A Versatile Architecture for Building IoT Quantified-Self Applications

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***Abstract*—The abundance of activity trackers and biosignal sensors as well as the evolution of IoT and communication technologies have considerably advanced the concept of Quantified-Self. Nowadays there are several frameworks and applications that realize the concept, focusing though strictly on specific areas, from daily use to professional activities such as sport and healthcare. This work proposes a versatile, cross-domain solution for building quantified-self applications exploiting the capacities for open-design, modularity and extensibility of the AGILE IoT gateway.**

Keywords-quantified self; gateway; iot; iot-architecture; sensors; activity tracking; open source;

I. INTRODUCTION AND RELATED WORK

Present mobile and sensor technology allows for extensive monitoring of all kinds of data on a person's daily lifestyle, such as exercise, steps taken, body weight, food consumed, blood pressure, cigarettes smoked, etc. This type of self-data tracking is often referred to as the *Quantified-Self* [1]. Research has shown that tracking such values, like body weight, is effective in itself as the mere activity of tracking makes the user conscious of its importance and in turn, lead to lifestyle changes [2]. Additionally, by tracking the value over time, the users get insights regarding their progress and are able to experience the direct relation between their efforts and the results thereof, i.e. visiting a gym twice a week leads to a decrease of body fat percentage [3]. Solutions available in the state-of-the-art include mobile apps for GPS tracking of cardio activities (i.e. Runkeeper, MisFit), like running and cycling, websites for tracking body weight, fat percentage and bone mass using Wifi connected body scales (Withings Body Scale), mobile apps for blood pressure monitoring, activity apps with integrated (wireless) activity monitor (Polar, Fitbit activity monitor, etc.) [4].

But for a variety of reasons, most wearables, quantified-self tools have a short-shelf life. Just as one example, over 50 percent of people using similar applications have given up on them after six months [5]. The main reason is that new apps with better characteristics and corresponding wearable devices, which do not collaborate with the previous ones, are constantly emerging. Thus, the adoption of a vendor-free solution like the one proposed in this work is necessary. This remains a complex process though, mainly due to the fact that each vendor uses different communication mechanisms and requires a separate application for the persistent storage and visualization of data [6]. Industrial services however, like Validic, promise connection between healthcare companies, apps and devices in order to store on the cloud, analyze the users' activity.

Several Internet of Things – IoT solutions have been proposed to realize the concept of quantified-self and the related challenges in the areas of healthcare and assisted living [6][7][8]. Their applicability varies, covering daily use or professional activities. Each approach is tailored for specific uses such as sports, healthcare, fashion and elders [9][10][11] making not applicable to other areas and the absence of extensibility and the lock-in to the specific solution is considered as a key factor for their short-shelf life. In addition, there several security and privacy concerns exploiting IoT sensors and systems for activity tracking which rise concerns for end-users and consumers, while the resolution of these issues often introduces heavy complexity and makes their use inconvenient [12][13].

AGILE [14] is an EU project aiming to build a modular hardware and software gateway for the Internet of Things (IoT) with support for protocol interoperability, device and data management, IoT apps execution, and external Cloud communication. The main concept behind AGILE is to enable users to easily build IoT applications and control connected devices through a modular IoT gateway and a set of full stack (OS, runtime and applications) IoT software components. Within the frame of the quantified-self pilot foreseen in the project, AGILE addresses the issue of vendor independent applications by creating a single point of communication for activity tracking and biosignal collection. The goal is to facilitate the integration of various devices and provide advanced functionalities for the utilization and secure sharing of the acquired data, demonstrating the applicability of AGILE in home/personal use.

The rest of the paper is structured as follows: Section 2 describes the AGILE gateway and highlights its design and features while section 3 presents the quantified-self concept in the frame of AGILE. The design and implementation of the application and the integration with the gateway is analyzed in section 4. The benefits of this approach in

business and technical levels are discussed and section 5. Finally, section 6 concludes this work and highlights the future plans.

II. IoT Fundamentals and The AGILE Gateway

The AGILE gateway is an open source, adaptive, reconfigurable data concentrator and manager for the Internet of Things. Its main features, specially designed to accommodate the needs of modern sensor based applications such as the quantified-self applications, are summarized into the following subsections.

