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Abstract. This document presents the development of an informational model of instrumental examination of a patient using the data flow diagrams (DFD). The developed informational model of the instrumental examination is presented in the form of a context diagram, its decomposition, and the decomposition of the subsystems «Registration and analysis of biomedical signals and images with locally concentrated features» and «Diagnostics». Taking into account the proposed information model, UML diagrams of the activity of the biomedical decision support system based on morphological analysis of biomedical signals and images with locally concentrated features, of the module for morphological analysis of an electrocardiogram, and of the module for improving the quality of visualization of biological objects on radiological images based on the IMRI method are developed.

1. Introduction

The introduction of information technologies in such an unconventional and conservative area as medicine began in the second half of the 60s of the 20th century with the work of N. M. Amosov [1], who for the first time in the world created a standardized medical history focused on computer use.

The creation of medical information systems (MIS) has begun. In connection with the rapid development of computer and information technology, as well as progress in medical technology, bioelectronics, molecular biophysics, physical chemistry, biochemistry, genetics, immunology, cybernetics, and computer science, there is a development of the theoretical foundations and implementation of MIS in various areas of medicine, the main purpose of which is to increase the efficiency of management processes (medical diagnostic, administrative, financial, and other activities) in health care to improve the quality of medical care to the population.

Currently, there are seven levels of development of these systems [2], from automated medical records to intelligent computer decision support systems in medicine (DSSM) using medical knowledge bases and using intelligent technologies for synthesizing computer diagnostics, monitoring and optimizing the treatment process. The use of MIS of the lower levels saves the medical staff from routine paper work, performs formalized data entry about the patient, accounting and statistical data processing, and so on. In addition, DSSM perform morphological analysis of biomedical signals and images (BMS/I) with locally concentrated features (LCF), automated preparation of diagnostic protocols, optimization and monitoring of the treatment process, and so on, which ultimately reduces the number of medical errors in a priori uncertainty and risk [3–6].

The process of information processing in the DSSM consists of a sequence of stages (from the stage of input and formalization of the initial data to the stage of forming a computer diagnosis and

optimization of the treatment process), and the task of developing the DSSM is divided into many local sub-tasks. Characteristics of the functioning of the DSSM are determined mainly by the choice and correct application of mathematical models and methods for processing biomedical data at all stages of their transformation. When creating such models, it is important to take into account the specifics of both the presentation and the manifestation of clinical information [5, 7].

The most common MIS received in the composition of diagnostic systems in the form of MIS for laboratory and diagnostic studies, through which various instrumental examinations of patients. The laboratory diagnostic MIS includes digital electrocardiological systems, digital X-ray diagnostic systems, computed tomography, ultrasound systems, and so on. Currently, the production of Ukrainian digital electrocardiographic telemetry systems has significantly increased [8, 9]. An example is the transtelephone digital 12-channel electrocardiographic complex «Telecard» developed by TREDEX Company (Kharkiv, Ukraine) [10, 11]. In addition, Ukrainian manufacturers have achieved good results in the development of ultrasound and X-ray equipment. It should be noted here that such developments of the Radmir company (a subsidiary of the Joint-stock company «Scientific Research Institute of Radio Engineering Measurements», Kharkiv) as digital mammographic complexes MADIS and SYMA [12]. Such developments require the creation of appropriate mathematical and software since the use of foreign MIS is associated with a number of difficulties, such as the very high cost of software and the impossibility of upgrading software code, given its closeness.

Thus, the urgent task is the need to create a modern Ukrainian DSSM, which does not have the above disadvantages.

2. Data flow diagram of instrumental examination of patients and of UML activity diagrams

Let us imagine the information model M_I of the instrumental examination using the data flow diagram (DFD) [13]. To build a contextual diagram of the model M_I, it is necessary to define external entities, storages and data flows. At the same time, informational data flows are indicated by solid arrows, and material ones – by dotted ones. In the case when the data flow can be both material and informational, let us designate it as a solid arrow. An example of such a data flow may be a referral to the examination. On the one hand, the referral to the examination is usually made out in the form of a paper document (that is, it is a material data flow), on the other hand it carries information about the purpose and method of the examination (that is, it is an information data flow).

