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Development of an edge-based digital clinical workflow and data processing wizard for low-resource primary healthcare systems

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Abstract. In low resource settings, paperwork hampers the elaboration of a digital clinical workflow and data processing. As a result, some of the challenges in a low-resource setting are related to obtaining historical records from a manual system (i.e., clinical guidelines, point of care charts, and other contextual documents), missing card-sheet information, and deficient readability of handwriting. Furthermore, limited infrastructure, resource constraints, deficient data readiness, and bridging the divide between evidence and practice are posing additional challenges. A WEB-APP clinical decision system (CDS) was developed and deployed on a Raspberry Pi 4 Model B, which has a quad-core 64-bit processor and 4GB of RAM. The Raspberry Pi 4 is intended to work with a power bank when there is no electricity in remote areas. The CDS instrument is accessed via a smart phone's mobile data or wireless network. Then, the system generates a digital clinical workflow and data processing wizard based on measured symptoms. The method improves the quality of existing clinical pathways by dynamically mapping a knowledgebase to data-driven methods. As a result, the CDS WEB-APP was able to provide a point-of-care clinical reference, data processing, and workflow generator, as well as an interactive data visualization and clinical guidance wizard for low-resource settings.

Keywords: Low resource settings, edge computing, healthcare digital-data processing, clinical workflow, clinical pathways

1 Introduction

In low resource settings, paperwork conceals a large amount of clinical pathway (or clinical workflow) data [1]. The Practical Approach to Care Kit (PACK) [2] was created to assist primary health care professionals in low and middle-income countries in providing high-quality primary care. PACK aimed to provide clinical decision assistance by meeting the clinical guidance needs of the patient, clinician, and health system. In Ethiopian primary care, PACK has been implemented and adopted [3]. It is an integrated symptom-based algorithmic guideline that aids frontline health practitioners in making evidence-based decisions and managing patients at the health center level [4].

Even though paper-based point-of-care instruments remain essential for managing chronic conditions in adults and long-term health conditions in older children, obtaining information and evidence from paper-based records has proven difficult and time-consuming [5]. In addition, retrieving historical records from a manual system, dealing with missing card-sheet information, and poor readability of handwriting are ubiquitous in low-resource settings [6].

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In order to address these challenges in low-resource settings, the Internet of Things (IoT) enabled automated point of care instruments[1] have recently had a growing impact on the healthcare industry, aiding in all sectors of health care. In particular, fog computing has emerged as a promising infrastructure [7] to aid the healthcare industry in addressing difficulties such as limited infrastructure, resource constraints, data readiness, and bridging the evidence-practice divide. Fog computing[2], also known as fogging, emerged to bring computation close to its data sources [8,9,10]. It aims to reduce the latency and cost of delivering data to a remote cloud. Edge devices do considerable computation (edge computing), storage, and communication both locally and over the Internet backbone. The end user may do offline computation at the fog layer, requiring only the most important results to be delivered to and stored in the cloud. Furthermore, fog computing has been developed to reduce cloud server overburdening by pushing computation to the network's edge and leveraging the capabilities of smart objects, mobile phones, and network gateways to provide services and processing on behalf of the cloud, as well as to enable real-time processing of medical data [11, 12]. For instance, George et al. 2018 explored the use of smartphones as sensors to monitor patients' health, as well as the use of fog computing for data processing [13].

Our study demonstrates the use of fog computing for creating a low-cost automated and symptom-based clinical workflow generator for ante- and postnatal care in low-resource settings. An interactive data visualization and clinical wizard are offered for quick reference, appropriate clinical management, and further data processing. Overall, the digital clinical workflow and data processing instrument aims to:

- offer a low-cost, automated, interactive, and dynamic clinical pathway generator (computerized clinical workflow),
- offer evidence-based recommendations (or a series of evidence-informed steps) at the point of care,
- assist routine and emergency services by swiftly identifying the referral and local treatment pathways for low-resource health posts and centers,
- bridge the divide between evidence and practice in low resource settings.

2 Methods

To begin with, a case study was conducted in a low resource setting on the usage of Ethiopian primary healthcare clinical guidelines in the Jimma health center, Ethiopia. The purpose was to analyze how the paper-based symptom-oriented methods were used in practice [4], and to assess the need for additional appropriate point of care tools in this low resource setting [6].

