Gquest: Modeling patient questionnaires and administering them through a mobile platform application

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ABSTRACT

Background: The use of surveys is becoming popular in the health care industry for acquiring information useful to the accomplishment of several studies. Besides their exploitation on a large scale for conducting epidemiological studies, surveys are being increasingly carried out on a narrower perspective through the administration of questionnaires aimed at assessing the quality of life perceived by patients or their clinical status during mid- or long-term treatments. This is useful for managing resources or optimizing and individualizing treatments.

Objectives: This paper describes Gquest, a platform for modeling, generating and administering questionnaires through mobile devices such as smartphones or tablets. Gquest was motivated by the need of administering questionnaires during home treatments, albeit its applicability is rather general. The main requirement was to have a very simple, clean and easy to use platform able to support (a) physicians in the design and delivery of questionnaires and (b) outpatients in sending self-recorded outcomes to the clinical staff.

Methods: Gquest has two basic components. The first one is a model devised for representing questionnaires which is extremely flexible. It allows the generation of questions and answers of different types, supports adaptivity in the dialog with the user and enforces simple consistency rules for checking his input. The second component is an application able to run instances of those questionnaires. It downloads questionnaires over the air in terms of XML files from a server and stores them locally into the mobile repository. Questionnaires become then available to the user, who in our case is a patient or one of his relatives. The user can select which one to fill-in, according to his needs and/or the specific treatment protocol. The selected questionnaire may be filled-in all at once or be completed in subsequent steps over time since any input provided is persisted on a local database. Finally, when a questionnaire is closed all the answers are transparently synchronized to a server for further evaluation or statistical purposes.
1. Introduction and background

In the healthcare industry, the use of surveys for epidemiological studies has become popular among pharmaceutical companies and organizations dealing with public health care [1]. Results emerging through those studies often have a great impact on starting public health care campaigns. The specific point of view of the patient is also gaining focus in the modern medical practice since it provides a deeper insight on the perception of the quality of care and accounts for its personalization [2]. To this aim questionnaires are being used in the health care and social welfare contexts for assessing the use of resources, the burden of diseases, the access to treatments, the quality of services provided and eventually the patients’ satisfaction [3,4].

A different perspective exploits surveys to assess the patients quality of life (QoL) [5,6]. The QoL is an indicator that provides an indirect estimation of the outcomes yielded by medical actions in terms of treatment efficacy or the patient’s own health perception and constitutes the foundation for economical (cost/utility) studies considering the costs sustained by the national healthcare services [7]. Questionnaires addressing the QoL may be classified into two main groups. The first one includes generic questionnaires that may be applied to any disease. The most popular one is the EuroQol-5D, developed by the EuroQol Group, a network of multidisciplinary researchers [8]. It is administered to patients in many countries and in a variety of clinical areas to assess the health status in terms of a simple descriptive profile and a single index value. Other generic questionnaires are described and compared in [9]. The second group of questionnaires are disease-specific and address not only generic health aspects, but also the most common consequences of the disease [10]. They are meant to compare and analyze the relationships between generic and specific indicators [11] and may be used as a data source for electronic medical records [12].

The need of regularly monitoring the QoL is becoming a prominent task with the increased prevalence of chronic diseases experienced worldwide, since a high number of patients now requires the administration of a treatment for the whole rest of their lives. With respect to this, surveys concerning the patient QoL are being used to monitor the effects of those treatments on a mid- or long-term basis, either to individualize the therapy or to counteract any possible side effect that may be experienced by the patients. For example, Caffo et al. [15] mention the importance of questionnaires as a means of collecting information useful to monitor changes in the QoL perceived by patients affected by uterine cancer that underwent postoperative radiotherapy. They also emphasize the need of collecting and processing smaller amounts of data on a daily basis, as opposed to more comprehensive and longer interviews occurring at less frequent intervals. This is useful to better capture the fluctuating day-to-day changes in patient lifestyles [14]. The need of regularly filling-in daily cards to assess the QoL during chemotherapy with the aim of possibly adjusting the treatment is also advocated in [15] for patients affected by small cell lung cancer and in [16] for those affected by breast cancer.