As external entities (EE) we will consider the patient and the medical staff. At the beginning of the examination, the patient brings a referral to the examination issued by the therapist, reports all the necessary information about him, and at the end of the instrumental examination receives the examination report and a list of recommendations. In this case, the patient himself is the object of study, therefore, acts as a material data flow. The medical staff on request for parameters of registration of BMS/I with LCF generates a list of such parameters for setting up the diagnostic complex. Based on the data of instrumental examination and preliminary diagnostic decision of DSSM, the specialist doctor forms the final diagnostic decision.

The instrumental examination is carried out in accordance with the legislation and regulatory documentation, therefore, a set of laws and regulatory documentation should be considered as data store (DS), from which the documents are requested as necessary.

Thus, on the basis of the external entities, storages and flows of data described above, the context diagram of data flows of the instrumental examination model M_I is presented (as shown in Figure 1).

To decompose the context diagram of the model M_I, the following subsystems can be identified (Figure 2): administration of patient (the subsystem 1); registration and analysis of BMS/I with LCF (the subsystem 2); diagnostics (the subsystem 3); formation of an examination report (the subsystem 4). In addition, the following data stores can be identified (Figure 2): patient information (DS 2); database (DB) BMS/I with LCF (DS 3); DB of protocols (DS 4).

Let us describe the information flows of the decomposition diagram of the model M_I of the instrumental examination. Each of the selected subsystems processes the input information into the

output on the basis of the relevant documents that are received at the entrance by the search requests of these documents in the data store «Code of laws and regulatory documents» (DS 1 in Figure 1).
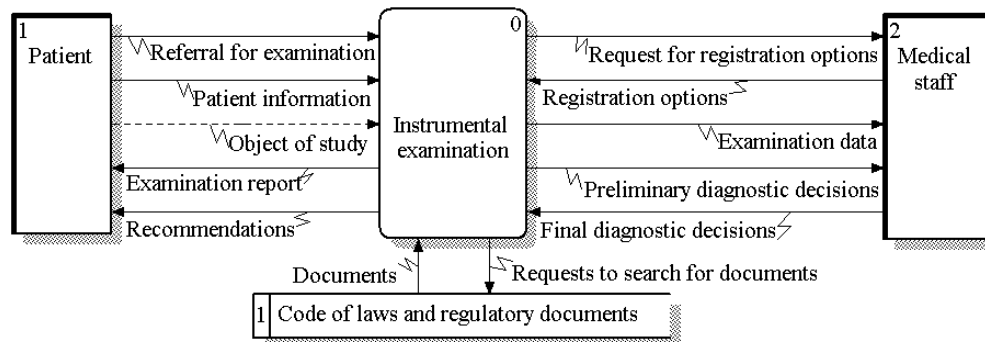

Figure 1. The context diagram of data flows of the instrumental examination model M_I.
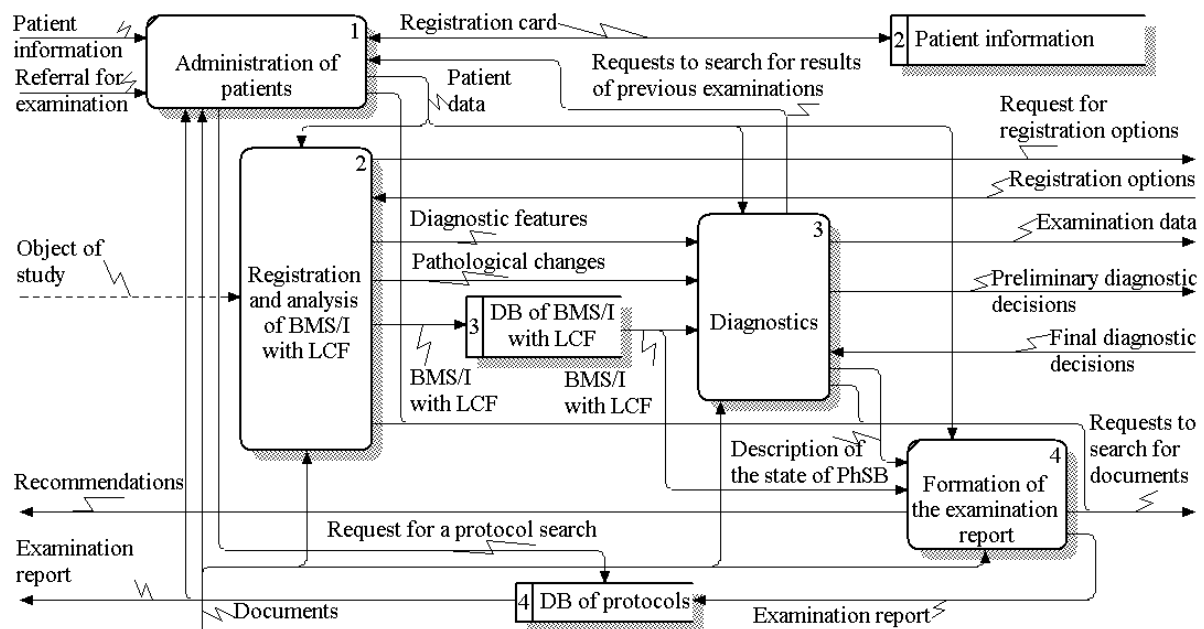

