An Experimental Study of Personalized Mobile Assistance Service in Healthcare Emergency Situations

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***Abstract*—Chronic diseases currently account for most deaths in the world. Despite the fact that these illnesses are generally incurable, they are often preventable and manageable, and concomitant risks are reducible. In particular, acute out-of-hospital complications of the chronic conditions can pose a threat to health and life. Nevertheless, in the case of early detection and timely treatment the remote patient has a good chance to survive. The success of the early management and resuscitation is directly related to the arrival time of the emergency medical services. In our approach, a mobile health (m-Health) service is introduced to healthcare. The service supports involvement of trained volunteers to first aid and resuscitation, dispatching them depending on the proximity to the patient, and provide a guidance. Our design concept of this service is heavily relies upon the smart spaces paradigm, namely, the personalized assistance in medical emergencies is delivered to mobile participants operated in networked environment as a result of knowledge reasoning over the shared information. In this paper, we study the architecture and key features of the service and its smart m-Health space. We experimentally evaluate the Smart-M3 based implementation to analyze the feasibility and applicability of such mobile information services for the case of medical emergencies.**

***Keywords*–healthcare; medical emergency; m-Health; personalized assistance service; smart spaces; Internet of Things; Smart-M3; performance evaluation**

I. Introduction

Over the last few decades, mortality of chronic diseases has decidedly risen and now they are the leading cause of death and disability worldwide, surpassing the infectious and acute ilnesses [1][2]. Almost half of the total chronic disease deaths are attributable to cardiovascular diseases (CVD), which is umbrella term for all diseases related to heart and circulation, including, but not limited to, coronary heart disease, heart failure, stroke and atrial fibrillation [3].

Due to the long-term and, mostly, outpatient treatment, complications of these diseases can be developed between visits to the doctor and resulted in acute worsening of chronic conditions. According to statistics, most heart disease deaths occur suddenly outside the hospital [4]. Most sudden deaths from CVDs are caused by a heart attack or acute myocardial infarction (AMI) with the survival rate 60–70% [5], and out-of-hospital cariac arrest (OHCA) with the survival rate 7–11% [6][7].

It is proven that the survival from OHCA is utterly time-sensitive and in case of immediate treatment the chance of survival is roughly 67% [8]. However, it rapidly decreases and after 12 minutes the patient dies almost inevitably [8]. Due to the hospital locations, traffic conditions and lack of free ambulance staff, the ambulance response time may vary over a wide range. Moreover, for better survival rate the so-called “chain of survival”, namely, a particular sequence of actions should be carried out. Among the links of this chain, the cardiopulmonary resuscitation (CPR) should be fulfilled, and being provided by bystanders, it extremely increases the survival chances [9][10].

Decreasing the emergency response time can be based on an integrated approach to healthcare. The approach aims at achieving the following properties.

1) Remote tracking out-of-hospital CVD events and outpatient care by means of continuous monitoring of the vital signs with personal wearable sensors and reliable identification of health state worsening.
2) Involving the bystanders and trained volunteers to the process of early management in healthcare emergency situations.
3) Supervising patients and caregivers with recommendations provided by personal digital assistants—information services—running on mobile devices.

The above properties characterize the growing class of mobile health (m-Health) systems, where the classic style of patient’s health monitoring by visiting a hospital is substituted with more effective and intelligent solutions [11]. They are essentially enabled by the progress in technologies of the Internet of Things (IoT) and smart spaces. An mHealth system is responsible to support and provision of healthcare services using mobile communication devices, such as mobile phones and tablet computers. Mobile devices are primarily responsible for collecting medical data, delivery of healthcare information to participants, real-time monitoring of patient vital signs, and direct provision of care (via mobile telemedicine).

In addition to the patient mobility requirement, mHealth services are essentially data-driven. They should produce “smart assistance” decisions on the basis of individual health data and a context information gathered from a variety of sources [12][13]. In this paper, we study the problem of reducing IT set-up costs and improve the quality of such mHealth services. Specifically, our approach is directed to the minimization of risk of CVD complications due to improvement of prevention, early diagnostics, forecasting of development of the disease. The service implementation is based on Smart-M3 platform [14]. The platform provides a promising open source solution for smart spaces based systems in IoT environments [15][16].

