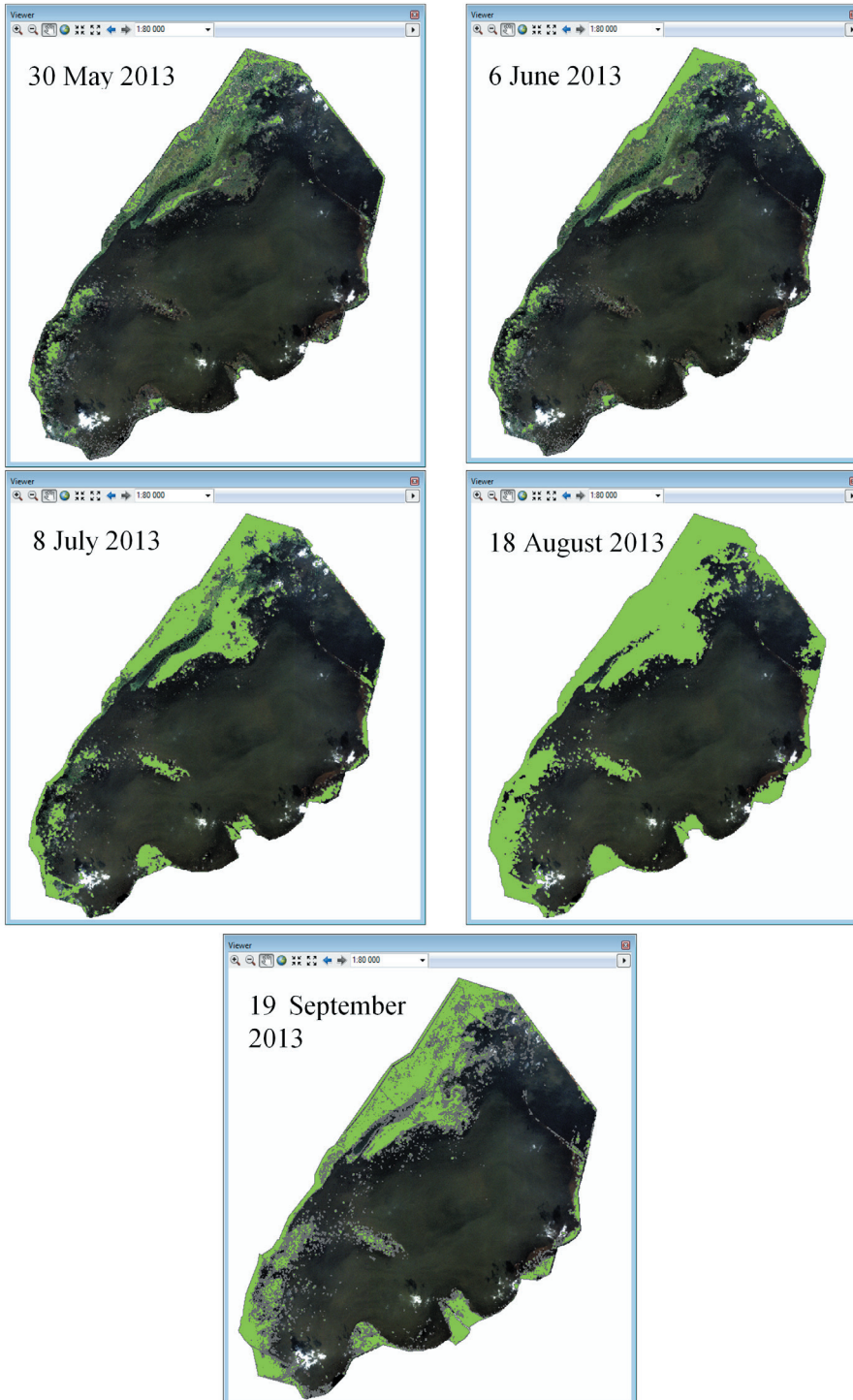


Fig. 4.19 The overgrowth dynamics of Lubans Lake during one vegetation period

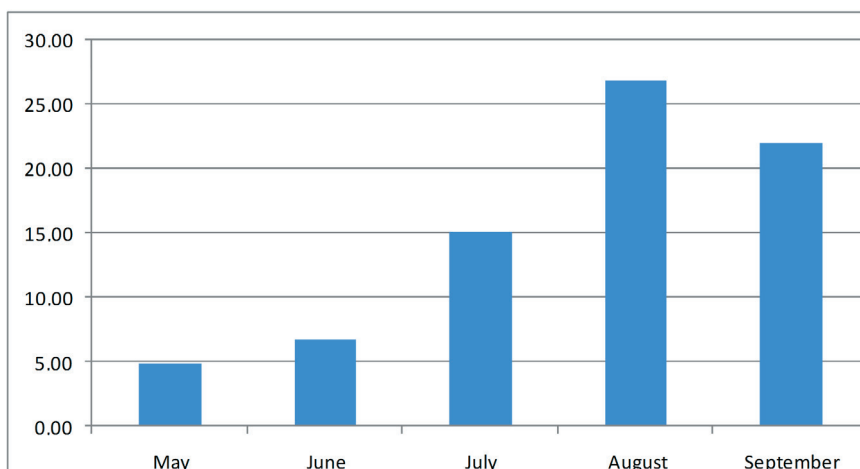


Fig. 4.20 The overgrowth dynamics of Lubans Lake during one vegetation period (chart)

Table 4.7

The Overgrowth Dynamics of Lubans Lake during One Vegetation Period

Month, 2013	Vegetation area, sq. km	The proportion of the vegetation area, %
May	4.18	4.91
June	5.72	6.73
July	12.81	15.06
August	22.83	26.85
September	18.68	21.97

The results of determining the overgrowth dynamics of Lubans Lake over years are given in Figs. 4.21, 4.22 and in Table 4.8. Moreover, the potential types of vegetation in Lubans Lake have been analysed (see Figs. 4.23, 4.24 and Table 4.9).

To study the overgrowth dynamics of Lubans Lake, the ERS data obtained from Landsat satellites have been used.

Table 4.8

The Overgrowth Dynamics of Lubans Lake over Multiple Years

Year	Vegetation area, sq. km	The proportion of the vegetation area, %
2002	8.79	10.34
2007	20.33	23.91
2010	14.16	16.65
2013	22.83	26.85

A specific feature of these data is the presence of long-term archives that require handling data from multiple satellites, i. e., Landsat 5, Landsat 7 and Landsat 8. However, the data in the channels of the visible red and near infrared part of spectrum, which are used in accordance with the methodology described in Section 3.3, have identical characteristics. This allows for uniform processing of data obtained in different years.

In addition, the ERS data offer medium spatial resolution for the task given the large size of Lubans Lake; this is a typical approach to solving such problems, and data requirements are satisfied by the data received from the Landsat satellites.