Figure 2. Decomposition of the context DFD of the examination instrumental model M_I.

In the subsystem 1 «Administration of patient», a registration card is filled out on the basis of information about the patient and the referral to the examination. If a patient (EE 1) undergoes an instrumental examination for the first time, a new registration card is entered, otherwise, the registration card of this patient is searched for in DS 2 «Patient information», in which new data is entered. In addition, the results of the examination are entered into the patient's registration card as a link to the appropriate examination protocol. The output of the considered subsystem is patient data which are transmitted to the subsystems 2 – 4, and patient data is transferred to the subsystem 3 «Diagnostics» upon request to search for the results of previous examinations. In the subsystem 2 «Registration and analysis of BMS/I with LCF», the medical staff (EE 2) makes a request for registration parameters on the basis of patient data. The medical staff configures the appropriate equipment of the diagnostic complex and registers the necessary BMS/I with LCF of the object of study. Registered BMS/I with LCF are stored in the corresponding database (DS 3). In addition, as a result of analysis of BMS/I with LCF, there are determined diagnostic features and pathological changes which are transmitted to the subsystem «Diagnostics». In the subsystem 3 «Diagnostics»,

based on the information obtained after analyzing BMS/I with LCF, as well as the primary patient data, examination data and a preliminary diagnostic decision are formed, on the basis of which the specialist doctor (EE 2) forms the final diagnostic decision. Based on the generated final diagnostic decision and examination data, a description of the state of the physiological systems of the body (PhSB) is formed, which is transmitted to the subsystem «Formation of an examination report». In the subsystem 4 «Formation of an examination report», based on the description of the state of PhSB, registered BMS/I with LCF and patient data, there is generated an examination report which is stored in the database of protocols (DS 4).

Since the subsystems 2 and 3 are of the greatest interest, let us perform further decomposition of these systems into relevant activities. For the decomposition of the subsystem 2 «Registration and analysis of BMS/I with LCF» the following activities are allocated (Figure 3): registration of BMS/I with LCF (the activity 21); preprocessing (the activity 22); morphological analysis (the activity 23); parameter analysis of structural elements (SE) (the activity 24). In this case, the following data storages are identified (Figure 3): models of useful one-dimensional signals (MUODS) or models of useful two-dimensional signals (MUTDS) (DS 5); rules of morphological analysis (DS 6); parameter ranges of structural elements (DS 7); rules for analyzing the parameters of structural elements (DS 8).
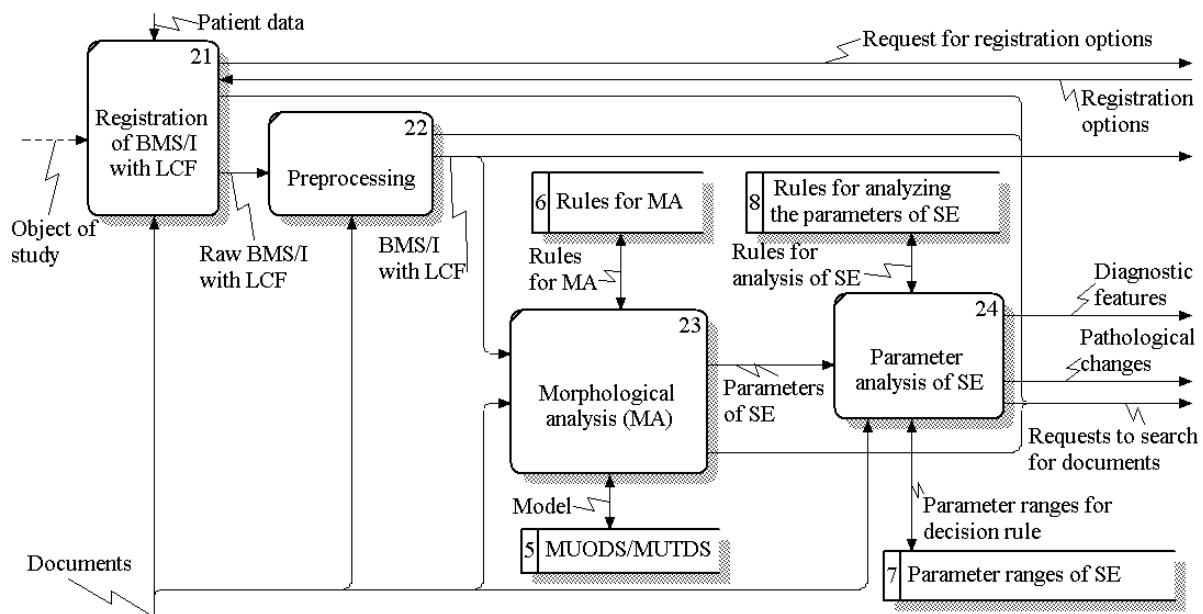

