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Pervasive and Personalized Ambient Parameters Monitoring: A Wearable, Modular, and Configurable Watch

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ABSTRACT An innovative, small, compact, light-weighted, configurable, and low power consumption wrist-worn prototype in the area of ambient parameters monitoring, in five physical layers, is introduced. The prototype is based on the multi-layer multi-sensor approach and is capable of measuring a wide range of toxic/hazardous gases, physical ambient parameters, and motion tracking. The proposed device operates in the stand-alone (BLE disconnected) and configurable (BLE connected) modes. The stand-alone mode supports real-time data monitoring on the display and data storage in an integrated external memory. The logged data are retrieved once BLE is resumed based on the user decision. In the configuration mode, sensors are activated and configured by the user via sending a command from the smartphone. The chemical parameters monitoring includes three hazardous gases (SO_2, NO_2, and CO one at each time). The toxic gas sensor along with the gas sensor driver forms the gas sensor node which is located at the top of the proposed device. Hardware flex interface is utilized as the second layer to facilitate the display and sound module connected to the host platform. The main platform that is expandable from both the sides in z-axis hosts the integrated sensors, microcontroller, and the chip antenna. Notification driver for the early user warning of abnormal status and battery holder is placed at the bottom of the device in two separate layers. Furthermore, the adjustable sensor sampling rate according to the battery level is applied in order to manage power consumption. Device configuration, prototype validation, data storage, power dissipation, and experimental results are discussed in detail at the end of this paper.

INDEX TERMS Personalized ambient air monitoring, wearable configuration, health-care, independent operation, power consumption, variable sampling rate, wearable device.

I. INTRODUCTION

A. WEARABLE DEVICES AND LIFE QUALITY

Nowadays smartphones are widely used and applied in many applications. This cannot be ignored since smartphones make the life easier by providing large flavors of facilities. However, the penetration rate of smartphones in the current lifestyle is saturating [1], [2]. Due to the current number of sensors included in the smartphone (e.g. for measuring physiological data) their use for health-care protection for elderly people is limited; additional sensors for data collection are required which have to be coupled to the smartphone [3], [4]. On the other hand, we are observing a fascinating new trend in the mobile device market which is supported by increasing demands. Individuals show an increasing interest in wearing a mobile device daily, that improves the quality of life in the way that smartphones cannot achieve [5], [6]. Smart watches, smart textile, smart glasses and wrist bands are some of the mobile devices that are used by people during the typical daily activities [7]. These devices are referred to as wearable devices or in short, ‘‘wearables’’. Wearables can sense, measure, collect and monitor physiological/non-physiological [8] or, ambient parameters [9], [10], can provide localization and navigation [11], [12], physical and

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mental health observation [13], [14], sport analytic [15], and medical insurance analytics [16], [17] in a 24/7 manner and provide the opportunities of a better quality of life [1]. These collected data more often are sent to a gateway (here PDA) and in some cases, consequently to a server to construct a personalized database. However, wearable devices and technologies are not a new phenomenon. There have been many efforts from commercials and academic communities to design, develop and implement these type of devices to serve as multi-tasking tools for several purposes. These attempts mostly were made during the last ten years with a concentration on fitness but not limited only to this topic [7]. During recent years, interests in wearable devices, have led to advent of many devices in the range of ambient, health, smart city, smart home, industry, agriculture monitoring and so on. The value proposition of wearables, in particular in the health monitoring, has some overlap with the research topic wireless body area network (WBAN) [18], [19]. The term of WBAN is much broader than wearable devices in number of sensors and actuators. Moreover, it seeks to a network construction of these sensors. Some of the sensors are medically implanted for a comprehensive and accurate health monitoring. Care must be taken that, WBAN requires significant efforts in physical, medium access control, and network layers before it can reach the commercial success [16]. In contrast, wearable devices are low-cost, easy to use, do not make any significant binding in medical professional, independent and personal use. These advantages and simplicity enable the wide use of wearables by individuals. As a results, wearable devices have received more attention from the research side and faster pace than WBAN [20], [21]. Generally, increasing the elderly population, prevalence of chronic diseases from different types and the cost of healthcare system are the most critical challenges to be focused [22]. In response to address these concerns, researchers have been actively seeking for efficient solutions to enhance the quality of patient life and ease of monitoring from one side and reduce the cost of healthcare through the early detection and notification, from the other side. In order to achieve these two goals, an effective observation, monitoring and notification system is required as well [23], [24].

B. AMBIENT PARAMETERS MONITORING: AIR QUALITY AND SOUND LEVEL

Air quality in terms of physical and chemical elements is an important factor in health protection, especially for the patients who are suffering from heart issues. Depending on the degree of risk, exposition to abnormal ambient conditions causes chronic diseases too [25]. The World Health Organization (WHO) recently has reported that air pollution has become the world's largest environmental health risk. This situation is notable since it is known that, one in eight of global deaths are caused by air pollution exposure each year [26]. Air quality observation may result in health protection as people are spending majority of the time in closed spaces (up to 80%). To emphasis on the importance of air quality monitoring, exposure of individuals for long time in carbon dioxide (CO) and nitrogen dioxide (NO_2) creates serious issues not only for patients but for healthy adults, too. This situation for elderly and children is even worse. As carbon monoxide (CO) is one of the major pollutants and the measured results are provided in detail in the following sections, the effects of CO on health is briefly described. The natural concentration of CO in clean air is 0.1-0.3 part per million (ppm). Generally CO becomes toxic for healthy adults at a level of 50 ppm. Heart patients experience pain on the chest when exposed to CO concentration of 70 ppm. Healthy people feel headache at 200 ppm. At the concentration of 800 ppm, the exposure might lead to death in less than 1 hour [27], [28]. Air pollutants are not only limited to indoor/outdoor toxic gases but long-time noise exposure (high sound level) is extremely harmful for individuals. The exposure of high sound level for long-term is the second focus of this paper. Noise annoyance created by long-time high noise exposure may cause cognitive disorders in children, sleep disorders, low sleep quality and ischemic heart disease. In general theory of stress described in [29], long-term noise exposure hypothesis is considered as a source cause, in addition to other more known parameters such as, the "autonomic nervous system", the endocrine system, and the homeostasis of the human body [30], [31]. In [29] has been discussed that long-time exposure to noise can affect the autonomic nervous system. This is becoming more critical when we consider that the autonomic nervous system regulates different functions of the body including black the heart rate.

C. RELATED WORKS

In this subsection the most recent related tools in market and presented by the scientific community are introduced. Not many available devices are capable of detection of both toxic/hazardous gases and sound levels simultaneously. The majority of the devices provided in the market are single task measurement in the area of noise detection and toxic/hazardous gas evaluation [32]–[42]. These devices are more portable than wearable. Although the resolution and accuracy in most cases are satisfactory and reliable but high cost of these devices make them more suitable to be used in industry and special chemical institutes and laboratories. The size and weight of these tools (form factor) avoid them to be applied for personalized ambient monitoring. However, the single-task mode of the tools is a huge obstacle from the pervasive aspect of monitoring. From the scientific community, relatively many prototypes have been implemented. Nevertheless, these tools are more focused on air pollution (gas detection) with limited applicability. More often the crowd sensing and context sensing methodology are utilized. The devices presented in [43]–[48] are wearable devices (wrist-worn, waist-worn or portable) for the detection of up to two gases (O3, VOC, CO, NO2 etc.). The evaluated data are sent to a smartphone for monitoring. Lack of data storage in BLE disconnected status and display for real-time data monitoring, fixed structure, predefined parameters monitoring, short-time ambient monitoring, lack of flexibility in terms of device configuration, form factor and user convenience are the typical bottlenecks in this area of research due to form factor, wearability, and as well as power consumption. These devices are taken into consideration in the comparison section of this work. These wearables are evaluated in terms of performance, power consumption,and features with the proposed prototype, presented in this work. To the best of our knowledge, there are 2 prototypes presented by Massachusetts Institute of Technology(MIT, USA) and Rostock University (Center for Life Science Automation, Germany) that measure both sound levels and hazardous gases, each with its own features and specifications. Fletcher *et al.* [49] presented a waist-worn device with capability of measuring two hazardous gases, sound level monitoring and physical ambient parameters (air temperature and humidity). This device (called Eco-mini) does not support real-time data monitoring and can only store the data in a SD external memory. The logged data are transferred to a PC for observation.

Haghi *et al.* [50] introduced a multi-tasking wrist-worn device for personalized environmental parameters monitoring. MLMS-EMGN-4.0 measures 3 major parameters including physical ambient parameters (air pressure, humidity and temperature), one hazardous gas at each time, sound level detecting and motion tracking as well. The device is connected to a smartphone for real-time data monitoring and data are monitored on a display, as well.

In [51] a multi-tasking wrist-worn device is presented. Although this wearable environmental monitoring system (WEMS) does not measure sound level, but it is capable of measuring three gases (SO_2, NO_2 *and* O_3) and UV in addition to temperature and humidity. The device monitors the sampled data on a display and transmit them through BLE to a smartphone. The most recent and relevant prototypes in this area of research are taken into consideration for a wide range of comparison in TABLE 2.

