

Supporting Doctors through Mobile Multimodal Interaction and Process-aware Execution of Clinical Guidelines

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Abstract—Providing operational support to clinicians during their daily activities in hospital wards is a challenge for information technologies. In particular, any possible solution should provide usable user interfaces, possibly deployed on mobile devices, and should be able to enact and monitor the execution of clinical guidelines. To tackle this issue, in this paper we present a medical system that supports clinicians in the management of clinical guidelines. The system exploits concepts from Business Process Management (BPM) and Service Oriented Computing (SOC) on how to organize clinical guidelines in the healthcare context and how to support the automation of their execution. As a viable solution for clinicians’ interaction with the system, we investigated the use of vocal and touch interfaces. Usability evaluation results indicate the feasibility of the approach.

Keywords—Service-oriented architecture; process-awareness; multimodal interface; clinical guidelines; healthcare

I. INTRODUCTION

Healthcare is conventional regarded as the diagnosis, treatment, and prevention of disease, illness, injury, and other physical and mental impairments in humans. It is based on many professionals working in a multidisciplinary environment with complex decision-making responsibilities. Healthcare settings are rapidly evolving, and in a bid to minimize medical error and ensure efficient access to information, hospitals and doctors have invested heavily in a wide range and number of computing equipment and devices [1]. It is not uncommon to encounter doctors who are required to interact with more than one core device at the same time, while still attending to a patient. This places many cognitive and physical demands on doctors making them prone to make medical errors. Notwithstanding the benefits of Electronic Health Record (EHR)

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systems, there are indications that the use of EHR systems often has a negative impact on patient-centeredness [2] and often cause doctors to lose rapport with their patients [3], [4].

As Laxmisan et al. have observed in [5] regarding emergency departments, multi-tasking and information transfers may be necessary aspects of healthcare environments, which cannot be avoided entirely. Steps rather should be taken to ensure the continuity of information flow, for instance by supporting mobile access to information and supporting doctors in the execution of *clinical guidelines*. Clinical guidelines are recommended care pathways (presented in form of “best practices”) providing clinicians with appropriate knowledge to enact medical treatments for particular patient conditions.

Technological designs may prove helpful in reducing the cognitive and physical burden on the doctors. A study by Oviatt et al. [6] found that “multimodal interface users spontaneously respond to dynamic changes in their own cognitive load by shifting to multimodal communication as load increases with task difficulty and communicative complexity”. Multimodal user interfaces therefore have the potential to reduce cognitive load on the doctors. While a technological solution that ensures continuity of information flow, supports doctors in the execution of clinical guidelines, and with the potential to reduce the cognitive and physical burden on the doctors is desirable, nowadays the most of existing efforts primarily focuses exclusively on one aspect of the foregoing desirable requirements or a partial combination of them.

Based on the foregoing, we have designed and developed a clinical system, referred to as TESTMED. The TESTMED system is the joint outcome of two projects, namely *TESTMED – meTodi e Tecniche per la gestione dei processi nella Medicina D’urgenza* (in English: *methods and techniques for process management in emergency healthcare*) and the following *SUPER – SUPPORTing E-health knowledge-intensive pRocesses*, which aimed at investigating vocal and touch interfaces as a viable solution for clinicians’ interaction with mobile devices,

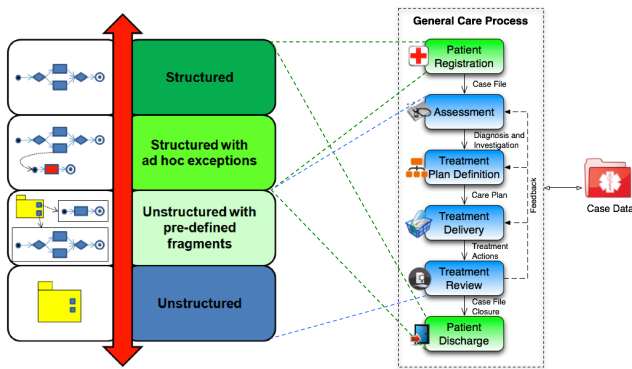


Fig. 1: Classification of a healthcare process [8].

and a process-aware approach for the automation of clinical guidelines. The TESTMED system supports:

- *Mobile multimodal interaction.* The system supports mobile, hands-free and vocal interaction with the core clinical devices, and does provide alternative support for multi-touch interaction and visual interaction.
- *Clinicians in the execution of clinical guidelines.* The system exploits concepts from Business Process Management (BPM) and Service Oriented Computing (SOC) on how to organize clinical guidelines and activities in the healthcare context and how to support the automation of their execution, in whole or in part.

