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Home Monitoring of Vital Parameters Using Intelligent Sensor and Storage Networks

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Abstract: The measurement and compilation of vital human data is of particular importance, as it opens up the possibility of supporting a person in their area of life and being able to provide information as to whether diseases are developing or, for example, the gait changes too much so that an early fall could be avoided. Volatile organic components analysis is very interesting possibility for detecting diseases in the home area in a very early stage. Older multimorbid people can also continue to live medically safely in their own home with the help of this supporting analysis of vital parameters and gait parameters, which is the aim of this home monitoring project. Here, the Harz University has developed components for a distributed sensor network for the spectroscopic analysis of air, step analysis and vital parameters collected by a standard smart watch. It measures the number of steps, walking distance, blood pressure, heart rate/ECG and oxygen content of the blood. After analyzing and testing various smart watches, the Fitbit and the OURA ring were used. A test course was developed that lasts around 5 minutes. The sensor system analyses the air in a room by measuring the optical spectral content of VOCs and the gait by a special developed 6D inertial measuring unit (IMU)-sensor in a smart shoe insole. The processing and audio-visual representation of the sensor data fusion represents a probabilistic model as an early warning system for the patient in the home environment. The aim of the work is the dedicated evaluation of the system components of the demonstrator for the subsequent analysis using artificial intelligence for the aggregated client data.

Keywords: Biosensors, Intelligent sensors, Volatile organic components sensors, Sensor fusion of real-time vital data, Gait analysis, Smart shoe sole, Artificial intelligence in medicine.

1. Introduction

Health services, especially for older people, have been introduced very intensively into everyday life in recent years thanks to the rapid development of the transmission technology of the Internet of Things (IoT) [1, 2, 3]. In particular, the focus was on the prevention of diseases and the early detection of disease-related restrictions with a high risk, such as the early detection of a heart attack.

For this purpose, new types of sensor networks [4] came into play, together with intelligent systems for monitoring patients and checking the patient's health status. The ability of such intelligent systems to save and transmit the recorded vital data is of great importance in many areas of health care in telemedicine. These systems are usually portable (e.g. smart watch) [5, 6], or integrated in the apartment in order to guarantee non-invasive and remote surveillance [7]. Essentially, these systems are used to monitor the symptoms and status of patients for screening, follow-up care, or in the monitoring of care patients [8].

In particular, the area of monitoring in the household for so-called Ambient Assistant Living Systems (AAL) has been pushed very hard in the last ten years [9]. These systems essentially focus on the physical signals such as heart rate, blood pressure, skin temperature, breathing rate and body movements, as well as step sizes and step frequencies.

The information that is available and collected by these signals can be further processed into clinically relevant information in order to prevent diseases. These wireless sensor networks include a number of biological sensors [7] that can be built and integrated electronically smaller and smaller and can therefore be easily integrated into a smart watch, for example. Each of these sensor systems has specific requirements for recognizing and recording symptoms [10].

In order to be able to provide support to needy and especially elderly people with technical assistance, it is necessary to record both the environmental parameters and the vital parameters of the people. Fig. 1 shows which parameters are typically recorded in the field of medical values: pulse rate, blood pressure, skin temperature, skin resistance, blood oxygen content, movement and steps.

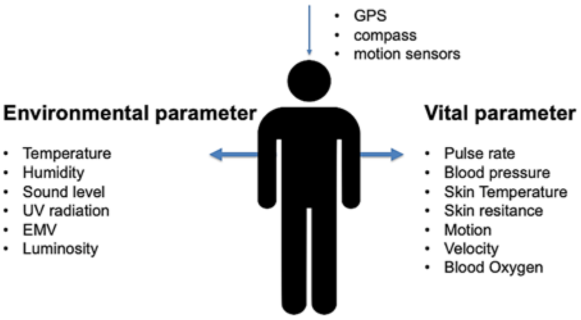

Fig. 1. Important environmental and vital parameters for AAL support of elderly people.

The environment in which the person moves is characterized by temperature, humidity, noise level, light radiation, MV radiation and UV radiation. In addition, the GPS data and the motion sensors with the inertial measuring sensors [11-14] (IMU) can provide further information.

Due to the increased integration capability, the components for applications have become significantly cheaper and are now in the low-cost range. They are relatively easy to install and, thanks to the long battery life, hardly any maintenance is necessary.

