MeAct: A Non-obstructive Persuasive End-to-End Platform for Active and Healthy Ageing Support

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Abstract. The essence of active ageing is embracing a healthy lifestyle, a choice that reflects on many aspects of a citizen's everyday life and routine, namely consumption and nutrition patterns, physical activity and stress management. Such a choice would effectuate a decrease in the risk of obesity, diabetes, dementia and other non-communicable diseases. Cardiovascular diseases and cancer are the dominant causes of avoidable deaths for people under 70 years old in Europe. Promoting and upkeeping health by integrating preventive practices in the daily lives of citizens is deemed a priority if not an urgency by policy makers. Modern technology and ICT tools are most valuable allies in this battle providing effective low-cost solutions. MeAct facilitates personalized and non-invasive guidance and encouragement in the direction of a healthier lifestyle. The approach introduced is a service-oriented, low-cost and easy-to-use integrated system, which, on the one hand, empowers and motivates citizens towards healthy and active living, while on the other hand, delineates the profile of their lives in terms of quality.

Keywords: Active ageing · Healthy lifestyles · wearable device · Service-oriented cloud services

1 Introduction

As ageing population has become a salient feature of western civilization societies into 21st century, most countries strive to enforce economically sustainable policies that would establish a high standard of quality living for ageing residents. Responding to this requisite, World Health Organisation (WHO) released the active ageing policy framework in 2002, to lead countries into the development of strategies and guidelines advocating a life of quality for senior population [1]. The concept of active ageing addresses the matter of prolonging life expectancy with a multitude of aspects [2, 3]. Attempting to cultivate healthy behaviors in all age ranges, WHO's global strategy and action plan from 2016 to 2020 endorsed healthy diet eating habits, physical activity and avoidance

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of tobacco and alcohol consumption, as means of preventing and impeding the development of chronic diseases. However, the limitations confiding health systems attending to the needs of low and middle-income citizens had to be taken into account [4]. Industry stepped up, capitalising on its expertise and developed new products or adapted existing ones to meet the needs of the users. The positive outcomes of this initiative are reduction of hospitalization days and degrees of surgery and abetment of self-care at home [5].

From a technological point of view sensors, wearable devices, communication protocols, networks and cloud computing are increasing in number and are becoming more personalized [6]. This allows for the development of tailored technological solutions promoting health. In this setting, a European Innovation Partnership on Active and Healthy Ageing (EIP on AHA) was launched during 2011 by the European Commission, aiming at improving the quality of life of ageing people and its vision is to sustain healthy living of European citizens [7]. The EIP on AHA can be considered a milestone in the EU Information and Communication Technologies (ICT) and ageing policy. While initially focused on active ageing at work, after 2007 the scope of the policy widened to support independent living at home, at work and in the community (e-inclusion). The inevitable next step was to include health in the EU's ageing and technology policy with 2012 EIP on AHA. The link between health and ageing is clearly stated in its ambitious goal, "*adding two years of healthy living to the average life expectancy of European citizens*". In addition, the partnership emphasizes the role of national, regional and local stakeholders, to best demonstrate the benefits of ICT for active and healthy ageing. The goal of ICT solutions is to focus on the well-being of the ageing population by collecting data regarding the daily routine of the elderly in order to produce information about lifestyle and assess how their choices affect their ageing. The impact and relevance of these solutions on the well-being of the elderly is very substantial, as they monitor and provide feedback on physical activity, sleep patterns, eating habits, social interaction, emotional state, cognitive state, etc. Nevertheless, they do not yet provide a holistic solution for the issues they are addressing, while in the same time avoiding to further stigmatize this already sensitive target population.