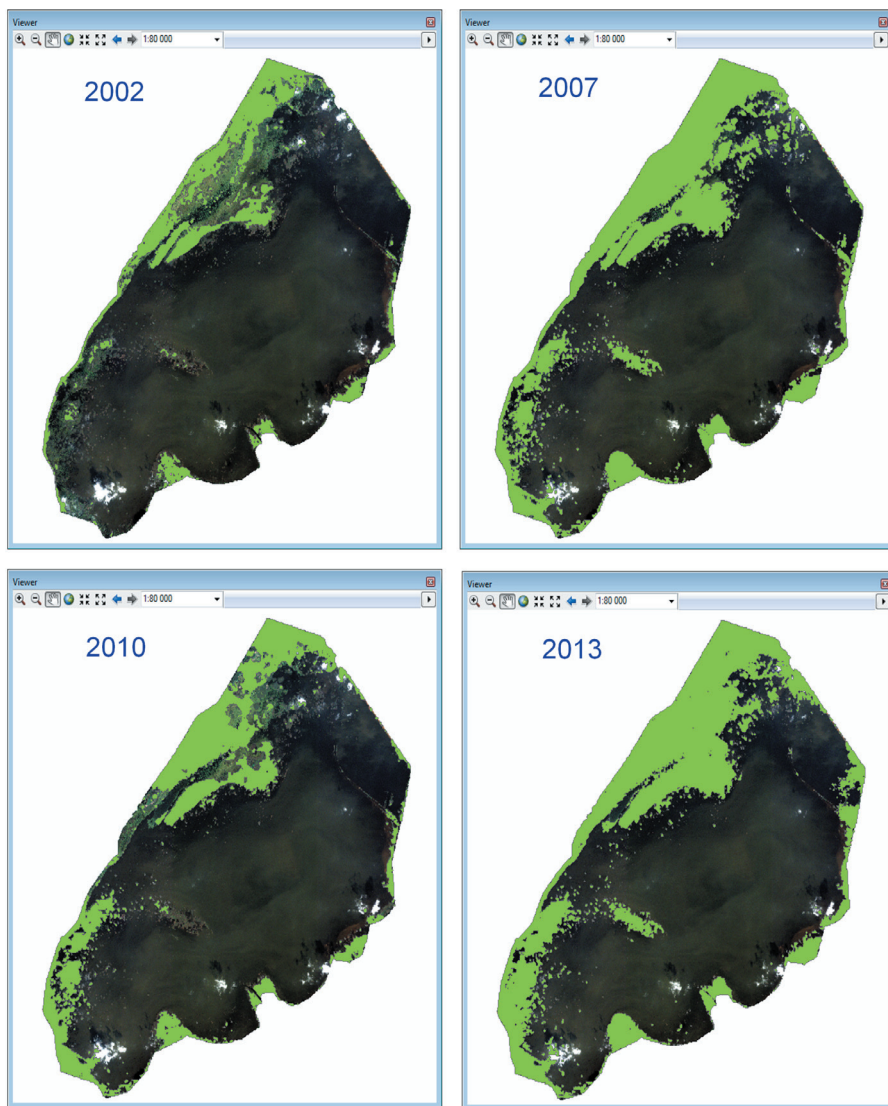


Fig. 4.21 The overgrowth dynamics of Lubans Lake over multiple years (satellite images)

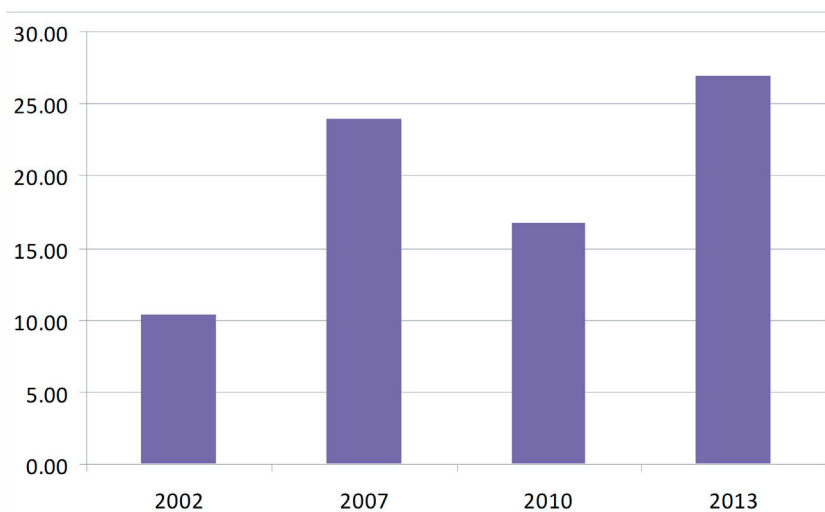


Fig. 4.22 The overgrowth dynamics of Lubans Lake over multiple years (chart)