In this paper, two new types of sensor systems are presented, which measure the air quality optically in the home, as well as measure the step size, foot pressure and foot temperature at different points on the foot print in an intelligent insole. The collected data are transmitted via radio systems to a data server, from where it is called up and visualized.

Additionally, more vital data are collected by using a standard smart watch (See Chapter 1.3).

The room air sensor uses special absorptions of VOC gases, which indicate the beginning of clinical pictures.

The presence of VOCs (volatile organic compounds) [15, 16] and other substances can provide indications (no conclusive diagnosis) of health problems:

- H_2 (hydrogen) -> lactose intolerance, fructose malabsorption, carbohydrate malabsorption, etc. gastrointestinal diseases;
- C_5H_8 (isoprene) -> indicator for lung cancer (if deficient);
- C_2H_6O (ethanol) -> lack of vitamin E and / or selenium;
- C_3H_6O (acetone) -> insulin deficiency -> poss. Diabetes risk;
- NH_3 (ammonia) -> liver dysfunction (e.g. liver cirrhosis).

In addition to assessing the quality of indoor air for AAL applications, this system is also to be used for the detection of VOC in breathing gas. Since the presence of certain VOCs in exhaled air enables conclusions to be drawn about diseases such as lung cancer or metabolic disorders, the integration of a non-invasive permanent gas analysis in real-time medical care is becoming possible, also in view of increasing bandwidths and decreasing latency times [17].

2. Network Setup

In order to collect and integrate vital parameters and VOC analysis data in a home environment, it is necessary to use an effective and fast network system in combination with an effective database. Such a communication system, which can be reached from every network segment, must be able to post and read structured messages in a data-technically secure manner. Furthermore, it must also guarantee simple client-server administration. These properties are in a so-called "Twitter for computers" (or M2M) with the help of the MQTT protocol guaranteed [18].

As a publisher, a measured value recorder transmits e.g., the step size data to an MQTT server (see Fig. 1), which loads the data as a json object and makes it available to the subscribers as a data source for retrieval. The MQTT server is created locally in the apartment and can be installed on any router so that the data is only saved locally. Special releases can then be given to reading devices such as smartphones or tablets as so-called publishers.

2.1. VOC Sensor

The air sensor is part of a more complex system, the basic mode of operation of which can be seen in Fig. 2. Data recorded by a sensor (e.g., CO_2 concentration) are transferred as (voltage) values to an Arduino board (Particle Photon Development Board module kit), which converts the values into volume concentrations, converts the data generated from it into an MQTT-compliant format and transmits it to a real-time server.

The data is displayed using a special real time Avatar sketch which is presented by Fischer, *et al.* [19]

in more detail. If limits are exceeded, a warning or recommendation is issued (e.g. "Please open window and ventilate" or "Please consult a doctor"). In addition to the data from this sensor, the MQTT server also receives data from different sensors that are developed by second project group.

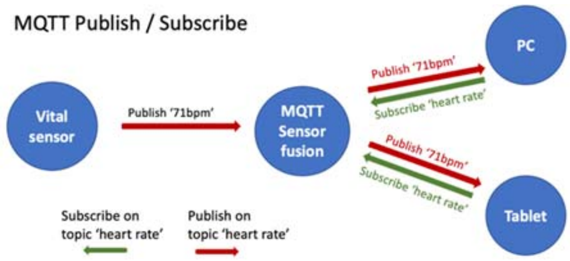

Fig. 2. Vital data fusion by MQTT server.

As can be seen Fig. 3 the processor board is shown, where the on the Arduino processor (1) is located with the corresponding inputs and outputs (2) for the sensors for recording the VOC concentrations. You can also see the power supply (3) and the digital / analog converter (4) and the communication module (5).

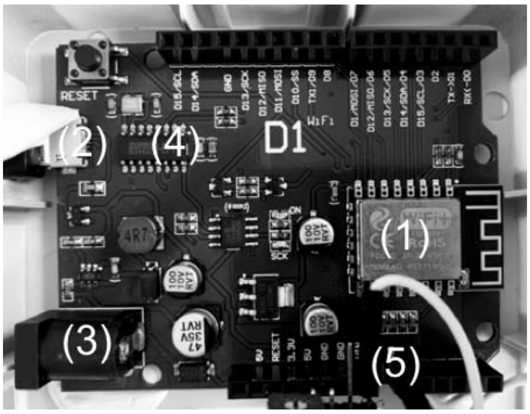

Fig. 3. Arduino setup for VOC analysis and communication module.