What is presented in this paper is a service oriented end-to-end platform based on an architecture aiming to promote a healthy and active way of living by continuously monitoring the users' activities, the quality of their ambient environment, the quality of their sleep, their psychological stress levels and their health status, recommending appropriate activities and supporting them to improve their everyday life quality. The proposed scalable architecture has been used to develop an m-health application for Android smartphones that fosters active ageing for elderly people. This mobile application allows users to perform different types of activities depending on their health and psychological status as well and makes sure the environmental quality conditions are the appropriate ones. The system employs off-the-shelf unobtrusive low-cost sensors efficiently mounted on a wearable embedded device based on state-of-the art microcontroller utilizing contemporary communications and exhibiting long autonomy.

The rest of this paper is structured in sections according to its content. Section 2 outlines the related work, Sect. 3 depicts the architecture of MeAct platform and the detailed description of its constituents, while in Sect. 4 the findings as well the validation steps are being discussed. Section 5 outlines the conclusion and reveals the next steps to be taken.

2 Related Work

This section examines existing work that is related to the proposed integrated platform by lining up various systems' architectures which support active and healthy ageing and presenting different solutions regarding their constituents, such as the portable sensing device, the mobile platform application, the dashboard and the services. Our goal is to present solutions aiming towards active and healthy ageing and how MeAct stands out in the case of user – centric approach. During recent years, numerous technologies and ICT frameworks have been proposed, mostly from the academia and lately from the industry, aiming at promoting active and healthy ageing. In relation to the increasingly ageing population, there is an increase in the use of ICT by the corresponding age group. In fact, older adults now represent the fastest growing population adopting Internet and ICT technology, so there is a clear evidence of adapting initiatives such as telemedicine, telecare, telepresence and the challenge of active ageing [8]. In this context, it is possible to analyse the users' individualities and collect data to guide the technological development in order to improve the human-machine interaction achieved. A considerable number of ICT-type solutions regarding interventions towards active and healthy ageing are presented below:

- applications on management and coordination of e-health interventions to promote physical activity [9]
- platforms to promote active and healthy ageing [10, 11]
- applications on personalized coaching of elderly persons to support active ageing [12, 13]
- cognitive training applications [14]
- telehealth applications to support self-management [15–17]
- telemedicine systems for direct intervention of the clinicians [12, 18, 19]
- applications targeting rehabilitation [20]
- systems targeting social inclusion and participation [21]

However, most systems are not user-centric yet and consequently the adoption and application of these technologies to real life conditions, especially those based on intrusive sensing devices is still limited. The main barriers to their partial success mainly involve:

- low acceptance and low system usability by the final users, and
- lack of interoperability with new and potentially advanced external devices, which implies a limited product and service suite to be offered to the users.

The first issue is directly connected to the system design that is highly technology-oriented instead of user-oriented. Indeed, systems are usually defined starting from the analysis of available technologies and not from the users' needs. Consequently, those systems are conceived by skilled and healthy people that are not deeply involved and fully aware how frail people live and think.

The second issue mainly derives from the adoption of the existing standards of communication (i.e. BLE, Bluetooth, WiFi, etc.), which can guarantee a set of compliant devices able to get into the network and exchange information. The result is a blinded system where personalization is hard to realize and evolution is limited to the development of a specific standard.

In this paper, we propose MeAct, an integrated end-to-end ICT platform, which aims to tackle the aforementioned deficiencies by proposing a rich set of cloud services from which the end user can benefit from, under the objective of essentially mproving the quality of life by utilizing a minimal intrusive state-of-the-art wrist wearable device able to collect the photoplethysmogram (PPG), the linear acceleration in 3-Axes (ACC), the ambient environment parameters (AEN) and the air quality parameters (AQU), along with a GPS equipped mobile device having access to weather data.

