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# Mobilemicroservices Architecture for Remote Monitoring of Patients: A Feasibility Study

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**Abstract**

*Recent developments in smart mobile devices (SMDs), wearable sensors, the Internet, mobile networks, and computing power provide new healthcare opportunities that are not restricted geographically. This paper aims to introduce Mobilemicroservices Architecture (MMA) based on a study on architectures. In MMA, an HTTP-based Mobilemicroservivce (MM) is allocated to each SMD's sensor. The key benefits are extendibility, scalability, ease of use for the patient, security, and the possibility to collect raw data without the necessity to involve cloud services. Feasibility was investigated in a two-year project, where MMA-based solutions were used to collect motor function data from patients with Parkinson's disease. First, we collected motor function data from 98 patients and healthy controls during their visit to a clinic. Second, we monitored the same subjects in real-time for three days in their everyday living environment. These MMA applications represent HTTP-based business-logic computing in which the SMDs' resources are accessible globally.*

***Keywords:***

Telemedicine, Wearable electronic device, Computer system architecture

## Introduction

The increased use of mobile device applications, cloud services, personal sensor technologies, the Internet of Things, and virtualization of computing power and networks provides new opportunities for remote healthcare and self-care [1-3]. These technologies can be employed to provide a set of scalable services for remote- and self-care of chronic diseases, thus enabling more effective follow-up and evaluation of the state and progress of these diseases [4]. However, there are few studies on real-time monitoring outside hospitals with many participants.

In this paper, a novel system architecture named MMA is proposed. The evidence of experience of employing MMA is reported in two journal articles [5, 6] that were thoroughly reviewed. This fact allows us in this paper to focus on introducing MMA and sharing the experience of constructing it. MMA enables flexible, scalable, secure, and easy-to-use solutions to collect real-time health data remotely without user interference. Remote monitoring of patients with Parkinson's disease was selected as a pilot. They experience varying motor function symptoms throughout the day and from day to day; the changes can be significant depending on the disease severity. Apart from the daily short-term transitions due to medication intake and the patients' lifestyle, there are long-term transitions in patients' symptoms due to the disease's progress [7].

The Unified Parkinson's Disease Rating Scale (UPDRS) is a commonly used set of clinical tests to assess the state of Parkinson's disease. These tests include, for example, a walking test for assessing the subject's gait [8]. However, Parkinson's disease symptoms' clinical assessment suffers from significant interrater variability due to its subjective nature [8]. For these reasons, an objective assessment method based on automatic analysis of the movement data recorded continuously in the patient's natural living environment would have the potential to significantly improve the effectiveness of care for patients with Parkinson's disease and other neurological diseases.

From the healthcare organization's perspective, the systems must be easy to use and maintain. Scalability is an essential topic as needs can change: New sensors might be needed as well as new computing nodes, i.e., increasing or decreasing the number of SMDs operating in the system. Patients can have severely reduced functionality, and they can have limited technical skills. Therefore, user intervention must be minimized. Inexpensive standard technology such as SMDs instead of specialized technology helps build more extensive remote monitoring use. There is also a need to record and transfer raw unprocessed measurement signals. This need is an essential requirement, especially for clinical studies. Medical doctors need unprocessed raw data or visual presentation of them to verify observations. Finally, like many other organizations, healthcare organizations usually have a strict policy not to open IP ports for access from outside to inside to the organizations' IT resources.

Next, we identify gaps in previous studies on remote healthcare architecture. Several architectural solutions have been developed for medical data collection and reported in the literature. ResearchKit by Apple Inc. is one of the ecosystems broadly employed in healthcare studies, for example, by Bot et al. [9] and Ramkumar et al. [10]. Generally, the ResearchKit architecture is based on traditional front-end-backend architecture, employing iPhones as a front-end and Amazon Web Services as the backend [11]. The ResearchKit employs a Secure Socket Layer for health data transfer [12]. Health data can be collected by employing various versions of the Bluetooth protocol and wearable devices.

The Wireless Body Area Network (WBAN) represents architecture for collecting medical data from a subject. The architecture consists of a control node that collects data from various body sensors and sends the data to the control center via the

Internet or a 3G or GSM network. The WBAN architecture consists of three tiers. It has been used, for example, in studies by Arefin et al. [13] and Pérez and Rodríguez [14].