In the recent years obviously ambient monitoring by the wearables have been an interesting field for the researchers to work on. In spite of designing the variety of wearables and improvement in this topic, the majority of works are concentrated on the gas detection and calibration. The lack of a new trend in parameters combination is getting more important where the importance of the ambient parameters on the health is clear. However, even the wearables and portable prototypes suffer from the serious lack of some essential features that users demand. With great improvement in semiconductor technology, sensors, integrated and optimized systems, individuals' trend is shifting toward real-time monitoring, mode of wearability, multi-tasking, comfortness, prolonged monitoring, standalone operation and low price. In this work, we are going to overcome on these challenges, issues and the problematic technical bottlenecks by introducing a physical approach that may accomplish what user demands.

D. CONTRIBUTION

This wrist-worn prototype is an improved version of MLMS-EMGN-4.0 and 4.1 introduced in [9], [10], and [50]. In designing the improved version, the hardware flex interface has been replaced with a more compact deisgn, and the wire connection to the display has been removed. Furthermore, the gas sensor driver is enhanced in gas sensor signal detection and resolution. The changes of the previous version also include the substitution of the battery with a higher capacity coin cell battery in a battery holder which makes the new prototype more wearable and easier to handle.The device measures, collects and transmits the physical (sound level, air pressure, air humidity and air temperature) and chemical (NO_2, CO *and* SO_2) parameters, during wearer daily activities. This paper concentrates on proof of concept for a wearable in 5 physical layers, and describes its features and specifications. Data logging in an external memory, sensor selection and device configuration via BLE command from smartphone, power consumption evaluation, and adjustable sampling rate of the sensors according to battery level are the main topics discussed in this work. The architecture, structure and data packet transmission are evaluated as well. Furthermore, data validation, practical usage and experimental results are provided. To the best of our knowledge, this is the first time that a wrist-worn ambient parameters monitoring is configured through smartphone command. This feature brings the flexibility in term of adding a greater number of sensors and prolonged monitoring by activating/deactivating of the sensors. By implementing the configuration feature, the complexity from the hardware is gradually moved to the software side. All physical layers (except the host platform) have been designed and implemented in center for life science automation (Celisca, 18119 Rostock, Germany). The main contributions of this paper are:

1) FLEXIBLE, EFFICIENT AND USER-FRIENDLY DESIGN

An innovative concept of physical approach is described. The concept is grown up by designing, developing and implementing the prototype. This new physical approach is based on building of physical layers (PCBs) on top of each other. This approach allows, an efficient space usage while size and weight (form factor) as the serious challenges in wearables design are under control.

2) MULTI-PARAMETER MONITORING AND SENSORS COMBINATION

Based on this approach, a multi-tasking (parameters combination) wearable is implemented for pervasive ambient parameters (physical and chemical) monitoring.

3) SENSOR ACTIVATION/DEACTIVATION AND CONFIGURATION

The proposed prototype can be configured via sending commands from the smartphone. As majority of the wearables and portable devices in environmental monitoring are single task with fixed predefined mission, this might be a revolutionary approach in this domain for further developments.

4) PROLONGED MONITORING

To extend the battery life as a crucial aspect of wearables, the technique of sensor sampling rate according to the battery level is applied. The effect and efficiency of this feature on the power consumption and number of samples to be logged in the external memory are investigated.

5) FORM FACTOR

The replaceability of gas sensor layer is also a special feature of this design. This specification directly improves the form factor, wider range of monitoring and battery life time.

The rest of this paper is organized as follows: in section (II) the concept, architecture and visualization of the proposed device are discussed. In section (III) the realization and implementation of wrist-worn prototype are described. Sensor activation/deactivation and device configuration are explained in section (IV). The power consumption, data logging in the external memory, adjustable sampling rates for gas sensor and sound level detector are discussed in detail in section V. Data validation, calibration accuracy and experimental results are presented in section VI, prior the conclusion.

II. CRITERIA AND REQUIREMENTS

As was discussed in the related works section, a multi-parameters monitoring device with an efficient form factor for prolonged monitoring is highly demanded. A flexible and user-friendly device that is conveniently carried by individuals and does not interfere with typical daily activities. This device should enable safe data acquisition under any situations to avoid data loss. In the design of such wearables, we are seeking of a solution to include the typical wearables' advantages and eliminate the weaknesses. To the best of our knowledge the most important and vital criteria and requirements which accomplish both technical considerations and user demands are summarized as:

1) PERVASIVE MONITORING

One of the main obstacle which makes the users to deny wearing the ambient monitoring devices, is single-tasking tools that interfere with the daily routine activities (form factor). The comprehensive ambient monitoring, demands wearing several single-task devices that may not be affordable and convenience. Therefore, in designing the proposed device, three types of parameters are evaluated during the measurements:

- ambient physical parameter including sound level, air pressure, humidity, and temperature.

- chemical ambient parameters such as qualitative and quantitative detection of CO, SO_2 and NO_2 but not restricted only to these three gases.

- Motion tracking for daily user's activities to uniquely identify each spot air quality (at the moment raw data are collected on the smartphone. The algorithm for user distance tracking during wearing the prototype is under development).

2) DATA ACQUISITION AND ANALYSIS

This wearable is supposed to operate as a personalized ambient parameters monitoring, thus, data collection and further analysis is necessary (personalized data base). This aim is achieved via data transmission from the device to a smartphone by means of BLE (short-distance transmission). Consequently these data are transferred to a server for permanent storage through Wi-Fi (long-distance transmission).

3) STANDALONE (INDEPENDENT OPERATION)

A personalized data base is created if and only if the smartphone is available and the communication channel is established between the wearable and the smartphone, otherwise the data are lost. Standalone operation could significantly improve the proposed device applicability. It is a part of technical solution to still observe and collect the data on real-time while the BLE is disconnected and smartphone is not available. In this case, an external memory and display utilization allocate the independent operation to the device. Furthermore, a modular design may improve the efficiency of the device. Each physical layer including a sensor is not the function of other layers. As the result, each layer may be removed from the prototype without interruption to other sensors;

4) WEARABILITY

A light-weighted and small wrist-worn device is highly desired. The wearability is one of the necessary criteria in wearable convenience and is strictly the function of form factor. The form factor itself, is the function of general design strategy. To achieve the ideal form factor, the general strategy of the proposed wearable must be based on a careful hardware design and efficient software implementation. MLMS approach is utilized to contribute in wearability effectively. Although, the presented prototype in this work, is designed as a wrist-worn, but might be used as a waist-worn or portable wearable as well.

5) FLEXIBILITY (DEVICE CONFIGURATION AND SENSOR SELECTION)

In particular, the proposed device can be widely applied to healthcare and ambient monitoring. But these two areas are not the only applications, it may cover the range of smart home [52], smart city [53], agriculture [54], chemical and life science automations as well [55]. As a result, the target users of the proposed device are not limited. This device may be worn by anyone from any working type. Each area needs its own parameters monitoring in chemical parameters. With this regard, the prototype is designed to be used ''by anyone in anywhere for any parameter evaluation (covered by the device)''. To do so, the proposed device must be capable of

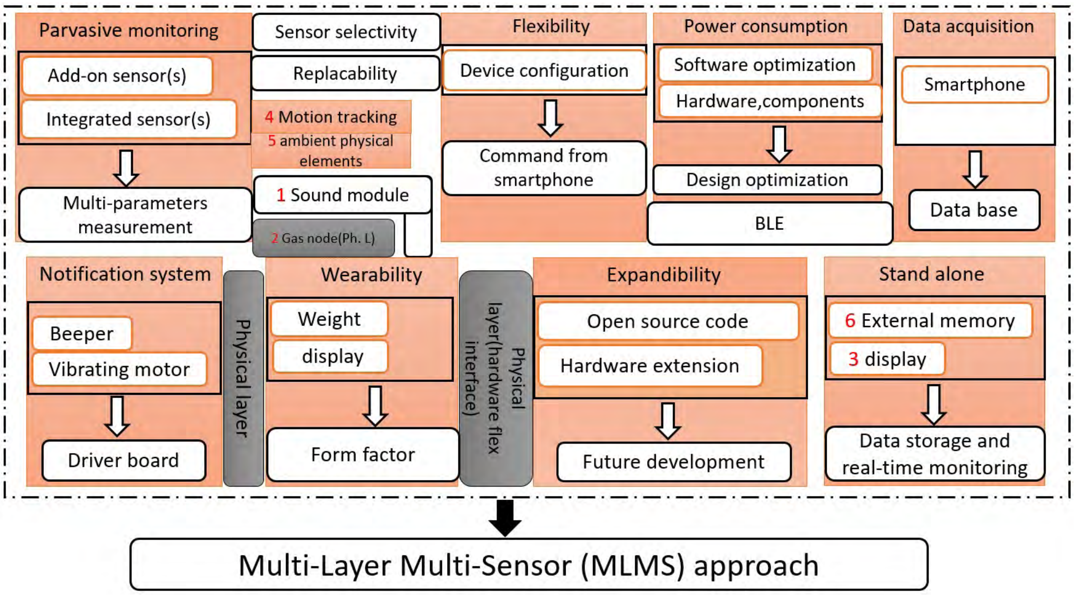

FIGURE 1. **The concept, criteria and requirements of the proposed wearable.1,2 and 3 are linked to the hardware flex interface. 4,5 and 6 are integrated and utilizing the I2C communication protocol. NOTE: Ph.L : physical layer, gray blocks indicates on the physical connection between layers.**

configuration by the user. The configurability in conjunction with replaceability of the gas sensor node accomplish the multi-gas sensor measurement. There are different sensors ready to operate, but the decision is dedicated to the user to activate/deactivate the sensor.