We consider a smart spaces based system for assistance in healthcare emergency situations. The use cases and system design were proposed in our previous work [13][17][18]. The focus of this paper is on experimental study of the architecture, the key features of the service and the created smart m-Health space for the patient. We experimentally evaluate our Smart-M3 based implementation to analyze the feasibility and applicability of the approach to mHealth development in the

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particular healthcare case of emergency assistance.

The rest of the paper is organized as follows. Section II introduces enabler solutions that are used in the service development. Section III describes our pilot implementation of the mHealth assistance service for emergency situations. Section IV provides the key results of the experimental evaluation. Finally, Section V concludes the study.

II. Enabler Solutions and Related Work

Let us consider solutions from IoT and smart spaces that enable development of the considered class of mHealth services. Most of the discussed solutions have been elaborated in our previous work.

The possibility to provide mobile healthcare service, outside of hospital, is a clear result of the emerging IoT technology, including the use of wireless sensors and personal mobile devices. As a reference health parameter the service can use the electrocardiogram (ECG) recordings obtained from personal cardiomonitor. An example mobile application of this health parameter monitoring is CardiaCare [19]. The application runs on a smartphone communicating with a heart activity monitor used by the patient. This variant of assistant service with heart rhythm analysis is pure local: arrhythmias detection for the heart function is performed directly on the smartphone.

The data heterogeneity problem for personal and body-area medical and well-being devices is discussed in [20][21]. One solution [20] is the enterprise service that guarantees interoperability and integration. For this purpose the intermediate semantic middleware is provided. Our solution [21] involves the architecture of the background service running on the smartphone. The architecture supports mashup health parameters gathered from a variety wirelessly connected sensors. Furthermore, a relational data model is proposed in [22], which is agnostic to the stored health parameters and supports introducing new vital signs with no need to redesign the backend database schema.

In [23], mobile and web applications are proposed to improve the efficiency of emergency services. Current location of the patient and his/her name and age are sent to the emergency command center for the purpose of better dispatching of emergency units. A particular design and its implementation are described in [14][24], where the service acts as a digital assistant aimed to dispatch closely located volunteers to the patients in healthcare emergency situations.

A smart spaces based platform is introduced by Vergary et al. [25]. The platform aims at the information interoperability between existing smart spaces based solutions in healthcare. The concept is illustrated with a simple demo application for the Smart-M3 platform. In particular, they focused on solutions to ensure an autonomous life to patients who would normally be placed in hospital. These solutions are based on ambient intelligence techniques and try to adapt the technology to peoples needs by building on three basic concepts: ubiquitous computing, ubiquitous communication, and intelligent user interfaces.

Reference scenarios for constructing emergency and other mHealth services are considered in [13][17][18]. The construction is essentially based on the mechanisms of semantic information sharing in smart spaces. The role of service intelligence and semantic relation of all available information when constructing assistance mHealth services is discussed in [11]. When a lot of data appears, then, knowledge reasoning over these data collections becomes inevitable part of the service. Based on deduced knowledge, recommendations to assist a patient can be constructed. A special form is prediction, which is important for early detection of patient state changes.

III. Personalized Mobile Assistance Service in Healthcare Emergency Situations

The analyzed mHealth service aims at providing personalized information assistance in healthcare emergency situations. The assistance is in the form of recommendations, both to the patient and involved medical professionals. According to the smart spaces approach proposed by Korzun et al. [13], the system is deployed at a set of networked devices, including, but not limited to, standalone or cloud-based server equipment, desktops, laptops and personal mobile devices, such as smartphones and tablets. The multi-agent Smart-M3-based architecture is shown in Fig. 1.

The basic software unit is an agent acting as a Knowledge Processor (KP). Such KPs run on the digital devices as a part of the application or background service. The KPs interact with users, sensor equipment, external information sources and other KPs. The data, gathered and processed by one KP, can be shared with other KPs by means of so-called Semantic Information Broker (SIB). SIB provides the functionality of ontology-driven common storage for the information shared by KPs and presented in machine-readable form of RDF-triples, the Resource Description Framework. Also, it supportsSPARQL queries for accessing the RDF-data.

