A review of air quality sensing technologies and their potential interfaces with IoT for asthma management

Fatmah Bamashmoos[1,2], Pete Woznowski[1], Theo Tryfonas[1]

[1] Faculty of Engineering, University of Bristol, UK
[2] Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia
{fb13007, p.r.woznowski , Theo.Tryfonas }@bristol.ac.uk

ABSTRACT

In recent years significant advancement has been achieved on the domain of assessing air quality and monitoring the condition of asthma based on sensing technology. The pervasiveness of relevant devices could have a powerful impact on enabling patients self-monitoring and increasing public awareness on the air they breathe. In this study, we investigated a variety of different sensors devices relevant to the monitoring of air quality and different devices for assessing the condition of asthma. Our approach at this stage has been based on feature comparison based on product specification sheets and published case studies. We found that there is no standardisation among such devices and that in order for someone to deliver a holistic intervention for the management of a condition like asthma, a significant amount of proprietary effort to integrate third party data and technologies would be required. Such a solution would include both typical air quality sensing and asthma indicators monitoring, but also elements to seamlessly integrate sensed data and logic about the management of the condition.

KEYWORDS

Air quality, E-Health, IoT, Asthma

1 INTRODUCTION

Recent advances on the developing of sensor devices for healthcare and air quality usage provide a way for living smarter by allowing public involvement in monitoring the quality of the air they breathe. These devices can smartly sense and accurately measure various air pollutants and asthma indicators. The measurement data is recorded and intelligently processed in a way that could result in taking right action for self-management.

There are many sensing devices for measuring air quality working in a centralized fashion. Their measurements are aggregated to assess the monitored area as one, not focusing on a specific spot around someone who may need it. However, there could be variation in the quality of the air depending on time and location. Therefore, for someone interested to know more specific measurements, the existence of portable or wearable sensor devices can be beneficial for measuring the surrounding air in more detail. Such devices could also be beneficial for asthmatic patients for the purpose of controlling their condition, as the measurements can assist with providing guidance. A patient might be alerted to move to a 'cleaner' area or might need to close their windows etc.

Traditional devices for diagnosis of asthma or measuring its effects, or even recording in a diary the administration of medication for patients are usually reserved for use in assessing the condition at the time of presenting to a hospital. Nevertheless, it is important to keep track of the progress of asthma levels when patients and follow medication treatment. However, instead of having a traditional spirometer or peak flow meter, there exist now some smart devices such as smart peak flow meters that feature embedded sensors to assess and record the results.

The existence of these devices leads to the creation of new services such as integration of the data from both air quality and asthma management devices. This paper review provides an insight into low cost, off-the-shelf technologies that seem promising from the perspective of integrating both topics which can strengthen the ability for asthma self-management.

The paper is subsequently split into two key sections. In Section 2 we discuss air pollution and various efforts for its measurement. The review of air quality measurement is limited to portable devices that can sense air pollutants that triggers asthma. Section 3 reviews asthma and existing devices for monitoring the condition.

2 AIR POLLUTION AND AIR QUALITY SENSING

2.1 Air Pollution

Air pollution is one of the major problems of today's society and is mostly due to chemical, physical and biological sources. Air pollutants have a direct effect on peoples' health. As indicated by the World Health Organization (WHO) [1], a high number of deaths are caused by exposure to air pollution. The effects of air pollution on health, range from short-term to long-term illnesses, based on the pollutant type and its concentration [2]. The length of exposure to air pollutants is also a major factor in chronic cardiac and respiratory diseases, in addition to individual characteristics and vulnerability to exposure [2].

Pollutants originate from different sources. Natural sources of pollution are pollen, dust, bushfire or mold. Some of the pollutants are an effect of human activities, such as burning fossil fuel, industries and motor vehicles. Such sources cause emission of pollutant gases to the atmosphere. Typical pollutants, which are known to have a direct effect on one's health are briefly listed here. A Particulate Matter (PM) forms as a dust, smoke, mold, dirt or soot. Nitrogen dioxide (NO2), carbon monoxide (CO), sulphur dioxide (SO2), lead (Pb), Volatile organic compounds (VOCs) and ozone (O_3) are types of gases which affect people's health [2].

