A Model for Real-time Remote Monitoring of Asthmatic Patients

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***Abstract*— Asthma affects a large number of people in the world and it is the most common chronic illness of the lung among children. Monitoring and assessing the severity of a child's asthma at home has proven difficult and costly in many low resource settings, like Kenya. This is due to lack of easy to use and cost effective in-home monitoring tools for children suffering from asthma.**

In this work, we present a user-friendly wearable device that allows in-home remote monitoring of asthmatic child and real-time determination of degree of asthma severity. The device captures simultaneous measurements of heart rate and oxygen saturation using a pulse oximeter sensor. These readings are then analyzed using clinical algorithm for asthma management, and the resulting severity level sent to both the parent of the child and the assigned clinician. The device was developed using Arduino Uno microcontroller, pulse oximeter sensor and Global System for Mobile Communication (GSM) module.

***Keywords*— Asthma, clinical guidelines, Arduino uno microcontroller, pulse oximeter sensor, GSM, Internet of Things.**

I. INTRODUCTION

Asthma is the most common chronic illness of the lung, characterized by respiratory symptoms such as shortness of breath, wheeze, chest tightness and cough, with children under-fives in particular, at the greatest risk [1]. Globally, it is estimated to affect over 300 million people [2]. Numerous reports indicate that the prevalence of asthma may be increasing in most parts of the world including low income countries (LIC) [3, 4]. The International Study of Asthma and Allergies (ISAAC) reported that asthma prevalence among children was increasing in Africa and has contributed most to the burden of disease through its effects on quality of life [5].

In most health care settings around the world, asthma severity is often under-estimated and preventative treatments either under-prescribed or overprescribed [6, 7]; this may result in poor asthma control and lead to an increase in degree of severity, thus a deterioration in patient's health. On the other hand, inappropriate treatment is a cause of a substantial cases of hospital readmissions.

The public health focus of asthma relies on early case detection and placement of the affected individuals on appropriate and largely lifelong treatment with proper monitoring in order to control the disease. In most LIC such as Kenya, there are no public supported asthma-care programmes designed to optimize care for patients with asthma which greatly compounds the diagnosis, severity classifications and treatment problems. Under these circumstances, the development of standardized, well defined home-tailored interventions together with sound professional practice is crucial. This has seen management of asthmatic patients [8, 9] as concerned bodies and many countries developing clinical guidelines in order to improve treatment and

In 2013, the Ministry of Health (MoH) in collaboration with the Kenya Medical Research Institute (KEMRI)-Wellcome Trust Research Programme, the Kenya Paediatric Association (KPA) and the SIRCLE saw the development and routine update of a basic paediatric protocol that constitutes clinical guidelines (algorithms) for under five years management [9]. These guidelines focus on various illnesses, including classification of asthma severity, criteria for admission, treatment and inpatient management of the major causes of childhood mortality and related conditions.

Monitoring and assessing the severity of a child's asthma at home has proven difficult and costly in many low resource settings, like Kenya. Parents finds it difficult to determine the severity of a child's asthma state in-home, and they often face challenges in deciding whether the child requires administration of medicines, a visit to the clinician or emergency medical care. Thus, they are unable to prevent unexpected critical episodes, such as recurrent readmissions to emergency rooms, unnecessary acute attacks and sometimes loss of life. It is a general premise that information technology (IT) can play a crucial role in addressing these challenges in order to ensure self-management of conditions such as asthma possible at home.

With the recent popularity of smart health monitoring devices in medical sphere and m-health, real-time remote monitoring tools can help monitor asthmatic patient's health state, classify degree of asthma severity and alert clinicians on the health state of the patient.

Here, we present a user-friendly wearable device that allows in-home remote monitoring and reduces the difficulty of assessing the degree of asthma severity. The device captures simultaneous measurements of heart rate and oxygen saturation using a pulse oximeter sensor. These readings are then analyzed using clinical algorithm for asthma management, and the resulting severity level sent to both the parent of the child and the assigned clinician in form of a text.

II. Literature Review

A. Asthma in Kenya

Asthma is a non-communicable disease characterized by recurrent attacks of breathlessness and wheezing, with varying severity in individuals, and may occur unexpectedly. In Kenya, a number of epidemiological studies that have shown that its prevalence is at 10% [8], and it is on the rise. The illness appears to be more prevalent in densely populated regions such as urban areas compared to sparsely-populated rural areas. The major drivers of the burden of asthma in Kenya, as in other parts of the world, are largely unknown even though it is appreciated that complex and poorly understood genetic factors interact with environmental factors to lead to the manifestation of the disease.