The system has been jointly developed and evaluated with DEA (“Dipartimento di Emergenza ed Accettazione”, i.e., Department of Emergency and Admissions) of Policlinico Umberto I, which is the main hospital in Rome (Italy). Evaluations of the system indicate a high degree of usability and appreciation among medical staff. The current version can be considered to have had made great strides toward meeting common design guidelines for multimodal user interface design (such as those proposed by [7]).

The rest of the paper is organized as follows: Section II provides background knowledge about healthcare processes and clinical guidelines; Section III introduces the system, whereas Section IV presents the outcome of the user evaluation of the system. Section V discusses relevant work and finally Section VI concludes the paper by discussing future work.

II. UNDERSTANDING HEALTHCARE PROCESSES AND CLINICAL GUIDELINES

The complexity of a healthcare process can be easily understood by classifying its main macro-steps along a spectrum on the basis of the degree of structuring and predictability they exhibit [8], as shown in Figure 1. At the highest level of abstraction, a general healthcare process encompasses six macro-steps [9] including: (i) *patient registration*, resulting in the creation of the current medical case file, (ii) *patient assessment*, resulting in an initial diagnosis and in specific required investigations, (iii) *treatment plan definition*, resulting in the development of an individual care plan, (iv) *treatment delivery*, resulting in treatment actions performed according to

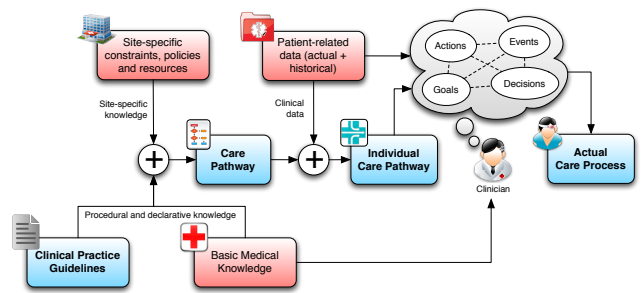


Fig. 2: From CPGs to the actual healthcare process.

the care plan, (v) *treatment review*, resulting in a continuous evaluation of treatment impact and efficacy that provides feedback for the previous steps, and (vi) *patient discharge*, resulting in the closing of the case records.

Administrative and organisational steps, including patient registration/discharge and other activities in the treatment delivery stage (e.g., patient transfer, bookings, management of prescriptions and lab tests) are typically structured, relatively stable and repetitive, and represent a good setting for the application of traditional approaches for process automation and improvement. Exceptional behaviours are limited and can be often anticipated and managed according to predefined handling procedures. Conversely, the diagnostic and therapeutic steps driven by clinical decision-making and case data are clearly knowledge-intensive activities that lead to loosely structured or unstructured processes [10]. Clinical decision-making is highly knowledge-driven, as it depends on medical knowledge and evidence, on case- and patient-specific data, and on clinicians’ expertise and experience. Patient case management is mainly the result of knowledge work, where clinicians act in response to relevant events and changes in the clinical context on a per-case basis, according to so-called diagnostic-therapeutic cycles based on the interleaving between observation, reasoning and action [11]. The overall healthcare process, even in the oversimplified view provided in Figure 1, reflects the combination of predictable and unpredictable elements. In practice the actual flow of work in a healthcare environment may include many concurrent activities and procedures, especially in the (common) case of patients treated for multiple conditions, leading to multiple interacting care pathways.

In the last decades, the medical community has been actively investigating, developing and promoting evidence-based *clinical practice guidelines* (CPGs) and care pathways, as a mean for standardising clinical practice and reduce errors and costs, while improving quality of care and patient outcome. The use of CPGs that capture both literature-based and practice-based evidence is becoming a reality in hospitals all around the world [12], [13]. CPGs are systematically developed statements to assist practitioners and patient decisions about appropriate health care for specific circumstances [14]. Guidelines are based on the best available research evidence, and are extracted by using a rigorous process centred on a

systematic review of clinical evidence, consensus statements and expert opinion. As a result of this process, (guideline) documents are produced that provide advice on clinical best practices in the form of evidence-based recommendations to support and facilitate appropriate decision making in patient care. A guideline may thus provide a high-level plan of suggested/expected care and serve as a reference framework for evaluating clinical practice, but usually does not define mandatory requirements nor prescribes specific steps. CPGs capture domain-specific knowledge but they are not defined to be directly applied to a specific patient in a particular healthcare organisational context, and need to be adapted to obtain concrete medical pathways, as shown in Figure 2.