6) PROLONGED MONITORING

Lower power consumption provides a reliable evaluation and larger data base with no interruption. In addition to battery capacity, efficient hardware design, sensor and electronics component selection, a careful device configuration and sensors' sampling rates can significantly extend the battery life and the monitoring period. In this work, as the battery level is reduced, the sampling rate is reduced too.

7) NOTIFICATION SYSTEM

The healthcare systems are working toward prevention and predictability (*P health*). Thus, ambient parameters are monitored to protect the individual by preventing the user from dangerous situations. A notification system is absolutely required early user notification in abnormal status. In particular, in gas detection such CO, that does not have a smell or flavor and high exposure concentration can lead to death. A notification via beeper and vibrating motor is implemented in the prototype.

8) EXPANDABILITY

Technologies and demands are continuously changing toward enriching the quality of life. Thus, in design, it is considerable to keep the window of development open. The wearable has the potential of being developed in future (hardware). The number of pins and relatively adequate space are reserved for add-on sensor(s) and module(s). This feature is granted by implementing a hardware flex interface as the heart of this wearable (see Fig. 1).

The criteria discussed above are the fundamental factors of proof of concept. To achieve each aim, there are several requirements that must be considered at the same time. There are mutual factors between each two criteria, also there are intersections. At some points, there are more than one common point between more than one requirements. Hence, to design a standalone wearable and prolonged monitoring, features of data logging, real-time data monitoring, configurability and adjustable sampling rate, are considered as well. All these aspects are discussed at the following subsection in detail.

A. THE PROOF OF CONCEPT AND ARCHITECTURE

Design and implementation of the wrist-worn with the described features and specifications requires a specific concept and approach. To ease of use, avoiding timing conflicts, safe data sampling and efficient pin utilization, a centralized data processing with distributed sensors in wire communication is used. For an efficient form factor and user convenience, in spite of conventional wearables, the $X-Y$ plane is not extended for sensor placement and device development. Instead, Z axis is extended from both sides for sensor utilization, feature implementation and specifications accomplishment. In this approach, each layer is designed and dedicated for a specific task. The layers are stuck on top of each other and Multi-Layer Multi-Sensor (MLMS) approach is created for the wearables. In this approach, the common pins are shared through a board to board connector and this connector also links the layers in a firm way (see Fig. 3). To utilize this concept, some serious concerns are addressed. To make this approach feasible, the operational sensors are categorized in two general groups and each, due to limited number of pins and space, use one of the two general protocol communications. Due to limited number of pins and multi-parameters and standalone operation (external memory and display also require additional pins), the efficient methodology is to share the I2C bus as the fundamental wire communication protocol in this approach:

- Integrated sensors (I2C)
- Add-on sensors (ADC)

According to this sectioning: from one side, Physical air evaluation sensors including air pressure, air humidity and air temperature, and from the other side, motion trackers with three gyroscope, magnetometer and accelerometer sensors are sharing I2C bus with each specified sampling rate. In addition to these integrated sensors, the display also uses I2C communication protocol. Sound module as an add-on sensor utilizes ADC. Gas sensors are add-on sensors using both I2C and ADC. This is described in detail at the following sections.

B. REALIZATION AND LAYERS' DESCRIPTION

The concept of MLMS was clearly stated in the previous subsection. In the approach each layer is designed for a specific task and these layers are located at the top of each other through board to board connector. To the best of our knowledge, this prototype is the first-of-its -kind. The layers specifications and functions are described as the followings (see Fig. 2):

- Host platform: is the only off-the-shelf physical layer in this prototype. This tiny host platform has to be capable of extension in both directions of *Z* axis. BTL3H3 from iProtoxi powered by nrf51822 microcontroller, with the integrated motion trackers and ambient air physical sensors as well as external memory that all share two I2C1 and I2C2 bus, is a proper selection for this approach [56].
- Gas sensor node: one of the major concentration of this proposed device is toxic/hazardous gas detection. The gas sensor node includes gas sensor and gas sensor driver, is located at the top of the proposed device for ease of gas exposure. Care must be taken that, an universal gas sensor driver is designed to be compatible with different 3-lead gas sensors. As a critical aspect, sensor selection is playing an important role in device form factor. After a comprehensive investigation, Spec gas sensor is selected for using in this device. Power consumption, resolution, response time, recovery time and size of the sensor are taken into consideration in sensor selection [57].

  To design a gas sensor driver, LMP91000 with a micro power consumption and complete Front End Amplifier (AFE) solution is utilized to amplify and converts the output signal of the gas sensor and feed it to the Analog to Digital Converter(ADC) [58]. Two filters for output signal, an external resistor for gain adjustment, enable pin and a board to board connector are included in the gas sensor driver as well. This driver with its current shape is compatible with all gas sensors from Spec family. The sensor and driver are soldered and considered as one physical layer (see Fig. 3).

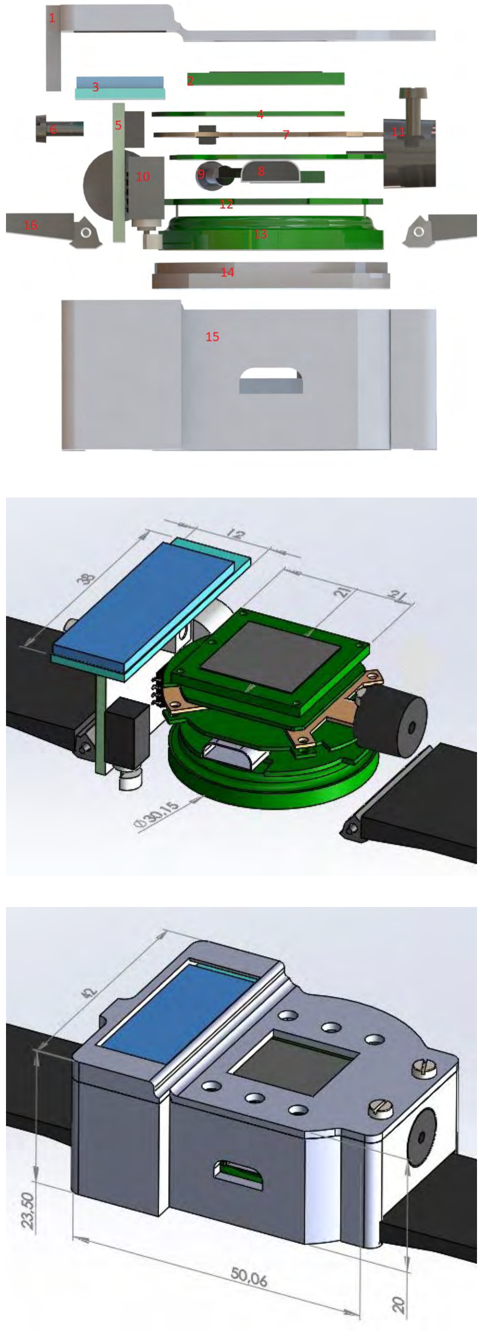

FIGURE 2. Graphic design of device in solidwork, layers, components and case. (1): top part of 3D housing, (2): gas sensor, (3): display, (4): gas sensor driver, (5): sound module, (6): screw of 3D housing, (7): hardware flex interface, (8): host platform and charging USB, (9): on/off button of 3D housing to the host platform, (10): vibrating motor, (11): screw of 3D housing, (12): battery holder, (13): coin cell battery, (14): bottom part of 3D housing to cover the battery, (15): the main part of 3D housing to hold the prototype, (16): bracelet.

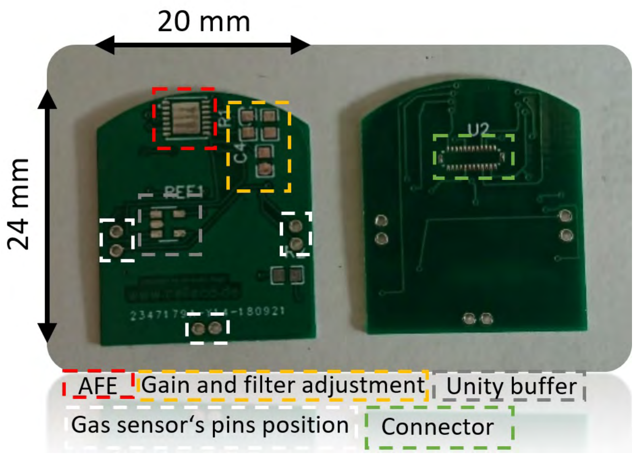

FIGURE 3. Printed circuit board(PCB) design of gas sensor driver.

- Notification system: for individual warning in abnormal status, a notification system is designed. Both haptic and sound alert through vibrating motor and a beeper respectively are implemented. To activate the beeper and vibrating motor a notification driver board is implemented and located at the bottom of the proposed prototype. The notification driver is activated in two abnormal status (low and high frequency) according to the degree of risk caused by gas concentration.
- Hardware flex interface: this physical layer facilitates the display and sound module connection to the host platform. The hardware flex interface is located between host platform and gas sensor node and links the sound module and display through the pinned tail to the host platform. Furthermore, it is used to reserve additional pins for future development (see Fig. 4).

