# Substantiation of the Required World Model Configuration for Autonomous Mobile Medical Service Robots

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Abstract: Development of smart mobile service medical robots is the actual and interesting problem in the modern biomedical instrumentation. This study is aimed at development of the theoretical basis of the modern medical robotics, in particular, of the theory of autonomous mobile service medical robots. Based on the expert analysis of typical scenarios of behaviour of service medical robots in clinics, the necessity of development of reasoning-based robots with built-in world model was substantiated. It was shown, that the development of the world model should be the key start point of all the process of development and design of such robots. General technical requirements for the robot's world model, for its composition and functionality, were formulated. It was shown also, that the world model of such robots must maintain a database of precedents of various events and must work taking into account both embedded instincts of the robots and general rules of the World.

## 1 INTRODUCTION

One of the sections of the contemporary robotics is medical robots, and in particular – autonomous mobile service medical robots (AMSMR) (Butter *et al*., 2008; Wang *et al*., 2006; Rogatkin *et al.,* 2013). The first AMSMR named "AMS-car" appeared in the middle 1970s in the Fairfax hospital (USA) to move containers with food trays for patients. From this moment, the idea of introduction of AMSMRs into the health care system has been flying up in the air, because there was a great need in medicine for diligent and exact implementation of plenty of different routine transport, information, and other auxiliary service procedures. Today, there are hundreds of articles in journals as well as in Internet devoted to different AMSMR including one of the first projects – «HelpMate» – the project of the transport service robot for delivery of different drugs, analyses, materials, and documents inside a hospital (Evans, 1994). Also, it is well-known the Russian robot «R-Bot» for telepresence in hospitals (http://www.plasticpals.com/?p=26770); the project of remote-presence medical robots «RP-7» and «RP-8» – information robot-manipulators allowing oral and visual communication of physician with a patient from any point of the Globe (Wang *et al.*, 2006), and a number of other similar projects. The last generation of the "RP" robot family – robots of the "RP-VITA" series – was approved in 2013 by FDA, and its invasion into clinics was really started (see in http://www.intouchhealth.com/products-and-services/products). Robots "RP-VITA" can move themselves round the clinic territory, find up the room of interest and a patient's bed without human participation. A doctor must only point out the aim for the robot by pressing the corresponding button.

However, the majority of publications about all these projects in different conference proceedings as well as in Internet have neither scientific nor engineer or technical features. They are of only advertising (demonstrational) character in the vast majority of the publications. They describe different robot resources and demonstrative examples of its usage without detailed and systemic technical description of concrete scenarios and algorithms of the robots' behaviour in clinics, without their target functions, without general fundamental regularities and (or) scientific background for development and design of both hardware and software for such robots. Meanwhile, in reality, AMSMR is an automatic, electronic, and mechanical medical equipment. Therefore, both the general system of medico-technical requirements according to existing



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standards and specialized demands, for example, for design of software exclusively specific for medical applications, in some degree or other, must be applied to AMSMR. Thus, there is an obvious gap in the engineer theoretical background for AMSMR.

Undoubtedly, during past several years, the theory of service robots for different fields of human activity including medicine became already an object of investigations (Fiorini *et al*., 2013; Rogatkin *et al*., 2013; Towle *et al*., 2014), though quite recently the majority of classical monographs on robotics (Young, 1979, for example) didn't refer to such studies. Voluminous articles and books on this subject described particular problems of construction of mechanical manipulators and (or) clamps, sensors, elements of mobile parts of the robot, and so on, but had none of the general theoretic problems of software elaboration for autonomous mobile service robots, especially for medicine. Only since recently, a special attention is paid to fundamental scientific mechanisms of the software development for service robots (Iborra *et al*., 2009; Somby *et al*., 2009; Towle *et al*., 2014). But, in the first place, it still concerns the design of the specialized software (ROS, Microsoft Robotics Studio, Skilligent) for developers and development of additional languages for high level programming in robotics (LABVIEW Robotics Module, for example). Until now, really smart AMSMR don't exist in our hospitals due to the complex problem of creation of intelligent machines. Today, there aren't general methodical manuals and rules for engineers how to create them. What should be done as the first step on this way? Should we create a hardware or a software first? In fact, this situation is preventing the worldwide adoption of robots as efficient service machines (Mastrogiovanni and Chong, 2013). For overcoming this situation, the real integration between techniques of artificial intelligence and a practical robotics should be reached.