In an effort to capture the QoL perceived by patients over time and perform some standardized assessments, qualified organizations are setting up and validating questionnaires addressing the specific requirements of several diseases. For example, the European Organization for Research and Treatment of Cancer (EORTC) [17] has set up and validated the questionnaire EORTC-QLQ-C30 to regularly assess the QoL in patients affected by cancer, as witnessed by several studies that are relying upon it since many years [18–21]. The above mentioned studies accomplished data collection mainly using traditional paper forms. However, the current widespread availability of computers and the pervasiveness of network connections push toward their adoption also for the acquisition of patient recorded outcomes. The EORTC, for example, has developed a new version of their questionnaire that has been adapted for an optimal rendering on electronic devices [22]. In designing that new version, they are leveraging on the Computerized Adaptive Testing (CAT) methodology [23] which foresees an estimation of the questionnaire outcome on the basis of the previous answers provided by the patient. That knowledge is then used to drive the subsequent selection of the most informative questions for further deepening that outcome. The advantages of CAT in designing questionnaires and surveys are increasingly being acknowledged also in many other areas involving the self-reporting of outcomes by patients. Examples are given by Anatchkova et al. [24] concerning chronic pain, by Caronni et al. [25] for estimating the QoL in adolescents affected by idiopathic scoliosis, by Kosinski et al. [26] concerning the impact of osteoarthritis or by Kocalevent et al. [27] for the patient perception of stress. This happens because CAT decreases the burden for the patient by tailoring the item set to the specific situation to be monitored.

In parallel with the development of questionnaires comes the need for platforms supporting their delivery in a standardized way which is adapted to the clinical context. Similar platforms should be decoupled from the survey modules in order to allow the administration of the set best fitting the
2. Motivation

As a laboratory of biomedical informatics, we are often involved in studies enrolling outpatients that need to regularly send self-reported outcomes to the clinical staff. The availability of a tool supporting the accomplishment of this task motivated the design and the implementation of Gquest. Two different sample scenarios were used as templates for shaping its implementation, concerning the acquisition of feedback from patients enrolled in the MobiGuide project and supporting a survey about Safe Discharges for Fragile Patients.

2.1. Supporting quality of life assessment in the MobiGuide project

MobiGuide [28] is a project funded by the European Union and carried on by a consortium of 12 partners from several countries in Europe (Italy, The Netherlands, Spain, and Austria) and Israel. It is aimed at developing an individualized, knowledge-based, guidance system for outpatients based on clinical practice guidelines that are tailored each time to the preferences of a specific patient and to the possibly different life contexts he may face. The main components of MobiGuide are a decision support system and a body area network. The former runs on the back-end and is devoted to the representation and execution of guidelines, while the latter encompasses a web of sensors and a smartphone in order to support patient telemonitoring. The overall aim is to harness the Information and Communication Technologies (ICT) to guarantee a better empowerment to the patients so that they can play an active role in managing their health and any associated treatment process. Whenever the need arises the MobiGuide architecture activates the so-called “patient guidance system” that provides an immediate assistance for the patient in a user-friendly way using the smartphone and suggesting recommendations relying on evidence-based clinical guidelines or experts’ consensus. At the same time the system informs the patient’s care providers and supports them in accessing any relevant data and in properly interpreting those to offer a better counseling on a mid-term period. MobiGuide is expected to provide support anytime and anywhere, while patients are at home, outdoors, at work, in vacation, etc... As a consequence, the availability of a mobile device for the patient represents a mandatory requirement to fit its context. The MobiGuide consortium partners selected Android as a platform for the mobile devices due to its low-cost, the wide range of available devices and the open source approach adopted for its developing environment.

In order to assess the MobiGuide architecture and demonstrate its effectiveness in improving the outcome of the treatments and the patients QoL, a clinical study has been planned later this year involving patients affected by Atrial Fibrillation (AF). During that study patients will be required to periodically fill-in a questionnaire about their satisfaction with the MobiGuide support, as well as two questionnaires (one general and one AF-specific) for their QoL. Given the strict requirements imposed by the project, the availability of an easy to use and configurable platform, running on the same mobile device used for the other MobiGuide functions, was required.

2.2. Collecting needs for fragile patients

A different context calling for a platform able to support the flexible administration of questionnaires was found within a regional telemedicine project meant to improve post-discharge home assistance for fragile patients. More specifically, the need to keep medical expenses under control is increasingly pushing toward home treatment as an alternative to hospital care, which results in earlier discharges with respect to the standard times adopted some time ago. In order to understand the needs of those patients and provide better services for them, within the context of that project we were asked to support the administration of a small generic survey. That survey is expected to be filled-in by patients or their relatives at least twice during the two-months period following their discharges. The survey includes generic inquiries concerning the administration of drugs, the visits required, the need to use medical devices along with the occurrence of remarkable events such as errors in administering drugs. Moreover, since fragile patients are not independent and require the aid of home caregivers either to support their treatment or to help them in accomplishing many usual tasks, a section of that survey is also meant to assess the increased burden on the family members. The generic questionnaire has then been customized to address the specific requirements of the two different classes of fragile patients targeted by the...
The need for a new platform