WHO has found that PM is the main pollutant that impacts health, especially with a diameter of 10 micron or less [1]. Exposure to PM_{10} or $PM_{2.5}$ is particularly of concern as it is respiratory penetrating. It can increase the risk of developing and also affects people who have already been diagnosed with cardiovascular, respiratory diseases and lung cancer. NO_2 is another major cause of health problem especially in asthmatic population who are particularly vulnerable to it. Epidemiological studies have shown that the increase of child's exposure to NO_2 lead to bronchitis symptoms, and slowest development of their lungs [1]. The exposure to O_3 can cause breathing problem and can trigger asthma in addition to limiting the lung functions [1]. Sulphur dioxide has the same effect on the respiratory system in addition to aggravation of the respiratory and eye irritation [1]. People whose immunological system is vulnerable to these pollutants, are highly affected by these factors.

Exposure to air pollution can be managed effectively but various environmental factors in the majority of cases, cannot be eliminated or controlled. For that reason, significant efforts are made in order to monitor air quality. The World Health Organization (WHO) set the limit of maximum concentration for each of the major pollutants, below which the effect of air quality on health in negligible [1]. This is to ensure that various countries and local authorities have a point of reference as to what an acceptable range of pollution is.

Many cities and research projects invested in air quality sensors or weather stations to effectively monitor the concentration of various environmental factors. This data if often opened to the public through APIs, websites and apps. However, crucial pollutants are not always measured, and the density of the deployed equipment may not provide useful information.

On the opposite side to measuring air quality via expensive, fixed measurement stations there's personable, wearable sensors. Such devices measure personal exposure to various pollutants, regardless of geographical circumstances to which fixed stations are limited. Their mobile nature implies both indoor and outdoor measurements. The characteristic of air quality in public indoor spaces such as shops, offices and cafes, is different to outdoors.

2.2 Air Quality and IoT Sensing

Air quality assessment provides guidance for managing and controlling the severity of the impact of air pollutants. Portable and wearable sensors, currently receive a fair amount of attention. Such technology has a huge potential as it increases people's awareness of what they breath, and through information dissemination, for example in the form of alerts, can guide them towards appropriate course of actions. An overview of such portable devices is presented in Table 1.

Work presented in [3] proposes a personalized wearable sensor system for sensing the surrounding air quality. Their focus is on particulate matter present on the air, aiming to measure the impact of dust concentration on the user. The study has assessed the air quality of the London underground stations. Authors found that there is a variation in air quality at different platforms depending on the number of people, time and place. The study concludes that their wearable sensor can provide the user with accurate data for guidance to exposure prevention.

OpenSense, is a project in Switzerland [4] which approached this problem by mounting sensors on public transportations such buses, trams and electrical cars. Authors of this work monitored the air quality through ten sensors nodes, capable of measuring O_3, NO_2, CO, UFP, over GSM network, where measurements also included GPS coordinates. Their aim was to assess the effect of user mobility and to pilot their sensors before deploying.

FooBot [5] is a portable air sensing measurement device. It detects PM2.5, total VOC, temperature and humidity and delivers its measurements to an app. The app warns and guides the user to take the appropriate course of action.

In ExposureSense [6] authors used accelerometers for detecting user's daily activities and their device also allows other sensors, such as O_3 to be plugged in. In their approach authors made use on an external sensor network (OpenSense).

CalFit [7] is a smartphone app for exposure assessment. The CalFit has improved the air quality exposure assessment through activity recognition in addition to sensor technology that is embedded into mobile system which can identify the user geographical location (GPS).

Aeroqual [8] is a portable indoor and outdoor air quality monitor, which accurately measures various air pollutants. It provides a low-cost, customisable platform for measuring different types of gases. It takes different sensor heads for each type of pollutants. In short, they allow to attach different sensor heads, which measure specific gases, to their base device to measure the quality of the air. Aeroqual comes in many series: 200, 300 and 500. Device measurement couple with cloud server website for data representing and sharing.

Tzoa [9] is a wearable device, which measures various aspects of air quality. It has an optical laser, which measures particulate matter 2.5 and 10. It samples humidity levels in addition to the levels of environmental ultraviolet rays of the sun. Based on the collected data, some guidance is presented through a smartphone.

Air quality Egg [10] is a small egg-shaped device for air pollution monitoring, where the pollutant can be chosen to be assessed from the egg and the result is presented on its smart phone app. The egg incorporates nitrogen dioxide, carbon dioxide and monoxide, sulfur dioxide, fine particulate and volatile organic compounds sensors, in addition to temperature and humidity. It can also host more sensors than those listed on Table 1. Both its hardware and firmware are open-source.

uHoo [11] is an indoor air quality sensor. It senses fine particulates, such as dust and mould, VOC, carbon dioxide and monoxide, ozone, air pressure, temperature and humidity. It comes with a free application to present the measurement and there is an option to share collected information with others.

