Monitoring Pandemics, using Sensor Data from Smart Ecosystems

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Abstract: In recent decades, new solutions, shaping smart city architecture. Data generated by healthcare and smart devices infiltrate into smart city solutions. This topic is heavily challenging and rapidly evolving. The constant and fast change in the subject technologies that implement an architecture and the sensitivity of data from human sources can be seen as key factors in these challenges. In this research, we have tried to present some possibilities that are obtainable by smart city solutions, in such a way, that they can be used effectively, by healthcare during a pandemic. Research focuses on how data from wearable devices can be collected and used, how these can be integrated into the ecosystem of smart cities, and how data can be used in health care. Access to health-related and personal data is regulated by the General Data Protection Regulation, which made the architecture use a high level of abstraction business definition and extensibility. The envisioned features of the above-mentioned architecture rely solely on the disciplinary areas of service-oriented architecture and component-oriented development methodologies. The described smart ecosystem offers the possibility of cognitive supplementation of human capabilities based on general bio-sensor data. It illustrates an example of use, for a healthcare workflow, where service abstraction plays a key role.

Keywords: healthcare; smart city; smart home; wearable; activity tracker

1 Introduction

Modern smart city solutions are compatible with several types of sensors. The complex, Smart City Systems, are gathering sensor data to take advantage of the perceptions gained from the processed data. The extracted information can be applied to control various devices, resources or improve services. Smart cities are organized in a network that can share raw data or extracted information with other smart cities or their institutions. With the information extracted from the accessible data, the consumers and smart city services can make many preferable decisions and provide value-added services.

Modern homes can be smart as well and can be connected to one or more networks. In this sense, modern homes are not individual systems, they can be a part of well-defined networks. If one or more smart homes are connected to a closed network, then they can share information. Smart homes connected to an open network can be linked to other services or other services can be linked to smart homes [1]. In this way, open smart home solutions can integrate into smart city solutions, they can communicate with each other and use each other's resources. Smart homes typically can share a large amount of sensor data with their environment, so smart cities can use these sensor data of smart homes to improve the quality of their services. In a modern smart city, the city's services need a lot of data and information to operate the services and the city's smart institutions [2].

In most cases, smart home solutions only spread to the extent that the collected sensor data is used locally to operate the building, thus optimizing operating costs and convenience. So, most of these solutions are exhausted in heating control, automatic control of shading systems, watering plants, and so on. However, next-generation solutions are now able to collect data from the users 'devices as well. This allows smart homes to access data that most users can only browse with the right target applications. Wearable activity tracker devices have thus become connectable to smart home solutions. In this way, the biosensor data collected by smart homes can be easily channeled into modern smart home solutions, thus providing useful data to healthcare institutions and services in the city [3].

2 Digitized Healthcare Services in a Smart City

The digitization of healthcare services is most often exhausted through the publication and storage of examination results in digitized form. However, in some cases, beyond this, digitalization involves the contribution of external services and making the services of a healthcare institution publicly available. In a smart city, institutions operating in the city should also take advantage of digitization. With the help of digitized health services, data from external sources can also be used in health examinations [4]. Using data from an external source, a general medical examination can provide a much more accurate picture of a patient's condition and make a more accurate diagnosis. Professionals also measure heart rate and blood pressure in a basic medical examination, but this only reflects the current condition and does not provide a historical data set that could be interpreted retrospectively [5]. In most cases, health systems do not even have access to such data. However, it is possible for tools developed for this purpose, but for personal use only. In some cases, for example, 24-hour blood pressure monitors and blood glucose monitors are used. The data provided by these tools are evaluated only after using the tool. In other words, the data is evaluated by professionals only after, all of the measurements are completed and any anomalies or optionally required reactions, can be reported.

However, tools to support a healthy lifestyle are becoming more widespread and popular. An increasing proportion of the population has such facilities. These devices usually collect data using several different sensors during continuous operation. Most of these devices have a unique mobile application that collects, reads, and interprets data. Most of these tools also provide a publicly available interface for extracting data. Some applications for devices can even synchronize measurement data to the cloud. Some smart home solutions are now able to detect these devices and receive measurement data. Also, there are smart home solutions that allow you to extend the implementation so that even other standard tools can be incorporated into the smart home ecosystem. Smart bracelets and activity tracking devices used by people are equipped with several different sensors. Even the cheapest devices can track heart rate data, more expensive devices can even monitor blood oxygen, and some devices also measure blood pressure, although this is not yet the case in this segment. The devices can export data in multiple formats, but some devices require the use of a special application.