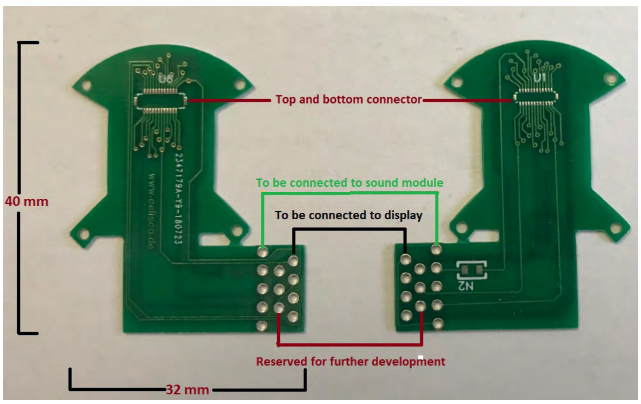

FIGURE 4. The top (left) and bottom (right) of hardware flex interface.

- Battery and holder: the battery holder including a coin cell battery (ca: 300 mhA) is the lowest layer [59]. The battery holder is soldered directly to the host platform and holds the battery by surrounding it (see Fig. 5).

Gas sensor node is the layer that has a specific design in order to reach Multi-gas monitoring. The multi-parameters monitoring is supported by the replaceability and configurability.

- Replaceability: from the design and implementation prospective, the only possibility to monitor several parameters and still keep the solution compact, is a replaceable gas sensor node. The gas sensor node is readily replaced by another gas sensor node and is configured to the desired gas sensor through sending a command from the smartphone by user. Two advantages are addressed by this feature:
  1-This proposed device is intended to be used in wide range of applications, therefore, the user from different categories are able to use the target gas sensor according to the condition and environment.
  2-This capability, avoids unnecessarily operation of several gas sensors simultaneously that in consequence lead to higher power consumption and larger device.
- Configurability: the only methodology to activate the gas sensor in replaceable mode and avoid gas sensor timing conflicts is configuring the sensor via commands from the smartphone. The gas sensor activation (selection) is extended to the other sensors and display, as well.

III. DEVICE CONFIGURATION AND SENSOR ACTIVATION

MLMS-EMGN-5.1 operates in two general statuses. The working strategy is according to the BLE status (connected/disconnected) (see Fig. 6).

- BLE is disconnected:
  When BLE is disconnected, MLMS-EMGN-5.1 is set to standalone mode automatically. Thus, the display is turned on for real-time data monitoring and external memory is initialized for data logging. By default, all sensors (ambient air physical and chemical and motion trackers) are initialized and start sampling based on the fixed sampling rate of 50Hz for motion trackers, 0.2 hz for gas sensor, 1hz for ambient air physical and 2 Hz for sound module. To avoid data loss, gas senor values and sound levels are stored in the external memory (Algorithm 1). The capacity of the external memory is 256 kB. Wherein the battery life and number of samples that can be logged in the external memory in standalone mode are critical, the logging time is measured for the initial sampling rates of the sensors. For sound level detector:
  $data\ length\ in\ each\ sample = 3B$
  $for: \ \ sampling\ rate = 2hz;$
  $number\ of\ samples\ in\ one\ minute = 120;$
  Therefore:
  $number\ of\ bytes\ in\ one\ minute\ sampling = 360;$
  The same calculation for gas sensor shows that:
  $data\ length\ in\ each\ sample = 3B$
  $for: \ \ sampling\ rate = 0.2hz;$
  $number\ of\ samples\ in\ one\ minute = 12;$
  Therefore:
  $number\ of\ bytes\ in\ one\ minute\ sampling = 36;$
  The summation of stored bytes for gas and sound module is 396B.
  $Total\ time\ of\ data\ storage: \frac{256K}{396} = 10.77\ hrs$

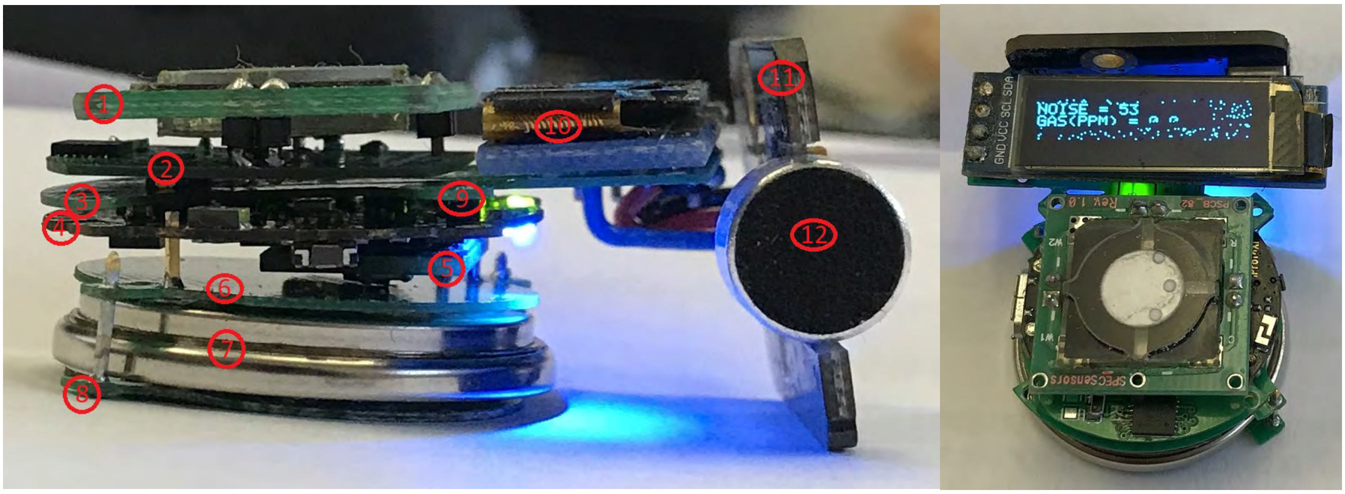

FIGURE 5. The assembled MLMS-EMGN-5.1. First layer (1,2): gas sensor, gas sensor driver. Second layer (3,9): hardware flex interface, tail of hardware flex interface. Third layer (4): host platform. Fourth layer (5): notification system driver. Fifth layer (6,7,8): negative and positive pole of battery holder, coin cell battery. (10): display, (11): sound module, (12): microphone. Dimension, altitude: 20 mm, length: 40 mm, width: 39 mm.

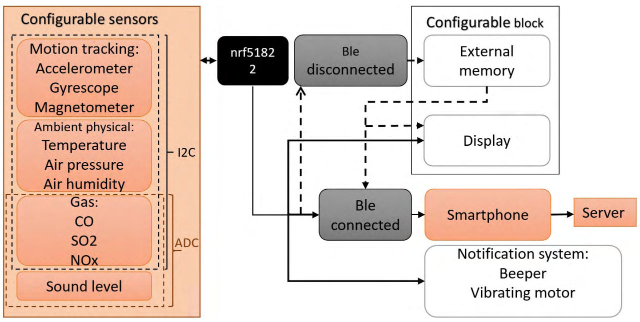

FIGURE 6. The general strategy of the prototype operation.

We will see that he sampling rate is reduced according to the battery level. Thus, as this calculation was based on the maximum sampling rate, the minimum calculated time of data logging for the external memory is guaranteed.

- BLE is connected:
In configuration mode, when MLMS-EMGN-5.1 and the smartphone are connected, by default device is configured to display off due to possible data observation on the smartphone. However, the display can be switched on by the user via sending a command from the smartphone (pressing the button on the application). On the other hand, the motion trackers and ambient air physical parameters are on operation. The air physical parameters are measuring as these are important in gas sensor calibration. At the same behavior, motion tracker sensors also are utilized during the daily activities for some area and space analysis. If all available sensors plus display in the proposed device are considered as the following:
$Sensor/Display\ collection \ni \{G, S, M, HPT, D\}$
where:
$G(Gas\ sensors) = \{G1, G2, ..., Gn\}$
$M = \{Gyrescope, Magnetometer, Accelerometer\}$
$D = Display$ and $S = sound\ module$
In this work $G = \{NO_2, CO, SO_2\}$
From these sensors, motion trackers and air physical sensors are excluded from sensor activation, thus:
$configurable\ parameters = \{G, S, D\}$
At each time from G_1,G_2 and G_3 only one can be selected in combination with sound level detector and display (see Fig. 7). There are following potential configurations:
$potential\ configurations = \{G_1|G_2|G_3\}\{D\}\{S\}$
$\{G_1|G_2|G_3, S\}\{G_1|G_2|G_3, D\}\{D, S\}\{G_1|G_2|G_3, S, D\}$
These data are sent through 4 packets (motion tracking, ambient physical, noise and gas), each with its own structure. The length of gas and noise packets is 4 bytes including sequence, ID and value. Motion trackers are sending a 19 bytes length packet and the ambient physical parameters packet is only 12 bytes length. The two way communication protocol and packet architecture are illustrated in Fig. 7.

As was mentioned, when BLE is disconnected the data are logged in the external memory. Whilst the communication channel is resumed, these data are retrieved for permanent storage. To prevent interference with normal data transmission, a button is implemented on the smartphone's application for logged data transmission. The user is fully authorized to transmit the logged data at any time that is appropriate according to his/her decision. The "gasnoise" command in Algorithm [1], indicates on pressing both gas and noise button. Under this condition, both gas sensor and noise module are on operation according to the specified sampling rate (see Fig. 9).