As a result of this cooperative information sharing, a semantic network is formed in the smart space. The network integrates various heterogeneous data sources and their consumers.

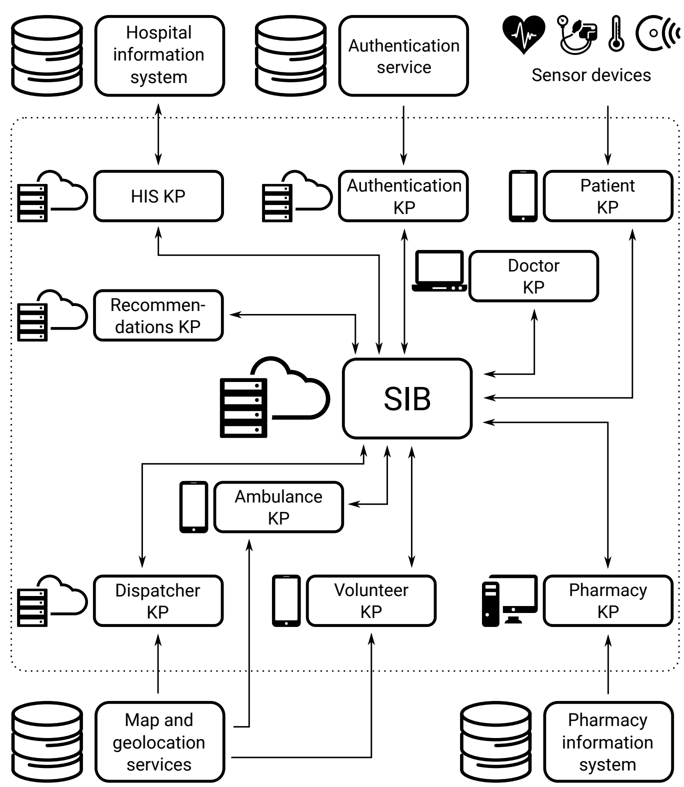

Figure 1. Multi-agent system architecture for personalized information assistance in healthcare emergency situations

In addition, this semantic information sharing provides high scalability in the condition of current trends in development of IoT technologies and the explosive growth of the market of m-Health equipment and applications.

The patient is equipped with a set of personal sensor devices that are able to continuously register the vital signs and send the recordings wirelessly to the personal mobile device. The mobile device has positioning capabilities, therefore, the location of the patient is also known. Besides, the health state is regularly assessed based on the questionnaire-based survey. The digital recordings of health parameters and the survey data are preprocessed on the local hardware and risk factors are identified. The Patient KP operates as a part of the mobile application, collects and shares the location and the risk factors in the smart space. The patient is also able to use the "panic button" to send an emergency alarm. The purpose is to address to the doctor timely and obtain further guidelines (e.g., call the ambulance or to take medications independently). Along with the alarm, the patient is able to send the complaints, selecting them from the predefined list, if in consciousness. The patient receives the machine-generated guidelines from the Recommentations KP.

The health data, provided by the patient is linked with the information from patient's electronic health record (EHR) elicited from the hospital information system (HIS) and published to the SIB by the HIS KP and is available to the physician via Doctor KP.

Alarms, locations and concomitant health data are available to EMS and, in certain limits, to volunteers. Bystanders, able to provide a first aid are guided by first aid assistant. Trained volunteers, able to assess the heaviness of the health state and provide resuscitation procedures, are informed on the important peculiarity of the patient, e.g., individual contraindications. Volunteer KPs also publish the locations to the SIB, as a result, volunteers receive alarms based on their proximity to the patient expressed in time to arrive the patient, elicited from the external map service. Both location of the patient, and locations of the appointed volunteers are accessible by ambulance squad through the Ambulance KP.

So far, the mobile applications for patients, volunteers, ambulances and physicians have been developed along with the authentication and dispatcher services. Current version of HIS KP interacts with the HIS mockup due to the lack of API of available HISes. For the same reason, the development of the Pharmacy KP is postponed. Scenarios of personal recommendations for the hypertension management and decreasing the risk of complications in hypertensive patients are currently discussing with the cardiologists from the Institute of Medicine of Petrozavodsk State University, preliminary discussion can be found in [26].