Measurement data from activity monitoring devices, embedded in smart home solutions, is not an advantage for the home to operate home units. For the most part, there is no need for this data, the building can be operated perfectly without it. Because smart homes make people’s lives easier not only in the area of operation but also in many other areas, these data can be useful in the area of well-being. Smart homes channeled into the smart city system can transmit these measurement data to the city or some of its services. Biosensor data collected by smart homes can be useful data sources for smart cities and their institutions [6]. In healthcare facilities, historical data may be the basis of the examination. Data that cannot be measured or generated locally can also be analyzed by professionals.

After analyzing the data, smart homes can perform additional useful tasks based on the results. During monitoring, smart homes can pay close attention to the occurrence of certain data and can even initiate alarms or other activities. In this way, smart homes complement health services with a user-operated ecosystem.

Fig. 1 illustrates an overview of the reference architecture in which the connection between smart homes and smart city health facilities can be established. The connector between the smart homes and the healthcare institutions is a third-party system, that has been designed to act as a hub between the smart homes and healthcare institutions. The Med-i-hub system will be described in the next section.

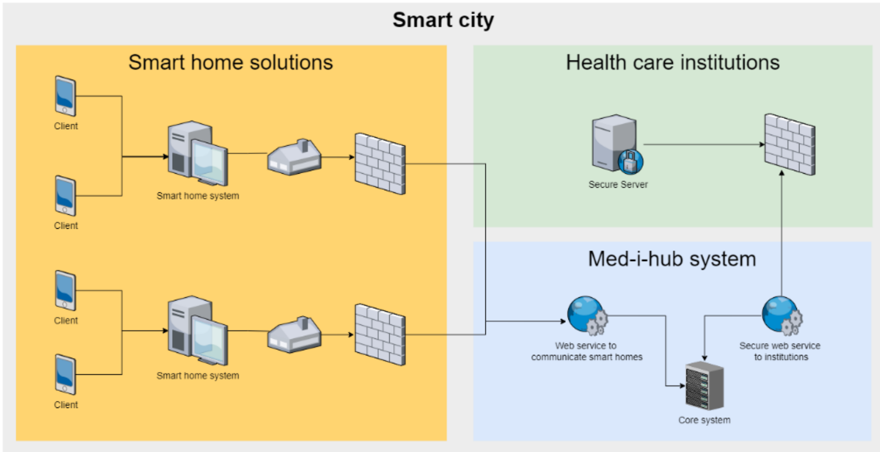

Figure 1
Reference architecture of a smart ecosystem

2.1 Adding Cognitive Extensions to Traditional Healthcare Solutions using the Smart Ecosystem

Information and communication technologies (ICT) are increasingly being used in healthcare management systems [7]. Significant progress in ICT in recent years offers a solution to the problems of healthcare management systems. Thanks to this development, generic healthcare systems can be endowed with artificial intelligence capabilities, with the help of which these systems can support the decisions of professionals much more effectively. Bio-sensor time series produced by individuals provide healthcare systems with data that allows individuals to benefit from the use of their data.

Traditional healthcare systems can thus be equipped with various cognitive extensions that access and use the patients' bio-sensor data while they live their everyday lives. With the help of accessible data, healthcare services can be improved in many areas, e.g.: Heart rate values are a base for most medical examinations. Exploiting the possibilities of smart cities is obvious in a smart ecosystem where the goal is to improve healthcare services with collective cognitive capabilities.

Monitoring and keeping under control, a pandemic situation requires such cognitive capabilities, that can recognize the positive cases in time. The most important criterion for protection and treatment is to identify and isolate positive cases and contacts as quickly as possible. The Med-i-hub system can help this work by connecting and supplying the healthcare areas with the sensor data.