IV. POWER CONSUMPTION, ADJUSTABLE SAMPLING RATE AND EXTERNAL MEMORY

A. POWER CONSUMPTION EVALUATION

The prolonged monitoring always is a critical aspect of wearable design. In particular, in MLMS-EMGN-5.1 with different sensors, a careful design in both hardware and software

Algorithm 1 MLMS-EMGN-5.1 Configuration

```
The device is configured by the smartphone. By pressing predefined
buttons on the smartphone the user decides for the sensor(s) and
actuator selection. NO2, CO, SO2, noise, display and datalog are the
buttons on the smartphone.
Result: Write here the result
S_n1 ← sampling rate(noise);
S_g1 ← sampling rate(gas);
if BLE is disconnected then
    display is initialized();
    display starts();
    external memory is initialized;
    disply ← "BLE is disconnected"
    noise module is initialized();
    LMP91000 is initialized();
    LMP91000 is configured by default to CO();
    S_n1 is set;
    S_g1 is set;
    noise module starts();
    gas sensor starts();
    return noise;
    disply ← noise value
    external memory ← noise
    return gas;
    display ← gas value;
    external memory ← gas
end
else
    if CMD ← display then
        display is initialized;
        disply starts();
        disply ← "BLE is conncted"
    end
    if CMD ← gas then
        LMP91000 is initialized;
        LMP91000 is configured to gas
        gas is calibrating;
        return gas
        display ← gas;
        BLE ← gas
    end
    if CMD ← Noise then
        Noise module is initialize
        noise module start sampling
        return noise
        display ← noise;
        BLE ← noise;
    end
    if CMD ← NoiseGas then
        both procedure of noise and gas are done
    end
    if CMD ← DataLog then
        BLE ← data are read from external memory and send
    end
end
```

is important. In this section the power consumption for each sensor is separately measured to evaluate the efficiency of the approach, after the design implementation and hardware assembly. Motion trackers, ambient air physical parameters, gas sensor, sound module, and display are assessed in power consumption. The effect of external memory in disconnected status and BLE in connected mode on battery life also is measured. To determine a baseline for current consumption, motion trackers and physical air integrated sensors which are frequently operating in high frequency ($50hz$ and $1hz$) are considered at the first stage. The current consumption of these sensors is less than 5mA and 6mA respectively (including all start up operating of platform). When the first and second group of sensors are operating at the same time, some over lapping is observed. The high peak of current consumption in the second segment is due to the summation of motion trackers and environmental physical parameters every 1 second. The thirst section in the figure indicates the display operation. The display is initialized with each sound level module monitoring (due to higher sampling rate rather than gas sensor). The swinging current consumption between 6 and 8 mA is caused by the reinitialization. The gas sensor evaluation is depicted in the forth segment. During this period the display is switched off but two first groups of sensors are on operation. The peaks with the largest amplitude are seen every 5 seconds. The variable values at the gas sensor peaks is due to synchronization with motion trackers and ambient air physical parameters. The maximum of the peak occurs when all sensors from the segment 1 and 2 and gas sensor measurement are synchronized. In green part, sound level module is evaluated along with first two groups, while gas sensor goes off. Due to 2 Hz sampling rate of sound level detection, the summation with first and second group may occur every 0.5 and 1 second respectively. Before the communication channel is established, all sensors and the display are switched on for current consumption evaluation. Care must be taken that, the external memory power dissipation is embedded during sound level detector and gas sensor observation. The last part of power estimation is dedicated to BLE connection while all sensors and the display are working. As it is observed the maximum current consumption is 15.8 mA. This is reached every 5 seconds, when all sensors are synchronized with gas sensor which has the lowest sampling rate (see Fig. 8). However, to calculate the battery life time in worst case, we have:

$$Total\ power\ consumption = \frac{300}{15.8} \cong 19\ hrs$$

B. VARIABLE SAMPLING RATE ACCORDING TO BATTERY LEVEL

In this subsection, a technique is applied to improve the battery life. As a obvious point, the battery life is directly a function of the sensors sampling rates. Due to accuracy of motion tracking, changing the motion tracking sampling rate is not suitable. On the other hand, physical ambient air sensors are consuming less than 1mA. So in this case also, reducing the sampling rate does not significantly decrease the power consumption. Sound module and gas sensors are two candidates for sample rate adjustment. Nevertheless, the sample rate adjustment does not apply in the way that the accuracy and environmental elements evaluation are sacrificed for the long-time monitoring. As it is depicted in Algorithm 2, the battery level is divided into four areas and each, is reduced by 20% and the area of the last zone (0-40%) is twice. The sampling rate for both gas sensor and noise is reduced accordingly but in different rates. As the sound is generated instantly, the noise sampling rate is much higher than gas sensor:

$$Battery\ level = \{L_i\} \quad \text{and } i = \{1, 2, 3, 4\};$$

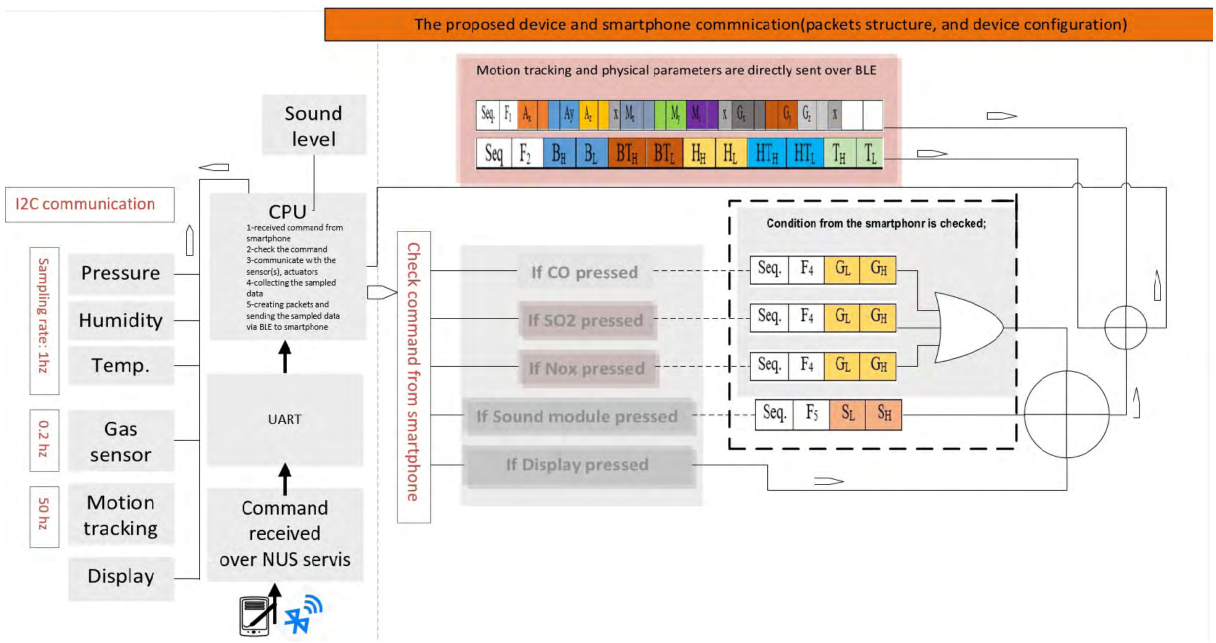

FIGURE 7. The data communication between the wearable and the smartphone, packets structure and command transmission.

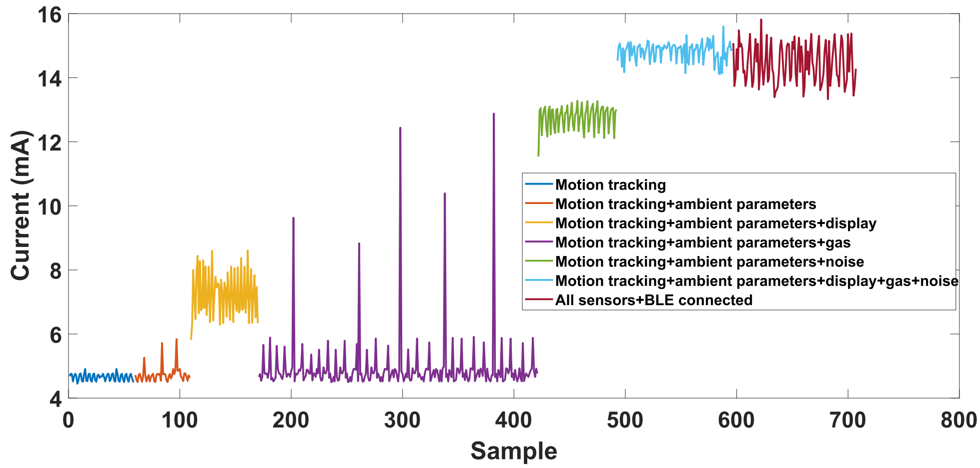

FIGURE 8. The total current consumption of MLMS-EMGN-5.1 in connected/disconnected status.

where L_1 is the level of battery between 80% and 100% and L_4 is the level of battery for less than 40%. Each level is reduced by 20%.Then:

$$sampling\ rate = \frac{4}{2^i} \tag{1}$$

The same calculation is implemented for gas sensor sampling rate but in higher sampling reduction.