The main objective of our theoretical study is the investigation and elaboration of general scientific approaches to the formal engineer description of the problem of AMSMR projecting and development, in particular – a formulation of scientifically grounded demands to the software for AMSMR. Firstly, in the section 2 of the present article, the basic concept (scenario) of AMSMR functioning in clinics is considered. In robotics research, in the general case, a formation of a scenario of a robot behaviour is not a novel clime. But for AMSMR we don't know such concept and results, which have been published and accepted by all. Secondly, we analyze the results of the proposed concept and formulate a number of its consequences. The main one - the generalized task of clinical AMSMR functioning is a finite task, limited (restricted) both in physical building space and in a space of possible decisions and actions, and is of the closed type, i.e. all possible situations and a spectrum of various methods of their resolution can be exhaustively described in the closed form. Another important consequence – only smart, intelligent AMSMR can follow the scenario in a full scale. So, AMSMR should have in its "brain" a full-scale World Model (WM), containing all necessary information about each object as well as about each possible situation in the robot's World. Formation of the internal WM of the "reasoning-based" AMSMR as the key element of its software is discussed in the section 3. Needed WM configuration and its functionality are substantiated there, as well. All these gives the answer on the question about the order of the AMSMR development and design.

## 2 CONCEPT OF AMSMR FUNCTIONING IN HOSPITALS

At the initial stage of our study, we interviewed physicians and patients of different departments of the multi-clinical and multi-functional medical research centre "MONIKI" and received the verbal description of the most prospective AMSMR applications in the health care system (from the point of view of both physicians and patients). Then, all results of these interviews were classified, generalized, and analyzed by the method of the expert assessment. On the basis of the outcome, in addition to the telepresence (remote-presence) function, which is often mentioned in publications as the main useful function for AMSMR, the following important and prospective tasks were also determined which are very interesting to solve and which can be solved with the help of AMSMR in real clinical practice:

- interactive lecture-excursion (10-15 minutes) for patients at the moment of admission to the hospital about daily routine in it, about building plan (wards, shower-bath, dining-room, etc.), therapy regimen, feeding, walking in the air, etc.;
- information of patients about the time of diagnostic and (or) treatment procedures, repeated reminding about it 15-20 minutes before the fixed time in the concrete day;
- searching within the clinics for a given patient, physician, or a nurse to inform them about concrete instructions, problems, including the urgent ones;

- delivery of drugs and medical materials to patients in their wards;
- delivery of food to the bed patients, removal of waste and scrap products of them;
- listening (recording) to requirements and complaints of patients and passing these information to medical personnel;
- a series of other similar informational, searching, and (or) transport tasks.

These functional duties of AMSMR (service and assistant functions) appeared to be common for the majority of departments of the multi-functional medical centre, and, consequently, they are typical to every medical institution of the health care system. Moreover, it becomes clear from the list above mentioned, that the vast majority of prospective scenarios of AMSMR behaviour is associated with a transport as well as with information-searching tasks within the limits of the room-type territory. Shortly speaking, AMSMRs are needed in hospitals to implement quite compact and rather unified set of simple instructions, such as: to implement different errands associated with seeking an object of interest, interaction with different objects, delivery of objects, receiving and storage information from people, information processing and transmission to other people.

It makes the generalized task of AMSMR functioning a finite one, limited (restricted) both in physical building space and in the space of possible decisions and actions, and of the closed type, i.e. all possible situations and a spectrum of methods of their resolution can be described exhaustively in the closed form. It allows us to create an abstracted and strictly formalized description of the generalized concept of AMSMR functioning in hospitals (Fig.1):

All tasks should be resolved by AMSMR algorithmically at the expense of its moving through the room-type territory to search for and then to contact with external objects (physician, patient, medical equipment, furniture, etc.), which all are programmed inside its WM as a set of variables for identification and communication. The robot moves around a clinic in order to solve the concrete task $T_i$, which is put before it by an external operator (physician or a patient). Various situations $S_i$ rise up during the robot motion including urgent ones (for example, a primary passage is blocked by an obstacle) which should be solved by AMSMR itself, without any operator participations. Also, AMSMR must be able to put and to solve intermediate situational tasks and subtasks $t_{ij}$, to create a situational behavioural strategy $Str_{ij}$, as well as to formulate its own situational target functions $Q_{ij}$ with special particular purposes (going round the obstacle, accumulator recharging, etc.). And only in the absolute insoluble situation the robot should stop completely and give an alarm signal of calamity (feebleness).