3 Med-i-hub Prototype System

One of the most interesting and difficult challenges for healthcare systems is dynamic scalability, based on the actual load. Currently, healthcare systems are not or not properly scalable and due to their possibly outdated architecture, are not suitable for adding additional resources as the load increases. Our experience shows that existing, mostly monolithic healthcare systems can operate using cloud services, but due to the lack of scalability options, they are unable to take advantage of cloud services, so most system components do not operate in cloud architecture and require unique and dedicated physical resources. It is often the case that a resource is shared by several services, which can impair the efficiency of services because a significant portion of the resources is shared with other services. If one service uses more of that resource, other services will have less of that resource. When designing these types of systems, the scaling of resources should take into account the number of components they share and the proportion of services that will use those resources. In the case of existing components, it is only possible to prepare the components for scalability by costly conversion. A system or component can be scaled in 2 dimensions: horizontally or vertically. The two dimensions are not mutually exclusive, it is possible to use both at the same time, however, cloud architectures mostly support horizontal scalability.

3.1 Scalability of the Hub System

In the case of horizontal scaling, existing system components are "cloned" and attempts are made to add more instances over time to perform multiple tasks. In this case, the system components have a separate set of resources. Vertical scaling gives existing system components more resources, such as processor cores, memory, storage, etc. This is more difficult to implement with cloud architecture and is a less-used solution. For the proposed system, horizontal scaling is used, but we do not cover the technological implementation of scaling in the description of the research results.

There are several conditions for horizontal scalability, the most critical of which should be considered when designing a system [8]:

- Replacement: during the design of the components, special care must be taken to add a new element to the system during the horizontal scaling if the load increases or to remove an existing element if the load decreases. Thus, "replacement" is a very important consideration in the state transitions of components during the design of individual business processes.
- Capacity planning: To facilitate scaling, you need to know how many resources are needed for a given number of transactions. Knowing the capacities will help you estimate the amount of scaling required for the specified load.

- Monitoring: continuous monitoring of the load allows the scaling to operate under maximum controlled conditions.
- Predefined route: in the case of a live system, scaling should be directed so that transactions reach newly added elements during up-scaling, but do not include transactions removed during down-scaling. Predefining routes helps to logically distribute the load.

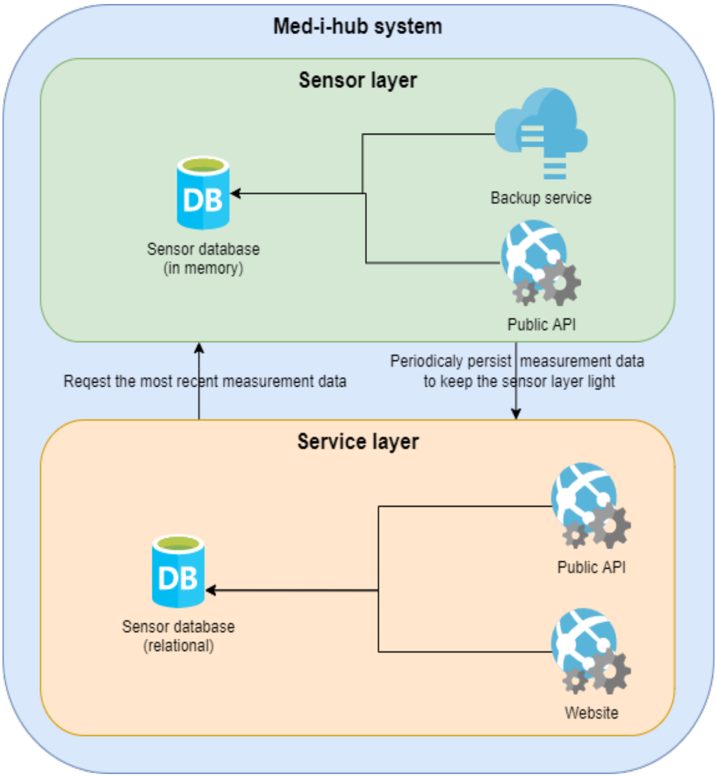

Figure 2
Reference architecture of the Med-i-hub system

In addition to horizontal scaling, the proposed system is designed to handle requests efficiently, even under heavy loads. In the research, the research team proposes a horizontally scalable hub system that works with bio-sensor data and can be easily integrated into the ecosystem of smart homes and smart cities. The proposed system is called the Med-i-hub. The architecture of the system can be logically divided into two major parts, the service layer, and the sensor layer.