2.2. Step Sensor by Smart Shoe Insole

The aim of the second vital sensor project is the development of instruments for the detection of gait changes and for controlled practice in the home environment [20]. The training of coordination skills (right/left coordination) and the feedback on the development of pressure in the lower extremities and the movement pattern (G-sensors) will be carried out in the home environment over a period of 3 months and the influence on the standing and gait safety can be quantified. The sensors are embedded in shoe insoles, which are depicted in Fig. 4. The data provided by the sensors are send by Bluetooth LE and merged also via the MQTT network and evaluated in a central cloud environment.

The next steps are the evaluation and validation of the analysis data and their fusion with the other recorded vital data for usability in the home environment. It is necessary to carry out the detection of a sufficient number of steps to calculate the parameters. For this purpose, a step course is set up, which can also be carried out in the limited home environment.

2.3. Smart Watch Vital Parameter Acquisition

In addition to the two sensor applications of VOC measurement and the next step with temperature and pressure measurement, a smart watch was used to measure the number of steps, walking distance, blood pressure, heart rate / ECG and oxygen content of the blood. After analyzing and testing various smart watches, the Fitbit Sense [22] and the OURA [23] Ring were used.

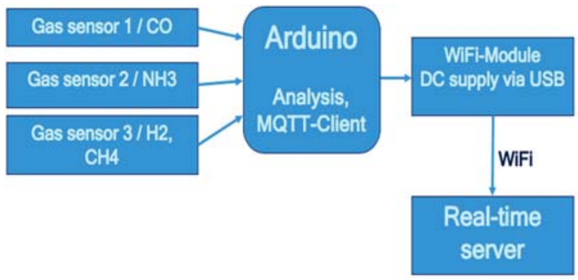

Fig. 4. VOC sensor setup.

A test course was developed that lasts around 5 minutes and includes the following key points:

Starting from 100 steps, either in a corridor in the hallway or as a tour in a room, if the course is to be held in the client's own home. Furthermore, two flights of stairs down and two flights of upstairs will have to be walked up in a stairwell in order to also be able to record changes in heart rate and breathing rate as well as oxygen uptake.

3. Results

3.1. VOC Results

The spectrum of several gases had been recorded using an optical spectrometer (ANDO AQ 8315 with a measuring accuracy of 0.5nm) by the measurement setup depicted in Fig. 4 and Fig. 5. The wavelengths used here correspond to the previously determined absorptions of the relevant substances.

If the substances are present in the air, the light from the source is attenuated in accordance with the concentration, which reduces the voltage values at the sensor output and the volume concentration can be determined. Actually, the temperature sensitivity and needed gas concentration is still causing problems.

Fig. 5. Smart shoe insole with 3D-G sensors, pressure and temperature sensors indicated by green spots (Figure and device fabricated by Thorsis [21]).

As it can be seen in Fig. 6, there are absorption lines of Propane, Bhutan and Acetylene at several wavelengths in the near infrared appearing.

In Fig. 6 the spectrum is shown between 300 nm in the UV via the visible spectrum up to the infrared region of 1750 nm.

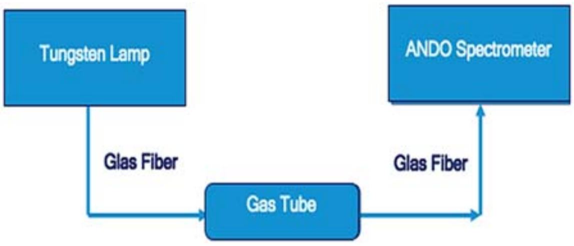

Fig. 6. Measurement setup of optical absorption spectra of VOC absorptions in the near IR region.

The absorption depth of several gases is depicted in logarithmic scale of dBm. Deep absorption lines are depicted in tube 4 boxes:

- Propane (orange) of -7 dB at 1180 nm, 1400 nm (4 dB) and 1710 nm (more than 20 dB);

- Ethine (yellow) absorption is very deep at 1530 nm (25 dB);

- Bhutan (grey) shows best absorption at 1620 nm with 5 dB and 1700 nm (15 dB);

- A reference measurement (blue line) was performed to show the limit of detection response.