AirBeam [12] is a small device that can measure fine particulates, which measurements gets presented through the AirCasting app. The AirCasting app is based on the idea of crowdsourcing hence it receives data from other AirBeams.

Air.Air! [13] is a small portable device measuring dust concentration. Again, the mode of information dissemination is via a smartphone app, which can warn the user when a certain level of dust concentration is measured. It detects dust in the air and very fine particles, but not mold.

LaserEgg [14] is a portable device for assessing fine particles either PM2.5 or PM10 in addition to humidity and temperature. It has different editions and LaserEgg 2 integrate its data with Kaiterra smart phone app.

Awair Smart [15], a portable sensors device that detect dust, CO_2 and VOCs in addition to temperature and humidity. Awair has an ability to connect other devices such nest for the need of filtering the air and solving the problem.

Table 1 summarizes the technologies reviewed.

3 ASTHMA AND SENSING

3.1 Asthma and Healthcare

Air pollution is proven to have a direct effect on people's health [1]. One of the most affected disease from the polluted atmosphere is asthma. Asthma is one of chronic diseases that occur when the lung passage swells due to inflammation of the air passages causing breathlessness. It causes wheezing, chest tightness, shortness of breath, and coughing. All age groups could have it but often start in childhood and it is common for children.

In August 2017, there were 235 million asthma sufferers around the world. This number has been estimated by the World Health Organization [16]. The number of deaths due to asthma was around 338,000 in 2015.

According to the National Institute for Health and Care Excellence (NICE) [17], severity of asthma can be measured by monitoring symptoms in addition to indicators such as the level of oxygen in the blood (SpO2), heart rate, respiratory rate, the peak expiratory flow (PEF), and the ability to talk. Also, through visible indicators such as agitation, confusion and cyanosis.

Asthma is diagnosed as *Intermittent*, *Mild*, *Moderate* and *Severe*. Intermittent Asthma is the level of asthma that describes people who have wheezing and coughing not more than two days a week or two nights per month. However, if the symptoms happen more often than this, it can be considered as persistent asthma. Mild Persistent Asthma is the level of asthma that describes people who has asthma symptom more than two days a week and not more than once a day. Moderate Persistent Asthma is a classification of asthma that happen daily. Severe Persistent Asthma is the classification when asthma symptoms occur daily and often. The patients' activities and sleep affected at that time.

NICE assess the severity of asthma through previous measurements with reference to age. They categorized severity in three levels, defined as: *Moderate*, *Severe* and *Life-threatening* [17].

Moderate asthma level is classified when the amount of oxygen in the blood (SpO2) is more or equal than 92 percent for all age groups. The heart rate in the children who are aged 2 to 5 years is less or equal than 140 per minute, and children older is less or equal than 125 per minute. Another indicator is the respiratory rate. If the respiratory rate less or equal than 40 per minute in younger children and less or equal than 30 per minute in children older, the condition is considered as a moderate.

Asthma can be considered as *severe* when the oxygen level remains below the standard limit for all age groups, when heart rate exceeds 140,120 per minute in younger, older children respectively. The respiratory rate is faster in younger children than older ones. Life-threatening asthma is the worst situation when asthma attacks occur. This could happen once the SpO2 stays below 92% in addition to silent chest, poor respiratory, agitation, confusion and cyanosis. [18] referred to some reasons such as patient non-compliance to the prescribed course of medication, incorrect inhaler usage and limited patient awareness about asthma triggers.

Asthma cannot be cured, but proper diagnosis, treatment and patient education can result in good management and control as what really matters is control before having severe attacks. Therefore, asthma should be managed properly to reduce risks and deterioration of a patient's situation. Asthma is managed through several ways such as turning up in hospital for regular face to face monitoring of symptoms and lung function, making patients aware of their situation and asthma triggers, in addition to actually managing trigger factors that affect their status. All of these components of management practice comprise the traditional way of controlling asthma.

3.2 Asthma and IoT Sensing

Most asthma patients are diagnosed when they visit a hospital. The assessment is done through checking their breath, pulmonary function, their symptoms and their response to medication. However, there is a lack of communication between asthma patients and health providers once patients leave the hospital and until the condition potentially becomes worse again.