In order to be effectively exploited in practice, the evidence-based knowledge provided by CPGs has to be complemented by additional “knowledge layers” that include clinicians’ basic medical knowledge (BMK), site-specific knowledge and patient-related information, such as current conditions and medical history. Care pathways thus represent site-specific implementations of CPGs. Care pathways are structured multi-disciplinary care plans that describe the tasks to be carried out together with the timing, sequencing and role constraints for these tasks [15]. They provide detailed guidance for each stage in the management of a patient, on the basis of intermediate and long term expected outcomes and goals.

Although the knowledge-intensive nature of clinical decision making leads to loosely structured or unstructured working procedures, the adoption of guidelines and pathways introduces a process-oriented perspective in the management of patient care. Process and decision support for patient management has been investigated in the medical informatics community through the development of models, languages and systems for the specification and execution of guidelines and care pathways. Over the years, many research groups have focused on so-called “computer-interpretable clinical guidelines” and different languages have been proposed for encoding, managing and executing guidelines, such as GLIF, Asbru, EON, PROforma, GUIDE, Prodigy and GLARE. Such languages can be broadly classified as rule-based (e.g., Arden Syntax), logic-based (e.g., PROforma), network-based (e.g., EON) and workflow-based (e.g., GUIDE). In addition, most of them are supported by systems that allow the definition and enactment of guidelines [16].

Despite the availability of different formalisms, none of them has emerged over the others. On the one hand, the efforts required to tailor and adapt guideline models to specific medical settings and changing conditions are among the main barriers to their uptake. Most of the existing languages are based on a process and activity-centric approach, and provide support for representing the procedural knowledge contained in guidelines mainly focusing on the control-flow dimension. Guidelines are modeled as so-called task networks, where modeling primitives for representing actions/tasks and decisions are linked via scheduling and temporal constraints, often in a rigid flowchart-like structure. The procedural nature of languages clashes with the knowledge-intensive nature and

flexibility requirements of medical processes. On the other hand, the use of systems able to interpret and execute guidelines by presenting them to clinicians through multimodal interfaces represents still a relevant challenge for the Healthcare Informatics research community.

In this paper, we tackle the above issues by presenting the TESTMED system, which provides a Process-aware Information System (PAIS) for encoding and enacting CPGs in a doctor-friendly way through a multimodal user interface.

III. THE TESTMED SYSTEM

The TESTMED system consists of two main components:

- a *user interface* supporting mobile multimodal interaction;
- a *back-end engine* that manages the execution, routing and monitoring of CPGs and relevant data among doctors.

User interface. The system supports mobile, hands-free and eyes-free interaction with the core clinical devices. This frees the doctor such that s/he can physically attend to the patient. In particular, the system supports:

- *Voice-based interaction*, to work in situations where doctor hands and eyes are occupied.
- *Mobile interaction*, for:
 - supporting the mobility of the doctor in order to attend to the patient;
 - facilitating the continuity of information flow by enabling instant and mobile access to information;
 - expediting the doctor’s decision making. A survey carried out by the Price Waterhouse Coppers’ Health Research Institute (HRI) [17] reported that 56% of physicians indicated that mobile interaction expedited their decision making.
- *Multi-touch and visual interaction mechanisms.*

The user interface is therefore based on an integrated mobile, speech-recognition, speech-synthesis, multi-touch, and visual interaction framework. More details on the user interface will be provided in Section IV.

Management of clinical guidelines. CPG are managed by back-end system components, which provide the run-time environment for interpreting, activating and executing a CPG. In TESTMED, a CPG is specified through a combination of different languages. On one hand, the PROforma language [18] is used to model a guideline as a set of tasks and data items, and the control flow between them. On the other hand, starting from the PROforma model, additional XML-based configuration settings need to be specified, to allow multimodal interaction and enable integration between system components. In such a way, a guideline is finally defined as a *guideline bean*, deployed into the system for being later executed.

