Intelligent methods for personal health assessment based on continuous user monitoring

Seminar I

Maja Somrak

Supervisor: Mitja Luštrek, PhD

Approved by the supervisor: _____________________
(podpis/ signature)

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Abstract

With the advancement of medicine, the population in industrialized world is increasingly growing and ageing. People tend to suffer from more diseases, often from multiple, complex or chronic conditions. The healthcare system is already confronting this challenges as well as conflicting demands for higher quality of medical services and reduced costs.

In recent years, autonomous health and wellness monitoring systems started introducing some radical changes into the traditional healthcare. These systems enable continuous monitoring and analysis of vital signs and other physiological parameters by integrating body-worn and ambiental sensing with intelligent methods. The implementation of this technology holds great promise in self-management of chronic conditions, assistance for elderly and disabled, diagnostics, telemedicine, therapy support, home rehabilitation and safety monitoring. Although these health monitoring systems currently still face some technological barriers, they can provide novel healthcare services and enable pro-active personal health management.

In this paper we describe the underlying sensor technology and overview the fundamental methodology used. We present current and past research, done in the field, to cover state-of-the-art applications. We identify present shortcomings and potential for improvements that present our aim in the future work. With the combination of different approaches, we intend to implement novel methods that use multi-sensor gathered and user provided data to improve diagnostics, as well as enable personalized analysis and prediction of user's health condition.

Keywords: health monitoring, wearable sensor devices, diagnostics, ambiental intelligence, therapy support, assistive technologies, personal health management
1 Introduction

In the years to come, healthcare is facing hard challenges. As the medicine advanced greatly in last few decades, people in industrialized countries are living longer, but have more diseases. Chronic conditions like diabetes and cardiovascular diseases have become much more prevalent in comparison to the previous generations. Especially the elderly often suffer from prolonged illnesses and need more frequent health assistance. Since many of them live alone, they might be unable to seek help in medical emergencies. In addition to them, there is a rising number of people with physical or cognitive impairment, who also require long-term care. Keeping all these people in hospitals would be both cost inefficient and overwhelming for the system that is already experiencing healthcare worker shortages. In the future, healthcare will need to satisfy conflicting demands for increased efficiency and high quality medical services on one hand, and reduced costs on the other. As the medical service costs are skyrocketing, money is being saved at the expense of prevention and early disease diagnostics – both of which could greatly reduce the resources needed for treating advanced and complicated medical conditions. Considering the current situation, the healthcare system will need to introduce some radical changes to successfully deal with all the challenges it confronts. Part of the solution may lie in recent technological advances that are leading towards miniaturization and improved performance of computers, sensors and networking technology [1]. A wide variety of related fields is under active development, resulting in miniaturized biosensing devices, smart fabrics, microelectronics, etc. As a result, new intelligent autonomous health monitoring systems are constantly being developed. These systems combine multiple sensing and communication technologies with intelligent methods to expand the range of healthcare services, independent of medical facilities. They enable health and wellness monitoring and analysis, emergency event communication, remote medical assistance, improved diagnostics and treatment support. Various solutions can be implemented either as an independent wearable sensor system or integrated into home pervasive networks. Such health monitoring systems represent cost-effective solutions that hold great promises of advancement in personal healthcare. This paper reviews current research in health monitoring and diagnostic systems, with the emphasis on solutions that utilize wearable sensors and ambient assisted living technologies. In Section 2 supporting sensor technology and underlying infrastructure is described. In the following, fundamental intelligent methods and algorithms are presented. A variety of selected implementations cover the current state-of-the-art solutions in the field. A critical assessment of presented research is discussed in the Section 3, focusing on the current challenges. In Section 4 possible improvements are proposed, providing the directions for further work. Finally, we conclude the paper by summarizing the findings in Section 5.
2 Review of the related work

2.1 Supporting technologies and infrastructure

Sensors represent an integral part of all health monitoring systems. Sensors gather the data about the user and his surroundings, and upon this information, the health condition of the user is evaluated. Health monitoring systems can employ a wide variety of sensors to measure different physiological, biokinetic and environmental parameters.