Table 1: Low-cost Portable/ Wearable Air quality sensing Technology Measurement

Product	Measured air quality parameters	Components	Features
Aeroqual [8]	Ammonia, CO2, CO, Cl, Formaldehyde, Hydrogen, Hydrogen Sulfide, Methane, NO2, Ozone, PM2.5, PM10, Perclorethylene, SO2, VOC	Aeroqual device Attachable parts for different gazes and cloud server	Portable any range fit your required can be chosen Internet needed

Tzoa [9]	PM2.5, PM10 Humidity, UV Light, Temperature	Tzoa wearable device Smartphone App	Wearable Bluetooth
Air Quality Egg [10]	NO2, CO, CO2, SO2, PM2.5 Temperature Humidity	egg devices smartphone app (Apple and android) cloud server	Portable WiFi enabled Data sharing enabled Able to house more sensors
uHoo [11]	PM2.5 (0-200 µg/m³) VOC (10-1000 ppb) CO (0-1000 ppm) CO2 (400-10000 ppm) Ozone (10-1000 ppb) Air pressure Temperature Humidity	uHoo device + smartphone app (Apple and android)	Portable WiFi enabled
AirBeam [12]	PM2.5	AirBeam device Smartphone app (Android AirCasting)	Portable Bluetooth enabled
Air.Air! [13]	PM (hybrid or mixture)	Air.Air device Smart phone app compatible with iPhone, iPod and Android	Portable Bluetooth 4.0 optical dust sensor IRED infrared-emitting diode a photo transistor
FooBot [5]	PM2.5 (0-300 µg/m³) Temperature Humidity	FooBot device, Smartphone app, Cloud server	Portable WiFi enabled
LaserEgg [14]	PM2.5 (0-999 µg/m³) PM10 Temperature Humidity	LaserEgg device, Kaiterra smart phone app compatible with iOS and Android	Portable WiFi enabled
Awair Smart [15]	PM dust (0-500 µg/m³) CO2 (0-4000 ppm) VOCs (0-2014 ppb) Temperature Humidity	Awair device, Smartphone app for iOS and Android	WiFi enabled Bluetooth supported

Questions that need to be answered are: when do patients need to visit the hospital again? How they know when they may approach an attack? Can their status be tracked and monitored?

For example, a lot of patients are inaccurate in the information they provide in their treatment compliance diary. Also, by not using the medication correctly, some are affected by different triggers and some are not actually need to visit the hospital. The development of sensor devices aims to improve self-monitoring and remote checking; recently asthma researchers started exploiting these improvements by developing dedicated sensors devices. A review of some of these is provided in Table 2.

In Australia, a device called AirSonia has been published for assessing wheeze activity of the patient [19]. AirSonia is a portable device and easy to use for patients to ensure their respiratory sound is on the perfect rate to be, as wheeze is one of asthma symptoms that assess its condition's level.

Another small and light portable sensor device is AsthmaPolis [20]. It is attached to Ventolin inhaler to track the medication intake for diary required, recording the data to its application called Propeller Health.

MySpiroo is a kind of spirometer having embedded sensor to integrate its measuring data with smartphone application called MySpiroo Clinic [21]. The app is compatible with Android, iOS.

Smart Peak Flow [22] is a small part device that can attach to a smartphone to integrate its reading of a peak flow measure of a patient. It requires light to work properly and it work by patient exhaling and inhaling activity.

There is further work related to integration of existing devices such as kHealth [23]. kHealth is an android platform utilizing three sensors devices: Foobot, Peak Flow Meter and FitBit charge2.

This platform has been developed by integrating knowledge about asthma and air measurement data. Their focus is on assessing the reading of the Peak Expiratory Flow and how that can be affected by carbon dioxide and particulate matter.

4 DISCUSSION

Based on our review of both sensor devices for monitoring air quality and managing asthma, we conclude firstly that existing air quality sensor devices are user friendly, small, portable and easy to use. Most of these devices couple with smartphone apps for presenting air measurement data, except Aeroqual that has its own screen to present the data to a personal desktop.

Some of these devices such as the Air quality egg, AirBeam and FooBot utilize the cloud. This enables the devices to push measurement data to store, retrieve it later or share it. They also take advantage of the cloud's more powerful analysis and processing capabilities.