The execution of CPGs is supported by properly routing data, events and activities, according to a process-aware and content-based approach where activity scheduling and message dispatching are event- and data-driven. The interaction between all involved components and services is guaranteed by

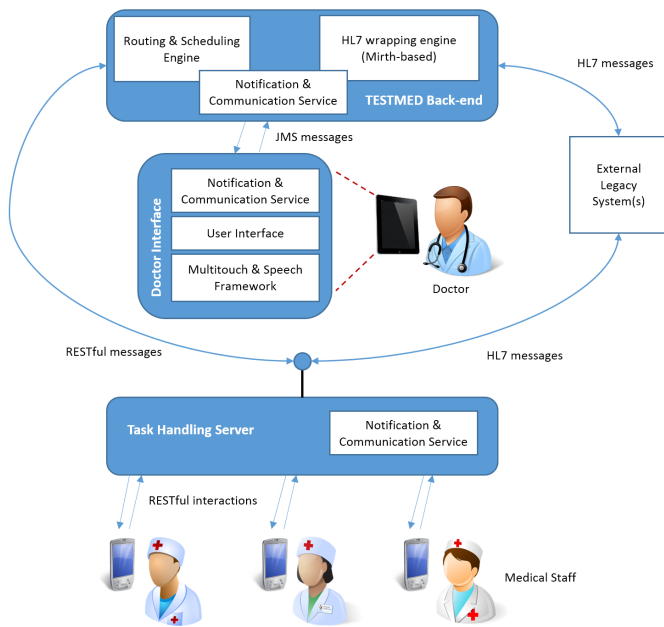


Fig. 3: TESTMED system architecture.

a routing engine that manages the routing of clinical activities, relevant data, and generated events among the different actors, services, and applications. In particular services are wrappers over pre-existing legacy systems.

The system architecture is shown in Figure 3. The doctor in charge of attending a patient is equipped with a tablet PC that runs the TESTMED system. The tablet PC supports mobile multimodal interaction, and enables the doctor to select, instantiate, and carry out specific CPGs. The multimodal interaction support is achieved by integrating the Multi-touch for Java framework (MT4j¹) with the Microsoft Automatic Speech Recognition (ASR) and Text-To-Speech (TTS) engines. The back-end is realized using the Tallis engine², which has been complemented with other components for managing the integration with existing legacy systems deployed in the hospital Policlinico Umberto I. All these components are J2EE-based and hosted on a TomEE³ application server. In particular, a JMS-based notification engine, namely RabbitMQ⁴, is used to manage the interaction between the doctor user interface and the back-end. The integration with the legacy systems is performed via HL7⁵ messages over Mirth⁶. Both the legacy systems and the back-end interact with a Task Handling Server via HL7 and RESTful messages. The Task Handling Server is in charge of notifying the medical staff (other clinicians, nurses, etc.) about the clinical activities to be enacted (e.g., to make a specific analysis, to administer a medicine, etc.) for

¹<http://www.mt4j.org/>

²<http://www.cossac.org/tallis>

³<http://tomee.apache.org/apache-tomee.html>

⁴<http://www.rabbitmq.com/>

⁵HL7 is a set of international standards for transfer of clinical and administrative data between hospital information systems. <http://www.hl7.org/>

⁶<http://www.mirthcorp.com/products/mirth-connect>

progressing the clinical guideline execution. Each member of the medical staff is equipped with a mobile device providing a specific Android client application, which interacts with the Task Handling Server through RESTful services.

IV. USER EVALUATION

The TESTMED system has been developed using the user-centered design approach, which places users at the core of the design process [19]. We have so far progressively and iteratively produced two software prototypes of the system. Each prototype has been evaluated through a wide range of usability evaluation methods involving the target users (i.e., real doctors), and in each case the outcomes have been used for incremental improvement of the design.

