Platform architecture empowering health and safe Product Service Systems for specific target groups

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Abstract

Nowadays social phenomena like ageing, the increase of obese people and diabetic people and the major sensitivity towards disabled introduce new social requirements for advanced products such as customized work and sport wear. This opens up opportunities for offering bundles of products and services that, relying on embedded sensors, allow the user to constantly monitor and intelligently handle biometric data related to his/her health conditions. In this paper, the platform architecture that supports the provision of such Product Service System is presented mainly focusing on its components and the functionalities they deliver. Possible usage extents and benefits of the proposed solution are analyzed so as to emphasize how the well-being of special target groups can be improved.

Keywords: Product Service System, distributed software architecture, specific target groups, personalized goods, wearable biometric monitoring systems.

1. Introduction

Demographic changes, with the simultaneous increase in many countries of elderly proportion and life expectancy, coupled with the significant growth of some diseases, such as obesity and diabetes, are posing new challenges to the single person as well as to the entire society [1]. This is amplified by the appearance of new lifestyles, such as the “active elderly”, as well as new issues, such as the need of ensuring the wellbeing of workers who are expected to retire later than in the past. The modifications of the health systems, calling for an increase of delocalized medical treatments and monitoring [2] along with the desire of ageing people for self-sufficient and self-determined lifestyles are further emphasizing these trends.

Technological innovations, especially those related to the Internet of Things [3], allow to effectively face these challenges. In order to meet this set of emerging requirements exploiting the technological advances, innovative business models along with Product Service Systems (PSS) have to be developed, ensuring the fruitful collaboration of a multitude of partners.

Aim of this paper is to address these emerging needs by proposing a platform architecture that, extending to this field the PSS concept, allows the combined use of product (sensors embedded in clothes/shoes) and services (collection and use of data) to generate value for the user. More specifically, the proposed solution introduces innovative services that can be provided thanks to the design and development of specific products, integrating miniaturized embedded systems for collecting and managing biometric data during leisure and professional activities. The social effect of this PSS is further stressed by the possibility to customize the system to individual needs.

The developed services ensure both the synchronous and asynchronous use of the collected information. The software architecture is such that the information is not only available to the end user of the system, but data can be accessible to third parties (i.e. doctors, service providers) who, in turn, can generate a feedback for the user (i.e. medical treatments).
The considered fields of application are work-wear and sport-wear goods. An example of the final result expected out of the whole project this research piece belongs to is a sock that allows real-time measurement of feet plantar pressure for obese workers involved in heavy-duty activities. In the case, the offered PSS includes: the sock itself, the embedded plantar pressure sensors and the apps enabling the real-time monitoring for avoiding overload and ensuring correct behavior in the long term thanks to historic data profiling and analysis.

The paper, after a brief review of the PSS concept, will present the conceptual framework for the provision of a bundle of personalized services for special target groups and work-wear and sport-wear products. After that the description of the Data Integration Platform (DIP) and the Smartphone Application architecture is introduced.

2. Product Service Systems (PSS)

The offer of a bundle of products and services is a common trend in several sectors looking forward strengthening the competitive position by diversifying the offer. This phenomenon is often referred to as servitization as it was first named by [4] and is expected to bring financial, marketing and strategic benefits thanks to the integration of value added services in the product’s offer [5-7]. An extensive review of literature about servitization is provided in [8]. A research field that is often associated to the servitization process is the one related to the Product Service Systems (PSS) that emphasizes the shift from selling products to selling functions while fulfilling the customer’s demand with less environmental impact. A PSS is a specific type of value-proposition (business model) that focuses on fulfilling a final need, demand or function [9]. A classification of different types of PSS has been proposed by [10] or [11] which distinguish between product-oriented PSS, use-oriented PSS and result-oriented PSS.

Even though the servitization concept was initially developed in the business-to-business environment, its logic can be extended to the consumer products and to the social arena. Claiming that existing methods and tools cannot readily assist manufacturers of consumer products to implement PSS, [12] proposes a methodology to develop PSS for consumer products. The PSS is a valuable strategy for reorientation of the production and consumption processes of society as stated in [13]: according to them, the use of PSS can act as a human obesity treatment that requires a systematic awareness of available alternatives to meet the individual needs. They also point out the usefulness of customization in the form of services based on specialized knowledge and skills to get a successful strategy.

An even more society-oriented use of PSS is described in [2] where they analyze whether point-of-care devices can be the core product of a product service system. In particular, they focus on glucometers and investigate what are the informatics requirements to develop a PSS providing point-of-care devices based services. The main service offered to customer is the possibility to translate stand-alone biological data into meaningful information that can be interpreted to enable and support the health management. The application of the PSS concept to devices for health care is quite recent and its exploration is of paramount importance from the social sustainability point of view. By addressing this gap, the paper focuses on a software architecture meant to enable a PSS in the work-wear and sport-wear sectors.

3. The conceptual framework

When developing a Product Service System (PSS), such as the one presented in this paper, several elements need to be integrated at different levels to allow service provision. On the one hand, there are the wearable sensor devices meant to acquire the biometric data and to feed them to the system while, on the other hand, there are services applications which can be synchronous, like real-time monitoring, or asynchronous, like browsing of historical data, that exploit this information for providing support and control in everyday activities.