Gøeg et al. [15] discussed the architecture in which the client, for example, a mobile device, connects a server employing HTTP POST protocol to store the medical data in the servers' databases. The architecture consists of modular blocks that can be employed to introduce a security layer. CyPhyS+ is a custom solution that employs 6LowPAN IP-based architecture to communicate with HealthMote, a gateway to BodyNetwork sensors [16].

According to Pérez and Rodríguez [14], healthcare solutions for the elderly employ various protocols for collecting medical data. They described ten protocols from which two employ RESTful HTTP POST, five WEB services, and one Open Service Gateway initiative. No studies in which SMDs run HTTP servers with the RESTful HTTP GET approach in mobile networks for remote healthcare are reported in the literature.

The prevailing trend in IT architecture is to build solutions based on microservices [17]. Microservices can be deployed independently, and the system can be scaled without duplicating a monolithic system. The microservice architecture usually employs RESTful web services using JSON. The microservice approach enables us to build Service-Oriented Architectures. Studies in which SMDs run microservices or light versions of them for remote healthcare are scantly or not reported in the literature.

There is a gap in research regarding how the latest mobile technology and operators' capability to provide extended network services can be exploited in healthcare. Thus, we investigated how to create a new type of architecture to collect patients' health data in mobile networks employing these microservices' features (Research Question (RQ) 1).

After the methods, this paper aims to introduce the Service-Oriented MMA that combines a practical healthcare solution in a clinical study (NCT03366558) with Mobilemicroservices (MMs) in an SMD [5]. These RESTful HTTP GET based services grant access to SMD's sensors. We also introduce our findings on constructing and using MMA-based solutions in practice. Finally, we introduce new concepts and future research avenues.

## Methods

We employ a clinical study to test the MMA design. The clinical study's details are reported in an article [5]. The MMA's implementation was based on the interviews and discussion during the implementation. We interviewed the sensors' manufacturers, both Suunto Oy and Forciot Oy, several times during the project. We had several discussions Orionpharma Oy that produce medication for Parkinson's disease. We exchanged emails on various topics concerning the implementation. We had several meetings with Satakunta's District Hospital's staff prior to starting collecting the Parkinson's disease patients and controls. Tampere University's staff was also consulted as their systems collected the data from SMD. The project documents consist of meeting minutes, write-ups, presentations, conference and journal articles, and various design artifacts. We employ constructive research methodology [18], which is based on employing the constructed artifacts in an actual environment. Totally 98 controls and Parkinson's patients employed the system during the project.

## Results

### MMA's premises for construction

Scalability and extendibility can be achieved if we build a modular Service-Oriented Architecture with RESTful APIs. Computing nodes are relatively easy to multiply. The network nodes can be arranged in diverse topologies. Security can be enhanced by configuring SMDs and networks with the help of the mobile operator [5, 19]. The situation is different from the security perspective when the server's and clients' roles are swapped. We make SMDs act as servers, and traditional servers act as clients. SMDs do not initiate access to IT resources. In other words, we swap the front and backend roles as they are employed traditionally.

Our target was that the proposed Service-Oriented Architecture (MMA) with lightweight microservices (MMs) for each sensor could provide the following benefits for remote patient monitoring [5]:

1. Scalability and extendibility: With MMA, it is easier to add new sensors, adapt the system for varying needs, and add new computing nodes.
2. High-level security: a combination of MMA and operators' services.
3. Easy to use, especially for patients: Data collection can be automated entirely with MMs.
4. Getting access to raw data is essential for diagnostic and research purposes: with the MMs' help, it is possible to collect raw data from the sensor.

In the MMA, the idea is to make various sensors easy to access remotely by employing high-level HTTP commands, which are available in most programming languages. Thus, high-level programming languages like Python can also be employed to access an SMD's sensors remotely via the Internet. We believe that the benefits can help various healthcare IT professionals, such as programmers, architects, and researchers, design new innovative services for patients, healthcare researchers, and professionals. As this approach has not yet been widely investigated, the question is whether this architectural approach is feasible and suitable for practical field studies. We anticipate problems relate to how suitable an SMD is for this use (RQ 2), how the operators support our efforts (RQ 3) in practice, and whether we can deliver these benefits to a healthcare organization (RQ 4).

### MMA's technical architecture

We employed various device technologies, such as Bluetooth Low Energy (BLE), Android-based SMDs, Long Term Evolution (LTE) mobile networks, and Windows- and Linux-based personal computers (PCs). BLE devices offer standard and easy access interfaces to transfer data from wearable sensors to SMDs. An SMD itself can have various embedded sensors to observe the patient's state [5, 6]. Many SMDs have acceleration and gyroscope sensors used for recording patient movement.