A. Experiment Setting

The case study has concerned the guideline enacted for patients suffering from Chest Pain⁷, which is one of the most common reasons for the admission in the emergency room (5% of all visits) with high mortality in case of failure diagnosis and improper dismissal (24%) [20]. Typically, when a patient suffering from chest pain visits the hospital, the doctor on duty in the emergency room checks her/his clinical conditions on the basis of general impressions, patient history, risk factors and chest pain score, to decide whether or not to admit the patient for clinical observation. The chest pain score is used to improve the diagnostic and prognostic accuracy, in order to safely classify patients into low and high-risk subsets for cardiac events. The pain score is derived by evaluating a set of four clinical characteristics: (i) the localization of the pain; (ii) the character of the pain; (iii) the radiation of the pain and the (iv) associated symptoms. A partial score is associated to every characteristic, and the sum of these values produces a final score that predicts the angina probability. Different values of the rate correspond to different clinical treatments to be followed by the patient. In general, a doctor needs to complete a survey useful for determining the chest pain score related to the patient. The use of the TESTMED system allows presenting the survey to the doctor both vocally, through integrated speech synthesis and recognition, and in a textual form through the user interface of the prototype (see Figure 4). Therefore, the interaction can be tactile or vocal. The doctor may wear a single-ear headset with a microphone linked to the tablet; s/he can listen to the questions related to the survey and reply vocally by choosing one of the speech-synthesized possible answers. Each answer is coupled with a specific characteristic and provides an associated rate. Vocal interaction ensures that the doctor's eyes and hands are free to attend to the patient. Moreover, since the device is mobile, the doctor can move about attending to the patient and can also have mobile access to information. The visual interface corresponding to part of the chest pain clinical procedure can be seen in Figure 4 (cf. the green panel).

⁷Chest pain is defined as a pain that ranges from the base of the nose and navel and between the neck and the twelfth vertebra and that has no clearly identifiable traumatic cause.

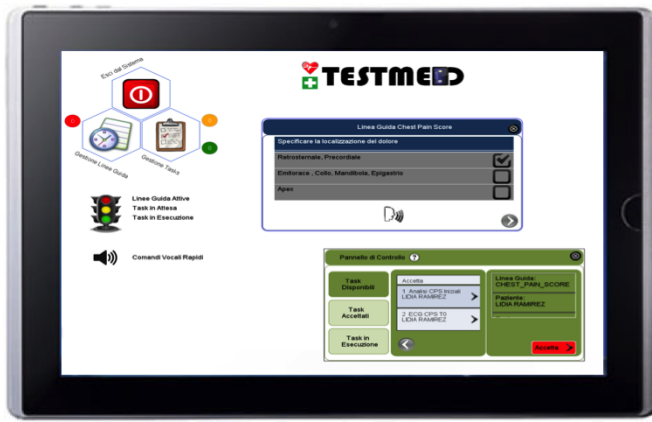


Fig. 4: Overview of the graphical user interface of the doctor.

After the survey completion, the system proposes - in the form of a care pathway - a therapy composed by a set of medical treatments and analysis prescribed to the patient. For example, if the chest pain score associated to the patient is greater or equal than 4 (it indicates an intermediate-high probability of coronary risk), the suggested care pathway involves the enactment of some general analysis for the patient (e.g., ECG, complete blood count, etc.) and, after 4 hours, to repeat some medical tests, like ECG and Troponin and Myoglobin tests. When the results of the analysis are ready, it is required to decide whether to hospitalize the patient or not. If the analysis outcomes present some values considered dangerous by the doctor, the healthcare process suggests to make further tests (in our case, a hemodynamics consulting and a coronary catheterization) and, based on the results obtained, to activate a further procedure concerning the hospitalization of the patient.

The enactment of the various medical treatments takes place in different moments of the therapy. The TESTMED system is able to trace the current status of the healthcare process, by recording analysis outcomes and clinicians' decisions. Reminders and warnings notify if new information is available for some patient (for example, if an analysis is ready to be evaluated). In such a case, the clinician can decide to see more details about analysis results, to have the updated view of the healthcare process status or simply to accept the notification. If there is any doubt about the goodness of the healthcare process for a specific patient a clinician can abort the process in every moment. As previously noted, the medical staff (e.g., nurses) are equipped with Android-based mobile devices and are therefore notified of the progress of clinical procedures and of the various activities that have to be carried out. Figure 5 reports a couple of screenshots of the staff's user interface.