Asthma patients face a number of challenges. Despite under-estimation of asthma severity levels, especially in children, poor prescription of drugs which could be either under prescribed or over prescribed, usually put their lives at risk [6]. In addition to this, there are no public supported asthma-care programmes designed to optimize care which greatly compounds the diagnosis, severity classifications and treatment problems.

Asthma being a chronic disease, implies long term health consequences for the sick, greater health resource utilization and a heavy economic burden to the country as a whole. Although a large proportion of these diseases are preventable through adoption of appropriate healthy lifestyles, there are no proven ways to prevent the disease.

Asthma has important individual health consequences. Uncontrolled asthma results in recurrent or persistent symptoms that impair quality of life, reduce self-esteem, reduce social interaction, increase psychosocial trauma and occasionally lead to fatal outcomes. The economic costs of uncontrolled asthma may be enormous and include direct costs from health resource utilization (medical consultations, drug and hospitalization costs), indirect costs from work absenteeism or premature deaths and intangible costs of persistent illness.

Therefore, in order to prevent the patients from frequent readmissions, ill-health and save them from unnecessary loss of life, an individual patient should be diagnosed and severity level detected early enough, be placed on appropriate medication and lifelong treatment. It has been documented that patients suffering any disease who are managed according to set guidelines fair better than those managed otherwise [10, 11, 12].

B. Classification of Asthma

Poor classification of asthma severity by clinicians while attending to asthmatic patients have been demonstrated in a number of previous studies [13], and this have detrimental effects to the health of an individual patient [14]. In order to administer an appropriate treatment to an asthmatic patient, the correct severity group for the patient needs to be established beforehand.

According to the Basic Paediatric Protocols for children under five years of age in Kenya, acute severe asthma has been classified by the Ministry of Health into severe, mild or moderate asthma [9]. Severe asthma is characterized by the presence of central cyanosis, inability to talk, drink or breastfeed, Alertness Verbal response Pain responsiveness and Unresponsiveness (AVPU) of scale at either V, P or U, with measurements of oxygen saturation < 90% and pulse rate less than 200 bpm for children under three years and pulse rate greater than 180 bpm for those between four and five years. On the other hand, mild or moderate asthma comprises all asthmatic patients with presence of wheeze, plus any of the following: lower chest wall indrawing or fast breathing (RR $\geq$ 50 for aged 2-11 months and RR $\geq$ 40 for aged 12-59 months).

C. Management of Asthma

With the escalating number of asthma cases witnessed globally over the decades [15], the disease need proper management plan. As a chronic illness with no cure, the nature of asthma requires proper diagnosis, appropriate severity classification, correct treatment and continuous monitoring by relevant clinicians [1].

Patients on treatment for asthma should be reviewed regularly and their treatment adjusted as may be necessary. With appropriate treatment most patients with asthma can gain and maintain asthma control and thus lead normal productive lives. The clinician should assess the severity of asthma or the level of control for diagnosed asthma on treatment, initiate treatment at the appropriate treatment step based on the asthma severity or level of control and arrange for a home-based monitoring process to assess response to treatment and patient's progress. The main aim of day to day management of asthma helps prevent frequent readmissions, ill-health, unnecessary attacks and to bring back patients to productive lives. This has seen national and international concerned bodies developing clinical guidelines in order to control the management of asthmatic patients [1, 2, 8].

D. Clinical Guidelines for Asthma Management

Clinical guidelines are part of better clinical practice. In any health care setting, daily bedside clinical decisions and rules of operation at these facilities are being influenced by guidelines. According to the Institute of Medicine, clinical guidelines are "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances [16]. Their benefits extend

to offering precise instructions on which diagnostic or tests to be done, how to administer or prescribe medications, how long patients should stay in hospital, or other details of clinical practice. Clinicians and policy makers see guidelines as a tool for ensuring consistent code of practice and for closing the gap between what clinicians do and what scientific evidence supports.