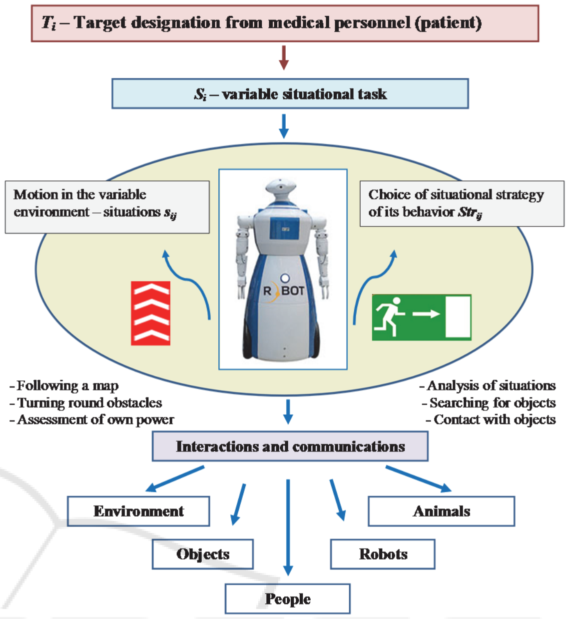



Figure 1: Generalized concept of AMSMR functioning in hospitals.

This general concept shows, that AMSMR must operate with various objects and terms (territory, room, passage, obstacle) in a complex environment, must "understand" both the regularities of mutual positions of these objects and possible changes in their locations in the space of clinics, as well as must take into account the logic and the history of such changes, providing a semantically meaningful interpretation of all these object interactions and a motion within a scene, especially if one of the participants within the scene is a man. Therefore, only smart, intelligent AMSMR can follow the scenario in a full scale; and the key element of AMSMR should be the full-scale WM in its "brain", containing all necessary information about each object as well as about each possible situation in the robot's World.

Today a number of approaches is known to formation of such WM for autonomous mobile robots (Roth *et al.*, 2003; Burgard *et al.*, 2008; Elfring *et al.*, 2013). However, the overwhelming majority of such WM are de-facto a simple geometrical description of the territory map and objects location in the indoor environment (Kułakowski *et al.*, 2010). They describe statistical panorama (situation) of the territory, but tell nothing of the history, logic, and the possible ways of this situation development with time. Such WM are, definitely, needed, but it is only one of the elements of the really required, full-scale, effective and workable WM for AMSMR.

Some publications (Burgard *et al*., 2008; Elfring *et al*., 2013)) indicate that a set of special semantic attributes of the objects describing sense (semantic) associations between all objects are needed to create WM of full workable. To our opinion, WM presented by B. Coltin *et al* (Coltin *et al*., 2010), is the most similar to the real required WM for "smart" AMSMR. It offers a modelling approach that differentiates among the motion models of different objects in terms of their dynamics, namely the static landmarks (e.g., goal posts, lines, corners), the passive moving ball, and the controlled moving robots, both teammates and adversaries. In their article WM is a tuple {O, X, S, M, H, U}, where: O is the set of labels of objects in the World, X is the set of possible object states, S is the set of possible sensor readings, M is the set of models of the objects, H: MxO→X is a hypothesis function that returns the current state of an object, U: MxOxS→M is the model update function. Perception of the state of the World by the robot with such WM is the most complete today, but, unfortunately, this WM is restricted by the objects of the football playing situation only. It is based on the concrete football-game data of robot's sensors (tuple S), and, therefore, it is not widely applicable for the more general types of robots, for AMSMR, for example.