When we faced the need to support the interviewing requirements of our projects we first looked for some already available implementations. While there are indeed many possible candidate platforms, we were forced to turn them down all as we verified that they failed to fulfill our requirements. A quick literature search returned popular tools such as SurveyMonkey (https://www.surveymonkey.com/), SurveyGizmo (http://www.surveygizmo.com/) or even Google Forms (https://drive.google.com). Those tools are mainly meant to be used on PCs, although they may also be accessed from a smartphone through a web browser or a dedicated application installed on top of it. The first two provide complete environments for the design and delivery of questionnaires. They are commercial tools that require the payment of a licensing fee but also provide free services with some limitations intended for demonstration purposes. They even include tools for automatically analyzing the answers provided by the users which makes them most suitable to accomplish marketing or opinion surveys. Their main limitation is represented by the fact that they just work in an on-line mode. With those systems questionnaires are delivered through a web browser which renders them on PCs or smartphones only when an active internet connection is available. Google Forms is free and is therefore very popular for the accomplishment of small scale surveys that are delivered either by e-mail or by sharing them on the most commonly used social platforms such as Google+, Facebook or Twitter. Nevertheless, even in this latter case the administration of a questionnaire requires the availability of an on-line internet connection, which invalidates the basic requirement of the MobiGuide project calling for the availability of patient support anywhere and anytime.

After ruling out any other tool operating on-line based on the above discussion, we focused on platforms available through dedicated applications installed on smartphones. In this category we considered systems such as Opinio (http://www.objectplanet.com/opinio), SnapSurvey (https://www.snapsurveys.com) and SurveyPocket (http://www.surveypocket.com/). Opinio is a commercial system designed to create, publish, manage and analyze surveys. Questionnaires created with Opinio are administered on the mobile device and data are transferred to the server automatically in almost real time when a connection is available. When there is no network coverage data are stored on the device and synchronized later resulting in a transparent behavior from the user’s standpoint. Unfortunately Opinio Mobile is an application only available for the iPhone, iPod touch or iPad, but not for Android device, which makes its exploitation unsuitable for the MobiGuide project. SnapSurvey and SurveyPocket are also commercial tools that allow to create, publish and distribute online surveys in different languages. According to the presentation material available on their sites they allow the definition of jump rules for selecting the next question to be presented based on the current answer, and support the administration of questionnaires on mobile devices based on the Android operating system. No trial version was directly available on the SnapSurvey site, while SurveyPocket provides a very limited environment for freely experimenting with their tools. The companies provide a high-end professional service through their software infrastructure, i.e. they act as consulting partners focusing on marketing research instead of selling a configurable and affordable end user solution. Moreover their service-oriented architecture requires saving all the patient data onto their servers which would not receive the approval of the ethical committees of MobiGuide consortium partners for the final study.

A last important requirement for several questionnaires in the healthcare domain is the calculation of one or more values, that are not only important for assessing a patient’s global score, but are also used in statistical correlation analyses with other clinical variables. In their simplest form, scores are calculated by just summing up all the item values. Quite often, however, they require to implement more complex formulas. For example, the EuroQol requires the computation of an expression including weights for every item and penalties upon the occurrence of specific combinations of answers. Weights and penalties also depend on the country where the questionnaire is administered. Other questionnaires may be partitioned into subsections, each one requiring the computation of a separate and specific sub-score. The above mentioned CAT methodology also requires incremental calculations in order to determine the next question according to its informative value. As a matter of fact, CAT uses an estimate of the score and its precision, computing them after each response, to determine if more questioning is necessary and, if so, to identify the question that would be the most informative at that point [26]. This feature was not available in the commercial tools that we investigated.

Based on the above considerations, and leveraging on our previous experiences involving the implementation of a synchronization infrastructure for telemedicine applications [29–31] we decided to design Gquest, with the aim of generating an easy to use and configurable tool. The guiding principle inspiring the work has been the remote administration of questionnaires supporting navigation among questions according to the CAT methodology and enforcing consistency over the input provided by patients.

3. Designing the new platform

The first task to be accomplished when setting up a questionnaire deals with identifying the way in which it is to be administered, how data should be collected, and deciding the actual design of the items building up the questionnaire itself. This involves preparing a clear textual definition for each
question, rendering them with a proper wording and partitioning all of them into suitable subsets so that they can be presented into the most appropriate order to the user [32]. Structuring the questions is particularly important as the target user perceives their sequence as a virtual conversation through which the investigator elicits his answers. In order to properly motivate the user and capture his attention, that conversation should avoid being repetitive, trivial or ambiguous. Thus the questionnaire should be adaptive, exploiting any previous answer provided by the patient to dynamically drive the conversation with him. This helps in enhancing the response rate, while a failure to achieve it may demotivate the user, reduce the accuracy of his answers and even force him to give up altogether. In a written questionnaire directions are also helpful for making explicit the meaning of each question and the specific intent associated with each answer, although a careful tradeoff should be considered: while the absence of directions could be misleading for the user and possibly result in eliciting the wrong answers, an overly long set of instructions could be perceived as obtrusive demotivating the user and yielding the opposite result [33]. For those reasons it is crucial to develop a model for a suitable representation of the questionnaire to be administered. In this section, we first describe such a model, and then we illustrate the architecture for managing the questionnaires supported by it.