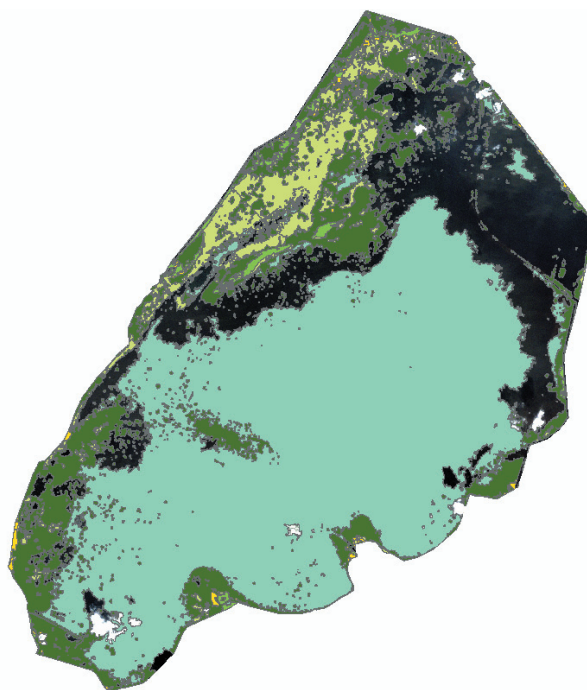
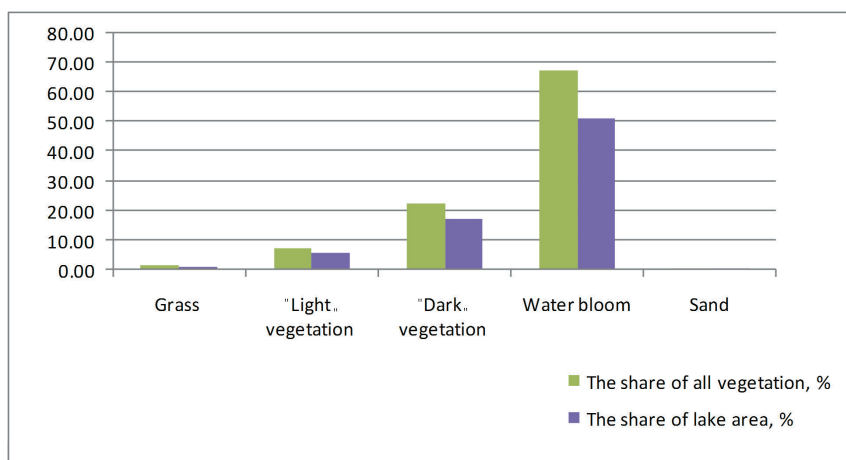


Fig. 4.23 Potential types of vegetation in Lubans Lake (satellite image)

The analysis of possible types of vegetation requires data with higher spatial resolution. Therefore, in this case data from the Pleiades 1A/1B satellites are used that provides high spatial data resolution.





**Fig. 4.24** Potential types of vegetation in Lubans Lake (chart)

*Table 4.9*

Potential Types of Vegetation in Lubans Lake

Vegetation types	Area, sq. km	Proportion of vegetation, %	Vegetation area, %
Grass	0.96	1.49	1.13
"Light" vegetation	4.80	7.47	5.65
"Dark" vegetation	14.62	22.74	17.20
Water bloom	43.45	67.57	51.10
Sand	0.47	0.73	0.55

The traditional problem of the use of optical remote sensing data is the presence of clouds covering the object under study. Therefore, remote sensing data selection in the archive must take into account this factor in order to select data without cloud cover (an ideal case) or with cloud cover that cannot have a significant impact on the results.

The results of the overgrowth dynamics analysis of the lake (see Table 4.7) show that its vegetation area during one vegetation period (i. e., in 2013) is close to a natural phenomenon with peaks identified in August. Therefore, to determine the overgrowth dynamics of Lubans Lake over multiple years data received for August have been used.

The overgrowth dynamics of the lake over multiple years has shown (see Table 4.8) that an overgrowing area has increased from 2002 to 2013, except for 2010. To identify reasons for the decline of vegetation in 2010, more comprehensive research should be performed. The location of the greatest concentration of vegetation of the lake has not changed significantly over the years.

The outcomes of the demonstration case on the overgrowth monitoring of Lubans Lake are defined as follows:

1. The overgrowth dynamics of the lake during one vegetation period has been determined with the vegetation peak identified in August;
2. The overgrowth dynamics of the lake over years has shown that an overgrowing area increased from 10.34 % of the lake area in 2002 to 26.85 % in 2013;
3. Water bloom covers the largest area of the lake in comparison with other potential vegetation types analysed within the project;
4. Location of sand in Lubans Lake has also been defined.

The overgrowing of the lake is favourable for numerous birds that use it for recreation during long-haul flights. On the other hand, the overgrowing process may have negative social impacts, including lack of clean water and reduction of fish mass in the lake. Thus, the results obtained in this demonstration case allow the local authorities to consider the need for further actions on Lubans Lake sustainability.

## 4.4 Increasing Quality of Input Topographic Data

In practice, geo-information measurements are often taken on-site to assure higher precision of input topographic data [16–18]. The following is an example of these measurements made for the demonstration case of Lubans Lake.