A. IoT Protocols

The gateway supports of a wide range of wireless and wired protocols through hardware and software modularity. The device comes into two hardware versions; one designed and built for industrial applications and one for quick prototyping. The industrial version comes into the form of a PCB board that provides connectors for easily attaching wireless and wired communication modules as well as a variety of sensors (e.g., air quality, temperature, etc.). The prototyping version is based on the popular RaspberryPi version 3.0 boards and consists of an extension shield with sockets for adding two wireless modules and a number of onboard sensors (humidity, temperature, light and sound). Both hardware versions enable users to attach a number of wireless communication modules (e.g., Bluetooth Low Energy, ZigBee, ZWave, LoRa/LoRaWAN, etc.) and enable interaction of the AGILE gateway with diverse IoT and quantified-self sensors and devices.

On the software side the AGILE software stack that runs in the gateway provides the automatic detection and configuration of the wireless communication modules. Thus, the user does not have to install or configure any drivers for enabling the usage of the wireless modules. The latter feature minimizes the need for skilled personnel to install and configure the gateway and enables the use of it especially from people who are less technical. Currently there is no golden standard to be adopted when it comes to IoT data and applications. Therefore, AGILE provides support for the most established and used communication protocols by IoT developers: IoTivity, openThread, uPnP, MQTT and CoAP are supported. The latter protocols operate in different layers, enabling from device & feature discovery to messaging and information exchange regardless the wireless network used.

B. Data Storage

One of the key features of AGILE is the ability to develop custom application logic and execute it on the gateway itself. The application logic can be used for processing (filtering, classification, etc.) or incoming or stored sensor data and for decision making (e.g., triggering a wireless actuator or sending a notification). This enables two important functionalities: a) better privacy and security since data can be processed entirely on the gateway without the need to rely on external applications or Cloud services, b) the data collection and visualization from connected quantified-self devices and other IoT sensors can happen also when the gateway is offline (i.e. not connected to the Internet).

To develop such application logic, a visual workflow editor (Figure 1) has been added by integrating existing open source software of Node-RED [15]. The editor enables users, even those who don't have programming skills, to create small applications that combine input from connected sensors, drive connected actuators, generate graphs and send notifications and information to external cloud services. Once the apps (called workflows) are designed by dragging and connecting graphical nodes, they can be deployed and executed instantly. Logic like control statements can be integrated in the workflows as nodes or implemented in short JavaScript functions.

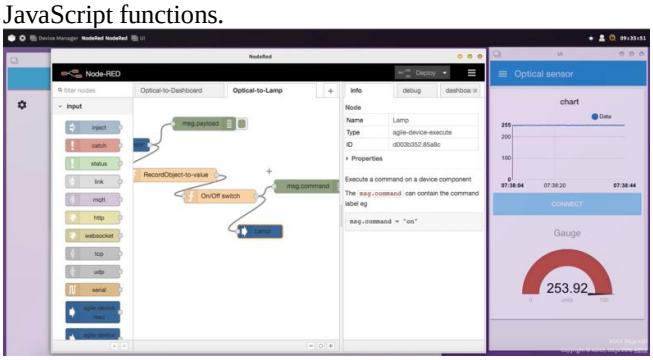

Figure 1: The AGILE Developer's Workflow Editor

Developers can still create custom applications that can be executed in any runtime on an embedded Linux environment (C/C++, Python, Java, Node.js/JavaScript, Go, etc.) and make use of the provided AGILE features: all developed functionality for IoT devices discovery, communication, data collection and storage is exposes through an internal RESTful interface.

C. AGILE Gateway Architecture

In order to enable the aforementioned functionality, the AGILE Gateway is designed and built following the notion of microservices (see Figure 2). Each functionality provided by the gateway (i.e. IoT device discovery, communication through an application protocol, data storage and handling, development of application workflows, etc.) is being developed and packaged as a software container using a modern containerization technology like Docker [16]. The containers come with the application runtime and all required dependencies. This approach offers two important advantages over other software development and distribution methods (e.g., software libraries); a) Users do not have to worry about dependencies and conflicts among dependencies and other software: the containers are completely isolated and executed in their own virtual environment without affecting the operating system or other software applications. b) The software containers can be developed using different programming environments and distributed over a common application marketplace (e.g., Docker hub). Once being installed, their initialization and execution takes place within a few seconds. Practically this means that the user can install new AGILE functionality on the fly without the need to restart the device or stop the execution of a current application.