3.1. The questionnaire model

Designing a platform for rendering questionnaires implies as a prerequisite the capability of representing the questionnaire itself. Thus we developed a model with a high level of flexibility in order to better capture and shape a big number of question types the user could answer. Within the model developed, a question is an information group that must be shown together to the user. Its main components are the question text and one or more answers. The former conveys the primary meaning of the question and provides a framework for the user’s input. Answers represent instead some ancillary information acting as placeholders and shaping the context for the actual input. Thus, a single answer may include multiple input items which are all considered related and should be consistently filled-in. An example is presented by the following question template which illustrates a portion of the paper version of the questionnaire implemented in our fragile patients scenario addressing preterm newborns (see Section 2.2). The example shows two questions, both composed of a first yes/no sub-question, and more detailed second and third-order sub-questions composed of different items to be considered just in case of affirmative answers to the first ones.

<table>
<thead>
<tr>
<th>Did the caregiver have problems with drug administration?</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>If yes, which type?</td>
<td>□</td>
<td>Wrong dosage</td>
</tr>
<tr>
<td></td>
<td>□</td>
<td>Forgot to administer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Does the child use some auxiliary tools?</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>If yes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cardiometer</td>
<td>□</td>
<td>private</td>
</tr>
<tr>
<td>pump</td>
<td>□</td>
<td>private</td>
</tr>
<tr>
<td>saturimeter</td>
<td>□</td>
<td>private</td>
</tr>
<tr>
<td>oxygen supplier</td>
<td>□</td>
<td>private</td>
</tr>
<tr>
<td>Nasal C-PAP</td>
<td>□</td>
<td>private</td>
</tr>
<tr>
<td>Other</td>
<td>□</td>
<td>private</td>
</tr>
</tbody>
</table>

*NHS = National Healthcare Service

An answer has fixed parts called labels, which are not user-editable, serving the purpose of introducing inputs where the user may actually enter information. Data may be entered into an input either by typing or by selecting one of the available choices associated with it. In designing the semantics of the input elements we capitalized on the HTML experience allowing a broad set of types such as text boxes, checkboxes, radio buttons and choice selections. We also allow structured input types, such as the yes–no choice which is rendered by the application through primitive types such as buttons or multiple choices. Finally, for those answers requiring it, answer instructions may also be available to better specify the meaning or clarify the question context altogether in order to facilitate the user choice.

Another important requirement of the model concerns the definition of constraints for the questionnaire which help in reducing errors and checking input correctness. We adhered to a very simple constraint model for fields where input can be restricted to the available choices, and possibly be marked as mandatory. Additional constraints may also be defined at the answer or question level, for specifying the number of mandatory input or answer combinations.

In order to provide a dynamic adaptation of the questionnaire which better captures the needs of a monitoring scenario in a clinical context, the model also includes navigation rules for shaping the correct sequence of questions according to the previous input provided by the user. For instance, a compound question might be, as shown in the previous example, “Does the child use some auxiliary tools?”. If the answer is “no”, no
further inquiry is performed; if it is “yes”, a section is entered asking specific information for further describing those tools. This should be repeated as many times as the auxiliary tools used.

Navigation rules can be set up on a whole question or on specific answers, as shown in Fig. 1. In fact, questions are arranged into blocks inside which the navigation proceeds sequentially unless a specific rule is established. For example in block blk1, question q1 is always followed by question q2 no matter how the user replies to the answers included in question q1. However, at the question level two different rules may be defined that are triggered if the user provides some input (i.e. onfill) or not (i.e. onblank). This is represented by the two lines departing from question q3. In that case if the user provides some input to question q3, question q4 is subsequently shown; if he does not, question q5 is accessed instead. Answers may specify instead only an onfill rule pointing to the next question to be accessed when the user provides some input to that answer. For example, the two lines departing from question q5 and pointing to questions q6 and q7 represent onfill rules relating to two different answers available in q5. When there are no navigation rules associated to a terminal question in a block the questionnaire is considered finished, as it happens for questions q6 and q8.

The navigation rules devised make it possible to skip some questions or move to explicit ones depending on the input provided by the user. Thus they help in better shaping the virtual interviewing conversation with him. By properly structuring a question in terms of answers and inputs, placing constraints at the question, answer or input level, and defining suitable navigation rules, a great degree of flexibility is achieved able to capture the requirements of almost any complex questionnaire scenario. This may be exploited to exclude some blocks altogether depending on the previous user input or to repeat some questions several times in order to collect all the user’s information required by a study.

Given the description of the model proposed, XML seemed the most appropriate language for encoding a questionnaire. Fig. 2 illustrates on the left the most important elements referenced in the XML schema, while the right side shows

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**Fig. 1** - Navigation rules set-up among the questions composing a questionnaire.

