Integrating Non-Functional Requirements for Marginalized Users in the Design of IoT Systems

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***Abstract*— The drive towards automating solutions to societal challenges has seen an increase in the use of emerging technologies such as Internet of Things (IoT). Subsequently a lot of research exists that focuses on designing IoT systems that fulfil their functional requirements. However, Non-functional requirements are often addressed later in the implementation phase rather than during the design phase. This research highlights the need to integrate Non-functional requirements in the solution design just like functional requirements. We evaluate the proposed design using a remote patient monitoring IoT system designed for marginalized communities and present the early results of the validation and verification exercise. The results show that integrating non-functional requirements in the design of IoT Systems forces designers to verify and validate them hence enhancing the acceptability of the solution by the user. Research investigating the efficacy of the proposed solution through different use cases is ongoing.**

Keywords— Non-functional requirements, System Design, Remote healthcare Monitoring, Internet of Things

I. INTRODUCTION

The emergence of Internet of Things (IoT) has generated a lot of research interest on Functional Requirements (FR) of these systems, with less focus on how the devices will achieve these requirements i.e. Non-Functional Requirements (NFR). The innovative aspect of this study is the integration of NFR during the design of IoT systems to ensure that they are adequately verified and validated before the system is deployed. To evaluate the approach, we set out to answer the following research questions: (i) How can we design a user-centred solution that integrates the contextual NFR for marginalized communities?; (ii) How can we implement an extensible IoT architecture that integrates NFR?; and (iii) How can we evaluate the effectiveness of integrating non-functional requirements in the design of IoT systems through selected verification and validation processes? The remainder of the paper is structured as follows: Section II provides a review of related work, Section III describes the integration of NFR in the design of IoT System, Section IV verifies the design through implementation of a prototype, and Section V presents the preliminary evaluation of the proposed solution. Concluding remarks are provided in section VI.

II. LITERATURE REVIEW

Several studies highlight the importance of focusing on the user's experience when designing IoT solutions that address user problems [1, 2, 4, 6]. However, when new technology emerges the focus is always laid on FR, which can render the technology unacceptable prematurely. Consequently, verification and validation processes are left to focus only on FR. The Validation and Verification process aids in the assessment of the system's usefulness in an operational situation [3]. The hardware limitations of IoT devices mean that the devices are harder to modify once deployed to consumers [7] hence the need to get it right the first time becomes crucial for adoption, usage, and retention. It is worth noting that the design of IoT Solutions presents new challenges such as connectivity [8] and lack of contextualization [6]. The need to bring economic reasoning when making software architecture decisions provides technical insights on product design that can be leveraged to manage market uncertainties and evolution [5] due to factors that spring from diverse environments such as marginalized communities.

III. SYSTEM DESIGN

To identify NFR for IoT users, we consider a use case of a remote infant screening IoT system that targets users in marginalized communities. The current infant screening process requires a mother to go to a medical facility with her baby which can be inconvenient, costly and time consuming especially in rural or marginalized communities. Frequent monitoring of growth is crucial for babies and especially for preterm babies or babies with special needs. Timely interventions can reduce the high infant mortality rate in these communities. Existing devices used to screen babies require skills, are not portable and are often too expensive for mothers to acquire. Additionally, they are only found in the health care facilities. In this respect the solution needs to be usable by people with limited medical expertise, portable to enable sharing, accurate for proper decision making, can work with unreliable internet connectivity, secure due to the confidential nature of patient data, affordable for low or no income users, and automated to reduce the user's effort. Consequently, we identified our NFR and categorized them using Somerville's NFR model [3] as illustrated in Figure 1.