Figure 3. Decomposition of the subsystem «Registration and analysis of BMS/I with LCF» of the examination instrumental model M_I.

All of the above activities are performed on the basis of the relevant documents which are received at the entrance by the requests for the search for these documents from DS 1 «Code of laws and regulatory documents». The input data flows for the activity 21 «Registration of BMS/I with LCF» are the necessary patient data obtained from the subsystem 1 «Administration of patient» and registration options received from the medical staff (EE 2) on the corresponding request for registration options. In this case, the material data stream is the patient himself as an object of study. As a result of this activity, there are recorded the necessary signals or images which are fed to the input of the activity «Preprocessing» in the form of raw BMS/I with LCF. As a result of the activity 22 «Preprocessing», the preliminary processing of raw BMS/I with LCF is carried out using digital signal and image processing methods in order to improve their visual quality. Received BMS/I with LCF arrive at the input of the activity «Morphological analysis». The input data streams for the activity 23 «Morphological analysis» are BMS/I with LCF, obtained as a result of preprocessing, the useful one-

dimensional signal model or the useful two-dimensional signal model obtained from DS 5 of MUODS/MUTDS, as well as the rules for morphological analysis, obtained from DS 6 «Rules for MA». As a result of the activity under consideration, there are determined the parameters of the structural elements which are fed to the input of the «Parameter analysis of SE». The input data flows for the activity 24 «Parameter analysis of SE» are the parameters of structural elements obtained as a result of morphological analysis, the parameter ranges for the decision rule obtained from DS 7 «Parameter ranges of SE», and rules for the analysis of structural elements, obtained from DS 8 «Rules for analyzing the parameters of SE». As a result of the activity under consideration, diagnostic features and pathological changes are determined which, along with BMS/I with LCF (output of the activity 22), are outputs of the whole subsystem 2 «Registration and analysis of BMS/I with LCF».