Two body-mounted movement sensors with BLE connectivity were paired with the SMD. The first device, the Suunto Co. Movesense, is an open platform containing a nine-degree-of-freedom movement sensor. The second device, the Forciot Co.'s smart insole, has 23 pressure-sensitive elements measuring the force distribution and the total force applied to the insole. The use of SMDs with the LTE mobile network connection lets us test the real-time connections with remote PCs. This technical architecture enabled us to transfer health data to monitor and analyze patients' health states. We also employed the SMD UI to collect data about patients' medicine intake.

**MMA's service-oriented architecture**

For remote patient monitoring, an approach similar to microservices makes it easier to extend the system with new sensors and modify the system for varying needs. MMA associates one MM to each sensor. This arrangement enables the sensor to be accessed remotely via the HTTP GET protocol. Android APIs were employed to build the interface for the sensors. There was no need to modify the sensors' firmware. Service-Oriented Architecture was also applied to construct the end-user services from various MM sub-services. An MMA-based solution consists of one or more sensors, MMs, SMDs, clients, and applications that are run concurrently depending on the case (e.g., see Figure. 1).

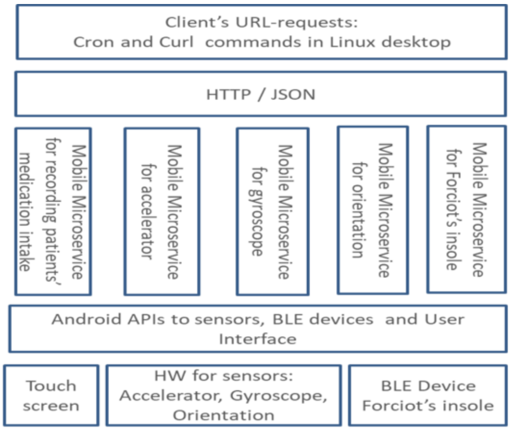


*Figure 1: MMA stack for this study*

Typically, gyroscope, accelerometer, and orientation data (i.e., Euler angles) are collected using SMD MMs. This client system can determine the sensors' sampling rates via MMs. The health data collection and its further processing occur asynchronously: The data are buffered in the SMD MMs until the data are collected for further processing on a physically detached client system. Right after the client collects the health data, MM clears the buffer, not leaving health data in the SMD. GDRS instructions are also otherwise applied tightly as the SMDs' content could not be accessed by unauthorized persons.

We designed the BLE sensors' MM to be robust and easy to use. For example, when subjects were beyond the reach of Bluetooth coverage, the connection was interrupted. The MM automatically reconnected the SMD and wearable devices when the subject was again within the range [5].

MM requires a relatively large amount of memory to buffer the sensor data between sequential HTTP Get requests. The memory use might not be a problem in traditional solutions in which sensor data are pushed to a server by the HTTP Post command. Less data are usually transferred at one time. The memory size of an SMD and the speed of mobile networks today supported the MMA approach's implementation.

**MMA's API definition for MM**

MM APIs resemble the RESTful API [17]. Access to an MM takes place through the HTTP URL commands that are divided into the following requests:

- send collected data and clear the buffer
- clear the data collection buffer
- send the status of the sensor's data collection
- set the sensor's threshold filter values
- set the sensor rate to data collection.

New commands are relatively easy to add as simple lexical, and syntax statements are employed in HTTP URL commands.

The response for the request comes in JSON format. The content of the response varies based on the type of the original request. Usually, all responses include information about the current Android version, the phone type, the version number of the MM, and the timestamp when the response was sent. If the response consists of sensor data, then the data include the values of the sensor's parameters, the index of the measure, and its timestamp.

MM related to an acceleration sensor can be asked to send its health data with the following URL command in the browser:

"http://191.168.0.121:8080/message?msg=psw: psw, cmd:snd".

The response includes data in the following JSON format:

"{m0": {"at":1183800805, "x":-0.024361406, "y":0.025361188, "z":-0.1328144}, { "m1":… "Snd":{"Version":…}}".

**MMA's demonstration system**

The MMA demonstration system worked with 98 subjects who engaged SMDs for three days in 2018. Eleven phones were employed simultaneously, depending on the availability of the subjects. The system included sensors related to acceleration, gyroscope, orientation, BLE-based Forciot insole, and the wrist-mounted Movesense gyroscope.