These absorptions are applied in the sensor and must be calibrated to different relative gas pressures according to the VOC grade to the different diseases shown in the introduction of this paper. The calibration is still under work.

A detailed section of the absorption line of acetylene at 1530 nm can be seen in Fig. 8. The output voltage of the electrically amplified signal is shown above the wavelength. One can see, however, that the maximum absorption fluctuates strongly, so that the middle wavelength cannot be clearly identified.

However, the absorption of acetylene is very broad in this area, so that the detection of the VOC acetylene can be easily detected. Both the presence of acetylene and various concentration levels can be detected. However, an absolute substance concentration is not yet feasible. For this purpose, further detailed investigations must follow.

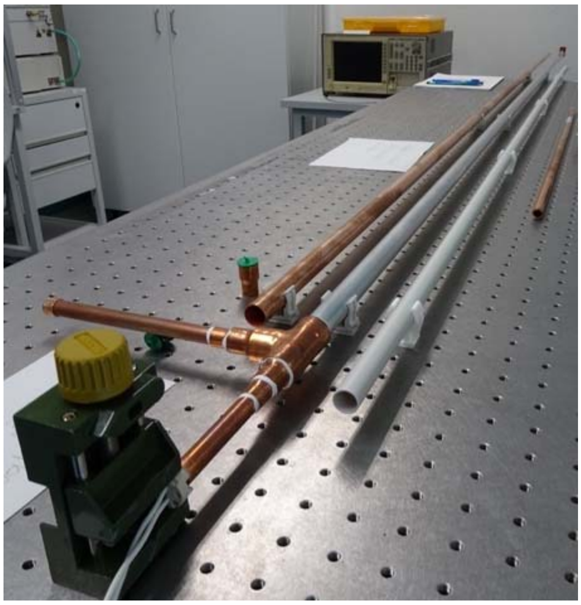

Fig. 7. Photograph of measurement setup.

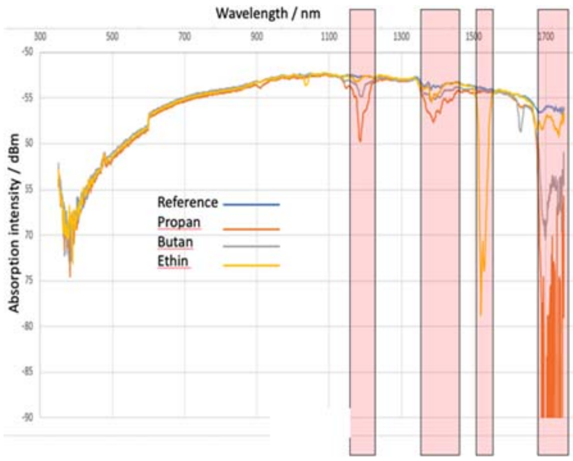

Fig. 8. Optical absorption spectrum of different VOC gas components.

After the clear proof that acetylene can be perfectly detected optically, an alternative modified setup was implemented which uses an LED with the specific wavelength of the absorption of acetylene instead of a broadband light source.

The possibility of using an inexpensive LED, which has a corresponding wavelength of 1530 nm, the absorption of acetylene, seems to be an inexpensive way of realizing an overall system.

The experimental setup was therefore modified and is shown in Fig. 9. The excitation light source (LED) can be seen on the left, which emits exactly into the volume to be measured. Acetylene could now be introduced into the volume of the measuring cell in a certain concentration and the attenuation of the radiation from the LED at the wavelength of 1530 nm could be observed with a Ge photodetector. The construction is therefore very inexpensive, since an LED with 5-20 € and a photodetector with 5-30 € can be obtained on the market.

The change in the intensity of the LED radiation with the photodetector was recorded with an oscilloscope, as can be seen in Fig. 10. One can clearly see how the voltage signal changes over time and thus the detection of the VOC acetylene can be clearly demonstrated.