3 The Proposed MeAct Platform

The platform's architecture proposed to develop an end-to-end integrated system aiming to improve and increase the activity levels of elders is depicted in Fig. 1. MeAct's contribution to the latest technology can be summarized in the following critical features:

- User centric design characteristics
- Fusion of data from various sources
- Personalized services based on incremental learning models
- Involvement of healthcare professionals and medical experts

The proposed platform comprises three main layers: the edge layer, the fog layer, and the cloud layer. Different modules comprise each layer as following: (a) the edge layer comprises the sensors (PPG, ACC, AEN, AQU), the wearable embedded device (ESP32 - based) and the firmware, (b) the fog layer comprises the smart mobile device (GPS, Weather Data) and the app, (c) the cloud layer comprises the back end, the front end, and the cloud services. Each of the modules has the capacity to collect data and perform computations at a different scale. As presented in Table 1, each module is responsible for acquiring different kind of data which are either processed locally or forwarded to the upper level. The design of the MeAct platform is based on the cloud offloading strategy, meaning that the data from the three processing layers are forwarded for processing to the next level, only if they need to be fused with other data sources. In any other case, the data generator module handles the processing locally, thus providing a stable, fault tolerant platform.

This section is divided into three subsections. The first subsection presents the constituents both hardware and firmware as well as the computations of the Edge layer, the second subsection reveals the characteristics of the application residing in the Fog layer and the third subsection reveals the details of the services residing in the Cloud layer.

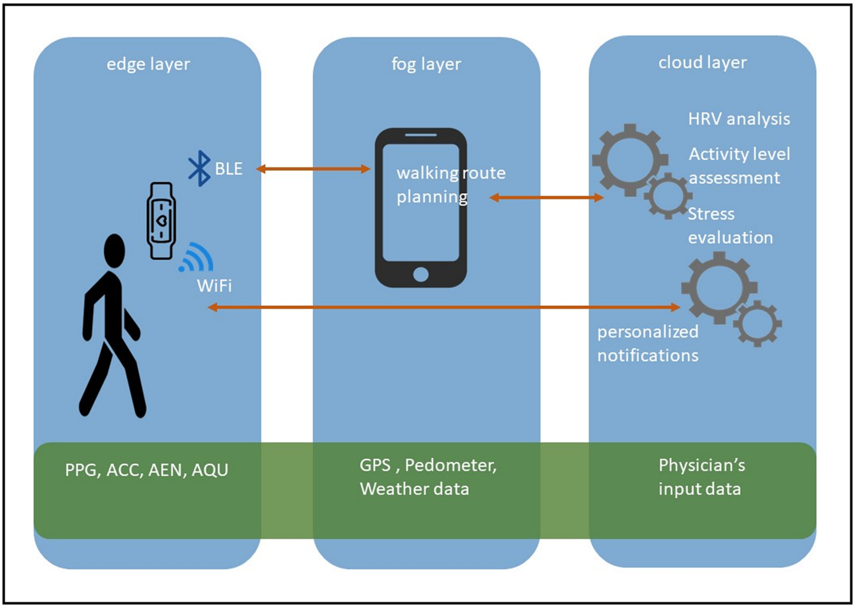

Fig. 1. MeAct platform architecture.

Table 1. Modules, collected data, computations.

Module	Collected data	Computations
Wrist Wearable Device	PPG, ACC, AEN, AQU	Heart Rate (HR), Activity Level, Environment Quality
Mobile Device	GPS, Weather Data	Suggestions about Time and Place to perform activities
Cloud Services	Physician's Data	Alerts/Notifications about: Training Schedule Heart Rate Variability (HR-V) Psychological Stress Sleep Quality Health Status

3.1 Edge Layer Components

- Wearable Embedded device

The wrist wearable embedded device is designed and developed in house based on ESP-WROOM-02 board which is a low power 32-bit MCU Wi-Fi/BLE module using the ESP32 chip which incorporates TCP/IP network stacks, 10-bit ADC and HSPI/UART/PWM/I2C/I2S interfaces. The ESP-WROOM-02 uses a 2 MB SPI flash connected to HSPI, which acts as an SDIO/SPI slave, with SPI speeds of up to 8 Mbps. The device is powered through a Li-Po 1600 mAh 3.7V battery, thus providing great autonomy. An external switch has been added to the board to easily turn on and off the device. The housing of the device is designed in Autodesk Fusion 360 and implemented in a 3D printer from PLA material.

