Design of an Interactive Medical Guideline Application for Community Health Workers

Walter Karlen, *Member, IEEE,* Cornie Scheffer, *Member, IEEE*

***Abstract*— Clinical guidelines, such as the Integrated Management of Childhood Illness (IMCI), are used worldwide to support community health workers in the assessment of severely ill children. These guidelines are distributed in paper form, complicating their use at the point-of-care. We have developed a framework for building advanced clinical guideline applications for the Android mobile phone OS. The framework transfers clinical guidelines into a flexible and interactive electronic format using an XML interpreter. The resulting application supports intuitive navigation of guidelines while assessing the patient, easy integration of patient management tools, and logging of performed assessments and treatments. The novel approach transforms clinical guidelines from a mere paper dictionary into a working tool that integrates into the daily workflow of community health workers and simplifies their task at the care and administrative levels.**

I. Introduction

Healthcare systems are struggling worldwide with high costs and lack of skilled health workers in remote and rural areas. Lay healthcare workers are being employed to overcome this gap [1]. So-called community health workers (CHWs) provide basic healthcare within their community. They visit patients at home that are either immobile or do not require urgent attention. Typical tasks for a CHW in low and middle income countries (LMIC) would be the administration of chronic medication (e.g. antiretroviral drugs to treat HIV), prenatal counseling, child health, wound care, dietary counseling and/or check of immunization status in children. CHWs also screen for severely sick patients that require urgent referral to a health center. CHWs training and practice rely heavily on clinical guideline handbooks that are issued and regularly revised by the World Health Organization (WHO). These guidelines are then adapted to local circumstances by governmental bodies. The guidelines contain diagnostic decision trees (charts) and treatment advice that have been defined and compiled by expert panels.

For the assessment of sick children, the WHO distributes the "Integrated Management of Childhood Illness (IMCI)" [2]. The IMCI guidelines are established chart booklets originally developed in 1995 and are regularly revised. IMCI provide evidence-based guidelines for the management of childhood diseases highly prevalent in LMIC, such as diarrhea, malaria, respiratory infections and malnutrition.

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W. Karlen is with the Department of Electrical and Computer Engineering, The University of British Columbia (UBC), 2332 Main Mall, Vancouver BC, V6T 1Z4, Canada. Contact: walter.karlen@ieee.org.

W. Karlen and C. Scheffer are with the Biomedical Engineering Research Group, Department of Mechanical and Mechatronic Engineering, University of Stellenbosch, Private Bag X1, 7600, Stellenbosch, South Africa.

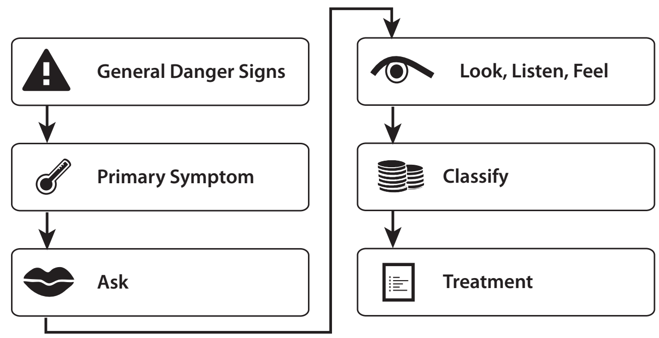


Fig. 1: Steps to complete an IMCI assessment of a sick child as described in [2].

The guidelines are simplified to the context of rural and community settings with limited access to specialized medical facilities, diagnostic tools and treatment. In the form of tabulated diagnostic trees, IMCI guidelines offer rules to assess patients, classify symptoms and signs and offer treatment advice based on this classification. According to IMCI, a sick child assessment is structured by first screening for "General Danger Signs" of childhood illness, followed by the selection of a primary symptom consisting of either "cough or difficult breathing", "diarrhea", "fever", "ear problem", "malnutrition", and "anemia" [2]. After this selection of a primary symptom, the CHW completes the assessment by following the steps of "Ask" and "Look, listen, feel". The observed signs are then translated into a classification which then provides treatment advice (Fig. 1). A limitation of the IMCI guidelines is that the tabulated form of rules is difficult to navigate and cross-referencing (e.g. when multiple primary symptoms are present) is challenging. Also, various treatment information is distributed over several tables and pages, and not all treatment options are covered.