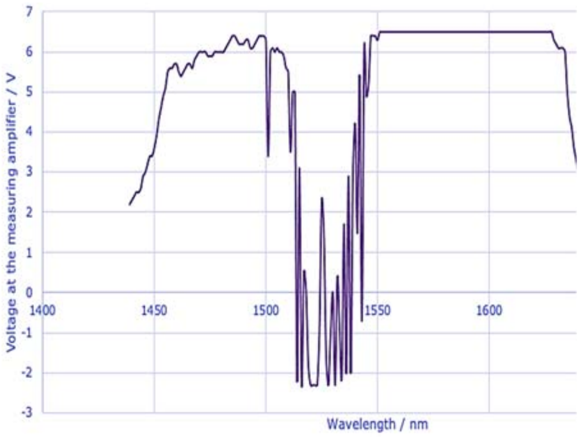

Fig. 9. Absorption line of Acetylene in high wavelength resolution.

Fig. 10. Adapted new setup for absorption measurement of Acetylene.

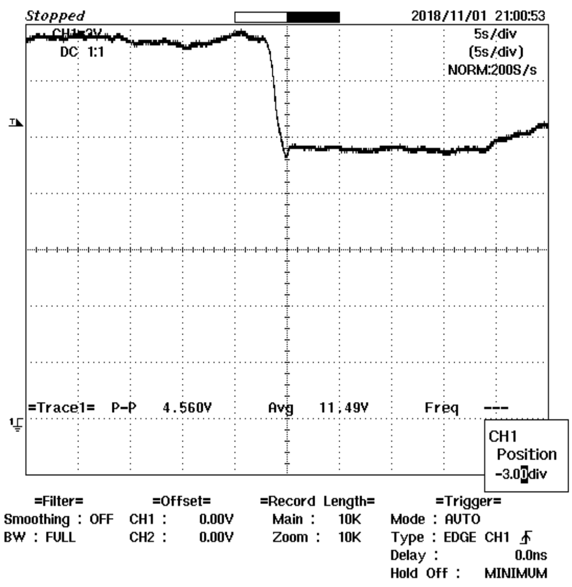

Fig. 11. Signal strength at 1530 nm by excitation with new setup with LED excitation.

The MQTT protocol is used as described above for the transmission of the evaluated VOC concentration values. The syntax is designed as a json object and has the following representation, for example 'HO / Sensor1 / gas1 / concentration'. There is a alerting when limit values are exceeded also with a json object. The patient is then alerted visually and acoustically via the real-time server.

In addition, the following gases are also monitored:

- CO: to increase the safety of air purity in the room
- Ammonia: liver dysfunction
- Ethanol: lack of vitamin E.

3.2. Vital Signs Transmission

In order to transfer the data of the vital parameters of the smart watch and the intelligent shoe sole to the Neuropathy MQTT server, some technical steps are required which should be shown in the following which can be seen in Fig. 12.

The data recorded by the smart watch is transmitted via the so-called Fitbit interface, which is located in the cloud. From there, the data is queried via the neuropathy app and transmitted to the MQTT server, which in turn is available as a data server for the artificial intelligence (AI) tool. Analogously, the data of the intelligent shoe sole is also transferred via the neuropathy app to the MQTT server as a json object and transferred to the database. The artificial intelligence (AI) tool that has yet to be developed will then carry out the evaluation and provide feedback to the client.

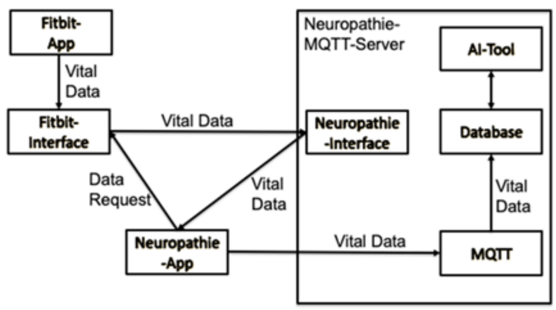

Fig. 12. Data acquisition via smart watch.

Fig. 13 shows the transmission chain of the Json objects in the form of the transmission from the Fitbit app to the MQTT server. The sequence of data shows that the time of data recording and recorded vital values are transmitted according to their arrival and are uniquely stored in the MQTT data. This data can then be called up again from the following database.

After the transfer to the database, the data pool of which can be seen as an excerpt in Fig. 14, the sequence of the json objects and their contents with the corresponding vital data can be recognized.