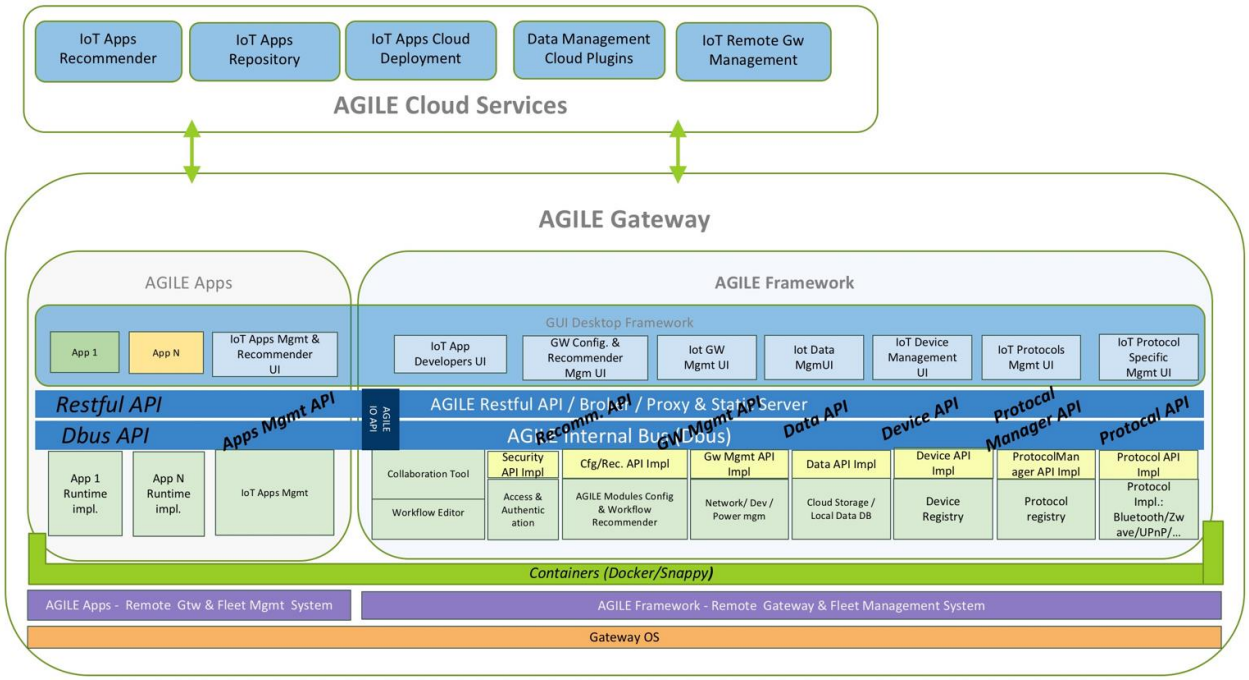

Figure 2: The AGILE Microservices Architecture

III. The Quantified-Self Concept

The realization of quantified-self concept requires the integration of several elements (Figure 3), which are orchestrated around AGILE Gateway. The gateway connects to the home network and through the gateway's management UI, the owner has access to all provided features, such as reporting and visualization tools, can manage (store/view/edit) their data and define an access policy to share data with their social circle. Wearable activity trackers and medical sensors automatically communicate with the gateway whenever within range, and offload the most recent data. Integration with cloud platforms allows data synchronization between the gateway and the owner's online profile, which enables the user to access their data through a web app. In addition, health and activity data can be downloaded to the gateway from the owner's personal accounts on relevant platforms.

As illustrated in Figure 3, each user of the Quantified-Self application is provided with a set of activity tracking devices and biosignals sensors (such as oximeters, blood pressure monitors or glucometers), to monitor their daily physical activity and physical condition. All activity data and biosignal measurements are stored locally, in the user's gateway. The user is able to visualize and manage their data, create reports and export the data from the gateway or even import past data from other cloud services they might have used before, such as Fitbit, GoogleFit, etc. In parallel, motion and lifestyle data may be processed and analyzed on the gateway, so as personalized recommendations are sent to the user's smartphone in order to encourage them to reach their physical activity goals. Moreover, users are able to share their activity data and achievements with certain people/users from their social circle, including relatives, friends and most importantly their physicians.

