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Wearable Smart Prototype for Personal Air Quality Monitoring

Attila Géczy, Lajos Kuglics, László Jakab, Gábor Harsányi
Department of Electronics Technology, Budapest University of Technology and Economics,
Budapest, Hungary
gattila@ett.bme.hu

***Abstract* — This work aims to present an advanced prototype of cost-effective wearable air quality monitoring equipment suitable for different use cases due to its small size, easy handling, and smartphone compatibility. In the paper, we present the chosen components and the system design. The prototype development is also presented, with the initial measurements and the aspects encountered during development. We used C and Arduino programming, Android software development. The proposed system comprises of an Arduino based microcontroller, a CCS811 sensor for volatile organic compound (VOC) measurement, a ZPH01 particulate matter (PM) detector, and an HC-05 device for Bluetooth connection. We investigated the prototype both in the laboratory and in a smart urban environment with different scenarios in Budapest, Hungary (street, campus, store, mall, underground). Also, the use of a smartphone connection for data loggings is presented. The paper shows examples of measurement results and the relation to similar results from around the world. The possible application in COVID-19 pandemic related questions is also discussed.**

Keywords— Air quality, sensor cluster, sensor platform, wearable, personal, prototype, cost-effective

I. Introduction

Air pollution is a serious question of the modern urban environment. The aspect of airborne particulate matter and volatile organic compound content both pose serious threats to health from different aspects - from cities [1] to the insides of living spaces [2]. Also, the industrial workplaces [3] should be investigated from air quality in the ambience around different manufacturing apparatuses.

Recently, questions were raised regarding the airborne diffusion of COVID-19 and various epidemiological threats [4,5] with contradictory results. Summing up, different solutions are required to tackle the problem on multiple scales. Some researchers are more moderate regarding the connection between air pollution and COVID-19 related morbidity and mortality. Comunian et al. [6] highlighted that PM alone could damage pulmonary cells. This can result in inflammation and oxidative stress. However, they point to the importance of further systematic studies, focusing on unfolding the mechanisms behind the connections, and placing PM measurement unit devices around the world in every critical location. They highlighted that the process needs further research concerning Angiotensin-converting enzyme 2 (ACE2) expression after PM exposure.

According to most recent research results (as of 2020 October), the daily PM2.5 and PM10 concentrations and the daily case fatality rate (CFR) numbers showed similarities in Wuhan during the peak of the pandemic. Similarities are with respect to the temporal variation curves, with a noticeable time lag between the results. [7] These results were also extended to the case fatality rate of 49 Chinese cities [8]. Later Yongjian [9] increased the city count under investigation to 120, and with a generalized additive model of pollutants, they linked significant positive associations of PM2.5, PM10, NO2, O3 with the confirmed cases. With the increase of PM2.5, PM10, NO2, and O3 with only 10μg/m3 concentration, the case increase was reported with 2.24%, 1.76%, 6.94%, and 4.76% on a daily basis. Wu reported [10] on conditions in the USA, with 3000 county data, where it was concluded that the 1 μg/m3 PM2.5 is combined with 8% increase in CFR. The extension to Europe focused on French and the gasoline/diesel-based transport sector. The machine learning-based research of Magazzino showed [11] that a pre-determined particulate concentration can foster COVID-19, in the meanwhile increasing the susceptibility of the respiratory system to the infection. As another article highlights [12], imbalanced reductions in primary pollutant emissions facilitated secondary emissions pollutants, creating haze pollution. VOCs were particularly highlighted in the results.

It is also important to note that a pandemic caused lockdown may positively affect the air quality. It was noted that COVID-19 lockdowns caused local and global air pollution to decline - due to transportation reductions and emission decrease. Particulate matter (PM2.5) levels were dropped with 31% on average [13].

The problem of air contamination can be investigated with fixed sensor stations planted by officials, or personal equipment measuring the environment on the scale of the person. For the latter aspect, novel, cheap, commercial sensors and easy-to-develop microcontroller systems might help achieve personal, wearable environment monitoring in personal, urban, healthcare, or industrial environments. In latter areas, the availability of clear air and appropriate ventilation is often not available due to the outdated industrial ambiance. In this paper, we aim to present the prototype of a cost-effective solution with results obtained from different areas, such as a city, public transportation zones, or a laboratory, where electronics manufacturing equipment (PCB fabrication, PCB assembly) is in order.