3.2 The Layered Architecture of the System

In the architecture of a proposed Med-i-hub system, the service layer and the system elements located here are responsible for communicating with biosensory devices. The sensor layer receives, transforms, and stores measurement data, it filters and marks possible measurement errors. It is not intended to serve web requests, although it does have publicly available programming interfaces through which it can receive the raw measurement data. The task of the sensor layer is to process the incoming data in near real-time and put it in permanent storage. It has to keep the response time to devices as low as possible.

Another layer of the Med-i-hub system is the service layer. The primary function of the service layer is data visualization. This layer is also accessible via HTTP. It makes the data placed in the persistent storage by the sensor layer available to users. In addition to the classic web interface, this layer also provides open programming interfaces for accessing data. It supports multiple message formats and is able to respond to callers in XML or JSON format, as well. It can be scaled horizontally by adding extra web servers, but this layer is not intended to guarantee near real-time response time as the load increases. Unlike the sensor layer, this layer does not use the same technology stack. The data is stored in a classic relational database, the system communicates with callers via general web servers without data manipulation. So, this layer is like a classic web application. Fig. 2 illustrates the reference architecture of the Med-i-hub system with the described layers.

3.3 Integration with External Systems

Because the system logically behaves like a hub and is still designed as a hub system, one of the most important questions is how to integrate it with other systems. The most important task of hub systems is to provide information or raw data to actors [9]. An open application programming interface (API) has been developed to allow the system to easily collect data from other systems equipped with bio-sensors. Open APIs can use multiple message formats for both request and response, which can be controlled by the caller in the request header. The client can specify the requested content type using MIME types. It must be sent in the request header. The following MIME types are valid for requests in the prototype system:

- application/json
- application/xml
- application/xhtml+xml
- application/fhir+xml
- application/fhir+json

These MIME types can be used in both layers, so the hospital information systems also have the potential to define the standard they know. With FHIR support, the system is able to support the use of better-known health standards.

3.4 Smart Home Extension

Using open application programming interfaces (open API), integration with external systems is quite easy. An open API is easy to discover using the appropriate browser. Multiple open-source toolsets are available to work with open application programming interfaces. While different smart home solutions have different capabilities and network interfaces, should implement an extension framework. In some cases, special systems are developed to operate the building so it is necessary to define an extension framework to proxy the data from the internet of things (IoT) devices to the smart institutions.

The research team is working on a smart home extension recommendation to support extending the smart home solutions with smart health care services. The extension helps to feed cognitive health care services with bio-sensor data produced by individuals.

4 Collection and Use of Health-related Data

Thus, the data transmitted by the devices used by the users can be collected and transmitted to the actors connected to the network. Different devices make measurement data publicly available in different formats. Some tools are familiar with industry standards, while others do not use standards. Because measurement data cannot be used without interpreting the data, it is important to extract the information from the raw measurement data. None of the actors discussed so far can be expected to interpret the data and have the expertise to extract the information [10]. It is necessary to introduce an intermediate layer to perform the following tasks:

- Receives the raw measurement data
- Clean, filter out measurement errors
- Transforms the raw measurement data
- Standardize the processed measurement data
- Stores standardized data
- Forward it to the appropriate actors

Smart home solutions do not have the task of understanding and using healthcare domain knowledge, it is also not the job of smart city solutions. It is not the job of health systems to understand and integrate different physical wearable devices [11].

Our proposed Med-i-hub system, described later in this research, can be used for this task, establishing a connection between user devices and health systems, taking advantage of smart home and smart city solutions.

4.1 Health Care Standards

Many standards are available in the field of health care, but only a few of these are widely used. One such common and the commonly used standard is Health Level 7 (HL7). Health Level 7 (HL7) is a widely used international standard for the transmission of health data, and electronic patient records [12]. The name of the standard refers to the seven layers of the OSI model. In the HL7 definition, the top layer, i.e. the seventh layer, is the application layer responsible for health data interchange, which defines how the systems can understand the electronic health records sent or received. The HL7 standard is the result of a private project run by the Health Level Seven consortium, also recognized by the American National Standards Institute (ANSI). The purpose of the standard is to develop a widely accepted health standard. Almost 55 countries are already members of the organization. At the time of this research, the most common version is v2. The v3 version contains some important changes that may help spread the standard. The widespread adoption of the new version is hampered by the point that healthcare systems are changing very slowly, more slowly than other types of systems, and the transition to the newer standards and technologies is also very costly. The HL7 v3 standard is backward compatible and supports the v2 version [13].