There is some variation of the devices' types of measurements and accuracy. Aeroqual can measure various pollutants with high accuracy as chosen per attached sensing element. However, it is not particularly user-friendly to be used with asthma patients. For asthmatic patients, a device that has high accuracy on measuring asthma air triggers such as PM2.5, PM10, CO, CO2, NO2 and Ozone as mentioned earlier is required.

From Table 1, we can see that uHoo is appropriate based on its measurement types. Air quality egg could be suitable too if we house PM sensors to it. Other devices could be chosen, if a required measurement is further specified. For instance, FooBot was chosen by kHealth app developers for measuring particulate matter to integrate it with asthma management devices.

Table 2: Off-the-shelf Asthma Technology Measurement devices

Product	Measured Parameter	Key sensors	Additional sensors	Components (Kit)	Body Position
AirSonia [19]	Wheeze (symptoms)	MSP430 >> measures respiratory sound		AirSonia device AirSense App (Specialist can share the information) Cloud server	Use it on the neck and exactly on the throat area
AsthmaPolis [20]	Adherence to the medication	actuation detection	GPS + time	Sensor device attached to the medication (AsthmaPolis) Smart Phone apps (Propeller Health) Website interface	Attached to the medication (Ventolin)
MySpiroo [21]	SpO2 FEV PEF Keeps track of pulmonary condition	IR LED sensor	Humidity sensor Pressure Temperature	MySpiroo device (Spirometer) MySpiroo Clinic (app for both apple and android)	Use it as spirometer
Smart Peak Flow [22]	PEF	IR LED sensor		Smart Peak Flow device Smart Peak Flow smartphone app for apple and android	attached to a smartphone and use it on the neck

Secondly, Asthma condition assessment devices have multiple features. The asthma sensor devices mentioned in Table 2 have features to measure different aspects of asthma symptoms and are worn in different positions. They are comfortable to wear, easy to use, improve patient's awareness of their condition, allow for early detection and real-time intervention, reduce the time of hospital visits and improve the quality of patients following up.

However, these devices could further benefit from existence of in situ asthma triggers assessment based on real time local air quality measurements, improving the quality of the evaluation. For example, if the device that measure asthma symptoms is recording asthmatic patient's data such the oxygen level, time, keeping the track of asthma progress and meanwhile the air quality device is recording air data that triggers asthma, we can make calculation and analysis, having more accurate results.

With this integration, we can enhance the accuracy of a study of asthma triggers impact by counting the breathing air and observing asthma progress while medications are taken. One of the ways to achieve this is to use smart application system for smart phone as an integration point and delivering way. For instance, kHealth that we previously mentioned is reading from different devices for the purpose of integration. Fig1. illustrates that concept. For that purpose, having different devices with different type of data will lead to the need of developing some more semantic data-driven application to combine asthma and air quality knowledge.

5 CONCLUSION AND FURTHER WORK

This review paper presented the state of art technologies for low-cost air quality sensing, as well as popular off-the-shelf devices for asthma monitoring. We found that there are a number of portable or wearable devices for assessing the quality of air for various pollutants that act as Asthma triggers. Further, there exist sensor devices that measure asthma indicators based on personal vital sign monitoring. Most of these devices work with a mobile system app for data presenting or processing, and some are processing their data in a cloud server, presenting the results on a smartphone app or through a specified website.

As some of those air pollutants trigger asthma, the integration between both domains is crucial for patients suffering from this condition. However, we could not identify any mature existing devices for asthma condition assessment, able to monitor triggers from air pollutants in real time and any work for integrating them in a way that contributes to asthma management. Our future work will therefore focus on the development of a semantic web-based knowledge resource for integrating those.

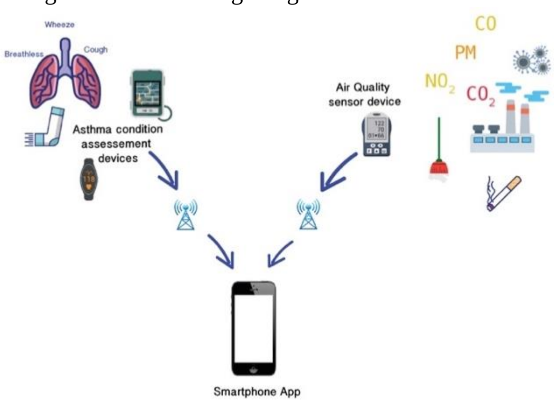

Fig 1: Integration of sensor devices through a smartphone app.