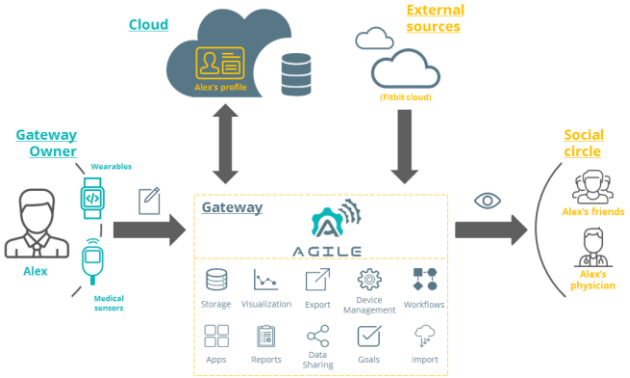

Figure 3: Quantified-Self Concept in AGILE

IV. Building The Quantified-Self Application

The quantified-self concept is targeting data acquisition on aspects of a person's daily life in terms of inputs (e.g. food consumed, quality of surrounding air), states (e.g. mood, arousal, blood oxygen levels), and performance (mental and physical activities) through a modern, health centric, social and mobile enabled, communication platform that resides in the gateway (in terms of collecting and visualizing data).

The application is developed using the AGILE environment and software stack, and uses the communication modules of the gateway to collect data from self-tracking devices of users: wristbands or smartwatches, weighting scales, oximeters, blood pressure monitors, etc. In addition, the cloud integration modules are exploited for periodically importing activity data and biosignals from other providers and applications through their public APIs.

A. Quantified-Self Users, Use Cases and Requirements

The main users of the application are the individuals who intend to measure their daily activity and biosignals, and need to keep track of their data in the local storage of the AGILE Gateway. The actions performed by the users (owners of the AGILE Gateway) are the following:

- Utilize the sensors to monitor their physical activity and health status
- Utilize smartwatches or bracelets to track their activity
- Store their biosignals and daily activities in the gateway
- Use AGILE UI to visualize the data and have access to reports and analysis results regarding the data.
- They are able to export the data
- Access rights for access to the data can be set
- The users can define targets and exercise plans
- They can also manage their data through the pilot application available on the cloud

In addition, the social circle of the main users is involved. Friends/Relatives/Physicians of the users can also login to the application, if allowed by the users, and access data and information that the users decide to share by defining explicit access rights and permissions.

The use cases and requirements of the application can be separated in four categories, which are discussed below: a) gateway management, b) sensor communication, c) data management and d) cloud communication.

1) Gateway Management

The AGILE Gateway should provide user authentication for the Quantified-Self users and ensure the typical security and privacy features of typical web application. In addition, the uses should be able to edit their account and profile in the application and add the personal information required for the effective analysis of the collected data. The functionality of the gateway should be available through a modern, intuitive and easy to use UI. Furthermore, the integration of wizards and recommendations to guide the users through all processes is also considered as a key requirement.

2) Sensor Communication

The users should be able to easily register new sensors to the gateway through the UI. Upon registration, the sensors will automatically communicate with gateway when they are in range in order to offload the data. The only communication protocol that is required for the sensors involved in the concept is Bluetooth and particularly BLE [17]. In addition, due to the nature of the application and the use of the gateway by users who are not always technology or IoT experts, some kind of display or notification mechanism is required. This mechanism, implemented as colored and blinking LEDs, will inform the users about the gateway status, and the state of the connection between the gateway and the various devices sensors.

3) Data Management

The use cases and requirements regarding data management are considered of high priority for the implementation of the Quantified-Self application and its success. Regarding data acquisition there are two sources: a) direct communication with the sensors via BLE and b) data import from the cloud APIs of activity trackers' manufacturers. In both cases, the data should be stored in the gateway using a common format that ensures their efficient analysis and processing, given the storage and computational constrains of the gateway. In addition, data visualization should be provided for both the raw and processed data, as well as notifications and reports about the users' progress compered to his/her average activity, average user, or predefined targets.