Figure 2 shows the MM capabilities while the health data were collected from MMs in one SMD system via LTE mobile network. The amount of data collected from the insole varies due to activities triggered by foot pressure: If there is no pressure, e.g., a patient is not walking or standing, then no sensor data are delivered. The sample rate and the sensors' data resolution define the amount of data collected from the MMs in 5-min intervals. The health data are transmitted to a client system upon request with Linux's curl command and optionally with timing daemons using Linux's cron command.

Health data were also collected from subjects using the Android UI: A structured dialog was designed to help the MM set this health data buffer in JSON format. The user dialog-based MM collected the time medicine intake occurred.

All client-server applications can be located on an SMD. Alternatively, the client and MMs can be set in detached devices, leaving many options for the computing nodes' physical arrangements. Figure 1 shows the MMA stack employed in this study.

**MMA versus traditional implementation**

Klugman et al. [20] encountered problems while employing the traditional client–server approach. We propose to test MMA in similar cases to validate MMAs benefits over the traditional approaches with this study's help.

Klugman et al. planned to collect data remotely from plug load power meters in Tanzania. They mainly used a single-instance software structure, while we employed a Service-Oriented MMA with multiple instances. Failure in one MM does not cause malfunction of other MMs or SMD. Each MM was coded to reboot itself in case of a failure in SMD.

Klugman et al.'s mobile platform system became unreliable without human interaction. We minimized traditional human interaction as we dealt with patients who have limited fine motor capability. We also locked the UI to prevent any action from disrupting the data collection and transfer.

Klugman et al. employed the Samsung J1 Ace with a plastic frame, two cores with 1 G memory, and a non-native Android version KitKat 4.4. We used the Nokia 6 with an aluminum frame, four cores, 3 GB memory with native Android version Nougat 7.1.2 to ensure that all MMs would run smoothly.

Klugman et al. reported problems within various Android versions. As soon as we found an SMD with a stable version of Android, we stuck with it. We did not need to upgrade the Android version as the SMDs were operated on a private mobile network defined by the APN.

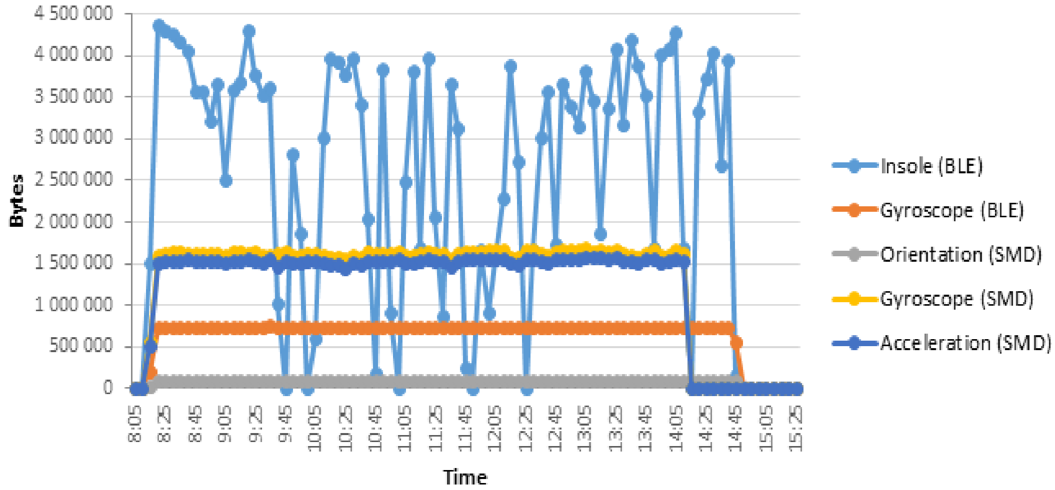


*Figure 2: Amount of motor function data transferred by the MMs through the LTE network during activities of daily living.*

## Discussion

A question can be asked why similar architecture to MMA has not been reported in the literature? One of the rationales can be that the SMD IP ports cannot be accessed easily for real-time data transfer with the HTTP GET method on the Internet. The reason is twofold: First, mobile operators do not keep SMD IP ports open for security reasons. Second, mobile operators seldom provide fixed IP addresses. The first workaround for the fixed IP address problem is to use DDNS. However, real-time DDNS servers for SMDs seem to be available rarely. The second workaround is to build on a VPN connection from the SMDs to the client. The configuration of various nodes for VPN with the proper client devices, applications, and protocols can be time-consuming.