From the viewpoint of infrastructure, sensors systems can be divided into body sensor / area networks and sensor networks in smart environments.

Body-Sensor Networks (BSNs) and Body-Area Networks (BANs) terms relate to the systems of interconnected wearable or implantable sensors and devices, predominantly intended for long-term monitoring of user's vital signs. These types of sensors are often worn as chest straps, bracelets, headbands or rings [2]. The latest technologies of e-textiles provides even more unobtrusive solutions, with sensors integrated into garments, such as jackets, scarfs and shoes [3]. Additionally, sensors can be simply embeded into the textile itself, by knitting the tiny conductive wires as regular textile yarn [4]. The textile-structured electrodes are more comfortable and flexible, and as such more suitable for prolonged monitoring, especially during movement [5].

Common wearable or implantable sensors and devices include [2][5][6]:
- motion sensors – accelerometers and gyroscopes (body movement detection and tracking, used for activity recognition, fall detection, freeze of gait detection, tremor recognition, post-stroke rehabilitation feedback, etc.)
- microphone (measuring respiration rate, apneas recognition)
- video and image sensors (throat inflammation recognition, ear infection recognition, identification of pallor, melanoma and other dermatological conditions)
- oxymeters, glucometers and other infra-red sensors (measuring of ambiental and body temperature, heart rate, blood oxygen saturation, blood glucose)
- galvanic skin response (measuring sweating)
- spirometer (measuring respiration rate, used for diagnosis of various lung diseases)
- photoplethysmography, PPG, and impedance plethysmography, IPG, (measuring changes in body tissue volumes, used for measuring blood pressure, respiration rate, etc.)
- electromyography, EMG (measuring electrical activity of skeletal muscles)
- electrocardiography, ECG (measuring electrical activity of the heart in a continuous waveform, used for determining heart rate, recognition of certain heart diseases (e.g. arrhythmias), cardiovascular disease risk estimation, cardiac arrest detection)
- electroencephalography, EEG (measuring electrical activity of the brain, used for epileptic seizure detection, sleep monitoring and sleep disorder recognition)
- electrodthermal activity, EDA (sympathetic nervous system activity)
- pressure sensors (activity recognition)
- biochemical sensors (measuring levels of chemical compounds in the atmosphere or in body fluids, toxic compounds detection)
- global positioning system, GPS (location tracking)

The obtained sensor measurements are transmitted to the system's central node, which collects and processes the data. The device used for this purpose is usually a personal computer, a portable personal computing device (e.g. PDA, smart phone) or a dedicated microcontroller device. The device can further communicate the aggregated data to a specific remote location. This may be utilized, for example, to provide the relevant information to the user's healthcare provider, to report an emergency
to the medical center or to store the user's data into the dislocated database. Example communication architecture is shown in Figure 1.

![Example architecture of a body-area network (BAN) communication system](image)

Figure 1: Example architecture of a body-area network (BAN) communication system [5].

Another important aspect of BSNs and BANs is their scalability and integration with other infrastructures and environments, such as Mesh Sensor Networks in Smart Homes [5]. Chan [1] uses the term smart home to relate to „a residence equipped with technology that allows monitoring of its inhabitants and/or encourages independence and the maintenance of good health“. Similarly, Alam [7] defines it as „an application of pervasive computing in which the home environment is monitored by ambient intelligence to provide context-aware services and facilitate remote home control“.

The vast majority of smart home services relies on the data, collected from the immediate environment through a system of multiple interconnected ambiental sensors. These sensors are integrated into the system either as an individual components or come already embeded into the household appliances, doors, windows, furniture or other electronic devices. The system's central node is usually connected to the internet so that the system can be both locally or remotely monitored.