The HL7 standard is based on the Systematized Nomenclature of MEDicine (SNOMED) categorization system. SNOMED is one of the most complete medical code systems in the world, allowing the most exhaustive medical description of patients [14]. It is based on the Systematized Nomenclature of Pathology (SNOP), created in the 1960s, which was initially designed to represent pathological concepts in a multidimensional system [15]. Fast Healthcare Interoperability Resources (FHIR) is a healthcare standard that uses the HL7 standard [16]. The HL7 standard was created by Health Level Seven organization to describe the message format and a standard application programming interface for the efficient and unambiguous exchange of health data. FHIR is based on the HL7 standard. It uses the HL7 data format, but is much more modern, making it easy to use. It allows the use of modern web technologies such as Representative State Transfer (REST) and Hypertext Markup Language (HTML) [17]. External systems can use the Javascript Object Notation (JSON) or Extensible Markup Language (XML) message format to exchange electronic health records [18]. The main purpose of the FHIR standard is to define cooperation between health systems and to standardize data exchange. Thanks to the HL7 and FHIR standards, data can be easily accessed by healthcare providers and individuals from a variety of devices, e.g.: a mobile device or a personal computer.

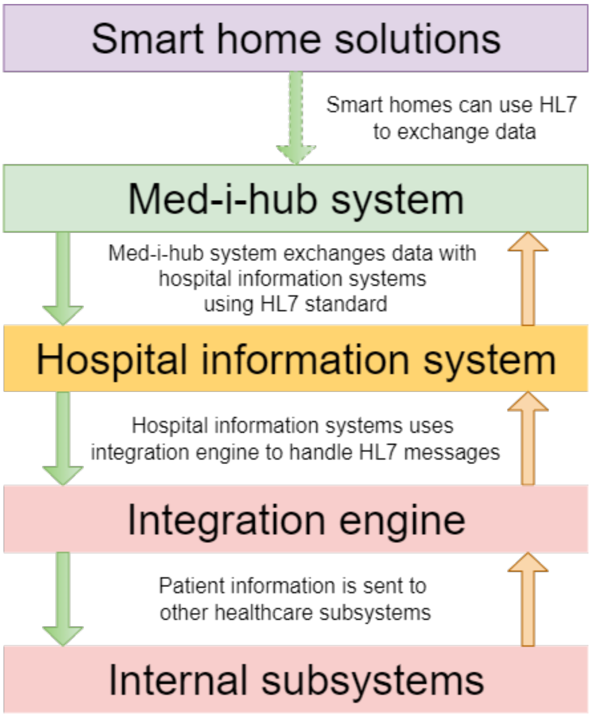

Figure 3
HL7 data flow using Med-i-hub system

As HL7 is a widely supported standard introduced in more and more countries, it is advisable to rely on it when developing new systems if the developed system exchanges electronic health records with other systems. Using the HL7 standard the national regulations can be applied standardized way. In this research, we relied on the HL7 standard. Fig. 3 illustrates the common HL7 data flow using the Med-i-hub system.

4.2 The Usefulness of Bio-Sensory Data during a Pandemic

A pandemic is an infectious disease that infects many people over a very large area, whether on several continents or worldwide. Officially, the World Health Organization (WHO) is entitled to declare a pandemic. In cases of an infectious disease that occur in a short time, in greater numbers than usual, and there is a link between them, it is an epidemic. If an infectious disease is persistent in a given area and occasionally produces new cases, then it is called endemic. Seasonal influenza, which affects large areas but not the whole world, is considered an endemic, not a pandemic, but a new influenza virus that is devastating to humans could cause a pandemic [19]. Mankind has repeatedly faced pandemic diseases. Advances in technology make it possible to detect positive cases in a short time and search for contacts effectively. The tools currently in use during the pandemic, while effective, do not take full advantage of the technology.