We ended up asking for the Access Point Name (APN) from the mobile operator. The APN helped us create a virtual private mobile network (VPMN) setup only for the SMDs allocated to this study [5]. The SMD identifications in this VPMN are based on SMD IMEI codes and SIM -cards. External devices were not able to access the MMs. The benefit of having a dedicated APN included static IP addresses. The overall experience was that the system was more stable and faster with the dedicated APN [5]. This observation is also confirmed in another article [19]. According to the mobile operator, this VPMN based APN works globally. We confirm that as the MMs were accessed from Finland, German, and Israel. However, few companies or government organizations employ mobile operators' dedicated APNs so far.

In the beginning, as we were not able to employ HTTPS, we built software to encrypt patient data. The problem was not encrypting but decrypting the data, as the encrypted data were not decrypted immediately. Therefore, the option of using the APN-based VPMN was very welcome. The APN-based VPMN ensures that the data are transferred securely [5, 19].

The users employed only one application UI of the SMDs to ensure that they also behave well from a security perspective. To avoid exposing the MMs' APIs, we applied a policy to keep only well-behaving computing nodes that we had secured inside the VPMN. Outsiders were not able to access our VPMN. The VPMN's access topology can be designed together with a mobile operator to secure computing and computing nodes from IP ports' exposures. We decided to avoid upgrading the Android version as it could have led to problems. Android versions are not downward compatible.

The scalability in adding new sensors means that a new sensor-specific MM must be constructed. As the API interface is defined, we have a MM specification for this sensor. Implementing a new MM for BLE devices includes updating the MAC address and the GATT service and character codes. We also tested several new BLE sensor devices, such as the Neurosky Mindwave EEG and the Movesense heart rate belt. Implementing a new proprietary communication protocol requires more effort.

Adding a new SMD node in the system required the following actions: a) configuring the SMD by adding relevant MMs, b) giving the SMD IMEI code to the mobile operator, and c) in this study, we needed to add a new Linux cron and curl command entries. The upload speed of 10 Mbps per phone met the data transfer requirement (see Figure 2). MMA's demonstration pilot was scaled from three SMDs to eleven SMDs [5]. The future collaboration with a mobile operator can lead to the fluent and automated configuration of the computing nodes.

With the MMA's help, we configured the SMDs to be simple to use even for patients with Parkinson's disease [5]. The health data collection was automated: users only had to remember to charge the SMD regularly. The UI of the service included one large button that patients pressed after they took their medication. However, this straightforward UI caused a problem for some patients.

The MMA is built on standard inexpensive technologies such as SMDs and mobile networks with the following benefits: (1) Resources to maintain and support are usually available. (2) Healthcare staffs have some experience in using these inexpensive technologies.

The MMA enables various value-added services for healthcare experts to be built. Various motor function assessments of UPDRS tests were automated with the help of the MMs [5]. We analyzed the health data collected in a neurological disease polyclinic while we conducted UPDRS tests for patients with Parkinson's disease [6].

Various machine learning systems were implemented by Tampere University and the Technical University of Munich. Many statistical features were calculated from the data from individual steps. These features were used to train and validate machine learning algorithms. The results indicated that the health data collected by using the MMA could be employed to classify a subject's gait as a "Parkinson's walk" or a "healthy walk" [6].

## Conclusions

Implementing the MMA concept, including its secure solution, meeting healthcare organization expectations, and value-added building services, represents new knowledge. We developed a novel MMA for remote patient monitoring that is not restricted geographically. The key benefits of the MMA are extendibility, scalability, ease-of-use, security, and the possibility to collect raw data without the necessity to involve cloud services. The implementation and use of the MMA was examined in an actual organization with the help of healthcare professionals [18]. We were able to collect health data from 98 subjects [5, 6]. Implementations of architectures similar to the MMA are scarce in the literature. We provide a unique set of IT concepts and information for further mobile computing and medical studies to be discussed and verified. Thus, with the clinical study's help, we answered the research questions concerning the MMA's implementation, SMDs' feasibility, operators support, and benefits to the health care organizations.

With the help of the MMA, various platform ecosystems can be designed similarly to the one that was created for healthcare in this study. This platform ecosystem supports unprompted innovation: UPDRS tests were digitalized [6], and various machine learning systems were implemented [6]. This study proposes technological alternatives to create a health care system keeping in mind a one world one health -approach.

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