B. Experiment Results

The first usability evaluation was conducted in the ward of DEA (Department of Emergency and Admissions) of Policlinico Umberto I in Rome. Figure 6 shows the TESTMED system being used by a doctor on a patient simulator. There were 7 participants consisting of: 2 physicians and 5 general practitioners. The participants were presented with and

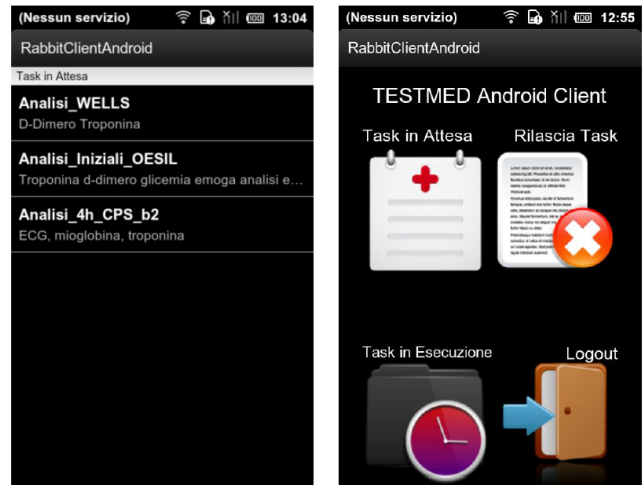


Fig. 5: The graphical user interface for the medical staff.

requested to interact with the initial prototype of the system. The participants were also given a questionnaire in order to collect information regarding their background and their assessment of the usability of the system (such as interaction modalities, error management, learnability, effectiveness, etc). Specifically, the questionnaire was composed by 11 statements and a 5 points Likert scale (that ranged from 1 - *strongly disagree* to 5 - *strongly agree*) that allowed users to express their agreement/disagreement with the statements:

- Q1 I have a good experience in the use of mobile devices.
- Q2 The interaction with the system does not require any special learning ability.
- Q3 I judge the interaction with the touch interface very satisfying.
- Q4 I judge the interaction with the vocal interface very satisfying.
- Q5 I think that the ability of interacting with the system through the touch interface or through the vocal interface is very useful.
- Q6 The system can be used by non-expert users in the use of mobile devices.
- Q7 The system allows to constantly monitor the status of clinical activities.
- Q8 The system correctly drives the clinicians in the performance of clinical activities.
- Q9 The doctor may - at any time - access to data and information relevant to a specific clinical activity.
- Q10 The system is robust with respect to errors.
- Q11 I think that the use of the system could facilitate the work of a doctor in the execution of its activities.

The results of the first evaluation are collected in Table I. On average, the participants indicated a high level of agreement that the prototype could facilitate doctors' work, correctly guided doctors in the execution of CPGs, provided doctors with access to information at any time, and enabled doctors to constantly monitor the status of clinical activities.

TABLE I: Results of the first usability test.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
User1	4	3	4	3	2	3	4	4	4	3	3
User2	4	3	4	2	4	2	2	3	2	3	3
User3	5	3	4	3	5	2	5	4	5	4	4
User4	4	4	4	3	3	4	4	4	3	3	4
User5	3	3	4	2	3	4	4	4	4	3	4
User6	3	4	5	3	3	5	5	4	4	4	4
User7	3	4	4	3	4	4	5	4	4	4	4
Avg	3,71	3,43	4,14	2,7	3,43	3,43	4,14	3,86	3,71	3,43	3,71

On average, the participants fairly agreed that the prototype supported learnability, error management, users who are not experts in using mobile devices. Moreover, the participants emphatically acknowledged the importance of supporting interaction that is less physically and visually demanding. This emphasized the appropriateness of vocal interaction. The participants even requested for the system to provide more support for vocal interaction. Notwithstanding the foregoing, the participants still appreciated the possibility to interact via multi-touch. They also emphasized the need for flexibility by giving users the option to choose, if they so wished, which modality to interact through. The initial prototype was consequently refined based on the results of the first evaluation in order to realize the second prototype.

The second usability evaluation was conducted on the second prototype. In this case, we performed a usability test of the system in the ward of DEA of Policlinico Umberto I in Rome with another set of 7 participants consisting of: 1 physician, 2 general practitioners, and 4 postgraduate students in medicine. During this usability test, we loaded the Chest Pain clinical procedure into the system. The participants were also presented with patient simulators assumed to be suffering from chest pain problems (see Figure 6). They were requested to attend to the patient (patient simulator) with the support of our system. The participants were also required to complete the same questionnaire shown above for assessing the usability of the system. The results of the second usability evaluation are collected in Table II.