We aim to overcome these limitations by transferring the IMCI guidelines to a flexible and interactive electronic format. This allows simplified navigation of guidelines, real-time training and information gathering for CHWs in the field. Additionally, an electronic version of the handbook allows for easy integration of patient management, analytics, as well as updates to guidelines directly over a communication network, reducing administrative workload on various levels. This approach transforms the clinical guidelines from a mere paper dictionary into a working tool that integrates into the CHW workflow and simplifies their task at care and administration levels.

It has been previously suggested to equip CHWs with mobile phones for clinical guideline applications [3]–[5]. In

[5], CHW increased compliance with guideline protocols by more than 30% when the guidelines were presented in an interactive manner (rich media).

In this manuscript we describe the development of a mobile clinical guide suitable as a work aid for CHWs. We have designed a modular framework that integrates patient assessment and treatment databases, user management, dynamic guide generation, and easy updates. The primary focus of our research was a CHW-centered approach that offered a simplistic navigation through tasks that also minimized workflow time. The results have been implemented into an application for the Android mobile platform called *ClinicalGuide*. Currently, *ClinicalGuide* integrates IMCI pneumonia management in children. The implementation of IMCI serves as an ideal demonstrator. With its modular and flexible design, *ClinicalGuide* is not limited to IMCI and can be used in various settings.

II. Methods

A. Specifications

Based on the requirements provided by stakeholders and identified from the IMCI guidelines, a series of requirements were defined. The application had to provide these elements:

- low maintenance costs
- simple and user friendly interface
- user and patient management
- tracking of activities and treatments
- longitudinal process, including alert systems allowing for follow-up of patients
- integration of guidelines which included symptoms, observations, decision trees, symptom specific recommendation classes, and corresponding treatment suggestions
- provision of training, help and support options integrated into the application
- flexible updates of guidelines and help/support features
- import and export of data, including generation of report for analytic use in health management and human resources
- encryption of user and system data to protect patient privacy and ensure data security
- capability of communicating with other health applications (such as vital sign monitors)

B. Constraints

In addition, some technical constraints were:

- framework had to run on low cost devices adapted to the target environment
- independence from network connectivity
- Android OS (2.3 and higher) was chosen as the platform because this was the most common OS of smart phones in the target environment

III. Results

A. Framework

The *ClinicalGuide* framework integrates 4 main modules to cover the essential tools to streamline the CHW workflow

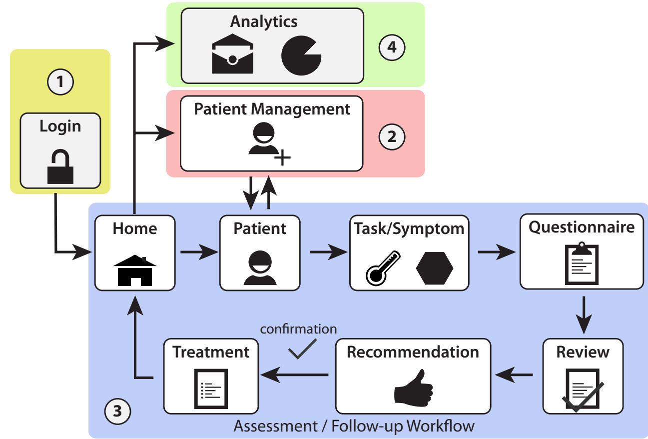


Fig. 2: Workflow of the *ClinicalGuide* application.

(Fig. 2): 1) The "Login" module manages user access, a minimum of data protection and confidentiality, and a user customization of patient and assessment history for new assessments, reminders, and reports. 2) The "Patient Management" module is used to add and edit patient information to the local database. 3) The "Assessment" and the "Follow-up" module integrate the main workflow for the assessment and treatment of a patient. This workflow integrates a complete IMCI assessment cycle (Fig. 1), preceded by patient selection. 4) The "Analytics" module supports the polling of the assessment database to summarize previous assessments and prepare reports using statistical functions. The reports can be saved as text and emailed.