By exploiting the Internet of Thing approach, communication between devices and applications of several kinds will enable the provision and use of data within the system. To this end a layer for handling and storing such data and for managing the interactions of the connected components is required between devices and applications.

This section is meant to sketch the overall system architecture, describing the above mentioned components and their interactions.

The high level of definition of the system architecture, depicted in Fig. 1, gives an overview of these components with a description of their main responsibilities and their relationships within the system.

The main purpose of this diagram is to show how peripheral systems such as sensors, services and production systems can interact with a centralized platform.

In the proposed solution, the Data Integration Platform (DIP) is the central component meant to supervise the overall system, acquiring sensors and biometric scanner data, providing means in order to monitor remote status of health parameters, to provide an efficient management of sensors feedback information, to drive the production process of personalized goods and to host a suitable data model for the representation of the acquired data.

A description of specific requirements, data models and software structures, identifying the main involved components, needed interfaces and exchanged data, follows in the next sections.

The here proposed software architecture is meant to be a formalization of the software modules, their responsibilities and relationships.
4. Data Integration Platform (DIP)

The different nature of the software components involved in the system requires a shared communication layer. The Data Integration Platform (DIP) enables centralized communication and data management in the distributed system.

The main functionalities of the DIP are:
- **Integration with biometric scanning systems** in order to retrieve the user health and biometric profile and to collect data in a suitable database able to harmonize and make them available to the other system components.
- **Integration with production system** in order to drive the production process of personalized goods starting from data gathered by the biometric scanner devices.
- **Management of sensors data** in order for them to be collected and managed by the Smartphone Applications that contain the logics in order to understand the sensor data streaming. The DIP provides the means to (i) ensure the persistency of such information and (ii) to make it available to the other High Level Services.
- **Communication with the High Level Services** in order to provide real time monitoring of specific health parameters.

Following a top-down approach, a more detailed architecture of the DIP is here described.

In Fig. 2 an overview of the high level components that constitute the DIP with a description of their main responsibilities and their relationships in terms of required/provided interfaces is presented.

This diagram is not the most fine-grained since some components need an additional level of detail such as Middleware and Service Managers.

This architecture emphasizes the decoupling of components used to identify the separation of software blocks that should not depend on each other. Some building blocks (subsystems) are generic and should not either know details of the other ones. This approach ensures the scalability and maintainability of the system.

Software components belonging to and interacting with the DIP are presented in the followings.

The **Common Database** embodies the main function of containing and managing large amounts of data coming from different sources with different meaning that has to be efficiently stored and accessed.

The DIP stores and retrieves information from the Common Database by using a provided interface called JDBC (Java Database Connectivity). JDBC provides methods for querying and updating data in a database.

The **Middleware** is in charge for the supervision of the overall components belonging to the DIP. It represents the software component placed in between external applications, services, users and the logics involved in the DIP.

The **Administration GUI** is meant to provide, in a user friendly fashion, the results of the data elaboration of the DIP and to manage administrative activities such as external application connection status, sensors systems registration, users authentication and similar.
The **Data Persistency Manager** is in charge of managing, through the IPersistency interface all I/O operations to and from the Common Database. The **Data Aggregation Manager** is in charge of selecting a subset of data from database, aggregate them and make them available to the Production System. The DIP implements remote interfaces enabling the system to be connected to existing production systems and biometric scanning devices. The main goal of the Data Aggregation Manager is to drive the production of personalized goods.

The main objective of the **Common Service Manager** component is to manage a set of functionalities that allow external applications (Websites, Smartphone Applications and Desktop Applications) to access the DIP data. In particular the main functionalities exposed by the Common Service Manager are:

- **Secure Login**: each application can access the DIP through secure authentication.
- **Data storing and retrieving**: each application can store data (for instance coming from sensors or preliminary locally stored data) and retrieve historical or real-time data by using a predefined set of methods.
- **Data analysis**: external applications allow users (doctor, patient, etc.) to perform data analysis by exploiting a set of functionalities exposed by the DIP.

The DIP interface with the **Production System** is meant to provide a generic Application Programming Interface (API) or web-services to query the internal Common Database. The Production System uses data coming from the DIP in order to retrieve customer’s requirements for driving the production of the customized goods.

The DIP interface with the **Biometric Scanning Devices** is mainly meant to provide generic API or web-services to save customer’s requirements into the internal Common Database.

**High Level Services** applications (Websites, Smartphone Applications and Desktop Applications) constitute the presentation layer of the architecture. They remotely communicate with the DIP sending data to be stored in the common database and retrieving structured information to be displayed to the end users.

### 5. Services Applications architecture

After the DIP presentation, the description of the system moves to the High Level Services. In what follows the architecture of one of this services, the Smartphone Application, is presented in detail as a relevant example of user interaction layer.

The multi-service nature of the Smartphone Application leads to an organic ensemble of functionalities whose mutual interactions enhance one another and provide various sub-categories of services.