TABLE II: Results of the second usability test.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
User1	4	4	4	4	5	3	4	4	4	4	4
User2	4	4	5	3	5	2	3	4	2	4	3
User3	3	3	3	4	4	3	4	4	3	3	4
User4	5	4	3	2	4	5	5	4	4	5	4
User5	1	5	5	5	5	5	5	5	5	5	5
User6	3	5	4	5	4	5	4	4	4	5	5
User7	3	4	5	5	4	4	5	4	5	4	4
Avg	3,29	4,16	4,14	4	4,43	3,86	4,29	4,14	3,86	4,29	4,14

On average, the participants indicated a high level of agreement that the prototype could facilitate doctors' work, correctly guided doctors in the execution of clinical procedures, provided doctors with access to information at any time, supported learnability, enabled doctors to constantly monitor the status of clinical activities, supported error management, and could be used by users who are not experts in using mobile devices. Moreover, the participants on average acknowledged that the prototype's support for vocal interaction and also for

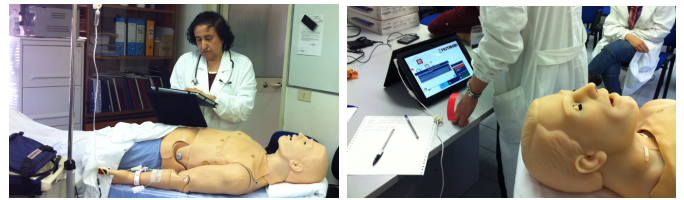


Fig. 6: TESTMED system being used by a doctor while attending to a patient (here a patient simulator) in a ward.

multi-touch was good. It is worth noting that the usability ratings of the second prototype increased tremendously, as shown in Figure 7, where we compare the results of the two evaluation tests on the basis of the average score for each statement. The second design prototype was considered to have made great strides toward complying with typical design guidelines for multimodal user interface design [5], for instance our design prototype supports: error management, system feedback (e.g. by enabling doctors to constantly monitor the status of clinical activities), multimodal input and output (e.g. by reducing cognitive and physical demands on the user by supporting eyes-free and hands-free interaction, offering users the option to choose modalities), etc.

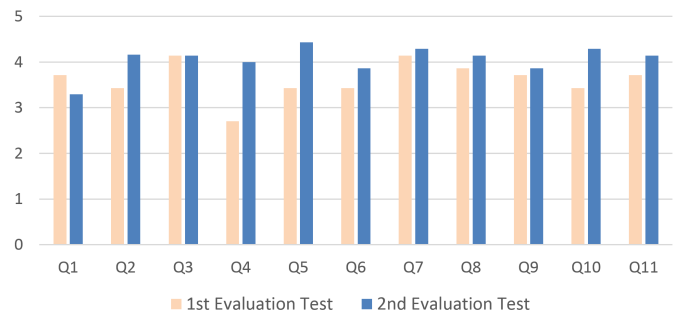


Fig. 7: Comparison between the questionnaire results of the two usability tests performed.

V. RELATED WORK

Process- and Service-oriented approaches to the modeling and execution of healthcare processes. Activity-centric modeling approaches (such as BPEL, BPMN, etc.) have been applied in healthcare mainly for the specification and execution of *organizational* processes that take place in clinical practice. In [21] the authors identify the different flexibility requirements related to the application of workflow technology in healthcare. Although they consider the diagnostic steps of a gynecological oncology process and implement them in four process management systems, the discussion and evaluation focuses on organizational processes and their flexibility requirements. In [22], the authors use the BPMN language for modeling pathology processes for programmed surgical interventions. The proposed models focus on the activities to be performed by different practitioners (including surgeons, nurses, attendants and other pathology department personnel)

before, during and after a surgical intervention, capturing the organizational knowledge for coordinating the involved healthcare professionals. However, the resulting models are mainly used for process understanding and improvement, and process enactment through a supporting system is not considered. BPMN is also used in [23] for the definition and analysis of clinical processes related to the tracking of a patient through a healthcare facility from admission to discharge.

A broader perspective on the use of BPMN in healthcare is provided in [24], where the challenges related to the definition of healthcare processes are considered, including the multi-disciplinary nature of the processes, the flexibility and variability of the involved activities and the interoperability requirements for multiple information systems. Interoperability, application integration and service coordination as starting points for organizational healthcare support are also discussed in [11], [25]. The authors observe that existing information systems deployed in healthcare settings include many different departmental systems that operate independently, and therefore the computerized support of cross-departmental organizational processes can be related to the problem of data and application integration. While different HL7 standards have been introduced to mitigate the system integration problem, functional integration (i.e., the cooperation of functions of different software components) has not been fully addressed.