**Fig. 2** - A graphical representation of the XML elements building up a questionnaire (on the left) along with an excerpt of a questionnaire (on the right).
an excerpt of a questionnaire referring to the same example introduced earlier at the beginning of this section. Ellipses (…) are used to reduce its text suppressing some elements. The root element is questionnaire including block elements which then encompass question elements. Each question is composed of several answers including labels as fixed components and input elements representing placeholders for the user input. The XML section also shows some navigation rules set up for questions and answers in terms of onfill and onblank attributes. Fill constraints are defined through the fillrequired and fillcount attributes. For example, in question b1q1 those attributes specify that it is mandatory to fill-in one answer, but more are allowed as well. The fillrequired attribute tells instead that filling-in each specific answer is optional, as it also happens for any input item. In fact, in the example shown each answer only includes a single input item so the same fillrequired value applies both at the answer and input levels. Finally, the instruction element and speech attributes provide suggestions which may be rendered as side notes or as spoken language by the platform.

In order to simplify the process of generating the XML file, an editor has been developed in terms of a Web application, through which the user may easily provide all the elements and attributes necessary to characterize the blocks and the navigation rules of the questionnaire.

3.2. The functional architecture of the platform

The model proposed allows the definition of a questionnaire along with all the associated constraints and navigation rules. However, this only helps in representing the set of questions and still leaves open the problem of collecting feedback from patients during clinical studies or surveys. Thus we needed an application able to support running instances of those questionnaires and we selected smart-phones and tablets as the target devices for the implementation. This is in line with current studies concerning clinical diaries showing that users are more comfortable with portable devices since they are available and ready to use at any time and in every place whenever they are needed [34]. The Android operating system was then selected because it is open-source and available on multiple hardware.

Fig. 3 shows the overall functional architecture of the platform illustrating the full workflow supported by it. That workflow starts (upper right) with the design of a new questionnaire, which basically entails creating the XML file representing it, and deploying it as a module on a server repository as shown in the upper part of the figure. The mobile application notices the availability of a new questionnaire module, then downloads and saves it into its local module repository. A questionnaire may either supersede an old one, therefore substituting it in the application library, or be stored as a new one representing an additional choice for the user. When the user accesses the mobile application he may select a questionnaire among those available in the local repository. Then he can start filling-in answers as required by its treatment protocol. We provide two different help modes supporting the user in filling-in a questionnaire. The XML model allows the definition of an associated instruction text for each question which is rendered by the application as a side note dynamically shown or hidden on user demand. Furthermore, the same model allows an optional explanation text for both questions and answers which the application renders through the embedded text-to-speech library provided by Android. Similarly when providing input the user may exploit the embedded speech recognition engine which is constrained by the type associated with the input field. Taken as a whole the possibility of using the speech both for hearing directions and entering input simplifies the task of filling-in a questionnaire and improves both the usability of the application and the user experience.

The answers provided by the user are incrementally persisted in a local database so that they are not lost if the user stops a session before finishing to fill-in the whole questionnaire. At the next access, he will face the option of continuing with the suspended one. In that case he may review the previously provided answers, modify them and finally close the questionnaire or delete the suspended work altogether. Each questionnaire may be answered multiple times by the user according to the treatment protocol, in which case the answers will be correctly grouped together by instance and remain consistent. When a questionnaire is finished, the answers provided by the user will be synchronized to a remote database in order to perform the required analyses by the clinical research staff. The synchronization task requires authentication in
order to save the results. Depending on the study, each patient can be allotted a different set of credentials for submitting his answers or use a shared space thereby enforcing anonymity.

3.3. The computational architecture of the Android application

The application for rendering questionnaires has been developed on top of the Android operating system, thus it is able to run on all the Android-powered devices which have very different capabilities ranging from small smart-phones to wide tablets. The feature impacting the application behavior at most is the screen size, and depending on the complexity of the information conveyed in the questionnaire it is therefore advisable to select a suitable device.

Fig. 4 shows the computational architecture of Gquest on the Android platform illustrating all the software components building it. The Downloading Service is responsible for downloading the files with the XML representation of the questionnaires, once they are made available on a server repository accessible through an internet connection. Those files are processed by the Validating Parser and eventually stored in the Questionnaire Repository where all the questionnaires become available for the user selection. The parser checks every file against the syntactical and semantical correctness of their XML and creates the Questionnaire Model which is a memory structure used by the application for navigating across the questions. There is mostly a one-to-one correspondence between the elements available in the XML representation and the object instances available in that memory structure. Checks enforced by the validator include testing the availability of the required attributes for each item and the consistency of the navigation rules expressed in terms of the onfill and onblank attributes. The Questionnaire Model is represented through a series of JavaBeans™ extending a common class, which contains properties and behaviors shared by all the different elements referenced by a question. The model is also responsible for managing the user input which is saved into the Answer Repository and recovered from it whenever previously answered questions are revised. That repository is implemented using the content provider feature exposed by Android that is based on a SQLite implementation.