IV. Experimental Study

A. Experiment Setup

The experiments with the implemented pilot mHealth service services in medical emergencies aim to analyze the applicability of smart spaces based approach to mHealth service implementation, as it was described in Section III.

Since the personal mobile device (e.g., smartphone) of a patient is continuously used for collecting and preprocessing of the vital signs from a number of health sensors, a problem of fast battery drain can arise due to the computational load. During our experiments electrocardiogram recordings were being continuously and wirelessly obtained from the portable ECG monitor to the smartphone. These recordings were being preprocessed to extract the R-R intervals for the purposes of further HRV analysis. Calculated HRV-metrics were then publishing to the SIB.

For the extraction of R peaks from the ECG recording, the one-pass algorithm based on the Teager energy operator developed in our previous work was used [27]. The performance of the algorithm was evaluated on the well-known MIT-BIH Arrhythmia Database containing 48 half-hour annotated two-channel ambulatory ECG recordings freely available online. According to the tests, the average sensitivity on these recordings is 98.94 ($\min = 92.03$) and the average positive precision is 99.47 ($\min = 97.13$). These results are comparable to the well-known algorithms of R peaks extraction.

In the tests, we have used the wearable 1-lead ECG recorder with Bluetooth LE connectivity. The discharge rate of the smartphone battery was being measured during the tests using standard tools provided by Android OS. There were 10 four-hour tests with lengths of R-R intervals extracting alternated with 10 four-hour tests with no preprocessing. Before the tests were started, the negligible difference in the battery discharge rate had been forecasted due to the features of used R peak detection algorithm.

The information shared by KPs is presented in the SIB in the form of RDF triples. Real world entities may need hundreds of triples to be represented in the semantic and machine-processible form. Therefore, the problem of evaluation of SIB performance regarding domain-specific information entities. In the proposed service, semantic descriptions of the questionnaires for the regular health state audit and alarm accompanying complaints, are those complex information structures. In the second experiment, the questions of the health state questionnaire were publishing to the SIB and then they were consumed by other KP. The time of readiness of the questionnaire to other KPs and the time of extracting the questionnare-related triples from the SIB were being measured in each test. The tests differed in the number of requested questions.

Since the purpose of these tests is to evaluate the performance of the SIB, they were fulfilled in artificial conditions, namely, the influence of the network load has been eliminated, the KP and the SIB were run on the same desktop computer. For the experiments 10 tests were constructed with 10, 20 and up to 100 questions. There were 100 runs for each questionnaire. Before the tests were started, we had predicted SIB to be able to deal with the semantic description of the questionnaire of any reasonable size.

Participants of the smart space operate in distributed networked environment and gain an access to the external services, and so, the third experiment is devoted to the evaluation of the functionality of remote access to the EHR that is stored in an external HIS. The EHR consists of the set of documents and for the purposes of reasoning a subset of these documents may be published to the SIB. During the tests, measurements of arterial blood pressure (ABP) were extracted from the HIS mockup and published to the SIB. For the purposes of the further data processing, patients were divided into the several groups depending on the number of ABP measurements in their EHRs, as it is shown in Fig. 2. The query processing time for all measurements of one patient was evaluated against the number of simultaneous queries for each group of the patients.

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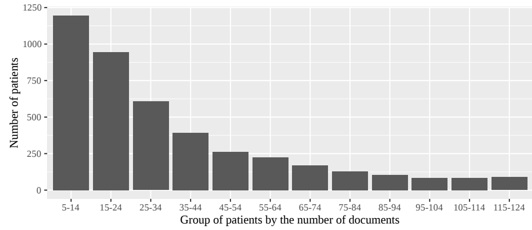


Figure 2. A histogram of the number of documents in patient accounts

The main service scenario is to appoint the volunteers to the emergency patients depending on locations in order to reduce the response time. Therefore, the process of volunteer dispatching was profoundly studied. In this experiment, the randomly distributed to the fictional map volunteers were being appointed to the patients. The patients were simulated with different rates of alarm arrivals. The waiting times of patients in the queue were being measured in each test. The tests differed in the number of available volunteers.