Here, process modeling and management systems can be used to define and execute the process logic that integrates the different workflow fragments and functions implemented and provided by the information systems. Assuming a service-oriented environment and exploiting the Web services technology, some proposed solutions tackle this problem through the definition of service orchestration specifications as BPEL processes. In [26], for example, the authors propose a semi-automatic model-driven approach for the creation of Web service orchestration specifications in BPEL, focusing on an administrative workflow that covers patient admission/discharge/transfer and the scheduling of medical examinations. Workflow technology, Web services and service-oriented integration are also proposed in [27] for the automation of inter-organizational emergency healthcare processes, and the approach has recently evolved towards a cloud-based architecture and the use of mobile computing [28]. In [29] the design and implementation of a Serviceflow Management System is presented. The system supports the overall care delivery process for the management of acute and chronic care that involves different organizational units. According to a three level architecture, each unit internally manages its own processes and publishes parts of them as services to allow communication with other units; on top of this service level, the overall healthcare process is modeled as a serviceflow that coordinates the available services. Another approach that aims at supporting healthcare workflows through a service-oriented architecture is presented in [30]. The authors focus on the procedures of sterile processing departments and identify the main architectural requirements for a workflow system able to manage and automate the work practices. To

enable heterogeneous information sharing, integrate different systems and services, and handle failures and exceptions, a service-oriented architecture for the system is proposed; the architecture has been implemented in a prototype system, validated in a decontamination working area.

Mobile interaction in the healthcare domain. Flood et al.'s work in [31] proposes a method for use by application designers during mobile application development in the medical domain to estimate when cognitive overload will occur and can redesign the interface if necessary. The method proposed by Flood et al. therefore targets mobile application designers and developers in the design of user interfaces for the medical domain. While acknowledging that the effort intends to estimate cognitive overload, the effort does not focus directly on design techniques for addressing the problem (such as through multimodal interaction). Jourde et al.'s work in [32] seeks to develop a user interface specification for a multimodal collaborative system for use in a hospital setting. The effort by Jourde et al. is therefore appropriate for application designers. Moreover, both works by Jourde et al. [32] and Flood et al. [31] do not directly look into execution of clinical guidelines. Another effort related to our work is HECTOR [33], which is a handheld computer system that was developed to support organizational audit and clinical handover within hospital emergency care teams. HECTOR therefore supports mobile interaction and supports medical staff in handover procedures. It is also worth highlighting the GuideView system which was originally developed as a system aimed at enabling astronauts, who are not necessarily medical experts, to provide medical support for themselves and each other during space exploration missions, when assistance from earth-based medical experts is impractical [34], [35]. It is worth noting that the GuideView system intends to support non-medical experts.

As we noted earlier in Section I, our work seeks to meet the following requirements: ensure continuity of information flow by supporting mobile access to information, provide support to doctors in the execution of clinical guidelines, and support mobile multimodal interaction in order to reduce the cognitive and physical burden on the doctors. Existing efforts such as the aforementioned ones have either primarily focused on exclusively one requirement, or a partial combination.

VI. CONCLUDING REMARKS

Nowadays, doctors are often being required to interact with more than one core devices at the same time, while still attending to a patient. This places a lot of cognitive and physical demands on doctors making them prone to make medical errors and to lose rapport with their patients. We consequently have observed in this paper that a technological solution that ensures continuity of information flow, supports doctors in the execution of clinical procedures, and with the potential to reduce the cognitive and physical burden on the doctors is desirable. This paper has also proposed and described a medical system that supports: mobile, hands-free and eyes-free interaction with the core clinical devices, thereby freeing

the doctor such that s/he can physically attend to the patient and also have mobile access to information, doctors in the execution and monitoring of clinical procedures. Moreover, the paper has reported preliminary evaluation results that indicate a high degree of usability, user appreciation, and compliance to common interface design guidelines.

In the future, we intend to engineer and realize the third prototype by refining the second prototype based on the results of the second evaluation. Further evaluation of the system will be carried out in order to assess the system's effectiveness toward alleviating cognitive and physical demands on doctors. We also intend to provide support for the execution of additional CPGs (the current system enacts 3 procedures). Moreover, future research will include the determination of quantitative and qualitative indicators that in the long run can enable us to understand or measure the impact of the system on the overall clinical decision making and collaboration process.

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