II. Experimental

A. Designing the hardware

For the central processing module, we chose an Arduino Nano, which is cheap and capable of controlling the given applied sensor modules and wireless communication. For software development, we used Arduino IDE 1.8.10. For the sensors, we chose a CCS811 module, which is used for VOC and eCO2 measurement, focusing on the former data. The sensitivity for the device is eCO2:400-8192 ppm and TVOC: 0-1187 ppm, respectively. The communication is performed via I2C communication. After initial testing, we applied Winsen ZPH01 particulate matter sensor, which has a PWM/UART communication, and it is sensitive for PM above 1 µm. For the communication, we used a cheap HC-05 UART-based Bluetooth module. The power is based on a 2200 mAh power bank with 5V/1A output. The small form factor and functionality rendered this component optimal for power use. The data is gathered via Bluetooth on a Redmi Note 7 Android-based phone. The MIT App Inventor was used for rapid software development and efficient smart application. Figure 1 presents the block diagram of the system.

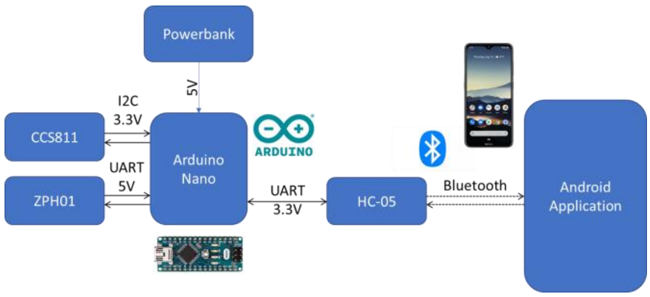

Fig. 1. Block diagram of the system.

In Figure 2, the initial working prototype is presented which was assembled in advance to investigate the capabilities of the given modules. Figure 3 illustrates the assembled prototype shield and Figure 4 shows the completed prototype wore by a person.

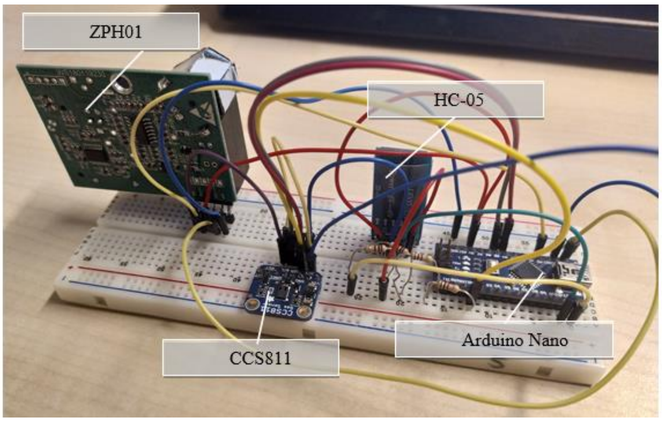

Fig. 2. Early prototype on a breadboard with presented components.

The final prototype adds a developed shield board, containing all essential elements on one board, while maintaining the form factor of a wearable device, which can be worn on the arm, similar to cell phone holders during sports. The construction shows the power bank too, which fits the arm pouch as seen in Figure 3.

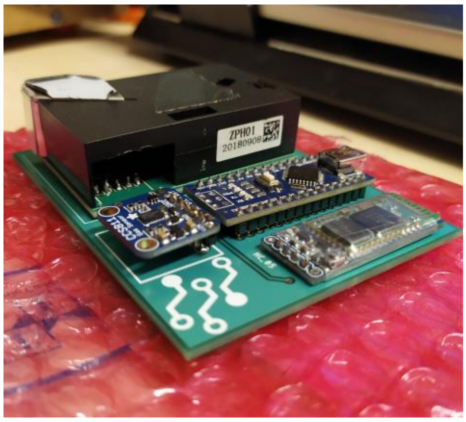

Fig. 3. Assembled prototype shield.

Fig. 4. Assembled prototype positioned on the arm of a person.