$$sampling\ rate = \frac{1}{5 \times i^2} \tag{2}$$

Gas measurement in higher time intervals does not affect the device accuracy significantly where in the worst case, still we have 1 ambient gas evaluation in 40 seconds (this sampling rate is acceptable while the gas sensors response time is 15 s). The battery life time extension depending on the sampling rate can be calculated according to equation (3):

$$I_{Total} = \sum_{i=1}^{6} I_i = \begin{cases} I_M + I_{HPT} + I_D + \underbrace{I_G + I_N} + I_{E.M.}, & \text{BLE dc} \\ \underbrace{I_M + I_{HPT} + I_D + I_{BLE}} + I_G + I_N, & \text{otherwise} \end{cases} \tag{3}$$

During the calculation, the worst case is considered. Between the BLE connected and disconnected status, when the communication channel is established more power is dissipated, thus the second case is taken for calculation. To evaluate the

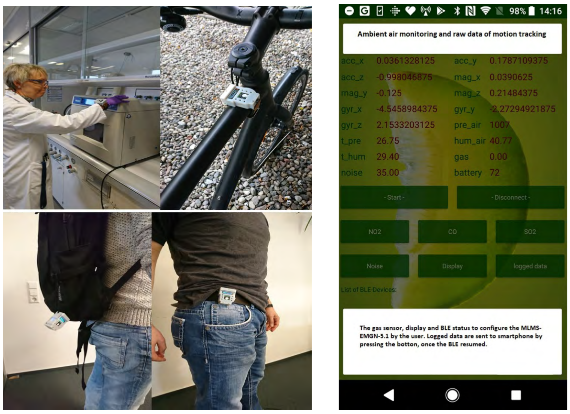

FIGURE 9. **Different wearability modes of MLMS-EMGN-5.1 (left) and application (right).**

effect of sampling rate, the basic power consumption in the lack of gas sensor and sound level module is defined as:

$$I_{base} = I_{Total} - \{I_G + I_S\} \tag{4}$$

The average current consumption of the prototype for the sensors and display excluding the gas sensor and noise is approximately 9.1 mAh (BLE is connected). This average for gas sensor and sound level detector is 2.2 mAh (14%) and 4.5 mAh (28%) respectively. This statistics indicates that 42 % of current is consumed by these two sensors. Thus, the theory of battery level and sampling rate adjustment can significantly reduce the power consumption. The correlation of battery level and sampling rate regarding current consumption is calculated as follows:

$$current\ consumption(noise) = 4.5 \times \frac{4}{2 \times 2^i};$$
$$current\ consumption(gas) = 2.2 \times \frac{1 \times 5}{5 \times i^2};$$

where: $i = 1, 2, 3, 4$; for $L_i = battery\ level$.

The coefficient of 4 and 5 at the above equations are to make the calculation straight forward and does not affect the final results. From the equations (5),(6),(7) and (8) the average current of 4 zones for gas and noise is extracted.

$$I_{Gi} = \sum_{i=1}^{3} \left(\frac{1 \times 5}{5 \times i^2} \times 2.2\right) + 2 \times 2.2 \times \frac{1 \times 5}{5 \times i^2 (i = 4)} \tag{5}$$

$$I_{Gi\ Ave} = \frac{I_{Gi}}{5} = 0.65\ mAh \tag{6}$$

and for average current consumption of sound module is:

$$I_{Si} = \sum_{i=1}^{3} 4.5 \times \frac{4}{2 \times 2^i} + 2 \times 4.5 \times \frac{4}{2 \times 2^i (i = 4)} \tag{7}$$

$$I_{Si\ Ave} = \frac{I_{Si}}{5} = 1.8\ mAh \tag{8}$$

The total battery extension according to hours is calculated as:

$$Total\ battery\ life = \frac{300}{I_{base} + I_{Gi\ Ave} + I_{Si\ Ave}} \cong 26\ hrs$$

Algorithm 2 MLMS-EMGN-5.1 Sampling Rates

```
The noise and NO2, CO, SO2 sampling rates are variable according to
the battery level. Four battery levels are considered and as the level
is reduced the sampling rate decreases.
Input  : L_j ← battery level
         j = 1, 2, 3, 4;
Output: S_ni ← sampling rate(noise);
        S_gi ← sampling rate(gas);
where :
samplingrate(noise) = 4/2^i;
samplingrate(gas) = 1/(5×i^2);
i = 1, 2, 3, 4;
Reading the battery level is prior than sensor sampling;
read battery level();
if (80 ⪯ battery level ⪯ 100) then
    L_1 ← battery level;
    S_n1 ← sampling rate;
    S_g1 ← sampling rate;
    read noise;
    read gas;
end
else if 60 ⪯ battery level ≺ 80 then
    L_2 ← battery level;
    S_n2 ← sampling rate;
    S_g2 ← sampling rate;
    read noise;
    read gas;
end
else if 40 ⪯ battery level ≺ 60 then
    L_3 ← battery level;
    S_n3 ← sampling rate;
    S_g3 ← sampling rate;
    read noise;
    read gas;
end
else
    L_3 ← battery level;
    S_n3 ← sampling rate;
    S_g3 ← sampling rate;
    read noise;
    read gas;
end
```

The sampling rate of noise sensor is reducing in a sharper slope rather than gas sensor due to nature of each parameter. However, this may be adjusted depending on the application and requirements (Algorithm 2). Therefore, the battery life is extended by 29%, at least. Care must be taken that, the higher sampling rates of environmental air parameters and motion trackers which consumes even less power (higher weights) for reliable calculation were ignored.

C. EXTERNAL MEMORY

Sampling rate adjustment, directly influences the number of samples and consumed bytes and consequently the used space of the external memory. In the same manner, the total time that the samples can be logged in the external memory is calculated. The estimation of total time of data logging in the external memory become more important, especially when the proposed wearable is not supposed to be connected to the smartphone during a battery life cycle time (from full charge until it is empty). During this period, in order to avoid data loss the equation (9) must be always correct:

$$T_{data\ logging} > T_{battery\ life\ time} \tag{9}$$

To satisfy equation (9), the sampling rates of gas and sound sensors must be defined properly. The number of

TABLE 1. The data logging in the external memory.

Bat. Level	L1		L2		L3		L4			
Time (hrs)	3,8		5,04		5,73		12,24			
	Sample	Byte	sample	byte	sample	byte	sample	byte	% of used space	% of memory space
Noise	27360	82080	18180	54540	10320	30960	11016	33048	94	78
Gas	2736	8208	909	2726	459	1376	551	1632	6	5
Total	30096	90288	19089	57266	10779	32336	11567	34680	100	83

Total sample	71531
Total byte	214593

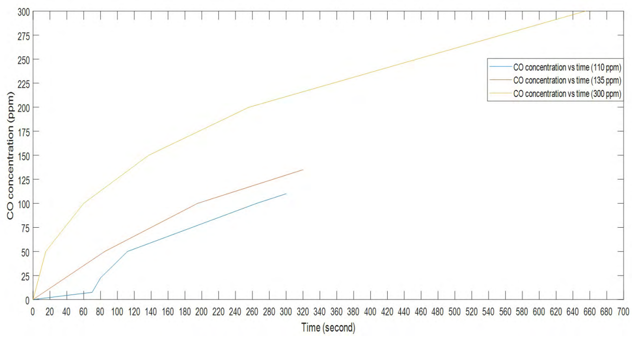

FIGURE 10. The *CO* response time for 110,135, and 300 ppm gas concentration exposure [50].

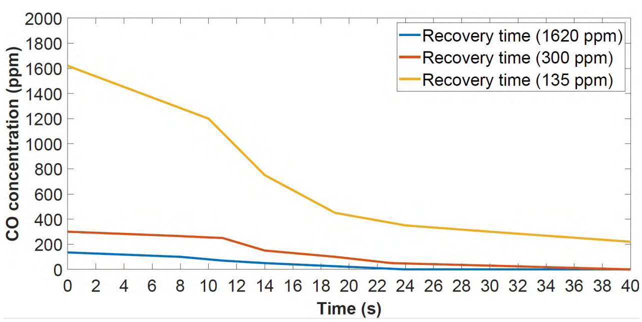

FIGURE 11. The *CO* recovery time for 135,300, and 1620 ppm gas concentration exposure [50].

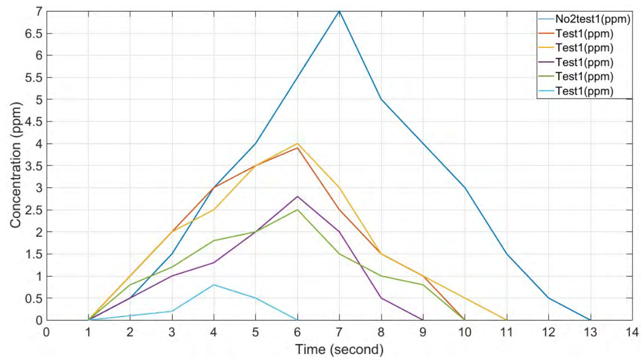

FIGURE 12. Response and recovery time of NO_2 test under the gas variant concentration during the realistic test.