The sensors that are most frequently utilized in smart environments are the following [5][7][8][9]:
- ultrasonic (location tracking)
- microphone (activity recognition, location tracking)
- video and image (activity recognition, location tracking)
- infrared (location tracking)
- light sensor (intensity of light)
- magnetic switches (doors and windows open or closed)
- RFID (people and object identification)
- temperature and humidity sensors
- pressure sensors (e.g. bed pressure sensors – quantity of sleep, detection of sleep disorders)
2.2 Methodology overview

In this section, most frequently used methods and algorithms are presented, including activity recognition, behavioral pattern discovery, anomaly detection, planning and scheduling and decision support [5].

2.2.1 Activity recognition

Activity recognition is well-researched, complex problem. All approaches are based on sensor collected data, but differ in number and types of sensors used, implemented machine learning algorithms and complexity of activities that can be recognized.

Measurements can be collected using only body-worn sensors that are either attached on the body or interwoven into garments. One or more three-axis accelerometers can provide information about orientation and movement of the whole body or a specific body part. Inertial information can be used to recognize postures (e.g. lying, sitting, standing), movements (e.g. walking, running, cycling, falling, etc.) and certain gestures. Ambiental sensors, such as infrared motion sensors, magnetic switches on doors and windows and furniture-integrated pressure mats can be combined with body-worn sensors to recognize location-based, complex activities, such as cooking or sleeping [5]. Although cameras, microphones and GPS can be utilized for activity recognition, they are often avoided due to privacy concerns. Additionally, activity recognition can be improved by recognizing activities that are characterized by interacting with specific objects (e.g. medicine taking). For this purpose, selected objects can have integrated sensors or RFID tags attached. However, activity recognition using only ambiental sensors can be a challenging task, especially when multiple residents are present in the same space.

Diverse machine learning methods are used for activity recognition tasks. They can be divided into template matching (nearest neighbor classifier based on Euclidian distance or dynamic time warping), generative methods (Naive Bayes, hidden Markov models, dynamic Bayesian networks, decision trees) and discriminative approaches (support vector machines, conditional random fields).

2.2.2 Behavioral pattern discovery

In contrast to supervised learning for activity recognition, unsupervised learning techniques are often applied for behavioral pattern discovery. Behavioral patterns, in this context, could be defined as „recurring sequences of unlabeled sensor activities“ [5]. Typically, mining techniques for finding frequent sequences, mining patterns using regular expressions or frequent-periodic pattern mining are used. Some of the techniques (e.g. genetic algorithms) can also recognize discontinuous patterns, pattern variations or interwoven sequences.

2.2.3 Anomaly detection

In healthcare applications, one of the most interesting and frequently used methods is anomaly detection. Anomalies are usually a sign of health condition deterioration or medical emergency. This method is perhaps most frequently applied for fall detection in elderly healthcare. However, applications of the method are broad and fundamental for safety monitoring. Anomaly detection is most accurate when it is based on behaviours that are frequent and predictable [5]. Common statistical methods (e.g. box plot, the CUSUM chart) and machine learning techniques (k-Nearest Neighbors, local outlier factor, clustering) are used for detecting outliers. Expert-defined rules and threshold based algorithms are also frequently applied for automatically anomaly detection. Anomaly detection
can be captured at different population (e.g. indentifying outliers in a group) or temporal scales (time spans of a single event, days, weeks, months, etc.).

### 2.2.4 Planning and scheduling

Planning techniques are most often used for scheduling daily routines to help dementia patients lead an independent lifestyle. Assistance for daily activities can be provided if the user is not able to complete a certain step. In addition to instructions, detecting insufficient task execution can be used to remind the patient or reschedule the remaining tasks. In contrast to activity recognition, anomaly detection or behavioral pattern discovery, scheduling methods usually rely on user provided information, rather than sensory input. Commonly used methods include graph-based, hierarchial and reactive planning techniques.