On the north and east sides of the lake, measurements have been taken close to the lake, but on the west – away from the lake while driving between different locations. In total, 5,418 measurements have been carried out in which the coordinates and altitudes of particular points have been defined. All received data have been processed in the Quantum GIS 1.8.0-Lisboa programme and presented by the black line in Fig. 4.25 (as these points are very close to each other).

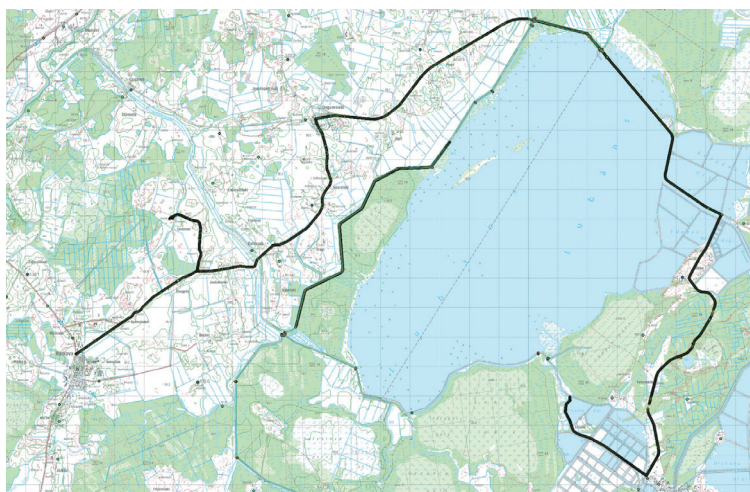


Fig. 4.25 Measurement road in Quantum GIS 1.8.0-Lisboa programme

Measurement track that started 9 km away from the lake on the south-west coast in a village Barkava went through a number of locations to the north of the lake, crossed the dam and passed Kvapanu and Idenas ponds. Then it turned to the forest direction, went through the forest, passed a little place called Teirumniki to Naglu pond and, finally, turned to the west. The measurement track ended at the Vecmalta River outfall from Zvejsola pond.

For 100 consecutive measurements made on the north of the lake, the altitudes are presented in Fig. 4.26. Every 11 seconds the variation between obtained data points is about 1.5–2.5 metres, where the average altitude is about 116–117 metres.

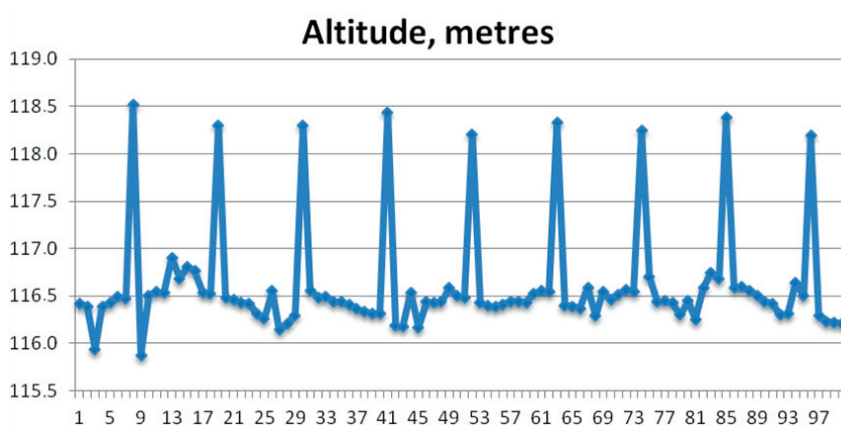


Fig. 4.26 Altitude dynamics for 100 consequent measurements on the north side of the lake

For the dam along the west, south-west and north coasts of the lake, 84 measurements have been carried out within walking distance. All obtained data have been processed in the Quantum GIS 1.8.0-Lisboa programme and some cross-sections have been identified. However, they have not well fitted a certain surrounding terrain as within several-metre-long section there have been about 3–5 measurements taken that have not been sufficient to set up a specific terrain cross-section.

For example, for 4 measurements (i. e., 68, 69, 70 and 71) the distance between them is nearly 49 metres and the height range is 6.233 metres (Fig. 4.27). Further on, a digital orthophoto map of the specific area (see Fig. 4.28), where the measurements have been made, and its image developed in Quantum GIS (Fig. 4.29) have been analysed.