4) Cloud Communication

Cloud communication use cases and requirements refer to the need for import and export of data to well-known cloud providers and the option to share row or processed data with relatives, friends or physicians.

B. The Ecosystem of IoT Devices in Quantified-Self Application

Quantified-Self application focuses on ease of use for all the processes related to the end-users in order to ensure wide adoption and minimum interference with the user daily life and behavior. To this end, the sensors and trackers that have been selected for the application follow the same approach, ease of use and minimum interference. Both requirements can be achieved by exploiting sensors and trackers that use Bluetooth communication and particularly BLE, so as to avoid additional wired setups or use of adapters for other communication protocols. In addition, there are several product offerings available in the marker, and also in competitive prices, that the users can buy and integrate with the application. The current list of devices, which are integrated and tested with the gateway, include oximeters, blood pressure monitors, weighting scales as well as smart watches and activity trackers.

Regarding the smart watches and activity trackers there are two integration approaches. For a limited list of devices for which the manufactures provide either the BLE protocol or API libraries for communicating with Linux based machines such as the AGILE Gateway, direct integration, communication and data offloading is feasible. However, in most cases the manufacturers provide only API libraries for Android and iOS, or specific applications for synchronizing the data with manufacturers' cloud platforms, neither of which is compatible with the proposed setup. In these cases, the activity data offloading is achieved via Internet and the public APIs of the cloud platform.

C. Quantified-Self Application Implementation

AGILE provides high flexibility to the developers for the design and implementation of IoT applications on the gateway allowing them to choose between native components, node-red based components or hybrid solutions. The Quantified-Self (QS) application is designed and developed using the node-red environment. The application consists of different components implemented as nodes in node-red following the approach of a modern application.

One characteristic of the particular application is the diversity of data produced by sensors [6], which makes the processes for cross-device visualization and analysis of data

challenging (Figure 4). The proposed solution, addresses this by adopting the Open mHealth specification [18].

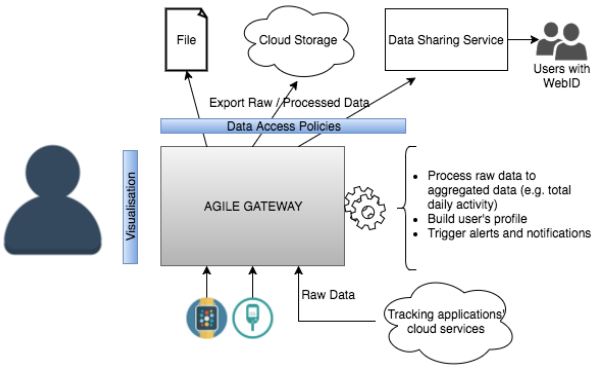

Figure 4: Quanified-Self Data Flow Overview

The data should be stored locally and visualized either during the measurement or upon the user's request. Uploading data to the cloud is also a requirement that should be probably achieved by developing a particular application. Generic export of data to popular cloud providers like Dropbox and Google Drive should be natively supported. Regarding analysis, the measurement data as well as the data imported from the cloud, should be analyzed to build the user profile and identify trends, risks etc. The application that will be developed in the frame of the pilot will communicate with the Cloud endpoints of activity tracking devices and applications.

D. Identification, Security and Privacy

The application is built on top of the identification, security and privacy components of AGILE by integrating with them and exposing their functionality to the end-users [19]. To this direction, the user authentication mechanism of AGILE is used as the default authentication approach. Currently only local users are supported however, in the future the single-sign-on features of the respective AGILE components will be also exploited. The users can define usage control policies, which are applied on all types of data (real-time data from sensors, imported data and processed data – user profile) in the gateway as well as on the tasks that involve user data such as data analysis and data sharing.