### 2.2.5 Decision support

Decision support systems (DSS) assist medical professionals with decision making tasks, such as patient data analysis and diagnosis. The knowledge based DSS incorporates the expert knowledge and the inference machine (see Figure 2). The knowledge database is usually represented in form of 'IF-THEN' rules and probabilistic associations between the data. The inference engine combines knowledge database rules and the acquired patients' data to generate new knowledge. The nonknowledge-based DSS don't rely on clinical expertise, but learn clinical rules from discovering patterns in the data. Various machine learning algorithms (e.g. decision trees) represent methodologies for learning clinical knowledge. DSS could be used combined with multimodal sensing and portable computing technologies for continuous monitoring and analysis of patient's vital signs and biokinetic data in order to make real-time decisions, such as in case of emergency events.

![Inference Engine in CDSS](image)

**Figure 2:** Reasoning engine in generic clinical decision support system (CDSS) [9].
2.3 Applications overview

2.3.1 Continuous health and wellness monitoring

Applications for continuous monitoring usually employ various body-worn sensors to keep track of the user's vital signs and his activities. Typically, the aim is to provide the user with information about his current health status and its progression over time. Such applications are developed for multitude of purposes, ranging from encouraging a healthy lifestyle in population at risk to recognition of certain medical disorders and emergency events detection.

Numerous commercial solutions for health and wellness monitoring have been developed by companies like Microsoft (HealthGear [10]), Intel (HealthGuide [11]), Philips (Telestation [12]), Honeywell (Genesis [13]) and Bosch (HealthBuddy [14]). Some of the research projects, especially worth mentioning include LifeGuard [15] and LiveNet [16]. The LifeGuard system, developed by NASA and Stanford, is a wearable physiological monitor for extreme environments. Personal monitoring device implements two-lead ECG / IPG and various commercial sensors to measure heart rate, respiration rate, blood oxygen saturation, body temperature and movement. Similar is the MIT-developed LiveNet, a health monitoring system based on physiologic sensing board (BioSense) with integrated three-axis accelerometers, ECG, EMG and galvanic skin response. The BioSense board is extensible, allowing additional interfacing with a variety of commercially available sensors. LiveNet system was tested in multiple scenarios including soldier health monitoring, epileptic seizure detection, Parkinson symptom recognition and long-term behavioral modeling.

2.3.2 Assisted living

The term ambient assisted living refers to intelligent systems, which provide assistance with activities of daily living, allowing people (elderly or disabled) to live autonomously longer. In the context of healthcare, these system provide medical services in the living environment. These include remote monitoring of the patient, self-management of chronic conditions, rehabilitation and recognition of emergencies.

Examples of such ambitious project is CAALYX [17], Complete Ambient Assisted Living Experiment, aims to increase elderly independence by developing convenient wearable device that monitors vital signs and detects falls. In case of emergency the system informs the healthcare providers. Similar projects, such as ENABLE [18], described trialing assistive technologies for use in homes of people with dementia [19]. These systems are designed to be straightforward and uncomplicated, requiring minimal user interaction, due to user's cognitive decline. Integrated intelligent appliances (e.g. water tap, cooker, etc.) operate in the same way as their regular counterparts, without confusing the user. These systems issue reminders about daily activities and medication schedule, help track lost items or intervene in case the user forgets to turn off an appliance. However, system should be unobtrusive, letting the resident with a feeling of control and independence.
2.3.3 Safety monitoring

Many applications of intelligent healthcare systems deal with the detection of emergency events. In case of such detection, the device typically responds by sending an alarm message to the emergency service center or contacts the user's personal physician or immediate family members.

A majority of solutions for safety monitoring are based on, or at least tightly interwoven with health monitoring techniques. Moreover, such solutions are often integrated with ambiental intelligence and assisted living technologies. For instance, AlarmNet [20] implements safety monitoring and healthcare services into a smart home. A network of numerous sensors and systems collects and analyzes the data from the environment to monitors residents' overall wellness, present medical conditions, daily activities and possible emergency situations.