B. Experimental scenarios

Two scenarios were drawn at the beginning of our work. We wanted to investigate, how a laboratory engineer or an operator is working around different apparatus in electronics manufacturing environment at our labs. We chose a vapour phase [14] reflow oven (Asscon Quicky 450), where manual loading exposes the operator to the work zone of the oven. The other machine is a semi-closed selective mini-wave [15] soldering oven (Jade S-200), where the operator is also in the same space of the machine. The laboratory has an intricate air ventilation system; both machines have their specific extraction collectors hanging from the ceiling.

The second scenario was in an urban environment in our capital city, Budapest, to reveal the changes of VOC and PM concentration around a pedestrian, who travels with public transport and visits urban locations, such as shops.

III. Results

A. Laboratory Environment

Figure 5 and Figure 6 present the the results of laboratory environment measurements in the vicinity of electronics assembly machines. The VOC levels increase during the working of different machinery. The Vapour Phase Soldering machine is analyzed in Figure 5. From the plot, it is clear that peaks around 300 ppb can be observed, which are in line with the opening of the PCB loading doors. The larger peaks above 1200 s simulate when the operator is leaning above the opened work zone, and the remaining heat transfer medium mist and the vapors of the flux reach the sensor.

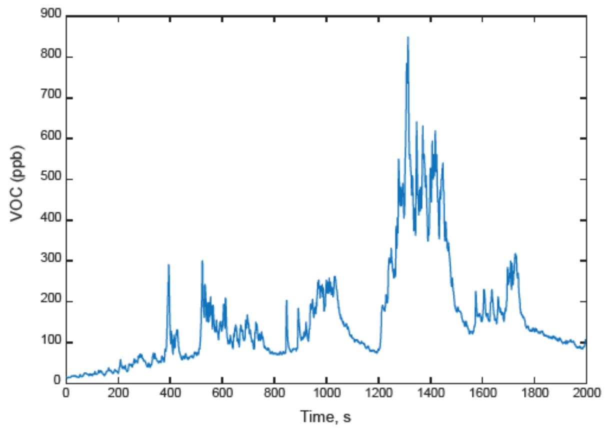

Fig. 5. VOC results around vapour phase soldering device.

The next figure presents two fluxing cycles in the close vicinity of a selective mini-wave soldering oven. As it is apparent, the values jump up significantly. According to the operator, he did not notice significant changes in the general senses of smelling – so it can be concluded that latent dangers (VOC concentration increase) can be revealed with such sensors in the workspace environment.

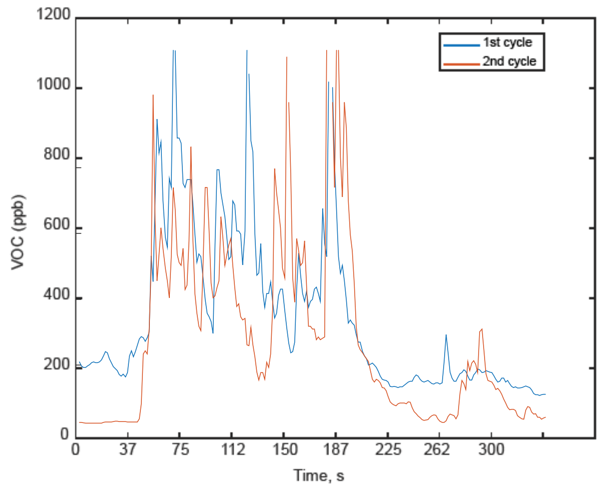

Fig. 6. VOC results at fluxing stages of a selective mini-wave oven.

B. Urban Environment

Figure 3 presents an urban travel scenario (A) which took place on the street, on the tram, and in a store. It is interesting to see that the street has elevated particles and low levels of detected VOCs. The active transportation in the city boosts particles in the air; also, the open-air enables better distribution of VOCs than in closed spaces. The tram has characteristically increased VOC and particle levels, since the people on the tram boost exhausted, used air, and the tram. Also, the particles can not ventilate correctly. Arriving at a store, further changes are recorded. The air of the store has low particle count, while the modern ventilation and air conditioning systems filtrate the particles. The store also has characteristically increased VOC levels, meaning that the human presence in closed spaces, the furniture, plastic inner decorations, and various cleaning and odor-reducing air fresheners increase the volatile organic compound in the air.