The framework structure is based on two essential elements: 1) A database is used to manage all application tasks that require storage of information. This includes tables for user management, patient management, performed assessments with corresponding answers and treatments (Fig. 3). The implementation of these components was done in SQLite which was natively available in Android OS. A questionnaire depends on the primary symptom and the number and type of questions are highly variable. This demanded for a relational database where answers and administered treatments are stored in separate tables (Fig. 3). Custom functions offer the export of database fields into tabular formatted files for report generation and synchronization with cloud based patient management systems (e.g. openMRS [6]). Data stored in the database are encrypted at entry and can only accessed through password login. 2) For the elements that required high flexibility and modularity, an XML parser was used. Primary symptoms, questions, conditions, and treatment options are defined within an encrypted XML file. This XML file is decrypted and then dynamically loaded at the start of the application and the flow for each task subsequently defined. The attributes of the <question> tag are "id" and "answerType". Additionally, sub-elements <label>, <info>, and <annotation> are possible. An <answer> tag can have two different structures. In its simple format, it defines a possible response and has the attributes "id", "for" (relating to a question id) , "value" (relating to a question state)

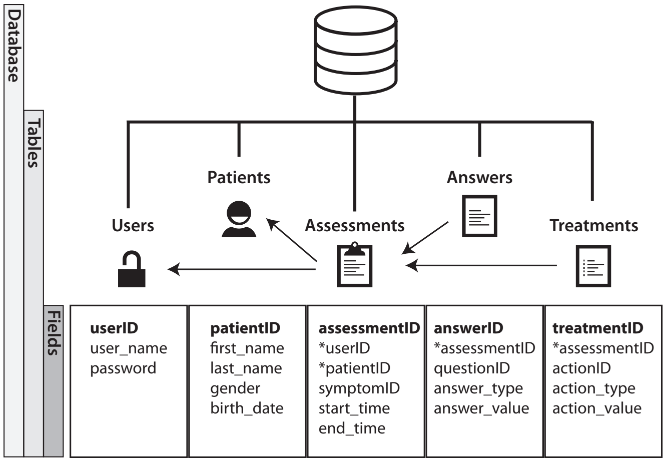
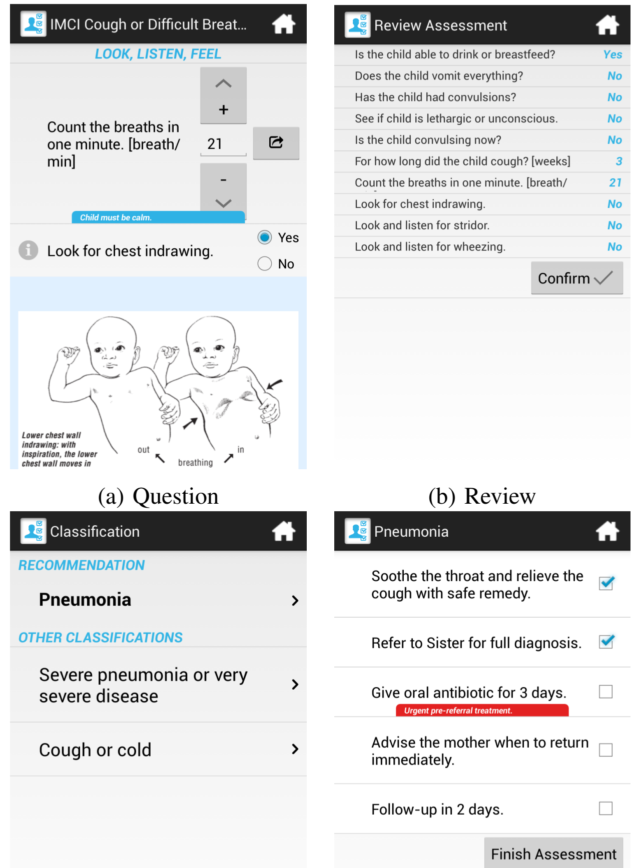


Fig. 3: Database structure for the *ClinicalGuide* and relation between tables. Patient fields, Symtoms, Questions and Actions are defined externally in XML.