COVID-19 has become a focus of research, so we have learned a great deal about hitherto, unknown information, concerning coronaviruses. Among other things, new research suggests that coronavirus infection can be detected from pulse data before a patient produces a positive coronavirus test result. According to the research, the infection can be detected up to 7 days before the onset of symptoms and a positive test by continuously analyzing heart rate data. The study identified a metric in pulse data that occurs before positive cases in most cases. According to the metric, there is a change in the time elapsed between heartbeats. Although a change in heart rate may not only occur in COVID-19 disease, it may be a clear indication that an individual's immune system is working [20].

According to another study, where the research was based on measurements at rest, the infection could also be detected with the help of everyday activity monitoring tools before it caused symptoms. The study states that the extremely increased heart rate indicated the onset of symptoms. Changes in heart rate data were observed in 81% of study participants who later produced a positive test result. This change in heart rate data can occur up to nine and a half days before symptoms. According to a study by Nature Biomedical Engineering published in November, the researchers used smartwatch data to identify nearly two-thirds of COVID-19 cases four to seven days before people developed symptoms. The study looked at data from 32 people, of more than 5,000 participants, who became positive for the virus [21]. In the study, the researchers retrieved raw heart rate data. The outlier values were removed. A measurement value was signed as an outlier the heart rate value was greater than 200 or less than 30. Heart rate features were extracted, such as median heart rate per minute and average heart rate per minute. Additionally, daily steps were calculated. The researchers were looking for the abnormal resting heart rate, and they created a metric to find the abnormalities.

The above researches also confirm that the work done by the research team is forward-looking. Measurements made by bio-sensory devices used by ordinary people can be used in a large number of areas. Analyzing the data can help detect certain diseases, manage the risks, and use the results of the analyzes to make medical examinations more accurate [22]. This, of course, requires the development of a solution that allows these data to reach healthcare institutions as well. The data is mostly not available to doctors and users do not keep it long enough. Few analyzes are performed on the measurement data, as no such target software or application is available on the market. The development of smart homes and smart cities, on the other hand, provides an opportunity to link the city’s health facilities and residents’ measurement data. With our solution, the Med-i-hub system with the help of activity tracker devices can be easily channeled into smart homes, and smart homes can transmit data or information extracted from measurements to the smart city’s institutions.

The Med-i-hub system has a prototype version. The system was operating for test purposes multiple times. The research team has historical data from voluntary participants. From such data, the research team has already performed various data processing operations.

4.3 Data Measured by Med-i-hub System before the First Positive COVID-19 Test

Using the Med-i-hub system, this data can be easily accessed and analyzed on an individual basis. The system also allows for the easy sharing of data with the appropriate healthcare institutions, who can make the necessary decisions or make recommendations to patients.

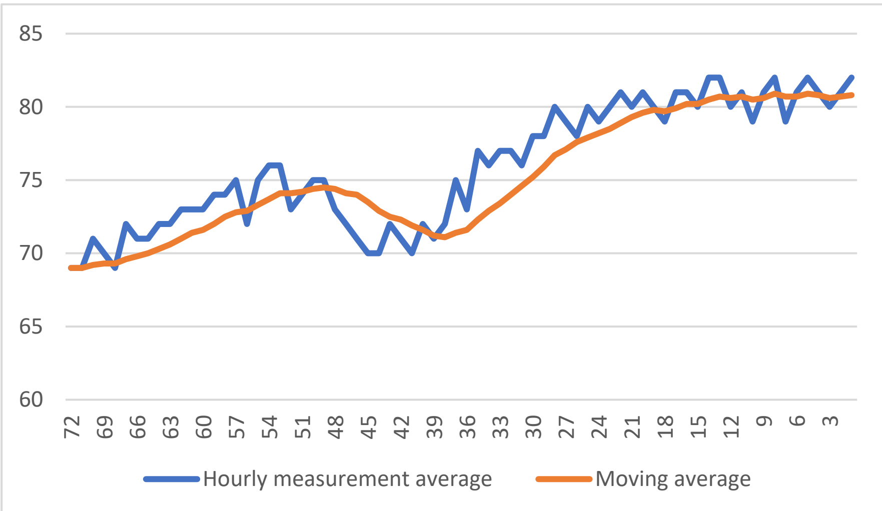

Figure 4
Heart rate values 72 hours before the first positive COVID-19 test (retrieved from historical data)