For the decomposition of the subsystem 3 «Diagnostics» the following activities are defined (Figure 4): administration of examination (the activity 31); assessment of state dynamics of PhSB (the activity 32); evaluation of treatment effectiveness (the activity 33); diagnostic decision making (the activity 34). In addition to these activities, the data store 9 «Diagnostic decision rules» is allocated.
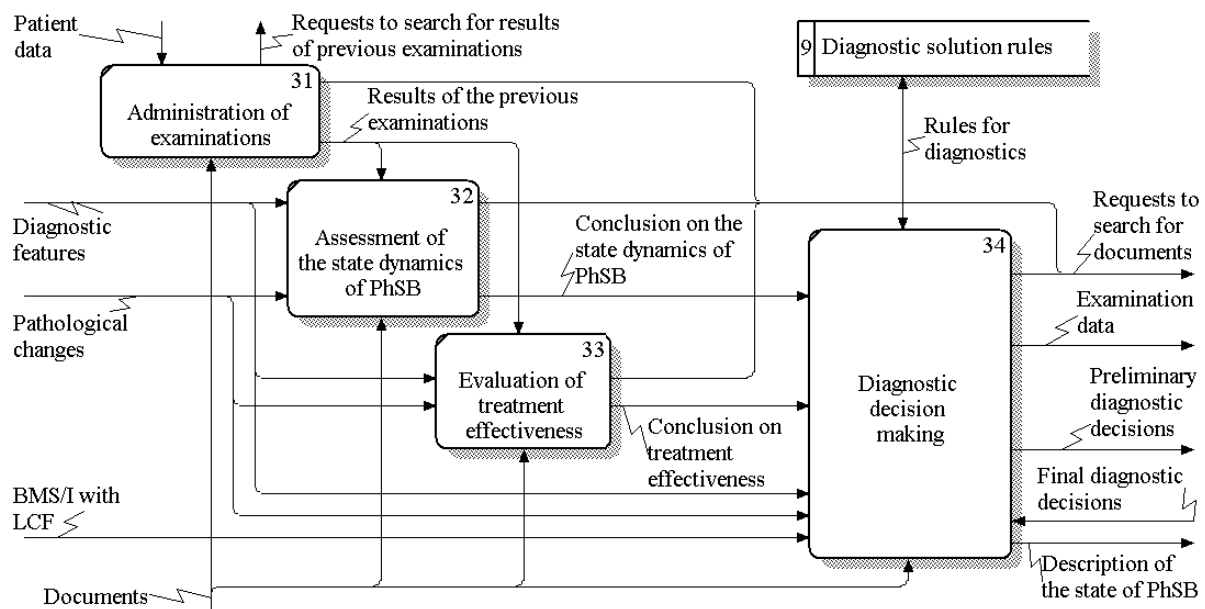

Figure 4. Decomposition of the subsystem «Diagnostics» of the examination instrumental model M_I.

As in the case of the activities of the subsystem 2 «Registration and analysis of BMS/I with LCF», all of the above-mentioned activities of the subsystem 3 «Diagnostics» are performed on the basis of the relevant documents that are received at the entrance to the search requests for these documents from DS 1 «Code of laws and regulatory documents». As a result of the activity 31 «Administration of examinations», a search is made for the results of previous examinations from patient data obtained upon request to search for the results of previous examinations. The results of previous examinations are received into the input of the activity 32 «Assessment of state dynamics of PhSB» (if previous examinations were performed as a result of, for example, screening) or of the activity 33 «Evaluation of treatment effectiveness» (if previous examinations were performed before treatment). If no previous examinations are found, then the activities 32 and 33 are not performed. In the case of performing the activity 32 «Assessment of state dynamics of PhSB», information about diagnostic features and pathological changes as well as the results of previous examinations are received into its input, and a conclusion on the state dynamics of PhSB is formed at the output (positive, negative dynamics or lack of dynamics). In the case of performance of the activity 33 «Evaluation of treatment effectiveness», as in the case of the activity 32 «Assessment of state dynamics of PhSB», its input receives information

on diagnostic features, pathological changes and results of previous examinations, and at the output a conclusion on treatment effectiveness is formed. The obtained conclusion on the state dynamics of PhSB or the conclusion on treatment effectiveness and BMS/I with LCF are input to the activity 34 «Diagnostic decision making». Using diagnostic rules obtained from DS 9 «Diagnostic decision rules», a preliminary diagnostic decision is formed, according to which, along with the examination data, the specialist doctor (EE 2) forms the final diagnostic decision. Based on the final diagnostic decision obtained, a description of the state of PhSB for the subsystem 4 «Formation of the examination report» is formed.

The proposed information model M_I of the instrumental examination is the basis for developing the information structure of DSSM. To simulate the behavior of the DSSM, it is necessary to detail the features of the algorithmic and logical implementation of the DSS operations performed.