The application is shaped against the architectural pattern named model-view-controller. In our case the model provides the in-memory representation of the questionnaire where both the definition of the question and the user input are stored. The view is responsible for assembling the layout of the questions and activating the text to speech concerning the help, while the controller enforces the Navigation Logic and the consistency rules defined in the model for the user input. Our implementation sees each model element matched with a view part responsible for rendering their graphical representation. There is a single Android activity for displaying the whole questionnaire which is dynamically updated by the different view parts responsible for rendering the layout whenever a new question is accessed. In fact the view parts are responsible for creating all the widgets representing the title, labels, checkboxes, radio buttons and textual input fields according to the specific organization of the current question.

The GUI Renderer displays each question either in read-write mode or in read-only mode according to the navigation rules. The latest question is always editable and the user can input a value or select one from the available choices depending on the case at hand. The editable question also has the capability of displaying help messages. Those messages may be uttered in spoken language by the Text-to-speech service based on the user preferences.

If the user navigates backward and accesses a previously answered question, that one will be recovered from the Answer Repository and shown with its input fields precompiled and disabled. On any previous question the user is given the chance to reopen it in order to modify his previously provided input. However, since the navigation has presumably been affected by that input, reopening a question implies the truncation of any other question answered from the reopened one onwards.

Once the questionnaire is finished, the renderer always gives the user a chance to review the full questionnaire in read-only mode, in order to delete or accept it and finally synchronizes the answers through the Synchro Service.
4. Results and validation of the questionnaire model

As previously mentioned, two medical scenarios motivated the development of Gquest. Their implementation is illustrated in this section. For those applications, we used different types of questionnaires, some standard ones and some others developed ad hoc for the specific medical contexts considered. The aim of this section is to show how Gquest renders those questionnaires that account for a wide set of question- ing constructs commonly found in many questionnaires. An assessment of the user experience perceived by real patients while using one of those questionnaires and the outcomes emerging through their answers is also provided.

4.1. Atrial fibrillation patients monitoring

In this scenario the goal of the questionnaires is to collect information about AF patients that accepted to be enrolled in MobiGuide. In the final study foreseen by the project two groups of patients (using/not using the telemedicine support) will be required to fill-in three questionnaires, the EuroQol, the AFEQT [35] that is specific for AF, and an ad hoc small survey on the satisfaction with the system. Since MobiGuide relies on the exploitation of smartphones as an empowerment tool for patients and their relatives, also the questionnaires will be administered through smartphones. Moreover, one of the MobiGuide aims is to provide patients with reminders in order to increase the compliance to their treatment plan. Since filling-in questionnaires is considered an important task, any failure to accomplish it is also subject to raise a reminder, eventually increasing the response rate. Fig. 5 shows how Gquest renders two portions of those questionnaires, that have already been administered during a pilot study to a small set of patients for testing the usability and acceptance of the system in sight of the main clinical study.

Twenty patients, 10 males and 10 females, participated to this pilot evaluation study of Gquest. The mean age was 66.2 years (range: 34–79), and they were affected by three different AF types, namely 9 persistent, 6 post-operative, and 5 permanent. One of them had a cognitive impairment and was not able to fill-in the questionnaires. The administration of the AFEQT and EuroQol required an average time of 11.7 min (range 5–20) and 3.2 min (range 2–5), respectively, including the time for their explanation (needed since this was the first time they were administered). Since those questionnaires, after the very first time, will be used routinely as self-administered tools, we estimated that time will decrease of at least 40%. This first result ensures that filling-in those questionnaires on a regular basis (e.g. once a week or once a month) will not represent a burden for home patients.

A second result was about usability issues experienced on the device used (i.e. a Nexus 7 by Google). Half of the patients had problems with both horizontal and vertical scrolling. This was the only issue related to the hardware device, so we are working to avoid scrolling as much as possible by a better framing of the text. Another usability issue is related to how the questionnaire engine manages the update of the previous answers. Since, in general, changing a previous answer will modify the subsequent flow of questions, Gquest actually clears all the subsequent answers already provided starting from the one modified onward. Of course this is annoying for plain questionnaires, that do not embed navigation rules.

The third result was obtained by analyzing the collected data. The Gquest database may be queried to perform elaborations on specific data. For example, physicians were interested in the correlation between the scores obtained with the two questionnaires. As shown in Fig. 6, the scores were not significantly correlated. The EuroQol provided lower scores than the AFEQT, showing that AF is probably only one of the problems affecting the QoL of those patients, and most likely it is not the worst one. As a matter of fact, the mean age of the patients in the pilot study justifies the presence of comorbidities.
Fig. 6 – Some statistics on the scores of the EuroQol and AFEQT questionnaires administered to a sample of patients during a Gquest evaluation study. Histograms of values distribution and scatter plot with the correlation coefficient are shown.
Moreover, some of the patients had post-operative AF. Thus their main problems were the underlying disease and other post-operative problems. Those findings will be very useful to help the interpretation of the results in future large scale studies.