# 3 GENERAL CONCEPT OF THE FULL-SCALE WM FOR AMSMR

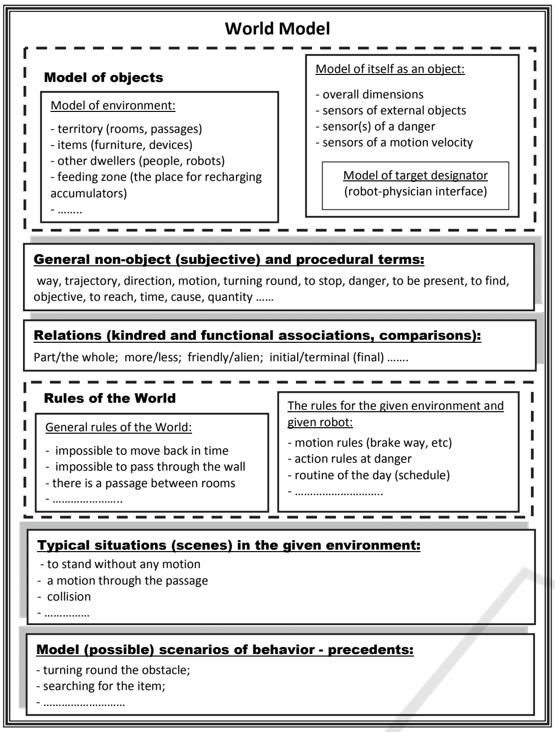
In our study, the general concept of the object-oriented WM is being elaborated for AMSMR. It is based on the abstraction from the concrete hardware of AMSMR and underlain by an assumption that all sensor organs of the ideal AMSMR as well as its object-recognition system allow separating from the information entering AMSMR sensors all necessary object identification signs installed within WM about the objects being observed. This, in its turn, enables exact identification of all objects by the robot, i.e. AMSMR is assumed to have ideal sensors and perfect object-recognition systems. How do the sense organs and the object-recognition systems work – it is a question beyond the concept under consideration, because only general fundamental principles of the "high level" WM functioning are an important subject of our investigation without detailing of how the sensor system and the object-recognition one works.

To make it simpler, the first stage of our study was restricted by a static description of the WM of 2D space. The general regularities of situational location of the robot and external objects in environment as well as general rules of their possible associations and an interrelationship were studied. It was shown that such a task for AMSMR requires formation of reasoning in the robot's "mind". The robot is to act on the basis of situational cases and extrapolation of a situation development. According to classification, such a robot is attributed to intellectual dynamic systems acting situationally in multi-agent surroundings based on adaptive logic reasoning and precedents (reasoning-based adaptive AMSMR). Therefore, formulizing causal rules of the World within the frames of the logic of the 1st order predicates calculation is necessary for the "smart" robot WM, with regard to the time and modality factors (temporal and modal logics). In addition, a list of environmental objects and its properties, as well as the knowledge of the intra-environment behaviour of them, definition of the dictionary of predicates, functions, constants, and a database of typical situational tasks in the environment are required. The block of prognosis and planning of situation development should be one of the blocks of WM functionalizing, as well. Shortly, WM of AMSMR, in the general case, should involve not only a structuralized set of categories (objects) of the environment and their characteristics but also should involve the means of description of the possible semantic associations between all objects, their possible interrelations, rules of such interrelations.

All these determine the needed structure of WM (Table 1). It must include, in addition to models of external objects (rooms, furniture, medical equipment, etc.), some general non-object and procedural (functional, semantic, etc.) terms: way (distance, trajectory), direction, motion, danger, to be present, to search for, to find, to implement, cause, quantity, etc. It distinguishes our full-scale WM from WM of other authors. In our WM, the general relations and kindred associations between objects are also determined: faster/slower, part/whole, friendly/alien, etc. Based on these terms, the basic rules and relations in the World are formulated.

As it was shown, all rules (regulations) existing in WM can be conditionally divided in 2 categories.

Table 1: World model composition.