Testing of the system was ongoing during the pandemic, so historical data were available that subsequently confirmed the association between increased heart rate and COVID-19 infection. The research team also conducted its experiment, assuming an analysis of the relationship between historical data and heart rate and infection. A small test group was formed, 10 Hungarian people who had no contact with each other. Participants continuously wore the activity monitoring devices and transmitted the measurement data to the Med-i-hub system using a mobile application developed for this purpose. The test lasted for half a year, between August 2021 and January 2022. Participants immediately make a rapid COVID-19 test for any symptoms of COVID-19. The result and date of the test were handed over to the research team. A positive coronavirus test was performed on three of the ten participants. One in November, another one in December, and in January.

In these three cases, the heart rate fluctuated during the infection but was higher than the previously measured average. Fig. 4 shows one of the three cases where the average heart rate is higher than before the infection.

Fig. 5 shows the official Hungarian COVID-19 statistics.

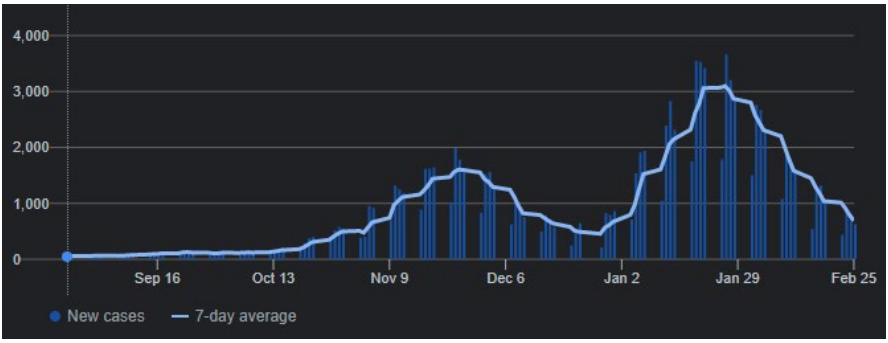

Figure 5
Hungarian COVID-19 statistics for the given period

Many other symptoms may precede a positive COVID-19 test result. Some of these can be tracked by an everyday person with wearable activity tracker tools, and the results can be easily analyzed [23]. The described hub system allows connecting common residential systems with the smart institutions in the smart city. The health care systems can access historical sensor data. This way, these systems can develop their services. Using real-time data or time series the institutions are able to provide more reliable and efficient service to the users. In the future, smart healthcare systems have to use data from external sources to provide more efficient services to their users. In the above cases, the healthcare institutions were blind, they do not know about the positive tests, the tests were made by third-party companies. The doctors became aware of the positive test from the patients, after hours of the test result. Smart processes with smart participants will result in smart healthcare services.

Conclusions

The described system is a good complement to both smart homes and smart cities, as it extends the functionality of the two systems while minimizing development tasks. The proposed system acts as a hub in a smart ecosystem while being able to perform computationally intensive tasks in near real-time. As a result, there is no need to expand the smart systems' hardware. With well-defined standard interfaces, the system can be easily integrated into existing systems without the need to implement different and complex data formats and communication interfaces.

In the event of a pandemic, several different defenses are needed. Each form of defense is designed to curb or stop the epidemic. The best solution to curb epidemics is to identify positive cases on time and quarantine those affected, minimizing contracts. Continuous screening is needed to recognize positive cases on time.

Continuous screening can be invasive or non-invasive. Both methods have advantages and disadvantages and can even be effective in combination as well. The research has proposed a solution for non-invasive screening solutions that allows positive cases to be screened in a way that does not involve an extra cost to individuals and the time spent is minimal. The proposed solution fits into the everyday lifestyle, of individuals and does not require extra effort. Smart homes are becoming more prevalent and smart cities are evolving with them. Combining the two smart systems and exchanging data provides an opportunity to develop cognitive healthcare services that simultaneously serve the well-being of individuals and the community without incurring additional work for them. Advances in information technology and medicine provide an opportunity to recognize and manage epidemic situations and thus minimize harm. The strength of smart ecosystems, lies in the quality of their cognitive services and the bio-sensor-based cognitive healthcare capabilities, that fit perfectly into this ecosystem.

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