4.2. **Fragile patients scenario**

The second scenario deals with fragile patients, for whom a telemedicine system was proposed as a means to improve home monitoring. Before starting the system development, a questionnaire has been devised to collect the actual needs of those patients and their relatives, and the costs they sustain, along with the national healthcare system, for their traditional care. This information will represent the baseline for evaluating the benefits of the telemedicine system that will be introduced.

Two versions of the questionnaire have been developed, one for elderly patients and one for the parents of preterm newborns. Most of the questionnaire sections are basically the same, but in the second case, the answering person may be either the father or the mother. However, some questions vary, accounting for the different ages of the target population. Both questionnaires represent a good test for Gquest, because they encompass several questions types, of different complexity, as illustrated below. Questionnaire sections concern:

- After-discharge home situation (address, family, social health facilities, auxiliary tools, drugs, etc.). An example of a complex question querying for that information has already been shown in the example introduced at the beginning of Section 3.1.

- Emergency situations that occurred at home during a certain time interval (e.g. the last month\(^1\)), This section embeds a set of questions that must be answered for every emergency situation that has occurred (of course the number of these situations is not predictable a priori). For example:

```
Describe the situation

External intervention type: No. of times
☐ Neighbour intervention ......................
☐ General practitioner called ..................
☐ Emergency service call (119) .................
☐ Emergency department visit at(location)  .........
☐ Hospital admission (Hospital name: ) ................
  location: ................................... hospital stay duration: .......... days)

To bring your baby to the control visit, did you need a job leave? Y N
  If yes, how many hours ...........

Did you need an accompanying person? Y N
  ☐ A relative ☐ A baby sitter ☐ A friend ☐ Other ..................................

Did this person need a job leave? Y N
  If yes, how many hours ...........
```

- Control visits. Since those visits could have been performed at different sites, for each visit the patient should provide information, such as distance, time spent, whether or not he needed an accompanying person, etc. For example:

```
• Emergency situations that occurred at home during a certain time interval (e.g. the last month\(^1\)), This section embeds a set of questions that must be answered for every emergency situation that has occurred (of course the number of these situations is not predictable a priori). For example:

```
Describe the situation

External intervention type: No. of times
☐ Neighbour intervention ......................
☐ General practitioner called ..................
☐ Emergency service call (119) .................
☐ Emergency department visit at(location)  .........
☐ Hospital admission (Hospital name: ) ................
  location: ................................... hospital stay duration: .......... days)

To bring your baby to the control visit, did you need a job leave? Y N
  If yes, how many hours ...........

Did you need an accompanying person? Y N
  ☐ A relative ☐ A baby sitter ☐ A friend ☐ Other ..................................