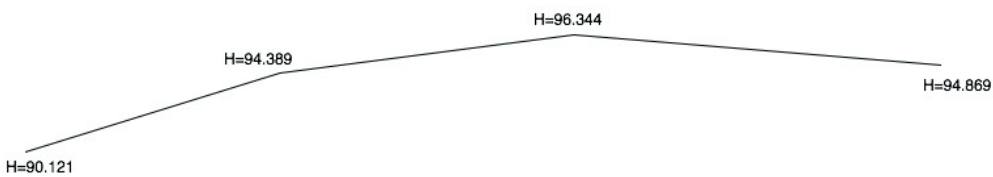


Fig. 4.27 Cross-section of measurement points 68, 69, 70, and 71



Fig. 4.28 Orthophoto of 68–71 measurement point locations

The measurements 68–71 correspond to the dam located about 4.2 kilometres from the south-west coast of the lake. On the west from the dam, the Vecsilinas River flows, and on the east side of the dam there is a swamp forest area.



Fig. 4.29 Orthophoto of 68–71 measurement point locations in the Quantum GIS image

## 4.5 Summary

The demonstration cases described above – Simulation-based Daugava River Flood Forecasting, Integrated Forest Monitoring at Madona Municipality and in Pskov Region, Monitoring of Oil Pollution in the Gulf of Finland and Overgrowing of Lubans Lake in Latvia – have proved the functionality of the developed technology platform, information processing and decision support tools as well as have shown the importance of increasing the quality of input topographic data for monitoring of complex systems, including natural, technological and social components.

## References

1. Chiang, P.-K., Willems, P., Berlamont, J. (2010). A Conceptual River Model to Support Real-time Flood Control. In: *Demer, 'River Flow 2010* – Dittrich, Koll, Aberle & Geisenhainer, pp. 1407–1414.
2. Corani, G., Guariso, G. (2005). Coupling Fuzzy Modelling and Neural Networks for River Flood Prediction. In: *IEEE Transactions on Men, Systems and Cybernetics*, 3 (35), pp. 382–391.
3. Tucci, C., Collischonn, W. (2006). Flood Forecasting. *WMO Bulletin*, 55 (3), pp. 179–184.
4. Merkuryeva, G. V., Merkuryev, Y. A., Lektuers, A., Sokolov, B. V., Potrjasaev, S., Zelentsov, V. A. (2014). Advanced River Flood Monitoring, Modelling and Forecasting. *Journal of Computational Science* (in press).
5. Bates, P. D., De Roo, A. P. J. (2000). A Simple Raster-based Model for Flood Inundation Simulation. *Journal of Hydrology*, 236, pp. 54–77.
6. Galland, J., Goutal, N., Hervouet, J.-M. (1991). TELEMAC – A New Numerical Model for Solving Shallow-water Equations. *Advances in Water Resources*, 3 (14), pp. 138–148.
7. Hunter, N. M., Bates, P. D., Horritt, M. S., Wilson, M. D. (2007). *Simple Spatially-distributed Models for Predicting Flood Inundation: A Review*. *Geomorphology*, No 90, pp. 208–225.
8. LISPFLOOD-FP, University of Bristol, School of Geographical Sciences, Hydrology Group. Available at: <http://www.bris.ac.uk/geography/research/hydrology/models/listflood>. Accessed: 29 April 2013.
9. Stevenson, W. J. (2011). *Operations Management: Operations and Decision Sciences*. 11<sup>th</sup> edition, McGraw-Hill/Irwin.