Kenya is making efforts to improve the health of its population through strengthening of the primary health care system, and thus there has been efforts to manage asthma. In 2006, the Kenya Association for the Prevention of Tuberculosis and Lung Disease (KAPTLD) in partnership with the Ministry of Health and the pharmaceutical industry developed a 'consensus statement' on the management of asthma in Kenya. This was later renamed the 'Kenya national asthma guidelines' to reflect the purpose for which it has been developed. The primary purpose of this new document is to provide clinicians, researchers, policy makers, health programme developers and managers with a road map to guide the care of individual patients with asthma in Kenya [8].

Further work in 2013 by the Ministry of Health (MoH) in collaboration with the Kenya Medical Research Institute (KEMRI)-Wellcome Trust Research Programme, the Kenya Paediatric Association (KPA) and the SIRCLE saw the development and routine update of a basic paediatric protocol as shown in *figure 2:1*, that constitutes clinical guidelines (algorithms) for under five years management [9]. These guidelines focus on the classification of various illnesses' severity, among them asthma, criteria for admission, treatment and inpatient management of the major causes of childhood mortality.

The guidelines represent a major milestone in the development of asthma care services in Kenya. It is hoped that these guidelines will be widely disseminated and used by all cadres of health care providers in Kenya to promote asthma care practices that ensure the best possible outcomes for individuals who suffer this disease.

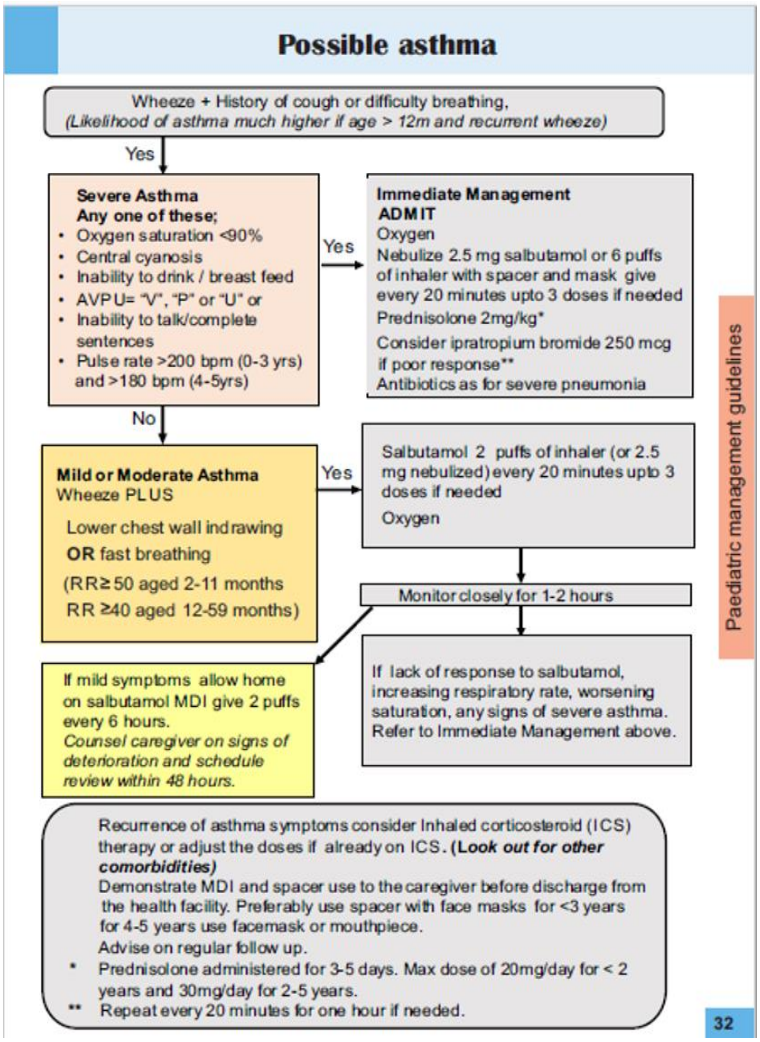

Figure 1:1: National Asthma Guidelines (Adopted from Basic Paediatric Protocol of Kenya 2016)

E. Existing Tools for Monitoring Asthma Management

There are a number of technologies that have been applied in health care to help monitor how asthma is managed both during hospital stay and at home. The aim of these tools is to ensure that asthmatic patients are treated as per the national clinical guidelines, and that they are saved from any danger that may arise as a result of poor management.

i. Related Applications

Persons suffering from chronic illnesses such as asthma should receive support to help them manage their illnesses as effectively as possible. A number of IoT-based healthcare novel technologies have been applied in health sector in an attempt to monitor and manage chronic illnesses [17]. Asthma is a growing problem among nations, and clinical guidelines have stressed the importance of at-home monitoring in the establishment and maintenance of asthma control, defined as the degree to which the manifestations of asthma are minimized by therapy [18].