Various autonomous safety monitoring applications are aimed at specific target groups, such as individuals with physical or cognitive disabilities or emergency-disaster personell. Significant projects include iWander [21], KopAL [22] and OutCare [23], which are aimed to provide safety for dementia patients in the outdoor situations. These systems are implemented as mobile applications that track user's location to search for deviations from regular routes, indicating of the user's disorientation.

Another application of safety monitoring is the detection of epileptic crises. The methods used for this purpose are predominantly based on the detection of falls and specific body movement, that occur during the seizure. Person undergoing a seizure is typically unconscienceus and unable to interact with the surroundings, producing characteristic changes in the brain signals patterns. Therefore, many of such systems and methods take advantage of the EEG, EMG, EDA and accelerometers to detect the onset of epileptic episodes [24][25][26].

Similar accelerometer-based applications include fall detection systems that are combined with airbags mechanisms [27], and some others use freeze-of-gait recognition techniques for safety monitoring of patients with Parkinsons disease [28].

2.3.4 Diagnostics and telemedicine

Health monitoring can be used for prevention and early detection of health disorders. Applications are aimed at recognition of certain sleep, heart, respiratory or other disorders. They rely on anomaly detection methods, however, additional studies suggest that individual pattern discovery could further enhance diagnostic capabilities.

MyHeart [29] is a major Philips Research initiative, aimed at cardiovascular disease prevention and early diagnosis. It utilizes smart fabrics with embeded sensors for acquiring, processing and evaluating physiological data. Many research projects deal with home sleep monitoring systems [30][31] and use bed or pillow integrated pressure mats for analyzing body movements during the sleep for sleep quality and duration estimation. Integrating advanced sleeping mattresses enables monitoring respiration, heart rate and snoring. Additionally, use of EEG-embeded headbands for brain activity tracking all help to improve evaluation and recognition of sleep disorders.

Most of health monitoring applications for diagnostic purposes are focused only on the detection of a particular kind of health disorders. There are, however, various solutions that use decision support techniques to predict different health conditions. Still, these solutions are predominantly based only on the user input, such as user's personal data and presence of symptoms, and do not include sensory information.

One of the solutions that is a step closer is the TytoCare [32] device. TytoCare incorporates MEMS, camera and microphone sensors in a personal diagnostic tool. It is intended for measuring the body temperature and basic examination of the mouth, throat, eyes, ears, heart, lungs and skin. TytoCare
also supports online examination, remotely by a physician, but is not capable of continuous user monitoring and personalization.

A research project by Pantelopoulos [33] strives to characterize collected multi-parameter data with the use of Prognosis, a context-free formal language. With the prior analysis of signal data, gathered from on-body sensors, patterns and specific signal states, indicative of pathological symptoms present in the signals, can be identified. What Prognosis works is to combine detected pathological symptoms to derive an estimation of user's health condition.

A project, lead by Mesi [34] aims to develop Tricorder-inspired device to combine continuous health monitoring and diagnostics. It features a wireless bracelet, designed for daily use, for monitoring of vital signs. The bracelet requires the use of additional wireless cuff, for measuring blood pressure, and a patch located on the ribs, for measuring oxygen saturation, temperature, electrocardiogram (ECG), respiratory rate and activity tracking. The bracelet communicates with a smart phone devices which collects and analyses the measured data. Data obtained by vital signs measurements and activity recognition are used to diagnose several health conditions.

### 2.3.5 Disease management

A wide spectrum of healthcare applications deals with disease management, including home rehabilitation, telemedical services, therapy and patient support.