{"dateTime":"2021-06-02","value":"0"},{"dateTime":"2021-06-03","value":"0"},
{"dateTime":"2021-06-04","value":"0"},{"dateTime":"2021-06-05","value":"0"},
{"dateTime":"2021-06-06","value":"0"},{"dateTime":"2021-06-07","value":"0"},
{"dateTime":"2021-06-08","value":"52"},{"dateTime":"2021-06-09","value":"175"},
{"dateTime":"2021-06-10","value":"0"},{"dateTime":"2021-06-11","value":"0"},
{"dateTime":"2021-06-12","value":"0"},{"dateTime":"2021-06-13","value":"0"},
{"dateTime":"2021-06-14","value":"0"},{"dateTime":"2021-06-15","value":"0"},
{"dateTime":"2021-06-16","value":"0"},{"dateTime":"2021-06-17","value":"0"},
{"dateTime":"2021-06-18","value":"0"},{"dateTime":"2021-06-19","value":"0"},
{"dateTime":"2021-06-20","value":"0"},{"dateTime":"2021-06-21","value":"0"},
{"dateTime":"2021-06-22","value":"0"},{"dateTime":"2021-06-23","value":"0"},

Fig. 13. Data view as json object for MQTT transfer.

timestamp	user	dateTime	seconds	level
2021-06-30 13:57:07	Cassy	2021-06-28 00:47:30	60	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 00:48:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 00:49:30	240	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 00:53:30	180	restless
2021-06-30 13:57:07	Cassy	2021-06-28 00:56:30	180	awake
2021-06-30 13:57:07	Cassy	2021-06-28 00:59:30	120	restless
2021-06-30 13:57:07	Cassy	2021-06-28 01:01:30	2460	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 01:42:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 01:43:30	120	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 01:45:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 01:46:30	4620	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 03:03:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 03:04:30	1380	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 03:27:30	240	restless
2021-06-30 13:57:07	Cassy	2021-06-28 03:31:30	120	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 03:33:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 03:34:30	2940	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 04:23:30	120	restless
2021-06-30 13:57:07	Cassy	2021-06-28 04:25:30	4020	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 05:32:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 05:33:30	120	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 05:35:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 05:36:30	840	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 05:50:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 05:51:30	300	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 05:56:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 05:57:30	1560	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 06:23:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 06:24:30	60	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 06:25:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 06:26:30	300	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 06:31:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 06:32:30	180	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 06:35:30	60	restless
2021-06-30 13:57:07	Cassy	2021-06-28 06:36:30	60	asleep
2021-06-30 13:57:07	Cassy	2021-06-28 06:37:30	120	restless

Fig. 14. Data view at the data base.

In the further course of the project, the complete data of the VOC sub-project as well as the smartwatch and the intelligent shoe sole will be transferred from the MQTT server to the database and evaluated in cooperation with the medical faculty of the University of Magdeburg. With the help of this evaluation, a subsequent analysis of the aggregated client data should be carried out with the aid of artificial intelligence. The processing and audio-visual representation of the sensor data fusion represents a probabilistic model as an early warning system for the patient in the home environment.

4. Summary

Volatile organic components analysis is very interesting possibility for detecting diseases in the home area in a very early stage. The sub-project VOC acquisition included the development of a distributed sensor system for the spectroscopic analysis of room air as part of the real-time sensor data analysis framework for intelligent assistance systems. It could be shown that it is possible to detect different gases or gas mixtures with optical technologies. A Demonstrator was realized which detected CO, ammonia, ethanol and ethylene.

Older multimorbid people can also continue to live medically safely in their own home with the help of this supporting analysis of vital parameters and gait parameters, which was the aim of these home monitoring project parts. Here, the Harz University has interconnected components for a distributed sensor network for the spectroscopic analysis of air and step analysis. The sensor system analyses the air in a room by measuring the optical spectral content of VOCs and the gait by special developed 3D G-sensors in a smart shoe insole.

The next steps in the project will be the following: In the first step we need to implement security functions like SSL, AES256 in the transmitted data, because the data are personally and should meet the international security level for secure personal medical date transfer. After that step, we need to integrate an account / profile system that will be able to connect a manifold of clients. These accounts must be integrated into the existing infrastructure of the MQTT data transfer.

After realizing the IT structure, user tests in the lab will be performed as a pretest to finalize the whole system. Afterwards the system will be applied in a 2-month field test in a care station. Here we want to collect real personal data to implement and test the artificial intelligence (AI) tool, which will give the clients clear hints for a saver vital live in their home environment. The AI tool will be developed in cooperation with our medical partner at the Medical Department of the Otto von Guericke University [20].

Acknowledgement

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