and optionally "constraint" (testing "value" for a defined constraint like "≥"). In its second format it defines a combination of answers. Sub-elements can be <choice> that combines a lists of <answer> with a logical **or**; or <union> that combines a lists of <answer> with a logical **and**. Consequently, the decision logic for a classification of a condition can be entirely defined in the XML structure. The lexicon for "answerType" contained text fields, radio buttons, and yes/no sliders. It was extended with two definitions for number entry using: 1) a number picker for manual entry and incremental increase; and 2) an additional button for polling values from an external applications. This polling was designed to obtain vital signs from independent measurement applications such as respiratory rate or oxygen saturation. The call of external applications is performed by creating an intent, an inherent capability of the Android OS that allows for sending and receiving of information between applications. For handling intents containing vital signs, a custom Android library defining the vital sign intent filters, called *ShareVitalSigns*, was developed [7].

B. User Interface

The user interface was designed using common building blocks from the Android API. For data entry in the questionnaire section, text fields, radio buttons, yes/no sliders, and buttons for connecting to external measurement applications were made available. Additionally, as the spinner was shown to be difficult to use by those not accustomed to advanced touch screen functionality [8], we designed a custom number picker using two buttons enclosing an integer field (Fig. 4a). Each question can be optionally equipped with an "info" button that allows expanding the question to obtain additional information about the question in the form of text and figures. Recommendations for performing the question/task are displayed and highlighted in color at the bottom of each question, if necessary. The review of the assessment questions and answers is presented as a compact list (Fig. 4b). The classification is presented with a recommended



(a) Question (b) Review

(c) Classification (d) Treatment

Fig. 4: Overview of the user interface for the 4 main steps in the assessment of the IMCI main symptom "cough and difficult breathing".

diagnosis and a list of other possible classifications (Fig. 4c). This allows for overriding the recommended diagnosis and selecting a different class. Treatments are presented as a checklist (Fig. 4d).

C. Analytics

The generation of analytic reports and usage statistics was designed to be modular. Similar to clinical guideline specifications, the content of reports can be specified using XML. The XML schema for reports contains fields to define time ranges, symptoms, mathematical and statistical functions (such as sum or mean), and other functions that allow operations on the database. This module allows the CHW to easily access information required to report to their supervisors, such as "Number of patients with difficult breathing assessed in last seven days". These functions also support more sophisticated analysis, useful for the planning of visits, such as "Average time spent for assessment of IMCI cough", or the quality control: "Number of manual override for IMCI diagnoses in last year".

IV. Discussion & Conclusion

Clinical algorithms and guidelines have traditionally been available to health workers in static tables and books. The emergence of PDAs and smart phones opened new paths to access these resources as standalone applications or over the internet. However, current applications make little use of the capabilities and flexibilities of mobile phones such as the large touch screen, access to databases, and computational power. Our goal was to design a software framework for mobile phones that facilitates the deployment of clinical algorithms and guidelines such as IMCI in a flexible and interactive way. This framework enables interactive patient assessment and provides diagnostic and treatment recommendations based on externally defined guidelines. The content of the guidelines (questions, diagnostic algorithms, diagnosis classes and treatments) are defined in an external XML file, which is loaded when the application is launched. This allows for easy customization of the content and adaptation to the local needs of CHWs.

The proposed design of the *ClinicalGuide* allows the collection of this data electronically in an automated way and store it securely on the mobile device. All information needed for analytics (number of patients visited, drugs administered, vital signs measured, etc.) are automatically recorded without interfering with the CHWs workflow. The integrated export functions allow for backup of data and the generation of reports that are requested by the CHW's supervisors.

The developed application provides a customizable link to external applications; for example when a vital sign is requested. This feature facilitates the quick assessment of physiological parameters without closing the *ClinicalGuide* application. Possible external applications could be the Phone Oximeter [9] or the Camera Oximeter [10] which provide heart rate and oxygen saturation. For the assessment of respiratory rate within the IMCI cough and difficult breathing task we developed an application that records the repeated tapping on the touch screen [11].

A specific feature that has not yet been implemented and tested is the inclusion of an alarm engine that will provide CHWs with automatic reminders to follow-up with their patients based on previous treatments. A formal usability test of the *ClinicalGuide* with the CHWs in the target environment is underway. Other than the usability of the interface, we are interested in the obstacles and risks that may arise with the implementation of electronic medical assistants like the *ClinicalGuide* in the community environment. For this, we are working with ethical consultants that will identify concerns of CHWs, supervisors, patients and their families.