Many researches deal with long-term continuous monitoring of chronically ill to improve clinical management of patients. Various projects are focused on managing patients suffering from diabetes, congestive heart failure or Parkinson's disease. AMON [35] is a medical monitoring and alert system, targeting high risk cardiac and respiratory patients. It features a wristband for measuring vital signs including blood pressure, skin temperature, blood oxygen saturation and ECG. Additionally, two-axis accelerometer is used for activity recognition. The system employs intelligent methods to correlate vital signs measurements with activities and evaluates the health status of the user. Health status can be classified as either 'normal', 'deviant', 'risk', 'high risk' or 'error'. Next, the system can use cellular connection to communicate with the telemedical center, where the physicians can analyze the data. Chiron [36] is a similar project, aimed at long-term monitoring of patients suffering from congestive heart failure. It features an ECG monitor for measuring the heart rate, a three-axis accelerometer for recognition of ten different activities (lying, sitting, walking, running, etc.) and other sensors to measure ambiental and body temperature, sweating and air humidity. Additional measurements, indicative of patient's health status are collected through weekly medical examinations at a medical center.

Medication scheduling and assessment of treatment efficacy are another examples of application in therapy support and disease management. Great example is iMat [37], an intelligent medication administering tool. The system automatically computes the user’s medication schedule based on a machine readable medication schedule specification (MSS) of user's prescribed medications. Custom generated schedule is then sent to the user's personal device (e.g. smart phone) that monitors and reminds him to follow the medication regimen.

To design completely personalized, optimal regimens, accurate and detailed information about both medication dosages and subsequent symptoms response needs to be provided. Patients diaries are often unreliable and misleading, due to perceptual bias and inaccurate reporting [2]. Several projects that successfully deal with treatment efficacy assessment aim at managing Parkinson's disease [38][39][40]. Patients with this disease typically exhibit specific motion patterns that can be captured via motion sensors, such as accelerometers. These systems quantify tremor, gait impairments, step symmetry and stride regularity to evaluate the severity of patient's dyskinesia. A physician with such
information at hand can assess the disease progression and adjusts the medication titration, tailoring the treatment to the patient's needs.

Home based rehabilitation combines sensing with interactive technologies to help the patient to gradually improve his impaired motor skills (e.g. walking, hand functions, etc.). One of the most advanced commercial systems is Valedo [41], a medical back training device. It employs sensors attached to the affected lower back and treats the collected data as an input to the video game. The system provides a motivating environment and real-time feedback, stimulating the patient to complete rehabilitation program exercises. Furthermore, Philips Research is currently developing the Stroke Rehabilitation Exerciser [42]. The device prototype enables physiotherapists to design personalized motor retraining exercises for individual patients, who can carry out the exercises in their homes. The system analyzes patient's movement data to evaluate compliance and progress, providing feedback to the patient and the physiotherapist.
3 Discussion

Health monitoring systems contribute to expansion and enrichment of healthcare services. The majority of applications is concerned with personal health management and safety aspects. There is a wide variety of applications of assistive and health monitoring systems that benefit especially the elderly and people with prolonged medical conditions or disabilities. When comparing different methods and implementations, it is important to be aware that there are significant discrepancies in research study designs, sensing equipment used and experimental conditions. Moreover, most of the presented studies used small samples and tested their system only in a very specific context. Even the systems that implement methods for a seemingly identical task, like classification of activity, use different numbers and types of inputs and have a different set of possible resulting classes predefined. For the above reasons, it is difficult to evaluate objectively and compare discussed methods with an universal criteria.

Activity recognition techniques, behavioral pattern identification and anomaly detection methods are frequently utilized over a broad spectrum of applications for health assessment, safety monitoring and disease management. Diagnostic methods are mostly implemented for recognition of a specific health disorder, where the data is enhanced by incorporating particular set of sensors. However, there have been certain attempts, but not an universal solution, for detecting arbitrary medical conditions. Moreover, there is a strong need for clinical validation of the diagnostic results, since these methods are not very reliable. Some of the applications thus incorporate telemedical services that communicate patient data to the remote physician. Integration of decision support also aids medical professionals in analysing patient data.