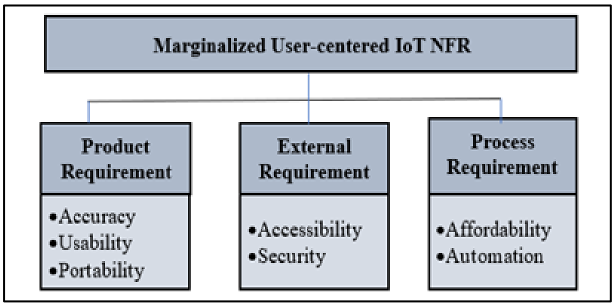


Fig. 1. Model of NFR for IoT users in Marginalized communities

A. Product Requirements

This set of NFR relate to the system developed. The ISO/IEC product quality model categorizes product quality properties into eight characteristics (functional suitability, reliability, performance, efficiency, usability, security, compatibility, maintainability, and portability) [11]. We identified usability, reliability, and portability as key NFR for users in marginalized communities based on existing literature [12]. These users have minimal technology skills due to low literacy levels and this calls for higher device accuracy levels. The devices should be simple to use, and portable for purposes of sharing or where a Community Health Worker (CHW) must provide support because the babies' caregiver is unable to take the measurements. The Circuit diagram provided in Figure 2 shows how we integrated various sensors using two Arduino boards to design a single portable IoT device. Typically, the choice of sensors should be driven by its ability to take accurate measurements easily on the first attempt, however they can be costly. To enhance usability despite the low-cost sensors selected, an LCD module was integrated in the IoT to provide on-spot verification for users.

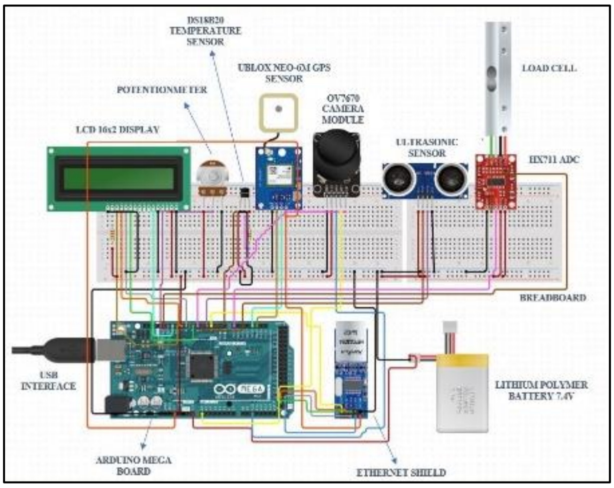


Fig. 2. Design of a portable IoT solution

B. External Requirements

In marginalized areas external constraints are brought about by poor infrastructure. The nature of patient data also calls for regulations on data privacy. We designed our system architecture to make provisions for local data storage on the IoT device in the absence of internet connectivity. The 3-tier architecture used also encompasses several layers of data security to safeguard the privacy of data. The Client tier provides an interface for the IoT device to temporarily store data as well as authenticating the user before using the system alongside the input and output modules. The application layer hosts applications that control data access by various users alongside the analytics modules. We included a data conversion module to transform measurements taken by low cost IoT sensors into a format that can be stored or used by the data analytics tools. For example, the images taken by the low-cost camera module had to be scaled down and compressed to a smaller size (from 300KB to 10 KB) for storage. The database layer enforces data integrity in addition to storing measurements taken by sensors, and the training dataset. The software architecture illustrated in Figure 3 shows how the external requirements of infrastructure constraints and privacy regulations are integrated in the software architecture.