B. Functional Testing

The results of the battery discharge rate evaluation experiment are summarized in Table I. We observe the difference within the small bounds. It leads to conclusion that the ECG preprocessing on the smartphone has no significant affect on the battery drain. Therefore, the computational resources of the smartphone can be used in smart services for sensor data processing taking into account battery usage.

The box plot for the experiment with the questionnaire publication is shown in Fig. 3. It shows a linear dependence between the publication/consumption time and the number of questions. The box plot demonstrates low variation in samples that can be explained by the absence of the influence of outside fluctuation sources such as network load.

Since the semantic representation of the questionnaire was constructed of up to 500 RDF triples, the overall time needed to publish the questionnaire to the SIB was quite inappropriate and amounted about 10 seconds for the 50 questions. Nevertheless, operations of publishing and reading of the questionnaires are quite rare and are carried out only when the questionnaire is modified, the semantic representation can be used in smart healthcare service for medical emergencies. It should be noted that the experiments were be carrying out with CuteSIB 0.2.0 [28] that has limitations in SPARQL support and the triples were publishing and consuming with a set of queries that could affect the performance.

The HIS KP was under study in the third experiment. Results of the query processing time evaluations are displayed on the box plots, as it is shown in Fig. 4. The linear dependence between query processing and the number of simultaneous queries was estimated. At the same time, 10 simultaneous

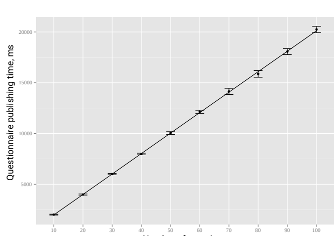
TABLE I. BATTERY DISCHARGE RATE EVALUATION

Test run	Battery discharge, %
1	9
2	10
3	10
4	8
5	9
6	11
7	9
8	10
9	9
10	9

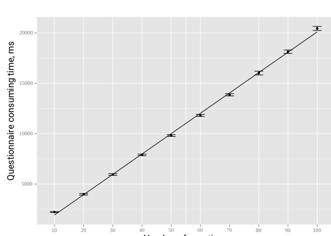
(a) Battery discharge with R peaks detection

Test run	Battery discharge, %
1	9
2	11
3	10
4	9
5	9
6	10
7	9
8	10
9	10
10	9

(b) Battery discharge with no ECG preprocessing

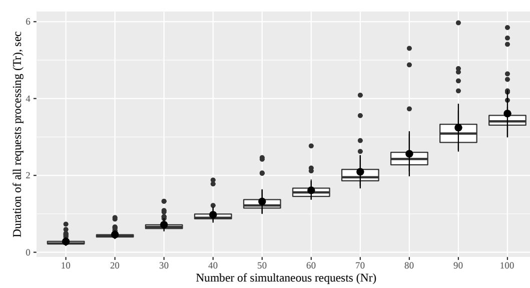


(a) Plot of the publishing time against the questionnaire size

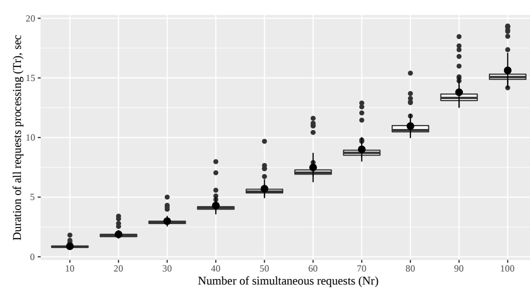


(b) Plot of the consuming time against the questionnaire size

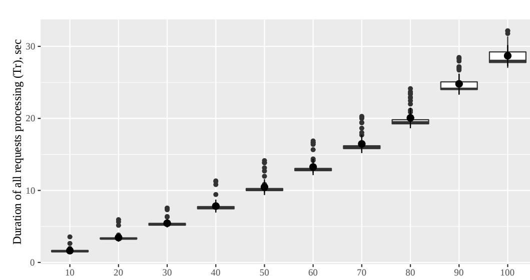
Figure 3. mHealth smart space: SIB performance evaluation



(a) Patients with 5–14 documents



(b) Patients with 45–54 documents



(c) Patients with 85–94 documents

Figure 4. Performance of query processing in dependence on the number of simultaneous queries for several groups of patients

requests result in readiness of the documents within the bounds of one second. It allows to conclude that developed HIS KP can be used in the assistance in medical emergency.