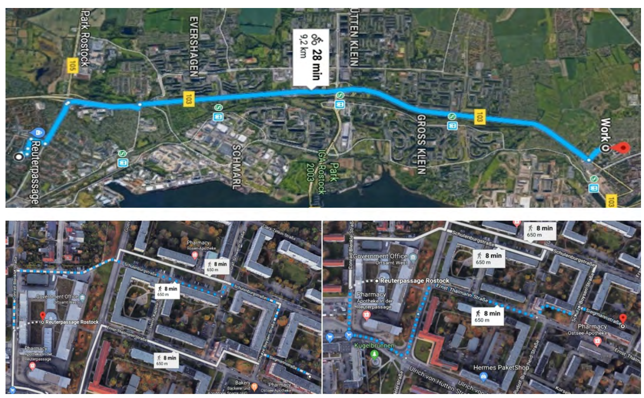

FIGURE 13. Route and the transportation mode during a realistic test.

collected samples for each sensor is different. As is seen in Table 4, the majority of the external memory is occupied by the noise samples. As long as the correlation of gas and noise sampling rates equation can maintain the equation (9), MLMS-EMGN-5.1 can collect the data safely. By application of this predefined sampling rate, 83% of the total external memory space is used. The sampling rate adjustment still might be changed according to the user demands and application requirements. To clarify the calculation, the battery level is divided into 4 portions and the lowest battery level (L_4), is twice of each level. In general 5 portions are considered and the last two (L_4) are summed due to the same category. However, this also can be discussed according to the user interests and application demands. With the first segment sampling rate, the battery level is in the first segment (80-100 %) for the total time of 3.8 *hrs*. The sampling rate is applied to second, third and fourth portions. Thus, the length of each period is 5.04, 5.73 and 12.24 *hrs* respectively that is longer than first segment.

D. COMPARISON

An extensive comparison of the MLMS-EMGN-5.1 and the previous version (MLMS-EMGN4.0) with the most popular devices in industry and also presented prototypes in academic is depicted in TABLE 2.

TABLE 2. Comprehensive comparison of the most popular environmental monitoring devices and MLMS-EMGN-5.1.

Device	Size(mm)	Weight(gr)	Wearability	Connectivity	Structure	Sensor replaceability	Display	Sound level
Gas sensor EVM [60]	26*26*50	NA	portable	BLE	flexible	no	no	no
TIDM-1CHP [61]	107.31*75.69	NA	waist-worn	no	fixed	two	yes	no
Gas alert extreme [32]	50*95*40	110	waist-worn	no	fixed	no	yes	no
MLMS-EMG-4.0 [50]	50*42*24	51.18	wrist-worn	BLE	flexible	yes	yes	yes
Eco Mini [49]	NA	NA	waist-worn	no	fixed	yes	no	yes
W-Air [43]	30*45	NA	wrist-worn	BLE	fixed	no	no	no
WEMS [51]	42*56*15	NA	waist-worn	BLE	fixed	no	yes	no
MLMS-EMGN-5.1	50*42*23	51.18	wrist-worn	BLE	flexible	yes	yes	yes

Temp., pressure, humidity	Motion tracker	Resolution(ppm)	Notification system		Device extendibility		Price ($)
			Vibration motor	beeper	Software	Hardware	
no	no	0.1	no	no	yes	no	599
no	no	0.1	no	no	yes	yes	NA
no	no	0.1	yes	yes	no	no	338
yes	yes	0.4 - 7.5	yes	yes	yes	yes	160
yes	yes	NA	no	no	no	no	Na
yes	yes	4.3 - 64 pbb	no	no	yes	yes	38
yes	yes	NA	no	yes	yes	no	NA
yes	yes	0.4 - 7.5	yes	yes	yes	yes	130

Battery length (hrs)	Sensor activation	Device configuration	Data storage	Adjustable sampling rate
CR2032-NA	no-manually	no-(manually)	no	no
USB-Battery	no-manually	no	no	no
1.5 years	no	no	no	no
15	time-schedule	no	no	no
950 mAhr LiPol-NA	no	no	yes	no
NA	no	no	no	no
2.5	no	no	yes	no
26	yes	yes	yes	yes

V. EXPERIMENTAL RESULTS

MLMS-EMGN-5.1 is a prototype with a flexible design and efficient form factor that is quite user friendly and may be utilized in wide range of ambient air monitoring (indoor/outdoor) applications. This prototype is intended to be used as a wrist-worn. But the appropriate assembly and 3D housing, support the waist-worn and potable modes as well. MLMS-EMGN-5.1 has been frequently tested (indoor/outdoor) for sound level assessment and chemical laboratories monitoring under different scenarios. Several groups of master students in biology and engineering, high school students, chemical laboratories technicians and individuals are the categories that successfully tested this prototype in a realistic environments under different conditions. At the following subsections, data validation and experimental results are provided to support the approach efficiency and the performance of the prototype.

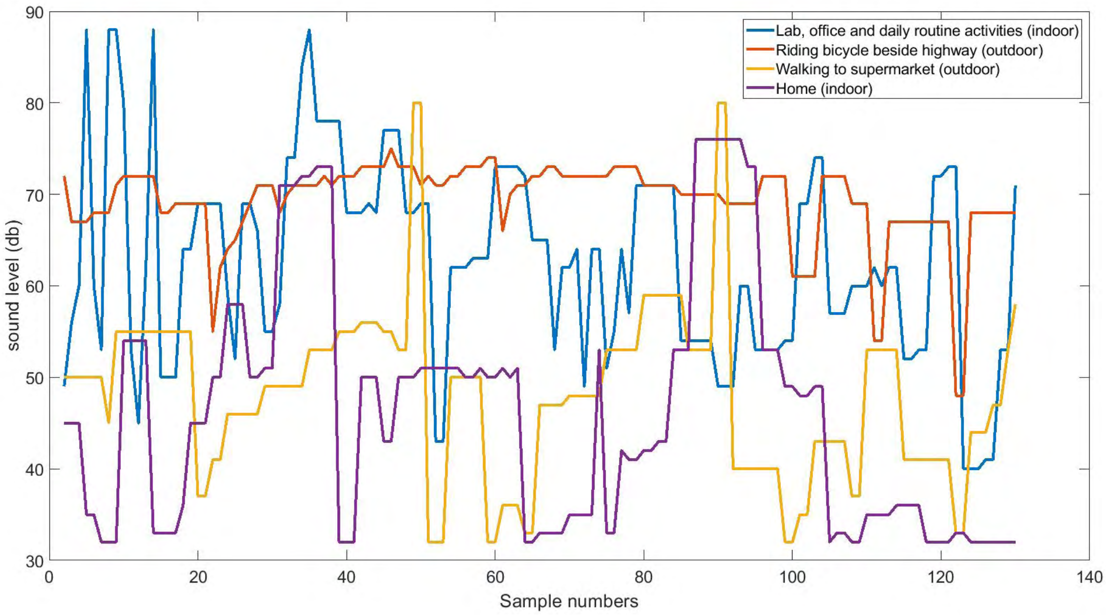

FIGURE 14. **The sound level test under typical daily activities of individuals (indoor/outdoor).**

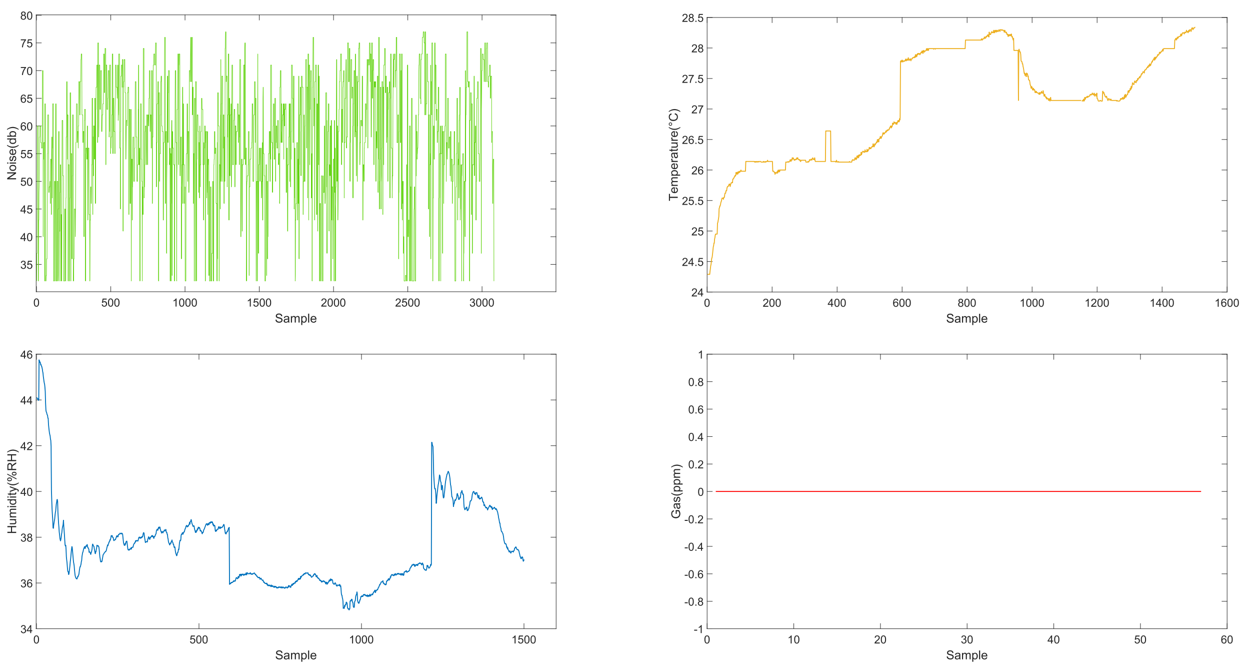

FIGURE 15. **The first day test (indoor/outdoor) and recorded parameters.**

A. PROTOTYPE ACCURACY MEASUREMENT AND DATA VALIDATION

Prior to indoor/outdoor evaluation, the prototype has passed a strict calibration for both gas and sound level detection. This short subsection is a brief introductory in data validation. Afterwards, the experimental results in realistic conditions are presented. The device introduced in [33], the well-known sound level detector, is the calibrator for noise assessment. The validation test was performed during 2 weeks, for several hundred times to guarantee the accuracy of the sound detector. The prototype and 2260 investigator were located at the equal distance from the source of sound and each time measured data were recorded to identify a reliable pattern. The reference distances were variable (10,20 and 30 cm) for the calibration, although the distance up to 1m also was considered for the accuracy adjustment.