To describe the behavior of the system and its individual elements (behavioral models), let can use the UML activity diagram. On the basis of the developed information model of the instrumental examination of the patient, as well as the generalized structural diagram of DSSM proposed in [14], a UML activity diagram of DSSM is developed based on the morphological analysis of the BMS/I with LCF presented in Figure 5.
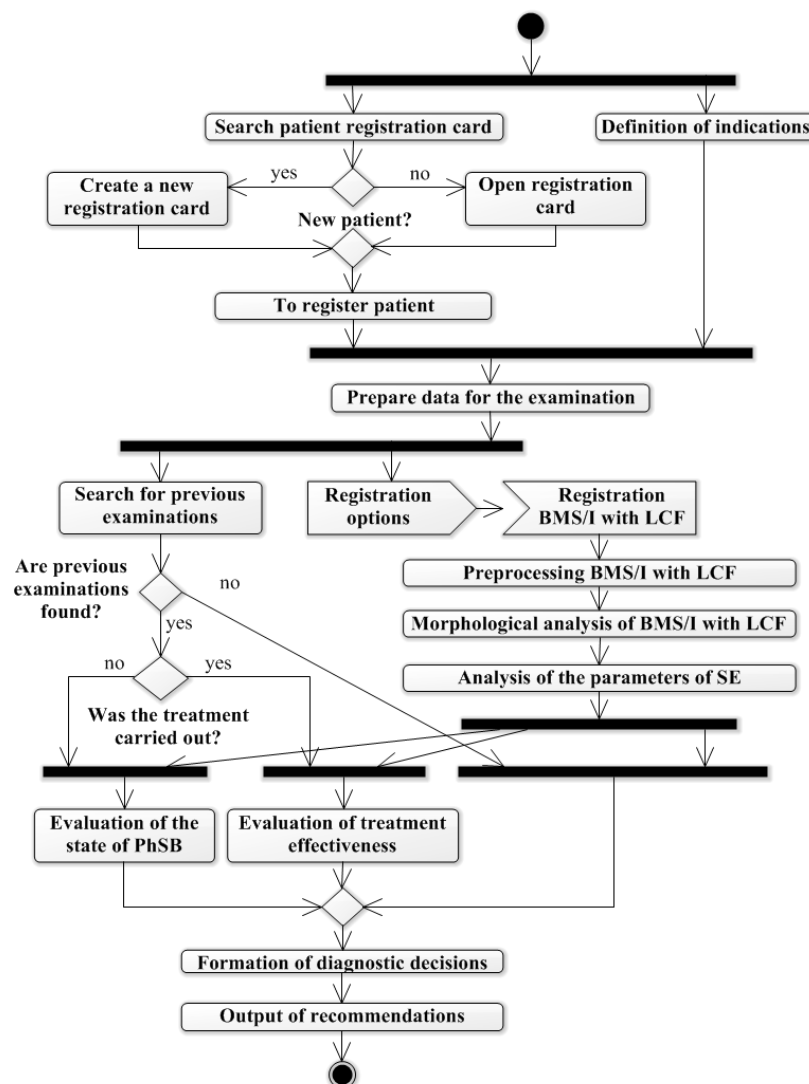

Figure 5. UML activity diagram of DSSM based on the morphological analysis of the BMS/I.

In addition, for the algorithmic and logical implementation of the operations performed in the morphological analysis module, which implements the method of matched morphological filtering of ECG [15], and in the module of preprocessing BMS/I with LCF, which implements the IMRI method of improving the quality of X-ray imaging [16], corresponding UML diagrams of activities are developed presented in Figure 6 and 7.
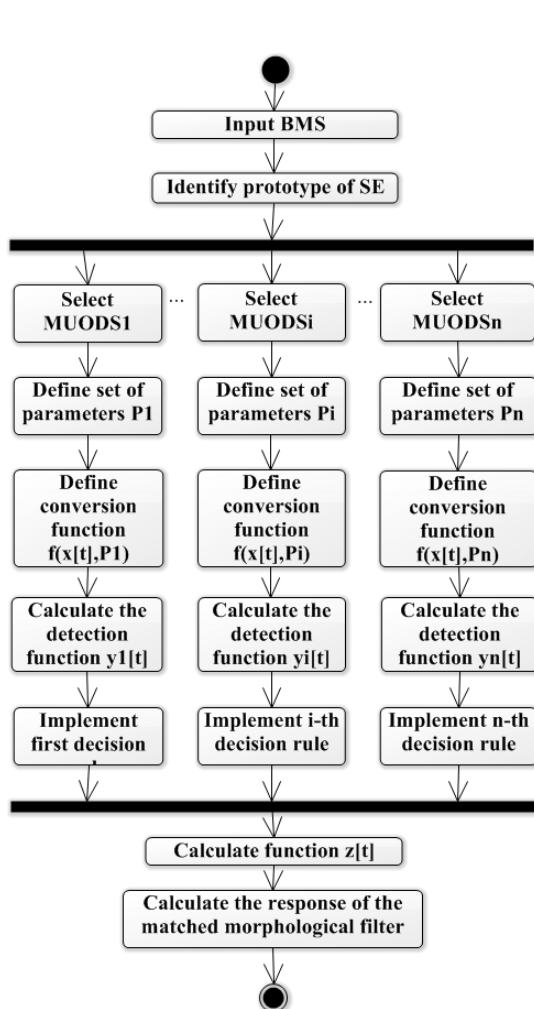