- Sensors and corresponding adapters

The photoplethysmography (PPG) sensor used is Maxim's MAX3010x, which can deliver an accurate reading of the user's pulse and be processed to extract the analog signal's metrics [22]. Analog Device's ADXl362 accelerometer provides the linear acceleration in 3-Axes, which is used to derive the movement status in form of rest, sleep, mild and intense activity as well as determine the reliability of the system's measurement as sensors readings are affected by sudden movement [23]. Bosch's BME280 MEMS sensor with high accuracy is used to aggregate ambient air temperature, air humidity and atmospheric pressure [24]. ScioSense's CCS811 sensor is used to aggregate the percentage of Organic Compounds in the air as well as the eCO2 (equivalent calculated carbon-dioxide) concentration [25]. AMS's TSL2591 is used for measuring indoors luminosity while SiSonic's SPW2430 is used for the ambient noise [26, 27].

- Processing/Computations

As the wearable device transmits its measured data either via WiFi or BLE, it is important to execute certain preprocessing techniques to reduce the number of total transmissions that greatly affect energy consumption thus battery life expectancy. Sensor fusion techniques undertake the transforming of sampling values into average measurements as well as extracting conclusions (i.e. movement status from acceleration data points, altitude from barometric pressure etc.). Signal processing techniques to filter the inputs of the analog sensors are also present, offering stable readings and noise artifacts removal, such as low pass filtering of the PPG signal and peak detection algorithms to calculate the HR. Kalman filtering acts as a smoother for time series measurements of the 3-axis accelerometer. Based on the calculation of the three-dimensional acceleration vector's magnitude and setting of the thresholds of the corresponding motion state to rest, mild or intense, the type of activity is eventually classified as idle, walk or run. The technique utilized for the classification is a neural network specially designed and deployed for microcontroller use from the edge impulse platform [28].The network model is tested online showing 1 ms inference time and 99.3% accuracy as depicted in Fig. 2.

3.2 Fog Layer

- Application Characteristics

The mobile app is designed under the basic principles of the Human-Machine interaction, while the User Interface is designed using a minimal color pallet. The mobile app acts as the communication interface between the end user and the collection of services. Thus, it hosts POST and GET endpoints, in order to interact both with the wearable device and the cloud infrastructure. Finally, the mobile application is used for everyday message exchange between the physician and the end user.

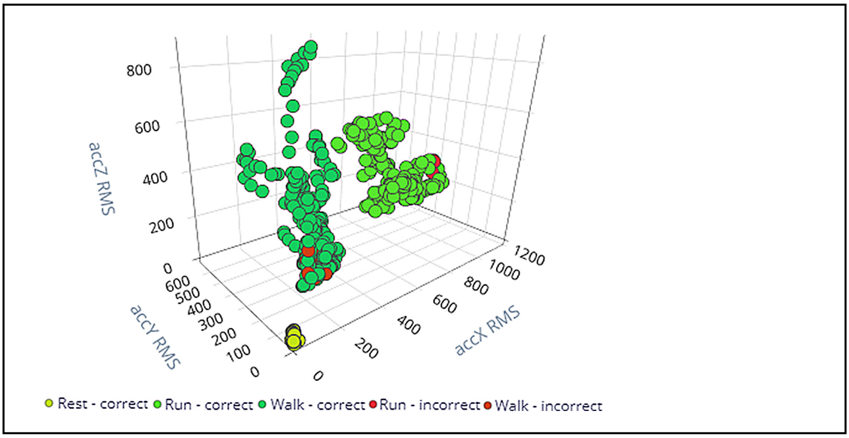

Fig. 2. Acceleration Vector Accuracy.

- Processing/Computations

The main service offered by the mobile app is the suggestions about the most preferable time of a day that the user can exercise outdoors, as well as the place-route where to perform the activities as depicted in Fig. 3. The suggestions are based on an incremental machine learning model which uses as input the weather data, the past actions of the user and the suggestions implied by the physician.