10. Bolshakov, V. (2013), Regression-based Daugava River Flood Forecasting and Monitoring In: *Scientific Journal of RTU, Information Technology and Management Science*, 16(1), pp. 137–142.
11. Affenzeller, M., Winkler, S., Wagner, S., Beham, A. (2009). *Genetic Algorithms and Genetic Programming: Modern Concepts and Practical Applications*. Chapman & Hall/CRC.
12. Merkuryeva, G. V., Merkuryev, Y. A. (2013). Advanced River Flood Forecasting and Simulation. In: Bruzzone, A. G., Jimenez, E., Longo, F., Merkuryev, Y. (eds.) *Proceedings of the 25<sup>th</sup> European Modelling and Simulation Symposium, EMSS2013*. 25–27 September 2013, Athens, Greece, pp. 525–529.
13. Potryasaev, S., Zelentsov, V., Petuhova, J., Merkuryev, Y., Rogachev, S. (2013). Integrated Space-Ground Floods Monitoring. In: Longo, F., De Bonis, F., Merkuryev, Y., Gronat, M. (eds.) *Proceedings of the 1<sup>st</sup> International Workshop on Innovation for Logistics, WIN-LOG 2013*. 14–15 November 2013, Campora S. Giovanni, Italy, pp. 1–5.
14. Матьяш, В. А. (2013). Анализ нефтяных загрязнений водных акваторий на основе наземных и аэрокосмических данных. Труды СПИИРАН, 6(29), pp. 95–110. e-ISSN 2078-9599. ISSN 2078-9181.
15. Trufanovs, A., Matiash, V., Mochalov, V., Zhukov, D. (2013). Системный анализ актуальных прикладных задач наземного аэрокосмического мониторинга эколого-технологических объектов, исследуемых в проекте ELRI-184. В: Труды СПИИРАН. Методологические и методические основы решения проблем наземно-аэрокосмического мониторинга. St. Petersburg: SPIIRAS, pp. 107–121.
16. Алешко, Р. А., Гурьев, А. Т. (2013). Структурное моделирование взаимосвязей дешифровочных признаков спутниковых снимков и таксационных параметров лесных насаждений. Труды СПИИРАН, 6(29), pp. 180–189. e-ISSN 2078-9599. ISSN 2078-9181.
17. Martino, P. (2014). *A First GPS Measurement of Vertical Seafloor Displacement in the Campi Flegri Caldera (Italy)*. Naples, Elsevier.
18. Haase, J. S. (2014). *First Results from an Airborne GPS Radio Occultation System for Atmospheric Profiling*. San Diego, American Geophysical Union.

# Summary: Take up Actions

This book presents theoretical developments that have been performed within the European research project INFROM (“Integrated Intelligent Platform for Monitoring the Cross-Border Natural-Technological Systems”) and discusses implementation of the developed methods and algorithms in the form of corresponding software tools. Examples of practical application of the developed information technology are introduced as well.

The INFROM project has been carried out in 2012–2014 under the “Estonia – Latvia – Russia Cross-Border Cooperation Programme within European Neighbourhood and Partnership Instrument 2007–2013”. Project implementation includes the following main steps:

1. Analysing the state of the art in space and ground-based monitoring of natural and technological objects;
2. Formulating the project methodology in terms of concepts, principles, requirements and approaches;
3. Developing the innovative information technology for integrated space and ground-based monitoring;
4. Developing integrated distributed information network and support tools for intelligent space and ground-based monitoring in several sample areas, including river floods, forests and water pollution;
5. Performing demonstration cases, including real-time experiments.

These steps are discussed in detail in the book chapters, namely, steps 1 and 2 – in Chapter 1; steps 3, 4 and 5 – in Chapters 2, 3 and 5, respectively.

The following is a brief discussion of the main project developments and results that are presented in the above-mentioned chapters.

The overall objective of the project [1] has been to develop a common intelligent platform for unifying efforts of specialists from Latvia and Russia to protect the environment based on space-ground monitoring of complex systems, including environmental, technological, economic, and social elements. The novelty of the scientific development within the project implementation is cross-functional application of combined methods and techniques for decision support in various monitoring problems, including forecasting and safety control of complex objects.

An intelligent information technology platform has been developed for real-time monitoring and control using heterogeneous data received from space and ground facilities; the technology provides methods and techniques for data processing and integration, predictive modelling, simulation of system dynamics, forecasting, output data visualisation, analysis of control scenarios, and techniques for automatic synthesis of monitoring software. The functionality of the platform is extended by



GIS, mobile technology and social networking for data crowdsourcing. Hardware and software infrastructures have been created that implement a unified approach to environmental monitoring and modelling of natural and technological objects and training of specialists in technology-related software and applications.

Technological solutions and software prototypes have been developed for environmental monitoring of selected cross-border areas and objects that allow automatically processing and applying different types of data and existing knowledge to assess their current state and analyse their possible development scenarios in the future. Different approbation studies have been performed to test and demonstrate functionality of the proposed technology for cross-border areas and objects selected and monitoring tasks defined in collaboration with target groups involved from both Latvian and Russian project areas.