Figure 6. UML activity diagram of the morphological analysis module of ECG
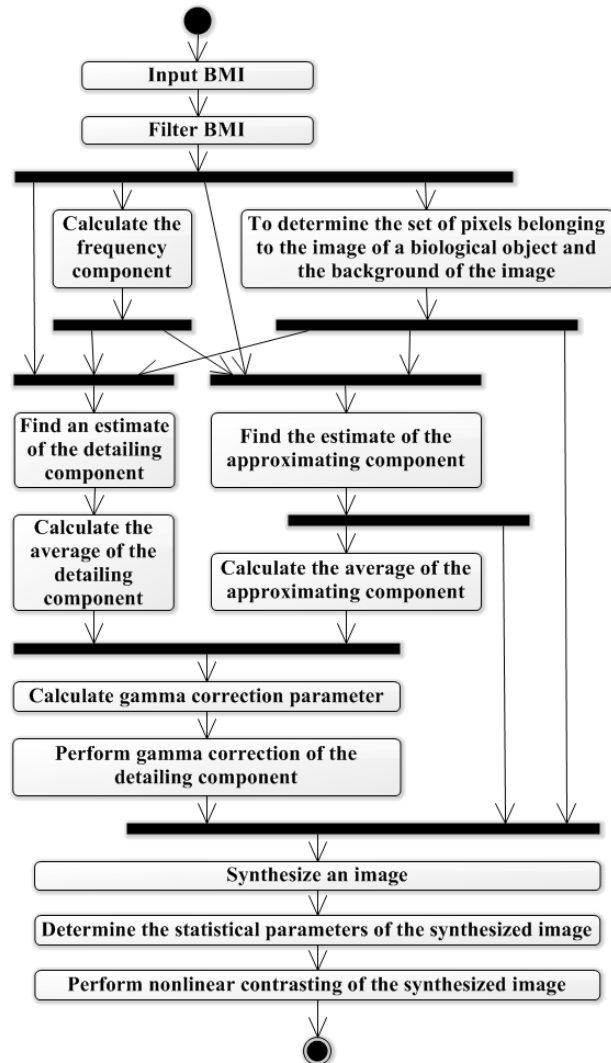

Figure 7. UML activity diagram of the module for improving the visualization quality of biological objects on X-ray images based on the IMRI method

Based on the developed UML activity diagram (Figure 7), the software of the module for improving the visualization quality of biological objects and their structural elements on X-ray images was created, which implements the IMRI method, which is confirmed by the certificate of registration of the copyright to the computer program [17].

3. Conclusions

The information model of the instrumental examination of the patient was developed, taking into account the stages of transforming information obtained including from the recorded biomedical signals and images. Decomposition of the subsystem «Registration and analysis of BMS/I with LCF» and «Diagnostics» showed that one of the most important activities is the activity «Morphological

analysis», as possible errors in the determination of diagnostic features obtained on the basis of the founded structural elements can lead to incorrect diagnostic decisions. In addition, the causes of such errors may be registered BMS/I with LCF of poor quality, therefore, the activity «Preprocessing» is also very important. The proposed information model of instrumental examination of the patient made it possible to develop UML activity diagrams of DSSM based on the morphological analysis of BMS/I with LCF, of the ECG morphological analysis module and of the module for improving the visualization quality of biological objects on radiological images based on the IMRI method.

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