In Figure 8, a similar situation is presented (scenario B), where the urban travel was extended to a longer trip. The street scenario gives similar, almost repeatable results according to the given parts of Figure 7 and 8. Also, it has to be noted that the weather and ambient environment relations were similar in the two winter days after each other. The two visited stores were loaded with VOCs and had a minimal particulate matter count in the air. In the larger spaces in the mall, the situation was somewhat balanced, where both VOCs and PMs were detectable, varying at different locations around the mall. Then the Metro Line 4 gave an interesting result of minimal VOC presence and large PM data. The peaks of the PMs were exactly at the arrival of the underground metro car, meaning that the dynamics of the transportation can be investigated via the rise and fall of PM concentration in the air. Also, the arriving train stirs up the particulate matter in the tunnels and stations. It has to be noted that both PM and VOC levels stayed lower on the street around the campus than in the city. The tram travels had similar aspects as before, with increasing VOC levels and occasional falls in VOC levels when the doors ventilated the air. It is also interesting to see that during the second tram travel, the PM levels rose, which can be attributed to the increasing traffic around the main tram line in the city center, as the day neared the end of the work shifts. The campus was again a quiet location from both aspects; finally, the store and the street gave similar results as before. The possibility of map integration is already realized in the application. The next step can be the building of a common database according to the results obtained from several users. The gathered data can (and in the future must) be evaluated with a comparison of official air quality stations positioned around the city.

It is also interesting to note that while the PM levels peaked in underground stations, the levels were different at different stations - this is due to the different status (state of disrepair, cleaning history of the lines, etc.) of the given stations. It must be noted that the recorded levels are in line with very recent research results, where London underground was investigated [16]. Some results are around the same levels, but the cited research gives significantly larger values too, most probably due to heavy rail and train component wear in the UK capital.

It must be noted that the PM concentration outside can depend highly on weather effects (wind, temperature, and consequential heating of households), too, so further analysis is needed during a whole year time to investigate the changes according to weather situations.

The results also point out that the proposed device would be able to record pandemic-related changes in urban situations as well, such as reducing of traffic and pedestrian density on streets, or inside malls, shops, closed spaces, or professional locations such as hospitals, laboratories, or workplaces.