3.3 Cloud Layer

- Services Characteristics

The method of interacting with the central platform in the Fog layer, in any case, is HTTP POST as POST is a reliable and efficient HTTP-supported method used by the World Wide Web. This method, which is commonly used to carry small loads of data, allows them to be sent as a packet in a separate communication which means that data sent via the POST method is not visible to the URL as parameters are not sent with the URL. These HTTP POST specifications make it ideal for interconnecting low-power and low-resources devices with the Internet, especially when there is an immediate need to send data to a trusted server. The cloud services residing at the server are responsible for performing complex computations in order to acquire useful analytics. As the system collects a lot of data whose volume changes as the recording time is extended, the heterogeneity of the data, as it arises from the nature of the different sensors, makes

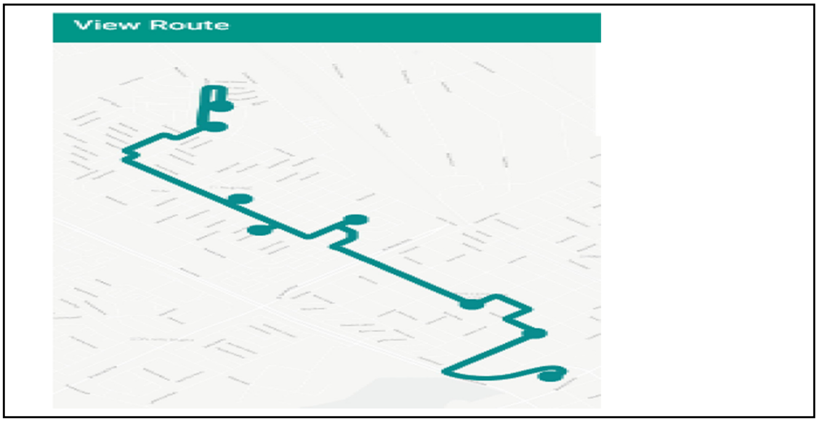

Fig. 3. Exercise Route Suggestion.

it necessary to come in a common format for the system to manage. Therefore, the requirement for homogeneity of data and their description by clearly defined models should be addressed. To this end, MeAct stipulates that all data that is handled and processed is described by the FIWARE Data Models which are based on the NGSIv2 standard and is part of a set of technologies and architectures proposed through the EC FIWARE project [29].

- Processing/Computations

A cloud service performs a meta-analysis of the HR by calculating a set of significant metrics related to the HR as the ones presented in Table 2. All these metrics are selected at rest timeslots and reported back to the physician in order to acquire useful insights about the user.

As a metanalysis streamline service, a psychological stress model is implemented assessing the user's corresponding levels and informing the physician accordingly, as proposed in [30]. The aforementioned model is based on a binary classification tree, which explores metrics such as lf and pNN50 to classify an HR window as stress or non-stress [31].

Additionally, fusing the above metrics with the user's activation levels and the guidelines of the physician, the "personal trainer" service is triggered to provide personalized suggestions about the amount of exercise a user should perform.

Another cloud service is responsible for issuing alerts about critical circumstances, as tachycardia, and informing the physician. While at this point the models for issuing the aforementioned alerts are knowledge based, machine learning models are planned to be incorporated after the collection of the appropriate datasets.

4 Discussion – Evaluation

MeAct is a modular platform which can utilize "as many data as it can collect", process them either locally or on the cloud and produce tailor made activity suggestions.