ACKNOWLEDGMENTS

Fatmah is a research student sponsored by King Abdulaziz University, Saudi Arabia, studying for a PhD at Bristol University.

This work was supported in part by the Engineering and Physical Sciences Research Council (EPSRC) through grant EP/K031910/1 (IRC-SPHERE).

REFERENCES

[1] 2016. WHO | Ambient (outdoor) air quality and health. *WHO*. (2016).

[2] M. Kampa and E. Castanas 2008. Human health effects of air pollution. *Environmental Pollution*. 151, 2 (Jan. 2008), 362–367. DOI:https://doi.org/10.1016/J.ENVPOL.2007.06.012.

[3] R. Zhang, D. Ravi, G.-Z. Yang and B. Lo 2017. A personalized air quality sensing system - a preliminary study on assessing the air quality of London underground stations. *2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN)* (May 2017), 111–114.

[4] J.J. Li, B. Faltings, O. Saukh, D. Hasenfratz and J. Beutel 2012. Sensing the air we breathe: the opensense Zurich dataset. *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence*. AAAI Press.

[5] Foobot Home Air Quality Monitor - Better Air, Better Life: *https://foobot.io/*. Accessed: 2018-03-26.

[6] B. Predic, Zhixian Yan, J. Eberle, D. Stojanovic and K. Aberer 2013. ExposureSense: Integrating daily activities with air quality using mobile participatory sensing. *2013 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)* (Mar. 2013), 303–305.

[7] A. de Nazelle, E. Seto, D. Donaire-Gonzalez, M. Mendez, J. Matamala, M.J. Nieuwenhuijsen and M. Jerrett 2013. Improving estimates of air pollution exposure through ubiquitous sensing technologies. *Environmental Pollution*. 176, (May 2013), 92–99. DOI:https://doi.org/10.1016/J.ENVPOL.2012.12.032.

[8] Air Quality Monitoring Equipment: Ambient Pollution Sensors: *https://www.aeroqual.com/*. Accessed: 2018-03-26.

[9] Tzoa wearable turns you into a walking air-quality sensor - CNET: 2014. *https://www.cnet.com/news/tzoa-wearable-turns-you-into-a-walking-air-quality-sensor/*. Accessed: 2018-03-26.

[10] Air Quality Egg: *https://airqualityegg.wickeddevice.com/*. Accessed: 2018-03-26.

[11] Most Advanced Air Quality Sensor | Know Your Air With uHoo: *https://uhooair.com/*. Accessed: 2018-03-26.

[12] AirCasting: *http://aircasting.org/*. Accessed: 2018-03-26.

[13] Air.Air! ~ Portable Air Quality Detector by Air.Air! — Kickstarter: *https://www.kickstarter.com/projects/1886143677/airair-portable-air-quality-detector*. Accessed: 2018-03-26.

[14] LaserEgg 2 - Air Quality Monitor compatible with Apple HomeKit: *https://www.laseregg.uk/shop/laseregg-2-smart-air-quality-monitor/*. Accessed: 2018-03-26.

[15] AWAIR | Know what's in the air you breathe – AwairUK: *https://getawair.co.uk/*. Accessed: 2018-03-26.

[16] 2013. WHO | Asthma. *WHO*. (2013).

[17] Asthma | Guidance and guidelines | NICE.

[18] J.A. Bellanti and R.A. Settipane 2015. Addressing the challenges of severe asthma. *Allergy and asthma proceedings*. 36, 4 (2015), 237–9. DOI:https://doi.org/10.2500/aap.2015.36.3874.

[19] Airsonia - Nicholson Design: *https://www.nicholsondesign.com.au/portfolio/airsonia/*. Accessed: 2018-03-26.

[20] Propeller Health | Digital Asthma and COPD Management: *https://www.propellerhealth.com/*. Accessed: 2018-03-26.

[21] Myspiroo. Take Your Breath: *http://www.myspiroo.com/*. Accessed: 2018-03-26.

[22] Smart Peak Flow - Asthma Control In Your Pocket: *http://www.smartpeakflow.com/*. Accessed: 2018-03-26.

[23] A. Sheth, P. Anantharam and K. Thirunarayan 2014. kHealth : Proactive Personalized Actionable Information for Better Healthcare. *Workshop on Personal Data Analytics in the Internet of Things* (Hangzhou, China, 2014).