In the experiment with the dispatching volunteers to the patients, the exponential dependence between alarm waiting times before the volunteer is chosen versus the number of patients was estimated. At the same time, according to the statistics, Petrozavodsk EMS receive a call every 5–15 minutes on average. At this rate of alarm arrival, the dispatcher allows to appoint the volunteers to the patients in a few seconds, and thus, is quite fast to be used in reference scenario.

Hereinabove, the results of four experiments are presented and briefly discussed. In the example of emergency assistance service, we showed that such a mHealth service can be constructed using smart spaces and, in particular, based on the Smart-M3 platform.

C. Emergency Response Time

The proposed system is aimed to the increasing of the efficiency of the first aid providing due to the mobilization of the trained volunteers. The volunteers that are located nearby to the scene of an accident receive an alarm along with the details and have the chance to arrive in a timely manner, and, in turn, to promote the increasing the survival rate in life-threatening conditions. Therefore, one of the goals of the experimental study is the evaluation of decreasing of emergency response times when using of the proposed system.

Simulation analysis was chosen as the method for assessing the merits of the approach. The process of receiving alarms and dispatching them to the volunteers was considered on the example of one of the urban residential districts of Petrozavodsk with the population of at least 50 thousand.

Since departure points of the emergency vehicles are known, the assessment of the emergency response time without the support of the volunteers can be obtained from the external map services taking into account the traffic conditions. We obtained the assessment of the arrival time of emergency vehicle to the scene in 9–17 minutes depending on the location of the patient on condition of lack of transport traffic jams. We have found out that this assessment is in accord with the statistics of the local Ministry of Healthcare claiming that the average response time in Petrozavodsk is approximately 14 minutes.

We had predicted the significant decreasing of the response times before simulations runs were started, as it is shown in Fig. 5. Using the map services we also obtained the assessments of the arrival times for all pairs of addresses of the selected residential district.

The simulation model is based on the assumptions that the patients and volunteers are distributed along the district according to the residential density and all the volunteers are available for alarm dispatching. In each series of simulation runs 20, 30, and so on, up to 100 volunteers were distributed over all the district map. During the simulation it is revealed that on condition of presence of the trained local volunteers the emergency response time decreases to 3–9 minutes depending on the density of volunteers.

V. CONCLUSION

This paper presented the experimental evaluation of personalized mobile assistance service healthcare emergency situations. For the service development, we reviewed the mHealth use cases, IoT-enabled solutions, and information-drive multi-agent system models. The evaluated implementation is Smart-M3 based pilot that aims at demonstrating the feasibility and applicability of the smart spaces approach to mHealth service development for deploying in emerging IoT environments. The presented experiment results indicate the possibility for creating a personalzied mHealth smart space around its mobile patients. We confirmed that the efficiency of the Smart-M3 platform is enough to implement and deploy such services even in complicated settings of IoT environments.

For the analysis of advantages of the approach, the developed personalized mobile assistance service is planned to be approved among the patients of Petrozavodsk Hospital of Emergency Care.

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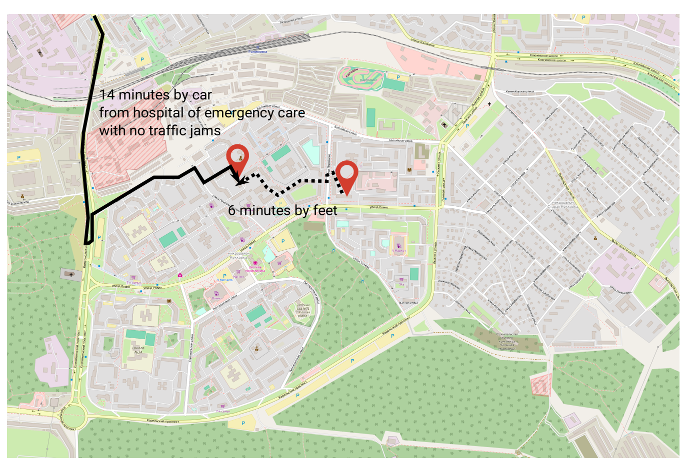

Figure 5. A district map: alarm and volunteer locations and response time assessments

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