Examples include Identi-wheez, a portable and low cost device that aims to reduce the difficulties of asthma diagnosis, [19] have been used as a device for in-home diagnosis of asthma. It is composed of a novel measurement hardware and diagnosis algorithm. The device acquires simultaneous measurements from multiple stethoscopes. The recordings are then sent to a specialist who uses assistive diagnosis algorithms that enable auscultation (listening to lung sounds with a stethoscope) at any location in the lungs volume by sound refocusing. The specialist is also presented with a sound "heat map" which shows the location of sound sources in the lungs.

In order to improve the condition of asthma patient, efforts have also been made to develop systems that monitor environmental conditions, such as air quality, and trigger warnings and alerts. Environment crowd sensing for asthma management has been developed for monitoring the environment, especially the air quality parameters relevant for asthma patients [32]. Recent work from Vasilateanu had suggested a mobile application- AsthMate, to be used by asthma patients to monitor their health by doctors and by institutions. The device is able to detect high risk areas for asthma suffers based on quality of air measurements and incidence of the use of short—term relief medication. A work Towards Real-time Monitoring and Detection of asthma symptoms on resource-constraint mobile device, [20] a smartphone application that could detect and quantitatively index early signs of asthma attack triggered by exercise. Here, the embedded microphone in the mobile phone records the user's breath sound while motion sensors- accelerometer, gyroscope and digital compass provide measurements on the level or intensity of activity and posture changes.

Though significant advances have been made in this field, there continues to be a lack of an ideal solution that would facilitate in-home asthma diagnosis. Table 1 presents a comparison of existing solutions and demonstrates where Home-based asthma severity monitoring tool finds its relevance.

Tool Functionalities	*Asthma symptoms monitoring*	*Asthmate*	*Indenti-Wheez*	*Asthma Severity Monitoring*
Designed as a child-friendly wearable device	No	No	Yes	Yes
Allows in-home measurements	Yes	Yes	Yes	Yes
Allows recordings for future references	Yes	Yes	Yes	Yes
Alerts clinicians via SMS in real-time	Yes	No	No	Yes
Allows asthma severity determination	No	No	No	Yes

Table 1: Relevance of asthma severity monitoring tool

F. Gaps in Exististing Tools for Monitoring Asthma Severity

There exists a gap in an attempt to manage asthmatic patients from home. The existing tools such as peak flow meter or spirometer are only found in hospitals, and are costly and difficult to use due to complications and contraindications. In addition, reliable results cannot be obtained as the patient instructions are complicated and the test causes chest pain. Moreover, children below the age of 6 years old are generally unable to perform an adequate test.

Currently, once diagnosed and treatment administered, the asthmatic children are discharged home and put under long-term drugs and inhalers. Rarely is their conditions monitored by clinicians at home during the treatment period. This could be attributed to lack of proper device to monitor and assess asthma severity level. Recent advances in medical sensors and smart health monitoring devices have greatly enabled remote health monitoring to support early diagnosis, detection of early signs of asthma attack as triggered by exercise and identification of conducive environment for asthmatic patients. However, the use of these tools as a home-based monitoring process to routinely assess patient's response to treatment and progress is yet to be exploited in low resource settings, like Kenya. With the knowledge of patient's asthma severity levels at hand at intervals of time, the clinician is able to review regularly and adjust patient's treatment as may be necessary. With appropriate treatment, most patients with asthma can gain and maintain asthma control and thus lead normal productive lives.

This project aimed to improve on the home-based asthma diagnostic tool by [19], and to develop further a simple to use remote monitoring tool based on pulse oximeter for asthmatic patients that will allow instant determination of severity level of asthma and alert the patient as well as the caregiver or clinicians about the patient status. This provides the caregivers and clinicians with real time information for better informed clinical decisions regarding the most appropriate treatment and care for the asthmatic child.