Five main groups of functionalities are implemented:

- **Connection with the wearable sensors** aimed to retrieve the real-time and historical sensor data.
- **Connection with the DIP** aimed to forward the collected sensor data and to retrieve previous historical sensor data, workout plans and patient profile related data.
- **Monitoring of user biometrics** aimed to detect possible severe situations which can trigger from alert messages up to emergency calls.
- **Real-time and historical visualization of biometrics for the user** which enables the user to have a snapshot of his/her current biometric readings and analyze past collected data enriched with for example, trends, peaks or other statistics.
- **Workout planning and monitoring** tailored for the user that provides him/her with notifications during the workout,
The structure of the Smartphone Application architecture mirrors the way functionalities have been grouped above. This is reflected in Fig. 3 that shows how the Smartphone Application is subdivided in smaller components and how they interact in order to deliver its functionalities. For each component its responsibilities follow.

The Operation System (OS) API are not actually part of the Smartphone Application but instead part of the operating system on which the app runs. The API is a set of services the OS provides to its applications. In the specific case of the Smartphone Application, the OS API are used for:

- Accessing GPS information in order to locate the user. The location is used for providing additional information to the contacts in case of emergency and also to track movement while a workout is in progress.
- Playing audio data on the smartphone speakers. This is used for simple GUI audio feedback but also in case of audio alert while performing workout or if an anomaly in biometric reading is detected.

The Bluetooth Connector component handles Bluetooth communication. It should provide an abstract and easy interface for the Sensor Manager to access the wearable sensor via Bluetooth.

The Sensor Manager component is responsible for managing the wearable sensor connected to the smartphone. It provides an easy and abstract interface for collecting data, enabling real-time communication and retrieve buffered data. It also dispatches events in case of sensor connection/disconnection, communication acquired/lost, etc.

The DIP Connector component handles communication with the DIP. It provides an abstract and easy interface for the Remote Manager to access the DIP platform.

The Remote Manager is responsible for exchanging data with the DIP. These data consist not only in sensor readings but also in planned workouts that can be uploaded via the DIP. It also enables the remote control of real-time biometrics monitoring by authorized users via encrypted channels.

The Local Connector handles local file-system smartphone communication, mainly used for data persistency. It presents an easy and abstract interface to access the local file system for storing and retrieving specific data.

The Persistency Manager is responsible for the persistence of live data used through the Smartphone Application. This persistency is maintained by a combination of remote storage through the DIP and storage into the local file system. The Persistency Manager will be able to retrieve/store both biometrics historical data and planned workouts.

The Emergency Call Connector sends out messages to the defined contacts list in case of an emergency. The message could be a SMS, or maybe even a composite audio message delivered via phone call. The Emergency Call Connector is able to compose the messages with the information useful for its recipients.

![Fig. 3 Smartphone Application detailed architecture](image-url)
The Biometric System processes the sensor data in order to produce meaningful biometrics measurements. This process is achieved by applying specific mathematical models to the sensor readings. For instance the heart rate sensor provides the raw voltage readings of the ECG, then it is the Smartphone Application responsibility to convert this voltage into beats per minute by applying, for instance, digital filters and peak detection algorithms.

The History System processes the biometric data in order to create an historical record, accessible for later review. This process ranges from basic value storing to the creation of timed averages, statistical representations, etc. For instance, the user could ask to have a diagram representing his/her weight evolution over the past three months in order to monitor his/her weight loss efforts.

The Workout System processes the biometric data over an exercise session in order to monitor them and guide the user in following the planned workout. It warns the user whenever the biometrics exceed or underperform the set threshold. It also records the session for later review and performance assessment. The system also allows planning and editing the workout either locally by the user or remotely through the DIP.

The GUI handles all user interactions, providing visual feedback to the user and collecting user inputs.

A brief explanation of the available GUls follows:

- **Real-time GUI** shows visual feedback of the current biometrics snapshot and allows focusing on a particular biometric of interest.
- **History GUI** enables the user to explore and analyze historical data of his/her biometrics.
- **Workout GUI** enables the user to plan and monitor his/her workouts.
- **Alert GUI** handles the viewing and user reaction of alert messages usually triggered by suspicious biometrics readings.

6. Conclusion

Being able to collect and analyze in real-time biometric data is of foremost importance in order to support people belonging to specific target groups in performing safely sport and work activities.

Real-time self-monitoring of the user biometric data directly through a smartphone, the possibility for his/her physician to observe the evolution of such data over a defined time lapse allow for the provision of personalized and more effective treatments as well as for preventing or handling possible dangerous situations.

By combining wearable sensors embedded in work and sport wear with a distributed software architecture, it is possible to offer a Product Service System that enhances the well-being of these people.

In this paper the description of this advanced software architecture has been presented. Its potential goes beyond the application context here addressed as its functionalities have already proved to be suitable for adaptation in several context, namely respiration rate monitoring for active elderly and heart rate monitoring for people suffering heart complaints, blood oxygenation measuring for diabetics.

The key value of the proposed architecture is then its extensibility and capability to be applied to any target group thanks to the integration of different devices and software components into a complete solution that take care of the single user.

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