Childhood pneumonia killed more than 1.3 million children under five years old in 2011 [12]. Many of these deaths are preventable with early detection and timely administration of treatments or referral to clinics. The *ClinicalGuide* could therefore contribute to an improved assessment of pneumonia by providing guidance to the lay health worker. However, within this scope of work we did not test if the guidelines provided by the WHO that were implemented into the *ClinicalGuide* are the appropriate choice for the target environment. Further investigations are required to validate the interactive presentation of IMCI guidelines to health workers on a mobile device. This will also open new opportunities to extend IMCI with new diagnostic measurements and procedures (e.g. pulse oximetry for pneumonia classification) which were previously not available.

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REFERENCES

[1] World Health Organization, *Management Of Sick Children By Community Health Workers*. Geneva: WHO/UNICEF, 2006.
[2] WHO, "Integrated Management of Childhood Illness," Geneva, CH, 2008.
[3] K. Källander, J. K. Tibenderana, O. J. Akpogheneta, D. L. Strachan, Z. Hill, A. H. a. ten Asbroek, L. Conteh, B. R. Kirkwood, and S. R. Meek, "Mobile health (mHealth) approaches and lessons for increased performance and retention of community health workers in low- and middle-income countries: a review," *Journal of Medical Internet Research*, vol. 15, no. 1, p. e17, 2013.
[4] B. DeRenzi, G. Borriello, N. Lesh, T. Parikh, C. Sims, W. Maokla, M. Chemba, Y. Hamisi, D. S hellenberg, and M. Mitchell, "E-imci: improving pediatric health care in low-income countries," in *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems - CHI '08*. New York, USA: ACM Press, 2008, pp. 753–762.
[5] J. F. Florez-Arango, M. S. Iyengar, K. Dunn, and J. Zhang, "Performance factors of mobile rich media job aids for community health workers," *Journal of the American Medical Informatics Association : JAMIA*, vol. 18, no. 2, pp. 131–7, 2011.
[6] C. J. Seebregts, B. W. Mamlin, P. G. Biondich, H. S. F. Fraser, B. a. Wolfe, D. Jazayeri, C. Allen, J. Miranda, E. Baker, N. Musinguzi, D. Kayiwa, C. Fourie, N. Lesh, A. Kanter, C. T. Yiannoutsos, and C. Bailey, "The OpenMRS Implementers Network," *International journal of medical informatics*, vol. 78, no. 11, pp. 711–20, 2009.
[7] W. Karlen, G. A. Dumont, and C. Scheffer, "Sharing Vital Signs between Mobile Phone Applications," in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2014, accepted.
[8] J. Hudson, S. M. Nguku, J. Sleiman, W. Karlen, G. A. Dumont, C. Petersen, C. B. Warriner, and J. M. Ansermino, "Usability testing of a prototype Phone Oximeter with healthcare providers in high- and low-medical resource environments," *Anaesthesia*, vol. 67, no. 9, pp. 957–67, 2012.
[9] W. Karlen, G. A. Dumont, C. Petersen, J. Gow, J. Lim, J. Sleiman, and J. M. Ansermino, "Human-centered Phone Oximeter Interface Design for the Operating Room," in *Proceedings of the International Conference on Health Informatics*, V. Traver, A. Fred, J. Filipe, and H. Gamboa, Eds. Rome, Italy: SciTePress, 2011, pp. 433–8.
[10] W. Karlen, J. Lim, J. M. Ansermino, G. A. Dumont, and C. Scheffer, "Design Challenges for Camera Oximetry on a Mobile Phone," in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2012, pp. 2448–51.
[11] W. Karlen, H. Gan, M. Chiu, D. Dunsmuir, G. Zhou, G. A. Dumont, and J. M. Ansermino, "Improving the Accuracy and Efficiency of Respiratory Rate Measurements in Children Using Mobile Devices." *PLOS ONE*, vol. 9, no. 6, p. e99266, 2014.
[12] UNICEF, *Committing to Child Survival: A Promise Renewed. Progress Report 2012*, D. Anthony and E. Mullerbeck, Eds. New York: United Nations Children's Fund (UNICEF), 2012.