G. Device Description

Figure 1:2 presents the system architecture of the home-based asthma severity monitoring device. This is a wearable and portable device that consists of a novel measurement hardware and analytical algorithm. The analytical algorithm is formulated from Basic Paediatric protocols' clinical guidelines for asthma that are used to classify severity of asthma in Kenya. On the other hand, the hardware constitutes Arduino Uno microcontroller that interconnects with pulse oximeter sensor and the Global System for Mobile Communication (GSM) module for texts communication.

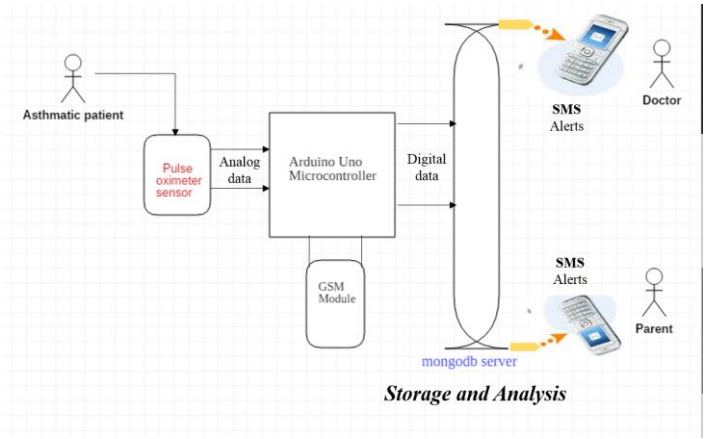

Figure 1:2: System Architecture

Figure 1:3: Home-based patient monitoring device

III. IMPLIMENATION AND TESTING

A. Working Principle of the home-based patient monitoring device

Arduino is used for controlling the whole process. With the pulse oximeter sensor fitted on the finger at intervals of time, the device is able to capture simultaneously the oxygen saturation and heart rate measurements of the asthmatic patient. The recordings are then sent to the server for storage before being analyzed instantly based on the analytical algorithm to determine whether the patient has severe, mild or moderate asthma. This is then automatically sent to both the parent and the clinician via SMS using GSM module. The real-time feedback is used by the clinician to inform clinical decisions regarding the patient's management.

Based on the feedback, the clinician is able to review regularly and adjust treatment according to the evolution of the severity state of the child. Furthermore, an urgent visit to the clinic in case the alert from the system indicates a severe health state can be recommended.

B. Testing

Table 1-2 gives summary of a number of system testing, some including functionality, user experience and usability testing that was conducted during post-survey among respondents perceived to be the intended system users.

Results gathered on the post-test analysis as indicated in *Table 1-2* gave a solid indication of the proposed solution meeting set objectives. The device was not only easy to use and highly acceptable to the users, but also good and tailored to the user needs. However, there is a substantial percentage of the respondents who suggested further improvement to the system. They advised the tool to be converted into a small, light-weight wearable device in order to ease patient's monitoring process.

Functionality, User Experience and Usability	**N= 8**		
	Yes	No	Neutral
The home-based monitoring device looks good	87.5%	0%	12.5%
The device is easier to use	100%	0%	0%
The device can be carried around with ease during monitoring process?	37.5%	62.5%	0%
The tool will help monitor and improve asthma management for the patient.	100%	0%	0%
I am willing to use the tool for my child's benefit.	87.5%	12.5%	0%

Table 1:1: System Architecture

C. Implementation

Upon further refinement of the device into a more lightweight and portable device with low power consumption, it will be implemented at health care facilities level under homecare asthma programme. Every asthmatic child who gets discharged home will be recruited into the programme. The implementation strategy is to provide them with the device at the point of discharge and assign them to relevant healthcare professional (doctor). The device will be used to track and monitor them while at home and send real-time notification at specified instances to the assigned doctors.

In order to capture and send real-time feedback to relevant caregiver, the asthmatic patient will be required to use the device in the morning, at lunch hour and in the evening before they go to sleep. This aims at ensuring that they get monitored at least three times a day.

IV. CONCLUSIONS AND FUTURE WORKS

This model presents an elaborate method to facilitate full management of asthmatic child under five years at home. The home-based monitoring tool employs the use of pulse oximeter sensor to measure asthmatic patient's oxygen saturation level and heart rate, which are among the key values used to determine severity level of asthma, among other factors. The data captured can also be visualize and the trend of patient severity followed over a given period of time. It would be worthwhile incorporating the use of other elements

such as measuring inability to talk, inability to drink, central cyanosis and in drawing among asthmatic patients.

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