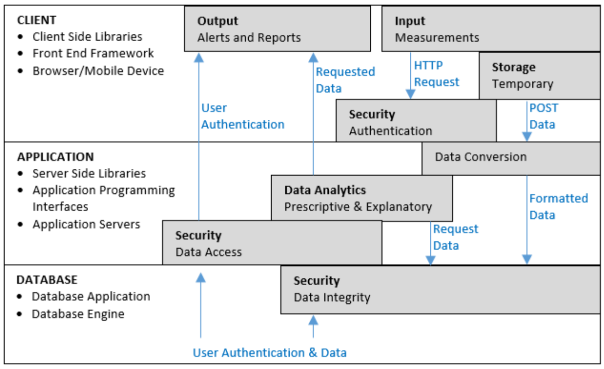


Fig. 3. Integrating NFR into the IoT System Architecure

C. Process Requirements

Our process requirements call for automation and cost effectiveness. Automation of a typical infant monitoring starts with the input of initial patient details during registration and subsequent growth monitoring measurements taken from the patient's home. Data collected is transmitted to a database for analytics using frequency and machine learning algorithms. Growth monitoring reports and alerts are generated and shared with parents, medical providers, or government health representatives. The only human intervention is required at the input phase for handling the baby as shown in Figure 4.

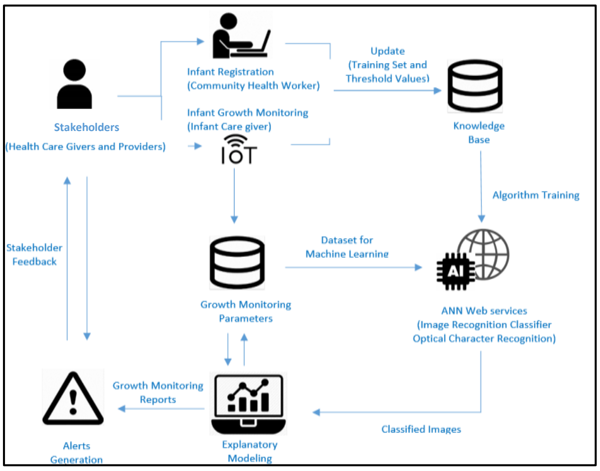


Fig. 4. Automated IoT Process Workflow for Infant Screening

IV. IMPLEMENTATION

In this section we describe how the NFRs incorporated in the system design were implemented for evaluation.

A. Implementing Product Requirements

The NFR of affordability was achieved by using simple low-cost sensors shown in Figure 5. However, this presents challenges due to the low accuracy levels of low-cost sensors. Such devices need additional configuration to enhance the quality of the data captured. For example, in our solution we used an *OV7670 Camera Module* which was approximately US ($) 6 at the time of writing this article. The default baud rate for this module is 340x240 resolution and 1Mbps which was unreliable hence we reduced it to 160x120. This enabled the camera to capture images faster as the bit rate was higher although the images were smaller.

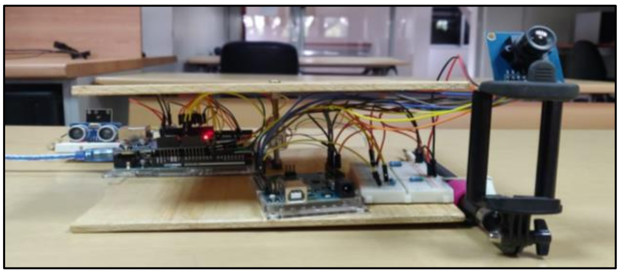
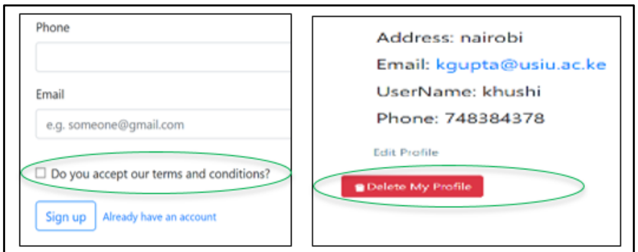


Fig. 5. Assembled IoT Device

B. *Implementing External Requirements*

The developed solution makes use of an *ESP8266 Arduino Wi-Fi shield* that allows the Arduino board to connect to the internet using the Wi-Fi library. We integrated an SD card using the SD library to allow for temporary storage in the device when there is no internet connectivity. Additionally, a *Lithium Polymer 7.4V* battery was used to power the Arduino board in the absence of power. Legal regulations require patient data to be protected, we made use of password encryption to secure stored data and JSON Web tokens to secure data in transit through digital signatures. To maintain the trust of users the application has *opt-in* and *opt-out* consent modules that give the caregiver control over the privacy of their data were implemented as seen in Figure 6.