The fact that data reside on the gateway is the first step towards addressing the required security and privacy levels of the quantified-self concept. Furthermore, the functionality for sharing -raw or processed- data with external entities such as the user's social circle or physicians, in an automated or ad-hoc fashion, is regulated by the control polices and mechanisms of AGILE. In future implementations, more detailed polices will be developed and applied which will include among others, encryption of data, data cleaning to remove sensitive information etc. In addition, the data sharing approach of Jolocom [20] which uses mechanisms based on WebId [21] and will be integrated into the AGILE software stack, will be also exploited.

E. Ethical and Regulatory Considerations

The AGILE system by its design focuses on preserving data privacy and security. Through the decentralized approach of AGILE, data collection and management is performed on the AGILE gateway. They have full access on collected data and the connected devices and can decide if, how and when to expose the latter to the Internet and/or share information with 3rd parties. Particularly about the Quantified-Self application, the collection of personal user data (activity levels, blood pressure, etc.) from wearable devices and/or smartphones, aggregated and stored in the AGILE gateway device is anonymized and not associated with the user's ID. And as already mentioned, if the user wants to share data over the Internet, privacy and security will be ensured.

F. Evaluation Instruments

The quantified-self application is one the pilot use cases to evaluation of the overall concept of AGILE Gateway and assess its applicability in terms of user acceptance and experience in the context of domestic use by the average consumer. This pilot operates in parallel with other AGILE installations such as integration with drones and deployments to industrial environments in weather stations and retail shops. Conclusions will be drawn on the basis of the user acceptance of AGILE by monitoring the main determinants of technology acceptance regarding perceived usefulness (PU) and perceived ease-of-use (PEOU) both for developers and end-users. The evaluation instruments to be utilized are a) user surveys for all members of the user groups, b) questionnaires for all members of the user groups and interviews with targeted users from both groups.

User surveys and interview scripts will be drafted based upon the identified determinant factors (i.e. use of Likert scales [22]) to understand the participants' usability experiences and technology acceptance. This can be defined as total satisfaction, real usage and the intention to utilize the AGILE solution again. Collated data from the questionnaires and logging data will be processed. To this end, the users' experiences and feedback as reflected on the surveys as well as the analytics gleaned from the use of the gateway itself, will enable a full end-to-end evaluation of the AGILE solution and the quantified-self concept.

V. DISCUSSION

The proposed quantified-self approach provides several benefits for the involved users, stakeholders and developers not only in technical but also in business level. Active people who wish to monitor their health and people suffering from chronic diseases have been identified the main uses of the application, while health insurance companies and health care providers may also be potential customer segments. The common need of the first customer segment mainly relates to integrated services that can monitor health statistics, while the second needs a solution that can extend the period of time people with chronic diseases can live at home. The added value of the solution includes the following:

- Monitor their physical, physiological and emotional status
- Enhance their well-being
- Allow detection and management of potentially dangerous situations

- Motivate them to engage in social, physical and self-caring activities
- Model their behavior to improve self-care

It is often the case with medical applications, that a complex value network will need to be leveraged, with healthcare professionals as one of the most important actors or stakeholders. The competitive advantage of the proposed solution lies in the holistic approach and the provision of an integrated service supported by experts (compared to a self-managed mobile app) that will evaluate the physical activity taking into consideration various factors, including the medical record of each individual. Furthermore, the solution proposes an unobtrusive and fully automated solution that requires minor engagement of the user, making it suitable for people unfamiliar with technology, such as seniors. The use of AGILE elevates the business position of the concept by supplying a reduced cost implementation and also ensures enhanced security and privacy exploiting the local data storage and data management features of the gateway.

The main innovation of the AGILE quantified-self approach is the fact that data remain on the user's gateway. It can be shared only upon request. The technical solution of the quantified-self in AGILE includes the communication with sensors for self-tracking and biosignal monitoring, visualization and storage of sensor data, data analysis and automatic detection of events such as anomalies or dangerous incidents (e.g. falls), sharing of data with friends/relatives or healthcare professionals (physicians, caregivers, specialists). The native support of the AGILE Gateway for modularity, extensibility and high customization, without the need to speed effort across the different layers and components of the gateway, is one of the most important benefits for the Quantified-self application allowing for its continuous evolution and adaptation following the users' growing requirements and the new technological solutions and trends in the domain.