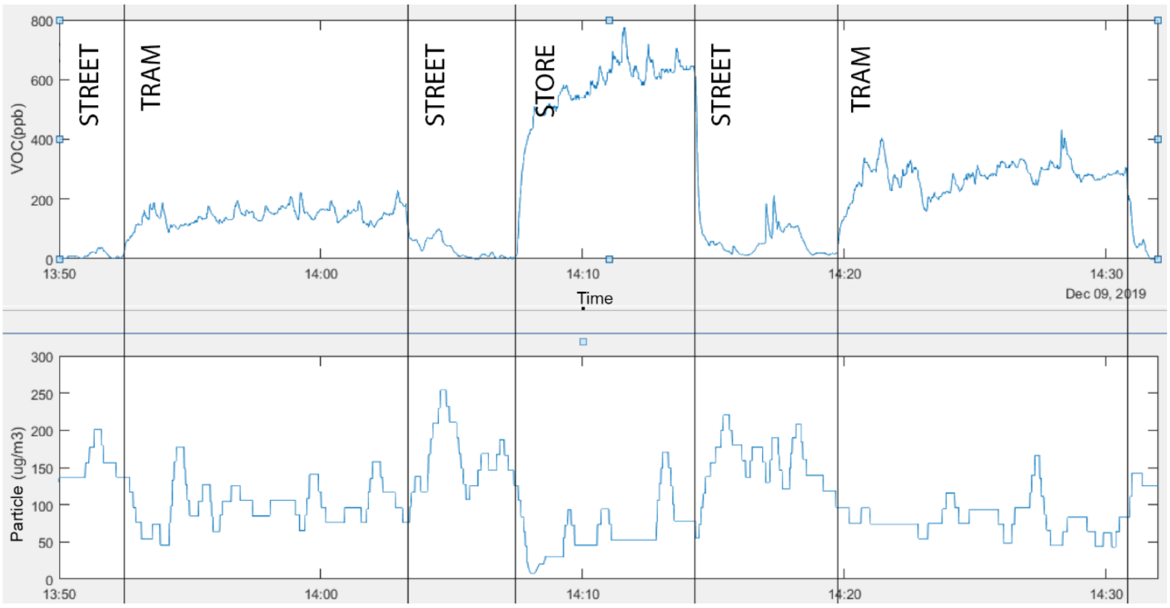

Fig. 7. Volatile Organic Compound (top) and Particulate Matter (bottom) measurements in an urban scenario A.

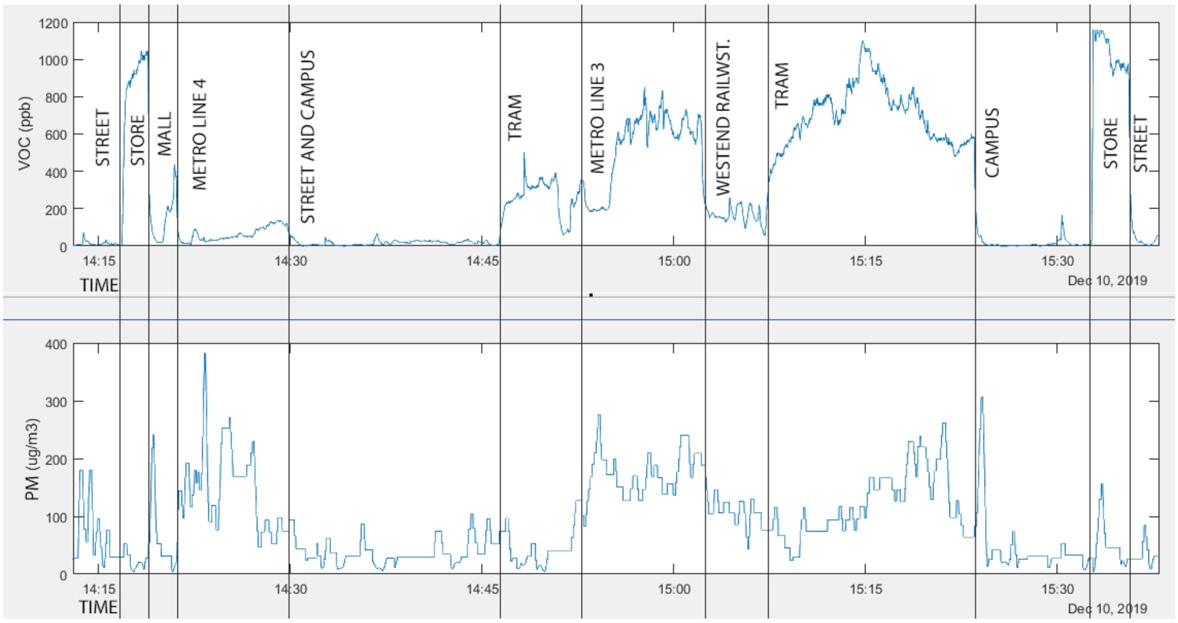

Fig. 8. Volatile Organic Compound (top) and Particulate Matter (bottom) measurements in urban scenario B.

IV. . CONCLUSIONS

The paper focuses on a novel wearable device capable of measuring VOC and PM concentrations around the users. We present a cost-effective solution for the prototype and the possibility of smart connectivity. The setup is tested in different environments, such as electronic manufacturing laboratory (workspace) and urban scenarios in Budapest. It is interesting to see that different results are in line with literature data and also that the characteristic changes are visible across different stages of e.g., an urban scenario. While it is difficult to classify or grade results according to quantitative results for a non-professional user, future investigations may need to point to standardized Air Quality Index referencing (AQI [17]), or a given ergonomic scaling (practical levels of air quality [18]) for easier commercial application.

The device also points to applicability in pandemic-related scenarios (e.g., COVID-19), where the caused changes in the transportation and resulting air quality, and more importantly, the knowledge of air quality itself is essential to avoid highly polluted areas. With connected devices, the aid of governmental control over pollution can also be visualized for future use.

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