(a) Opt-in consent module interface *(b) Opt-out consent module interface*

Fig. 6. Dashboard showing growth monitoring reports and alerts

C. *Implementing Process Requirements*

Once the user data is collected by the IoT, the analytics module interprets the data to generate actionable information in the form of stakeholder reports and alerts. The NFRs here calls for automation of the data analytics and the alert generation processes. To generate alerts, threshold figures were used for comparison against measured data as defined by WHO [9]. The algorithm used to automate the generation of alerts is provided in Figure 7.

The automation process also called for developing an API to a machine learning module for making decisions that would typically be done by an expert. We integrated our solution with an image recognition algorithm to detect skin rashes as well as read the baby's registration card using an Optical Character Recognition tool to identify the number.

```
START
GET baby details from the database
Parse CSV with WHO average baby metrics into JSON
CALCULATE age (birth date - today's date)
If temperature falls out of the range THEN
        Log an issue message
END IF
If baby has rash THEN
        Log an issue message
END IF
LOOP through the parsed CSV
    Check baby gender and WHO values in JSON
    IF baby age = current object's age THEN
        IF baby length is out of the range THEN
            Log an issue message
        END IF
        IF baby weight is out of the range THEN
            Log an issue message
        END IF
    END IF
END LOOP
IF no issues have been found THEN
        STORE No Issue Alert and Date
ELSE
        STORE All Issue Logs
END IF
STOP
```

Fig. 7. Algorithm for generating alerts in the IoT solution

V. PRELIMINARY EVALUATION

The architecture evaluation approach used in this study is the Simulation-based evaluation. This method relies on a high level implementation of some of the components in the software architecture for purposes of evaluating quality attributes such as performance and correctness of the architecture [10]. Validation is conducted to check if the system is what users in marginalized communities need.

A. *Portability and Affordability*

Users in marginalized communities need devices that can be easily moved around to facilitate sharing within the community as necessary. The developed solution weighs 0.65KG and can fit into a 20cm x 20cm x 10cm box as illustrated in Figure 8. This is approximately the size of a notebook computer, validating the portability requirement.

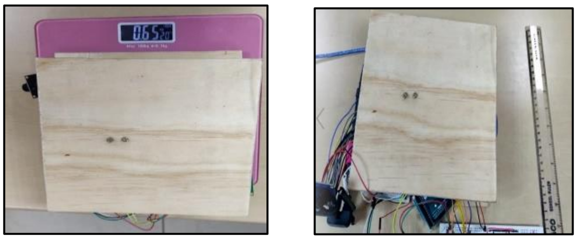


Fig. 8. Device Weight and Length

To ensure that the solution designed was affordable, we used low cost sensors. The total cost of the assembled components was US ($) 93 at the time of writing this article, which is the equivalent to a middle-to-low cost SMART mobile phone. This cost can be further reduced with mass production. Additionally, it eliminates the need for costly hospital trips and reduces the strain on limited health centre resources. The device can be shared within a close community to further reduce the cost.

B. *Accuracy and Usability*

To get accurate results, we tested our IoT device using predetermined measurements. We placed a 2Kg Load on the load cell, 50cm from a wall and maintained it at 25°C at a location with the geo-coordinates 1.2184° S, 36.8791°E. The results displayed in Table I illustrates that the IoT interface accuracy levels were within acceptable ranges when an average of 10 separate measurements was taken.