General World regulations and rules independent of the concrete robot environment (general philosophic regulations of the world) can be attributed to the first category. To the second category attributed are laws and rules currently in force for the given concrete environment (clinic) and for the given concrete robot design. All these rules may be formulated as the sense logical statements (predicates) as follows:

1. There is a closed-type set of non-crossing concepts (terms) in the world: object, property, rule, quantity, cause, consequence, time, space, etc.
2. Any task or situation in the World can be described using these concepts.
3. In the World there are many external objects, characterized by different sets of its properties, which can be detected by sensors (sense organs).
4. Objects of the World can be simple and complex (consisting of other objects).
5. There is a basic set of strong (non-changing) rules and restrictions in the World.
6. The life goes on in the environment determined by the territory map.
7. Each existing object has its own location in the environment.
8. There is a single location for each object in the given moment of time.
9. Two different objects cannot be located in one place in the given moment of time.
10. It is impossible to return back in time.

Such system of knowledge and rules enables description of WM in the most natural way for the human beings. In total, the set of the object models and the world rules must allow description of all typical situations (scenes) possible in the chosen environment. The sequence of scene sets organized in time must allow modelling possible situations, predicting and planning the robot behaviour.

The AMSMR model itself is, also, an important element of WM. It allows a robot to determine itself as an element (object) of the World able to move, communicate with other objects, and simultaneously (in a certain way) as a special “subject” of the World, which means impossibility to ordinary communicate with itself (with the object “I am”) like with other objects. For example, it is impossible to search for itself. The latter requires the presence in WM several models of the robot’s “physical” and “analytical” opportunities. The important and necessary element characterizing WM of AMSMR is an interface of a target designation, i.e. the “robot-physician” interface, which allows to realize all information interchanges with physicians and to perceive from them all orders for implementation.

However, the given model tells nothing yet about motives of the robot activity. It isn’t locked in the sense of the absence of the tasks for the robot. For efficient AMSMR functioning, a target designation or other motive for its activity is required. But it is well-known, that the task of the target designation cannot be solved today in a frame of the artificial intelligence theory (Russel *et al*., 1995, 2003). Therefore, it has to be solved additionally by formulation or determination of the external tasks and external motivations for the robot activity (motivation from “outside”). In this case, all motivations should be ranged by priorities to exclude indefiniteness in the case of multitask situations. In our project, we offer the following postulate as a rule for any action motivation: the robot acts according to the “instincts” programmed within it. The example of instincts (with priority diminishing) may be as follows:

- instinct of saving the human being (avoiding collision, warning about danger)
- instinct of self-preservation (avoiding collision, falling down, overheating, etc.);
- instinct of hunger (taking urgent steps to satisfy the hunger when batteries are discharged);
- fear of the unknown situations (avoiding situation non-modulated within the given WM);
- instinct of execution of the target designation: to act in the case of the target designation from a

doctor or a patient;

- instinct of "laziness" (to act if a motive is present; otherwise, to return home and "sleep") – a condition for "locking" the general task of the AMSMR functioning. Here, the "home" is the place for charging batteries.

The last instinct is the main procedure for the AMSMR to act. It determines the main loop of the robot's activity in its software.

# 4 CONCLUSIONS

We have tried in our study to develop the new, formal and scientifically based engineer approach for soundness of technical requirements to AMSMR "from the first principles". The expert analysis of the basic scenarios of AMSMR behaviour in clinics enabled classification of such robots as intellectual dynamic systems acting according to a situation in a multi-agent environment and basing on adaptive logical reasoning. AMSMR are expected in clinics to implement different errands associated, mainly, with seeking an object of interest, interaction with it, receiving and storage information from people, information processing and transmission to other people. As it was shown in the study, to follow the scenario in a full-scale, such a robot must have well developed model of our World – the World Model (WM). Studying the principles of WM functioning showed that WM should involve, in addition to the models of all external objects, some general non-object and procedural terms (to find, to be present, to execute). Semantic relations between objects should be also determined, as well as the basic world rules (impossible to pass through the wall, etc.) should be formulated. The model of AMSMR itself should also be given in WM, and its behavioural instincts as general motivations for a robot to act should be formulated and determined, as well. It distinguishes our WM from other ones. Correctness and efficiency of the offered approach should be proved by further experiments, but it is evidently now, that the first and key step of AMSMR design and development is the WM configuration design.

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