VI. CONCLUSIONS

This work presented an open, modular and extensible approach for the realization of the quantified-self concept based on a modern IoT gateway. The solution addresses effectively the different challenges and reequipments related with the concept simplifying the communication with sensors and IoT devices, facilitating data management and integration with external systems (clouds and APIs) without deductions in required security and privacy levels. The application will be further extended focusing on data sharing and the definition of more complex polices and workflows for data management and analysis.

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REFERENCES

[1] Swan, Melanie. "Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0." Journal of Sensor and Actuator Networks 1.3 (2012): 217-253.

[2] McGrath, Michael J., and Cliodhna Ní Scanaill. "Wellness, fitness, and lifestyle sensing applications." Sensor Technologies. Apress, 2013. 217-248.

[3] Munson, Sean A., and Sunny Consolvo. "Exploring goal-setting, rewards, self-monitoring, and sharing to motivate physical activity." Pervasive computing technologies for healthcare (PervasiveHealth), 2012 6th international conference on. IEEE, 2012.

[4] Pcmag.com: The Best Fitness Trackers of 2017, Available online at: http://www.pcmag.com/article2/0,2817,2404445,00.asp

[5] Inside Wearables Endeavour Partners Report, 2016

[6] Menychtas, Andreas, Panayiotis Tsanakas, and Ilias Maglogiannis. "Automated integration of wireless biosignal collection devices for patient-centred decision-making in point-of-care systems." Healthcare technology letters 3.1 (2016): 34-40.

[7] I. Maglogiannis, C. Ioannou, P. Tsanakas, "Fall detection and activity identification using wearable and hand-held devices" Integrated Computer-Aided Engineering IOS Press 23(2): 161-172 (2016).

[8] J. Wei, "How Wearables Intersect with the Cloud and the Internet of Things : Considerations for the developers of wearables.," in IEEE Consumer Electronics Magazine, vol. 3, no. 3, pp. 53-56, July 2014.

[9] M. R. Ebling, "IoT: From Sports to Fashion and Everything In-Between," in IEEE Pervasive Computing, vol. 15, no. 4, pp. 2-4, Oct.-Dec. 2016.

[10] Vivek Chandel, Arijit Sinharay, Nasimuddin Ahmed, and Avik Ghoseet al. 2016. Exploiting IMU Sensors for IOT Enabled Health Monitoring. First Workshop on IoT-enabled Healthcare and Wellness Technologies and Systems (IoT of Health '16). ACM

[11] Billis, A. S., Batziakas, A., & Bamidis, P. D. (2015). Towards a Quantified-Self web application for seniors' self-tracking. In 2015 International Conference on Interactive Mobile Communication Technologies and Learning (IMCL) (pp. 315–317). IEEE.

[12] Zhou, Wei, and Selwyn Piramuthu. "Security/privacy of wearable fitness tracking IoT devices." Information Systems and Technologies (CISTI), 2014 9th Iberian Conference on. IEEE, 2014.

[13] Weinberg, Bruce D., et al. "Internet of Things: Convenience vs. privacy and secrecy." Business Horizons 58.6 (2015): 615-624.

[14] AGILE-IOT, H2020 EU Research Project: http://agile-iot.eu

[15] Node-RED, http://nodered.org

[16] Merkel, Dirk. "Docker: lightweight linux containers for consistent development and deployment." Linux Journal 2014.239 (2014): 2.

[17] Gomez, Carles, Joaquim Oller, and Josep Paradells. "Overview and evaluation of bluetooth low energy: An emerging low-power wireless technology." Sensors 12.9 (2012): 11734-11753.

[18] Estrin, Deborah, and Ida Sim. "Open mHealth architecture: an engine for health care innovation." Science 330.6005 (2010): 759-760.

[19] Parra R. J. D., Schreckling, D. and Posegga,Joachim., Addressing Data-Centric Security Requirements for IoT-Based Systems. In Proc. of International Workshop on Secure Internet of Things (SIOT 2016), IEEE, 2016.

[20] Jolocom UG (haftungsbeschränkt), http://jolocom.com

[21] Sporny, Manu, et al. "Webid 1.0: Web identification and discovery." W3C Editors Draft (2011).

[22] Allen, I. Elaine, and Christopher A. Seaman. "Likert scales and data analyses." Quality progress 40.7 (2007): 64.