Then, a state-of-the-art review was conducted to identify novel strategies for designing clinical pathways (CP) at the point of care in resource-constrained settings [14].

Subsequently, based on the results of this state-of-the-art review, we developed a low-cost, automated, and interactive point-of-care (POC) device incorporating dynamic and automated clinical pathway processing algorithms to assist front-line health workers in their decision-making process. The clinical pathways processing algorithms are based on the integration of knowledge-based and data-driven tactics and provide a link between evidence and practice in low-resource settings [15]. The clinical guideline indicators [4] served as the gold standard for the clinical pathways processing design. For the demonstration, we solely used antenatal care (ANC) and postnatal care (PNC) indicators from clinical guidelines (CGs). The proposed algorithm generates all potential clinical workflows using a measured symptom [15]. The following steps were included in the CP generating process.

- First, all CPs based on the first measured symptom are generated.
- Then, a ranking of CPs is conducted identifying “referral” and “locally treatable” cases.
- Next, pruning of the dynamic CP list is conducted.

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[1] *The **Internet of things (IoT)** describes physical objects equipped with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.*

[2] ***Edge computing** involves computation occurring at the network’s edge, close to the data creation. **Fogging** acts as a mediator between the edge and the cloud. The **cloud** provides on-demand computer system resources, especially data storage (and computing power, without direct active management by the user*

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- Finally, the Naive Bayes algorithm and historical records are used to provide data-driven evidence.

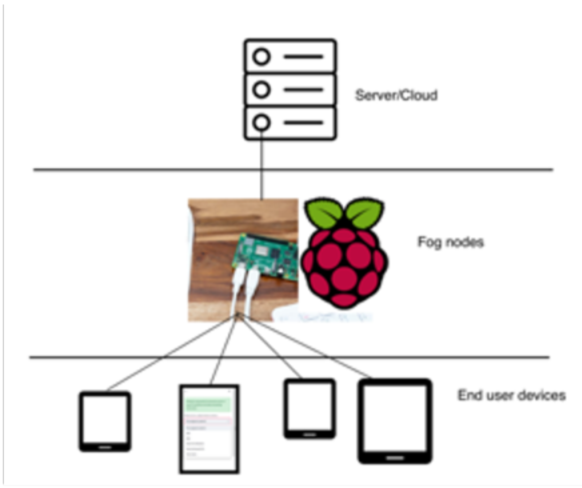

Figure 1: Low-cost architecture for digital clinical workflow data processing

The preceding steps are repeated for each additional measured symptom. In the end, the front-line worker must make the final decision based on the suggestions made by the algorithm. A more detailed step-by-step description of the algorithms is found in [15].

In the current study, we used fogging to design and implement our clinical pathways algorithm on a low-cost platform such as Raspberry Pi 4. On top of it, an automatic antenatal and postnatal assessment plot based on the front-line workers' decision was implemented.

For the development and deployment of the WEB-APP CDS tool, we used (i) Raspberry Pi 4 hardware, (ii) Python 3, Pandas, and Numpy for the development and implementation of the CDS POC instruments, and (iii) an open-source Streamlit framework for developing data-driven POC Apps.

3 Design and Implementation

The fog computing architecture was used to develop and deploy the WEB-APP clinical decision support POC instrument [16, 17]. Figure 1 illustrates the proposed low-cost architecture.

The edge computing devices, such as the Raspberry Pi 4, were used to create the fog node, which is low-cost and portable for use in rural areas and is used for computation, storage, and communication [7-10, 16-17]. The WEB-APP CDS instrument was controlled by the Raspberry Pi, which operates according to the user commands received from the mobile phone, tablet PC, or laptop running a web browser. A mobile data or wireless network can be used to access the WEB-APP CDS instrument. The CDS WEB-APP may also be accessed without an internet connection by setting up a local network and connecting directly to the Raspberry Pi. Furthermore, portable power banks can power a Raspberry Pi when there is no other source of electricity available.

We adapted the clinical pathway algorithms which were introduced in [15]. The adapted CP algorithms perform a variety of functions, including initiating entry points, generating CP, ranking, and pruning the generated CP. Overall, CP algorithms integrating knowledge-based approaches with data-driven techniques to reduce arbitrariness in symptom selection have been implemented in order to process and to generate clinical pathways and generate a concordance table. This concordance table is a multi-criteria decision analysis output that includes measured symptoms, urgent attention, generated CP, diagnostic findings (based on measured symptoms that lead to "referral" or "locally treatable" CPs. For example, if the blood pressure is 160/110 without proteinuria, referral CPs are most likely due to severe hypertension and the finding will be severe hypertension, evidence (historical records), probability (accuracy, prior probability), and so on. Figures 5 and 6 include further information.