The main outputs and results produced to achieve the project objective and raise an impact on the target groups during its implementation are as follows:

1. Support tools and application cases for environmental assessment and monitoring of selected environmental objects such as Daugava River flood forecasting in Daugavpils (Latvia), forestry inventory and analysis in Madona district (Latvia) and Pskov region (Russia), monitoring of oil pollution in the Gulf of Finland (Russia) and overgrowing of Lubans Lake (Latvia), assessment of the ecological state of Pskov region border area and spatial data processing for Razdolje Rural Settlement (Russia);
2. Real-time experiments performed for operative flood forecasting and visualisation of inundated zones in Daugavpils district with a social action “Daugavpils against Floods” organised through the web page <https://daugava.crowd-map.com/main> and geo-portal <http://flood.aerospaceinfo.ru/> in spring 2013;
3. More than 40 specialists from municipalities and academia have been trained. Target groups from Riga city, Daugavpils, Madona, Gulbene, Aluksne, Lubana and Jaunpiebalga municipalities (Latvia), Pskov region and Razdolje Rural Self-Government Administration (Russia) have actively participated in project conferences, seminars for target groups and trainings, selection of approbation objects, task definition and assessment reviews;
4. The publicity and visibility materials, e. g., press releases, booklets, posters, articles in mass media, radio transmissions, and videos on TV have been produced.

To ensure sustainability of the project results, the international research and educational institutions network and training centre have been created.

The successful cooperation between project partners (Riga Technical University (RTU) and St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS)) for implementation of project activities has provided the synergetic effect in exchanging knowledge and expanding the level of expertise

in the field of monitoring cross-border natural-technological systems. The significant collaboration result is the developed space-ground monitoring system for flood forecasting and performed real-time experiments with a social action “Daugavpils against Floods”.

Project associate partners (Committee on IT and Communications of the Government of St. Petersburg; Latvian Transport Development and Education Association, and Diplomatic Economic Club (Riga, Latvia)) have actively participated in project conferences, seminars for target groups and training organisation for specialists in Russia and Latvia.

The international research and educational institutions network has been created to support further collaboration of partners and target groups after the end of the project.

The impact of the project on the target groups defined for the project and the cross-border region is provided by active involvement of beneficiaries and target groups in the project conferences, joint meetings, seminars and trainings, as well as in the selection of cross-border approbation objects, performing approbation studies and assessment of received practical results. The positive feedback has been received in the assessment reviews from 9 municipalities. Moreover, 40 specialists have been trained in Latvia and Russia to be able to use new knowledge and skills in the interests of their organisations.

The cooperation within the project has resulted in knowledge transfer between the partners, particularly, RTU – in remote sensing data processing and integration of heterogeneous information, and SPIIRAS – in GIS, modelling and forecasting. The cooperation within the project has also led to an increase in the level of partners' expertise in developing monitoring techniques, IT platforms and software, and their competitiveness on the global markets. The SPIIRAS has got possibilities to show innovative aerospace technologies to the target groups in the Latvian project area.

The horizontal policies addressed by the Programme, in particular on sustainable development, environment, public procurement and equal opportunities, have been adequately addressed by the project. The specific cross-border problem addressed in the project is support of sustainable development of partnerships between Latvian and Russian researchers and specialists in the field of integrated ground-space data monitoring and control. The project promotes the research, innovations and joint actions aimed at protection of the environment and natural resources. The main project outputs provide an innovative IT platform, techniques and software prototypes for monitoring and protecting the environment and natural resources. Processed and obtained data have been made equally available to the project partners providing equal opportunities, competition and public procurements for all institutions involved in the project.

The achieved outputs and results cause the multiplier effects resulting in the economic benefits, creation of new workplaces and new business opportunities. The pro-

ject outputs provide efficient intelligent support tools for municipalities, agencies and environmental centres to perform improved environmental assessment based on space and ground data, and to operate quickly in case of technological and natural disasters (e. g., oil pollution, forest changes, river floods, etc.) in order to improve public safety, reduce economic losses and mitigate social damages. The implementation of the developed integrated intelligent platform will provide new workplaces and new business opportunities as well as additional civilian control of the cross-border ecosystems.

## References

1. INFROM project. Available at: <http://www.infrom.eu>. Accessed: 29 April 2014.