Did this person need a job leave? Y N
  If yes, how many hours ...........
```

This last example is rendered in Gquest as shown in Fig. 7.

5. **Discussion**

Our specific interest toward the availability of a platform for delivering questionnaires to patients was in exploiting it during evaluation studies involving home patients. However, we believe that the potential applicability of a similar platform is much wider. Several systems for the remote monitoring of home patients have been already described in the literature, helpful either for a long-term prevention and rehabilitation in elderly people \[36\], for managing chronic diseases \[30\], or as a means of overseeing the patient during specific events \[37\].

To this aim cloud-based approaches are being investigated \[38\] to complement traditional knowledge based systems that relied on a web browser for acquiring data \[39\] with network and sensor technologies centered on mobile computing. The goal is to provide an innovative set of healthcare services leading to personalized health systems \[40\] and ultimately

\(^1\) The time frame depends on the frequency of the questionnaire administration.
improving patient self-management. In all those cases the plain monitoring of vital parameters should be complemented by the acquisition of contextual information in order to simplify the human supervision, help in early detecting hazardous situations that need to be contrasted and facilitate the individualization of treatments.

While designing and implementing Gquest we first investigated and addressed all the possible limitations faced by patients. Then we combined the intuitiveness and easiness of use experienced adopting a paper and pencil approach with the advantages arising through the use of a CAT methodology. In so doing we also leveraged on the technology of web administered surveys, although in our case a dedicated application for rendering questionnaires on tablets was preferred. The main reason is that a similar approach eliminates the requirements of possessing on the user side both the skills for accessing and navigating the internet and the need for a broadband connection. Thanks to the native connectivity exhibited by mobile devices, Gquest can be started with an action as simple as a click on an icon, while everything else occurs transparently for the patient. Furthermore, the implementation on a mobile hardware improves the overall user experience since the patient is not required to be sitting in front of a networked PC for answering questions. The task of completing the survey may be accomplished with fewer restrictions and is more comfortable for the user who can bring the device with him while he is busy during his work hours. As a result there is a higher chance that any question involved by the study protocol will be answered in the most accurate and timely fashion. Once the questionnaire is downloaded and stored in the local library, it may be accessed anytime even when no network coverage is available. The user is always free to navigate among the questions he has already seen, possibly revising his input, and when he decides to complete the survey that input becomes eligible for synchronization. This is sensible, because the information to be provided using questionnaires is never “urgent”.

Another major concern affecting the quality of a survey relates with factors such as question ordering that capture the user attention and affect the response rate [41]. It has been found that preceding questions may affect how users consider and interpret latter questions especially when some kind of relationship exists among them [42]. We capitalized on those results devising an adaptive model for representing the questionnaire, so that whole question blocks may be skipped whenever their answers can be inferred by those provided

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**Fig. 7** – A section of the questionnaire concerning the home care requirements administered through Gquest.
earlier or they turn out to be not applicable altogether. Visual disposition arranges separate questions on different screens so that each one may be associated with the suitable help to support the user in providing the answers. A special effort has been devoted also to the implementation of an enhanced help supporting the user in properly understanding the question. This is available in the form of annotations to the questions but may also be rendered in spoken language using the text-to-speech engine available in Android. Since mobile devices customarily already embed speech recognition capabilities for speeding up textual input, it follows that voice and graphical user interface capabilities are merged within Gquest. The result is a better user-experience overcoming the limitations experienced during the first experiments of adaptive spoken dialogs occurred in the past decade [43].

An important issue for surveys is represented by the need to ensure an adequate quality of the data collected. This should be achieved through a careful design phase where the researchers prepare a suitable set of questions whose answers are consistent with the study to be accomplished. At a knowledge level, since the delivery of questionnaires may be considered as a multi-agent scenario, the availability of standard ontology and terminology servers [44] could play a key role enforcing a common semantics shared among all the participating actors. Those encompass at least the questionnaire editor, and the environment where the subsequent analysis is expected to be accomplished. No matter how the questionnaire is generated or analyzed, it is important to keep its relevance up to date with the study. In fact, much too often a survey is deployed just to find out, soon after data collection has started, that it cannot be used for establishing valid and reliable explanations concerning the investigation because of some mistakes occurring in the way questions are structured [45]. As we are mainly concerned with surveys for collecting information during clinical studies we faced a similar problem when dealing with unexpected situations. In those cases there is no way to anticipate the problem providing consistent questions in advance. The only way to cope with that situation is to account for the adaptivity of the questionnaire itself. Once again, having implemented the engine as an application on a mobile device, we are able to dynamically update and download new questionnaires over the air as the clinicians deem to do so in a transparent way for the user.

Finally, we would like to point out a limitation of Gquest in its present implementation. Although we addressed some issues related to the questionnaire usability, we did not rely on standards nor were we concerned thus far with an optimal organization of the question layout. Of course we recognize the importance of advanced layout and presentation issues but we did not address them in the current version of Gquest based on the following considerations:

- any interface to be presented to patients should be kept as simple and clean as possible, avoiding the use of many different colors or icons;
- in order to exploit questionnaires that have been already validated by international study groups, a compelling requirement is that they are presented adopting exactly the same layout, without introducing new graphical setups nor optimized renderings as they could alter the patient’s perception of the questions.

Thus, instead of focusing on research addressing the user experience from the human–computer interaction point of view, we have been more concerned thus far with issues aimed at improving the flexibility in arranging and composing the questions. Certainly, human–computer interaction issues will represent one of the first topics to be addressed in future versions of our tool.

6. Conclusion and future developments

The paper reported on a platform for administering questionnaires to patients enrolled in clinical studies. The specific application context required features not available on existing software, such as adaptivity in the virtual dialog established with the user, consistency checks on the answers already supplied, and calculations of specific scores. This called for the design of a questionnaire model and the implementation of an application able to run its instances. The application was developed on the Android operating system so that it is available on smartphones and tablets, which allows for a better comfort and user experience.

Questionnaires are made available on a server repository and are automatically downloaded as they are deployed. At any time the user is allowed to select a questionnaire to be filled-in according to the specific study. Once questionnaires are completed, the input provided is synchronized to a server for a subsequent analysis step.

The specific features of the application make it possible to exploit it in other clinical contexts or even in different, non-clinical domains. For example, the adaptivity of the navigation among the questions, combined with the possibility of constraining the user input, make our application suitable for enforcing checklists, that encode procedures for managing processes in a standardized way. Checklists are already being used in several domains and are becoming popular also in medicine. With slight adaptations, Gquest may be profitably exploited for their implementation and dissemination among clinical and paramedical staff. With respect to this, the navigation paths among the questions offered by Gquest combined with its inherent synchronization capabilities make it particularly suitable to oversee the compliance with the standard procedures or to record any condition which justifies deviating off them. Thus Gquest may be part of a distributed patient workflow management system [46] or even help in improving standard practices in health care.

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