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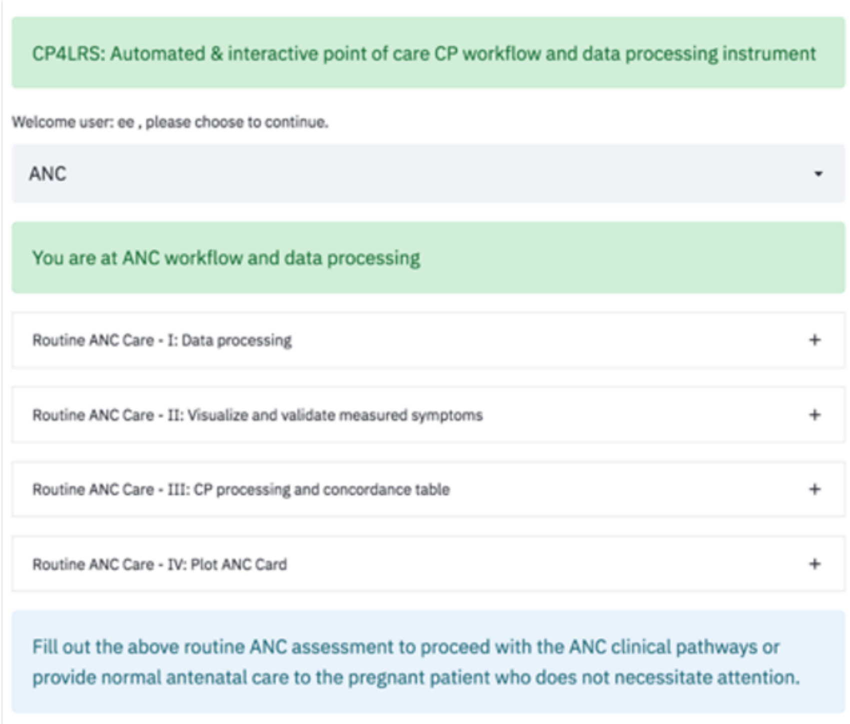

Figure 2: CDS WEB-APP workflow or steps for generating clinical pathways

The WEB-APP CDS POC digital clinical workflow and data processing instrument (i) provides a digital wizard for data processing such as accepting measured symptoms, (ii) visualizes and validates the measured symptoms and (iii) provides CP processing and a concordance table. Figures 2-6 provide more information about a high-level overview of the CDS WEB-APP system. It depicts a workflow that begins with accepting measured symptoms and continues through CP generation, output presentation, CP selection, and endorsement.

Following the approval of clinical pathways based on the generated clinical pathways and concordance table, an automated antenatal care or postnatal care digital-card is plotted. This digital card plot contains the important information that is available at various antenatal and postnatal visits, with the ability to quickly retrieve or track the required information and explore the clinical guidelines-based indicators. Figure 7 shows a sample screenshot of a typical automated antenatal care assessment digital card.