TABLE I. IoT INTERFACE ACCURACY LEVELS

Load Cell (g)	Ultrasonic Sensor (cm)	Temperature Sensor (°C)	GPS sensor (Latitude, Longitude)
1980.75	50.11	25.47	(-1.22463°, 36.87259°)

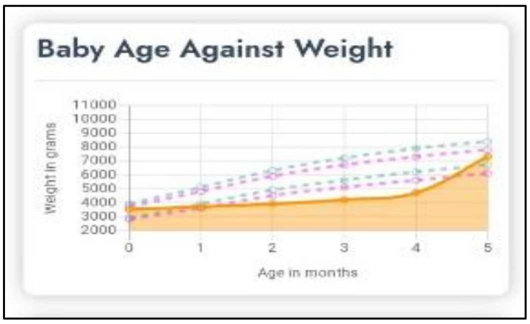
To model an accurate classifier, the system had to be trained for optimal results. The classifier was able to detect the presence of a rash when a colored, black and white, or blurred image were used as shown in Table II. Similar tests were conducted on the baby's registration number with the OCR module. The results also show that the numbers were able to be recognized with 100% accuracy even when the image taken was blurred, validating the accuracy requirement.

TABLE II. IMAGE CLASSIFIER ACCURACY LEVELS

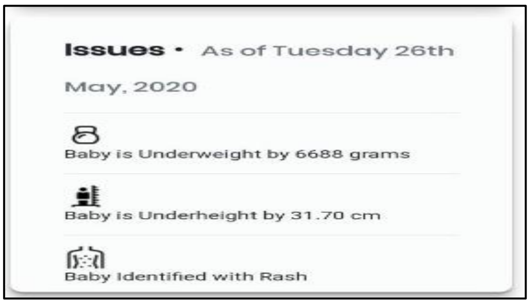
Image	Test 1	Test 2	Test 3
			
Irregularity	None	Black & White	Blurred image
Accuracy (%)	96% - Rash 4% - No Issues	88% - Rash 14%-No Issues	83% -Rash 32% -No Issues

C. Automation of Monitoring and Security

The final NFR validated in this paper is the automated process for minimum human intervention and patient security. Automation was achieved through computerization of the decision-making process using machine learning algorithms for image recognition and data analytics algorithms for generating alerts. To evaluate the system's ability to analyse and provide alerts we simulated records for several infants and observed the reports generated. The infant's dashboard showing growth reports per baby and sample alerts is displayed in Figure 9. This interface is part of the infant's dashboard.



(a) Growth monitoring report



(b) Health Alerts Generated

Fig. 9. Dashboard showing growth monitoring reports and alerts

D. Privacy and Security

Patient data is treated as confidential and therefore it should have controlled, authorized and proper access methods put in place to increase user acceptance. We used encryption and authentication tokens for security. At the client layer a user is required to log in and the login interface expires after a given time as shown in Figure 10. The system also includes opt-in and opt-out consent modules as discussed.

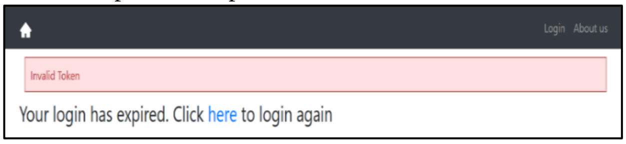


Fig. 10. Client Layer Security

VI. CONCLUSION AND FUTURE WORK

The user-centred nature of IoT systems highlights the centrality of NFR in the usability of such systems. These requirements should be integrated in the design of IoT systems for enhanced user acceptance. We have shown that through integration, designers can conduct verification and validation checks to ascertain whether the system was designed according to the NRF specifications. This is especially key for users who are constrained by factors in their environment, such as users in marginalized areas. During the study, several challenges were encountered which provided a basis for future improvements. A notable lesson learnt is that low cost sensors present accuracy challenges hence usability challenges. Additional configurations were required to attain acceptable levels of accuracy. Achieving NFR that are conflicting often calls for trade-offs which need to be factored in the design. Some NFR such as security were easier because they are in built in most modern tools. Future work calls for evaluating it on a different use-cases, adding sensors to enhance the solution and investigating trade-offs between various software quality attributes for users in marginalized communities.

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