TABLE 3. Sound level measurement and data validation [50].

R1=10 cm, R2=20cm, R3=30cm					
MLMS-EMGN-4.0	Calibrator	MLMS-EMGN-4.0	Calibrator	MLMS-EMGN-4.0	Calibrator
R1	R1	R2	R2	R3	R3
48	46.6	45	43.5	37	40
54	53.9	50	50.1	45	45.2
60	59.6	57	57.2	51	51.8
66	63	63	63	53	54.7
78	75	76	74	73	71.5

TABLE 4. *CO* measurement and data validation [50].

MLMS-EMGN-5.1(ppm)	45	67.5	105	115	150	302
Calibrator(ppm)	42	65	111	126	152	300

From the toxic/hazardous gases, CO and NO_2 data validation are presented. Gas alert extreme [32] device (Honeywell analytics, Canada) was the calibrator. The tests were demonstrated in laboratories where both proposed prototype and the calibrator were placed at the same container. The container was connected to the gas source with adjustable and measurable volume. The data collection, conversion,and calibration were demonstrated under the same conditions for different gas sensors with divers calibration factors (TABLE 3,4).

B. CARBON MONOXIDE AND NITROGEN DE-OXIDE EVALUATION IN CHEMICAL LABORATORY

Depending on the target gas detection, the gas sensor was placed and configured through the sending command to the prototype to start the initialization. During the tests in the chemical laboratories, it was worn by the technicians to measure the generated NO_2 and CO to protect the individuals from risky gas exposure [62]. These two sensors have quite different ranges of operations. In the experiments, NO_2 and CO are assessing in the range of 0-7 ppm and 0-1650 ppm respectively. Due to the nature of these gases, two threshold points are set for the notification system which are >2 ppm for NO_2 and >300 ppm for CO. Response time (sensitivity) of the sensor and the recovery time which indicates the required time to prepare the sensor for the next measurement are serious factors that were taken into consideration during the tests. The tests were demonstrated in indoor environment under realistic conditions.

C. SOUND LEVEL MEASUREMENT (NOISE) IN REALISTIC CONDITIONS

Environmental sound level evaluation is another major aspect of this work. After a careful prototype calibration in several hardware and software steps and data validation in comparison with the calibrator, the prototype is tested under realistic conditions during daily routine activities of individuals (indoor/outdoor). MLMS-EMGN-5.1 was carried by several

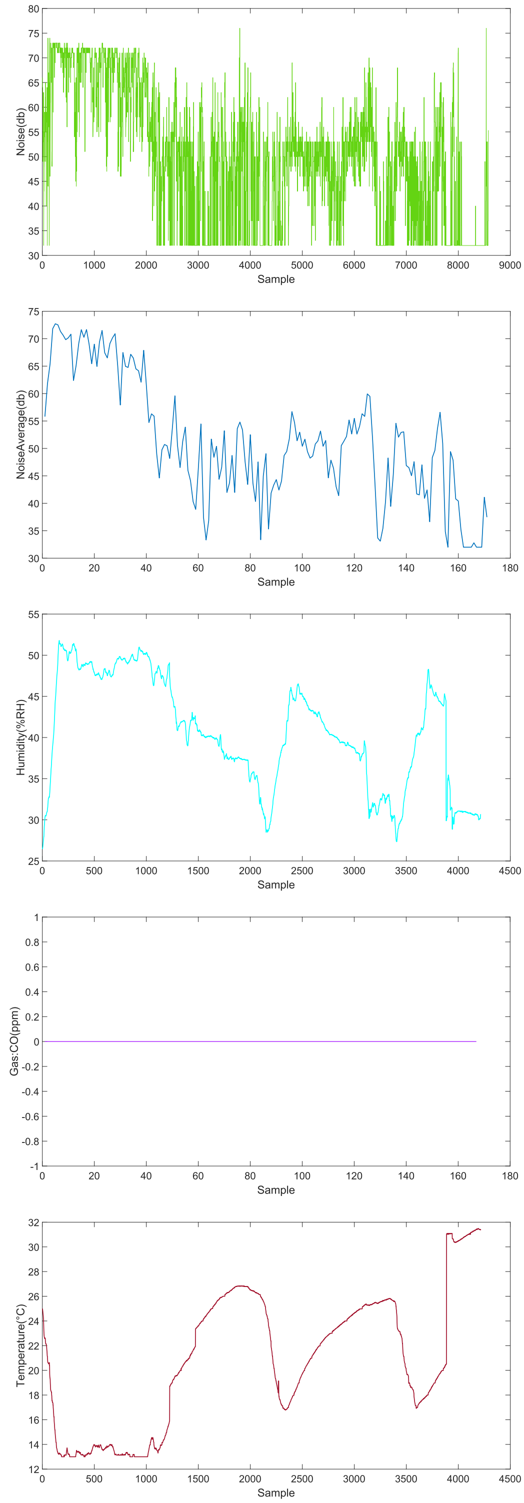

FIGURE 16. The second day test (outdoor/indoor) and recorded parameters.

users for several days. However, due to large generated number of data, only a limited data are shown in Fig. 14,15,16, to support the performance of the prototype. To differentiate the variation of noise levels in indoor and outdoor environment and to identify the efficiency of the prototype, one minutes sampling in 4 status of indoor/outdoor and walking/cycling/sitting and in general a daily routing of an individual are presented in Fig. 14. The presented data (see Fig. 15,16) show the results of two test days with two users under various conditions. The first day included user tests in an indoor environment for 8 hours. The test was started at 8:30 am and ended at 4:30 pm. The individual performed a typical daily activities in two floors, several offices and laboratories. The prototype was carried during the lunch time as well. The notification system's threshold was 70 db for > 1 hour exposure. User notification was activated at 11:30 am. A disconnection was experienced due to long distance between the smartphone and the sensor device. The display update between ''data logging'' and ''BLE is connected'' statuses was observed by the individual. The second day included tests in outdoor and indoor environment under three modes of riding bicycle, walking and being at home. The wearer carried the prototype for almost 30 minutes cycling, 20 minutes walking in streets to supermarket for shopping and 2.5 hours at home. 1 minute sampling from the first day and 3 minutes noise evaluation in second day (1 minute in each mode) are shown in Fig. 14. The data presented are the complete day test without specific parameters consideration. Temperature, humidity, noise and gas (NO_2/CO) are depicted in two general tests figures. The noise is swinging between 32 (the lower boundary detection of the prototype) to 80 db. In these tests no gas has been detected as was predicted. The results are from indoor and outdoor under different modes of transportation and various conditions and area of the city. For a clear perspective of the noise measurements, the average noise measurement also is added to Fig. 16.

VI. CONCLUSION

In this work a novel wrist-worn device for pervasive personalized environmental parameters monitoring was introduced. The wearable, utilizes Multi-Layer Multi-Sensor (MLMS) approach and each layer is dedicated to a special function. To connect the different layers and share the same buses, a board to board connector is used. MLMS-EMGN-5.1 operates in BLE connected and disconnected (standalone) mode. The smartphone independent operation is supported through real-time data monitoring by a display and data logging in an external memory. In addition, the logged data are transmitted to the samrtphone by pressing the button on the smartphone's application. This device consists of 5 physical layers including gas sensor node at the top and battery holder at the bottom. The other three layers are host platform, notification system driver and hardware flex interface. The hardware flex interface as the hearth of prototype, facilitates the connection of display and sound module to the host platform. Furthermore, the device is configurable via sending command from a smartphone. Another feature of MLMS-EMGN-5.1 is the prolonged ambient monitoring through variable data sampling according to the battery level. The battery levels are divided into 5 potions and as the level of battery is decreased the sampling rates of gas sensor and sound level detector are reduced accordingly. This device is capable of comprehensive environmental monitoring for 28 hrs(worst case).

FUTURE WORK

It is expected that in the future work, the algorithm for the motion tracking sensors which support 9 DoF is completed to observe a graphical view of user activities. Furthermore, a new design of hardware interface which include noise module and UV index sensor is under development that can significantly reduce the size of prototype. Integration of PM sensors and physiological parameter detectors (heart rate and skin temperature) are planning to be developed. In addition to hardware development, the data fusion with physiological sensors in server is under construction.

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