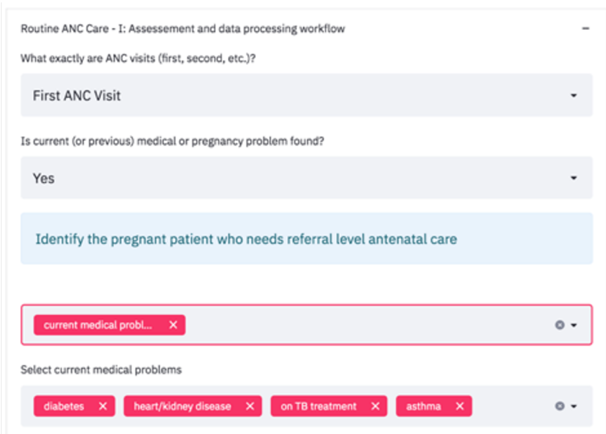

Figure 3: CDS WEB-APP user interface for accepting measured symptoms

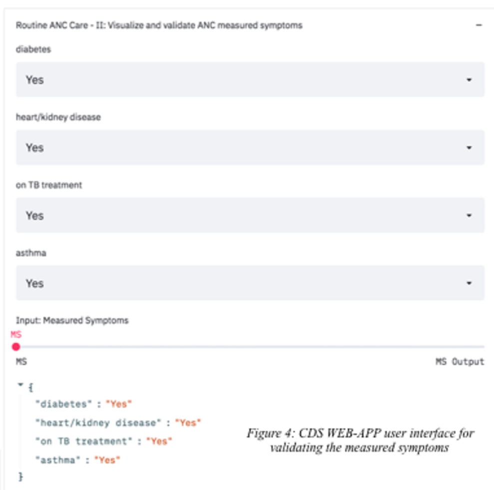

Figure 4: CDS WEB-APP user interface for validating the measured symptoms

Furthermore, the proposed CP algorithm was originally evaluated using 719 records, 532 of which were treatable locally at Jimma Health Center and 187 of which were referred to a nearby hospital, such as Jimma University Specialized Hospital or Shanan Gibe General Hospital [15]. The WEB-APP instrument was then tested in Jimma Health Center during the deployment phase with a total of eighteen cases, six of which were referrals. When implemented appropriately, WEB-APP CDS tool can maintain health care process standardization, improve patient outcomes, reduce costs, empower local healthcare practitioners, reduce unnecessary referrals, improve document completion rates, and reduce delays. In addition, the proposed point of care instrument will be open-source and tightly integrated with other existing health information management systems, such as OpenClinic GA (an open-source integrated hospital information management system3), in order to be used in day-to-day practice.

[3] *https://sourceforge.net/projects/open-clinic/*

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Figure 5: CDS WEB-APP for displaying the generated clinical pathways in a concordance table (i.e. multi-criteria decision analysis output) and pruning the generated clinical pathways using the pruning criteria you've chosen.

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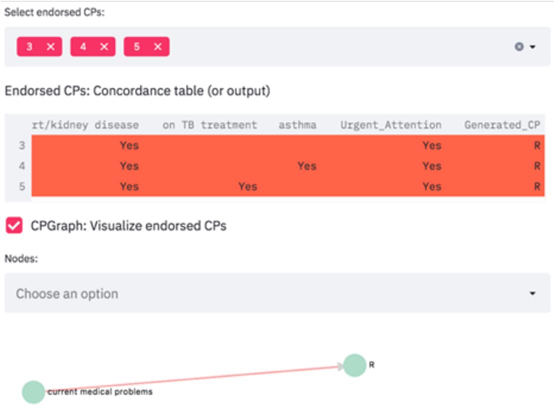

Figure 6: CDS WEB-APP user interface for displaying and visualizing the clinical pathways that have been selected or approved.

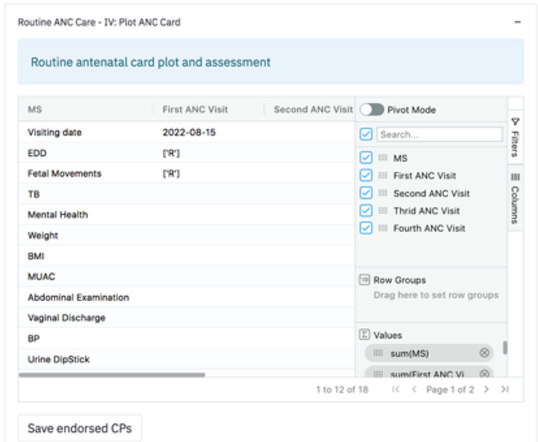

Figure 7: Sample screenshot of an automated routine antenatal digital-card plot and assessment.

4 Conclusion

A low-cost WEB-APP CDS system was created to assist front-line workers with the identification of referrals and locally treatable cases. The CDS system was developed and deployed on a Raspberry Pi 4 Model B, which has a quad-core 64-bit processor and 4GB of RAM. The CDS instrument web-app is accessed via a smart phone's mobile data or wireless network. The purpose of the system is to assist healthcare workers in identifying referral and locally treatable cases, guide patient care activities, support documentation of the care process, improve standardization of the care process, and reduce delays in seeking care, resulting in higher quality of care. However, user acceptability studies, field testing, and evaluation are required to establish that the CDS WEB-APP is acceptable.

5 Conflicts of Interest

The authors declare that they have no competing interests.

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