From the technological perspective, this field is still confronting some issues. The most obvious is the energy consumption of devices for long-term monitoring, which are burdened with huge amounts of data. The sensors are prone to environmental noise and wearable devices typically require careful positioning on the body – otherwise the recordings can be interrupted, especially during movement. Advanced sensor and data-processing equipment is required, especially for systems, intended for real-time, local processing. The methods used for this purpose are often inadequate in terms of accuracy and personalization. On the other hand, improved algorithms tend to be computationally intensive and are consequently inappropriate for real-time applications. Other solutions use remote services to utilize advanced computational methods, but confront privacy issues.

Privacy issues are even greater with the systems that use telemedical services for communicating the data to the medical professionals. If this devices reveal more information than users desire, they may withhold or disclose misleading information. With addition to personalization options and privacy concerns, system design can also have a great impact on user satisfaction. Sensor devices, either wearable or ambiental, should be unobtrusive, so that the user can easily forget about their presence. The required user interaction should be optimized for user comfort, but without compromising the functionality. The assistive services of these systems must implement methods that produce outputs, meaningful and helpful to the users, otherwise they will tend to alienate from this technology. Understanding user needs and desires hence plays a major role in general applicability and broader acceptance and of health monitoring technology.

However, there is still a lot effort needed to bring the technology into every day use. The utilization of personal and intelligent health monitoring devices can reach its full potential not only by being complementary, but by directly integrating with the traditional healthcare system.
4 Directions for further work

The directions for further work focus on integration of different approaches to develop novel methods for health condition analysis and assessment. Our research is a part of already mentioned project, lead by Mesi team [34].

For the future work, we plan to focus on:

1) Combining data from sensors with user provided information
   Combining sensory and user input (see Figure 3) is used in order to identify possible pathological symptoms of a broader spectrum.

2) Context-aware, personalized data interpretation
   One measure does not suit all; while for some people blood pressure of 135/85 might be very high, for someone suffering from hypertension it could indicate an improvement. Similarly, a heart rate of 130 might be high if a person is resting, but normal during running. Data needs to be analysed in both, personal context and in the context of current activity, to be appropriately interpreted.

3) Pattern discovery in historical data
   Additionally, discovering patterns in user's physical parameters and activity recordings over longer periods of time may help not only to improve his health assessment, but also enable future predictions of health condition changes. For instance, if the user is generally physically active, but there are multiple occurrences of days with low physical activity, followed by health condition decline, the system could anticipate similar situations in the future, when user again becomes less active.

4) Hierarchial multilabel classification of health conditions
   We aim to implement novel machine learning methods for hierarchial multilabel classification for assessment of health conditions. The purpose of multilabel classification is to recognize one or more diseases that the user can have present at the same time. Hierarchial classification is intended for identifying the type of health condition (e.g. lung disease), when the data collected may not suffice to identify the exact disease (e.g. asthma, bronchitis, pneumonia, etc.). This approach would enable better assessment of complex and multiple pathological conditions and provide directions in seeking further specialist help.

The goal of our system is to take into account as much data as possible in order to produce accurate, personalized health assessment— we use both the sensory input and user provided information to identify possible pathological symptoms, according to the user's personal health background and history.
Figure 3: Diagram overviewing the course of our diagnostic process.
In this paper we reviewed health and wellness monitoring systems, covering both research prototypes and commercially available solutions. Personal health monitoring and diagnostic systems provide novel services for independent health management, extending beyond the traditional healthcare. They provide safety monitoring, therapy and rehabilitation support and living assistance, deemed especially useful for people in vulnerable groups, such as elderly, disabled and chronically ill. In addition, health condition monitoring, intelligent diagnostics and automatic emergency event communication can benefit every single individual. Currently, there are still certain technological shortcomings that need to be overcome in order for these systems to be more applicable in real-life situations. A lot of potential for improvements also remains in terms of diagnostic capabilities of different methods, algorithm accuracy and personalization. In the future work we presented our idea to combine multiple approaches and implement novel methods that will hopefully benefit personal health management and diagnostics.
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