Table 2. HR metrics

	HR metric	Description
Time domain	bpm	Beats per minute
	ibi	Inter beat interval
	sdnn	Standard deviation if intervals between adjacent beats
	sdsd	Standard deviation of successive differences between adjacent R-R intervals
	rmssd	Root mean square of successive RR interval differences
	pnn20	Percentage of successive RR intervals that differ by more than 20 ms
	pnn50	Percentage of successive RR intervals that differ by more than 50 ms
	hr_mad	Median absolute deviation of RR intervals
	sd1/sd2	Length of the transverse/longitudinal line of the Poincare analysis
Frequency domain	br	Breathing rate
	vlf	Absolute power of the very-low-frequency band (0.0033–0.04 Hz)
	lf	Absolute power of the low-frequency band (0.04–0.15 Hz)
	hf	Absolute power of the high-frequency band (0.15–0.4 Hz)
	lf_nu	Normalized power of the low-frequency band (0.04–0.15 Hz)
	hf_nu	Normalized power of the high-frequency band (0.15–0.4 Hz)

As the wearable wrist device offers both WiFi and BLE communication interfaces, it can communicate directly with the mobile app and/or the cloud services. This system design feature enables the assessment of both indoor and outdoor activity levels, allowing the MeAct platform to support the end users in both settings. While reducing the indoor time is one of the objectives of MeAct, assessing the activity levels during the time an end user spends at home is crucial. By incorporating edge computing applications, the wearable device can infer the intervals the user performs no activity and according to user's profile, to produce a recommendation. For supporting the outdoor activities, the utilization of the sensing and computation capacity of the mobile device is necessary, in order to acquire more accurate readings of the user's activity levels, mostly based on the pedometer sensor of the mobile device.

MeAct platform has undergone preliminary laboratory testing phase with respect to usability and system performance. The evaluations of the various components of the platform regarding the usability, the quality and the easiness of the interactions, are ongoing and performed mainly by experts depicting their subjective findings in questionnaires and interviews based on the System Usability Scale (SUS) [32]. System performance evaluations include functionality tests of the system components such as dependability measures, task execution robustness and timeliness, wearable devices performance and autonomy, transmission reliability and performance, and services responsiveness.

This preliminary phase provided the opportunity to listen to the feedback from caregivers/experts comprising a critical users' group. This users' group noticed the need related to the fusion of HR metrics with the user's activation levels, entailing to the implementation of the "personal trainer" functionality making the system personalized and engaging the users to goals setting. Regarding system performance, the wearable device exhibited remarkable findings since there was no observation of system halts or hesitations and its autonomy ranged between 36–40 h depending on the various internal operations modes applied. The performance of the backed end system and the corresponding services kept very stable regardless the number of virtual users, thus providing us with confidence about its robustness.

5 Conclusion

This work is about presenting the architecture and the constituent components of the MeAct platform, which provides services promoting active ageing to all citizens. The overall solution consists of two subsystems that are integrated via well-defined interfaces, but each one performs autonomous functions in an opaque manner. Those two are: i) the subsystem of bio and environmental parameters collection - recording and ii) the back-end subsystem of storage, data processing and services. This platform continuously monitors physiological parameters and activities, performs health and psychology status assessment, and provides personalized feedback to improve well-being. The novelty of the proposed platform predominantly lies on the minimal design of the wearable sensing devices, allowing a least disturbing interaction with the end user. The role of the wearable is to collect biosignals, facilitating the creation of the user's profile based on calculations of a set of metrics and analytics. Having established that profile, a persuasive coaching agent uses it as a base, in order to encourage the end user towards a more active way of living with improved physical activity. Furthermore, in comparison with similar solutions, MeAct platform has the advantage of functioning without the aid of a paired smartphone for collecting and delivering the biosignals to the back-end system, thus enhancing its user-friendly attribute for users with low digital literacy.

Albeit MeAct platform is a novel well-thought design, there is still room for future improvements. The independence of the wrist device, meaning it will be working "smartphoneless" especially during outdoor activities, can be achieved by including a GPS sensor and a 5G GSM communication module instead of the existing WiFi & BLE. Moreover, the robust estimation of the respiratory rate will render possible by implementing additional health-oriented algorithms. Adding the gamification process to the solution with enhanced capabilities, should further motivate the user by setting a game like environment with scores and highlighting the optimal way to reach the set goal.

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