Towards Efficient Odor Diffusion with an Olfactory Display Using an Electronic Nose

Miguel Garcia-Ruiz[1[0000-0002-7048-7286]]
, Laura Gaytan-Lugo[2[0000-0002-7007-7500]], Pedro Santana Mancilla[3[0000-0002-4184-0116]] and Raul Aquino-Santos[3[0000-0002-8242-0695]]

[1] Algoma University, Sault Ste. Marie, Ontario, P6A 2G4, Canada
[2] University of Colima, Coquimatlan, Colima, 28400, Mexico
[3] University of Colima, Colima City, Colima, 28040, Mexico

miguel.garcia@algomau.ca, laura@ucol.mx, psantana@ucol.mx, aquinor@ucol.mx

Abstract. Olfactory displays (human-computer interfaces that generate and diffuse odors to a user with a purpose) have been researched to complement or supplement other human sensory modalities, as well as using odors as effective sensory stimuli. We developed an olfactory display with a commonly-used microcontroller board and off-the-shelf components. A challenge in olfactory displays is diffusing the right odor concentration to a user. We developed and applied an electronic nose (e-nose) to determine if an intended odor is not lingering, otherwise our olfactory display will generate an excessive amount of odor. As a proof of concept, we developed a virtual environment that activates our olfactory display when a virtual lemon is visible on it, diffusing a lemon odor if the odor is not already present around the user, detected by our e-nose. Our informal prototype tests shown that it is feasible to use an e-nose to control the odor concentration generated by an olfactory display, thus avoiding an excess of odor that may produce a negative user experience. The Evolutionary Prototyping methodology was very useful for developing our olfactory display system and electronic nose.

Keywords: Olfactory Display, Electronic Nose, Smell, Odor, Virtual Environment, Microcontroller Board.

1 Introduction

Since the 1990s [1, 2], computer-based olfactory displays have been proposed and researched in a number of domains, with the purpose of complementing and supplementing sensory modalities with the use of the olfactory modality. An olfactory display is a computer system with a human-computer interface that generates, controls and diffuses one or more odors towards a user with a purpose [2, 3], providing an olfactory stimulus to its user. In the nineties, olfactory displays were initially researched as a technology that could incorporate the sense of smell in multimodal virtual reality (VR) [4]. For example, [5] explored the use of smell in a virtual reality simulation to support firefighters training, exposing them to possible smoke smells. Odors in virtual reality and virtual environments may support training transfer and immersion[6]. Recent research on odors in VR include support for well-being and relaxation (e.g. [7]) and for supporting education and training [8], among other applications. Olfactory display research has been conducted on odor generation and delivery technologies [9], including research about how users perceive and interact with the diffused odors generated by olfactory interfaces. The sense of smell has been underused in human-computer interaction [2], although recent advances in microcontroller boards (small self-contained computers used for controlling sensors and actuators) have facilitated the prototyping of olfactory display applications [8]. For instance, [10] used an ATMega2560 microcontroller to control the fan speed of an olfactory display system.

A major challenge in olfactory displays is removing the odor from the environment after its use. Many odors tend to linger, and in some applications they need to be removed quickly [8], for example, when they are used in video games [11]. Some olfactory display systems include a mechanism for removing the diffused odor when it is no longer used or needed, such as fans and air filters [12]. A way to overcoming this challenge is to produce the right concentration of odor in an olfactory interface to avoid olfactory adaptation or over-saturation [13, 14]. Other problems with lingering odors may occur, such as masking (an odor suppresses another one) and multiplicity (an odor enhances another one) [9]. In this paper, we describe a method to produce a controlled odor diffusion in an olfactory display system using an electronic nose, or e-nose. An e-nose is an electronic sensing system that detects one or more specific odors, and their concentration in the environment [15]. An e-nose can be used to analyze one or more specific gases or volatile organic compounds (VOCs) and their concentration in the air [16, 17]. This can be useful to avoid an excess of odor production that may affect the user's odor perception. The e-nose analyzes the air surrounding the user and the olfactory display generates a particular odor if that odor is not lingering around the user. There is previous research on olfactory display systems using e-noses. [18] successfully used an e-nose for evaluating the accuracy of odor concentration diffused by an olfactory display. [2] and [9] describe a number of techniques for storing, generating and diffusing odors in olfactory displays. Scented essential oils have been used in olfactory displays [19], where the odors can be diffused towards the user with the help of a fan [20].

2 Statement of the Objective

The objective of this paper is to demonstrate the use of an e-nose for controlling the odor diffusion of an olfactory display that is activated by a virtual environment. In our prototype, the e-nose analyzes the air surrounding the user and the olfactory display generates a particular odor if that odor is not lingering around the user, thus avoiding an excess of odor production that may affect the user's odor perception.

3 Our Olfactory Display System + Electronic Nose Prototype

We describe in this section the technical aspects of our olfactory display and our e-nose. An Arduino Uno [21] microcontroller board was used for controlling a computer fan and an odor generator (an off-the-shelf Honeywell Mini Mist humidifier [22]), containing an essential oil reservoir. The microcontroller board also controls a computer fan that suctions air through a filter that we made with an activated carbon sheet. The frame holding the air filter was 3D printed to give it robustness. Another Arduino Uno microcontroller board obtains data from a Keyestudio SEN-CCS811 odor sensor module [23]. This microcontroller board and the sensor module makes up the e-nose. The SEN-CCS811 sensor module measures the concentration of total volatile organic compounds (TVOC) in the environment. TVOCs are human-made organic chemicals that evaporate at room temperature, used in many household products such as aromatizers and essential oils [24], although VOCS are also present in nature [25]. The SEN-CCS811 odor sensor module used in our prototype can detect TVOC concentrations from 0 to 32,768 parts per billion (PPB). We used in our olfactory display the Ellia 100% pure lemon (Citrus Limon) essential oil, developed by Homedics [26], by placing 10 drops of the essential oil in the humidifier's reservoir. After a number of trials and as part of the prototyping process, we found that this number of drops was optimal for its diffusion using the humidifier. Lemon odors have been successfully used in olfactory displays, providing an effective olfactory sensory stimulus [27].

Fig. 1 shows the main components of our designed olfactory display system and our e-nose. We decided to use the Arduino Uno microcontroller board because it is easy to program and to interface with, and is powerful enough to control the PC fans, the odor sensor module and the odor generator. We used a special electronic circuit with transistors and a 12v external power source for controlling the fans. The microcontroller board interfaces through a USB cable with a MacBook Pro laptop computer with 16 GB of RAM, containing the M1 microprocessor. This computer is used to read data from the e-nose to activate the humidifier and fans, and to run a 3D virtual environment created as a proof of concept for testing the olfactory display system and the electronic nose.

The Honeywell humidifier that we selected for our olfactory display is low-cost and easy to operate, facilitating our prototype development. The Ellia lemon essential oil that we used in our olfactory display is easily available from many department stores and online distributors, as well as the activated carbon sheet used for the air filter.

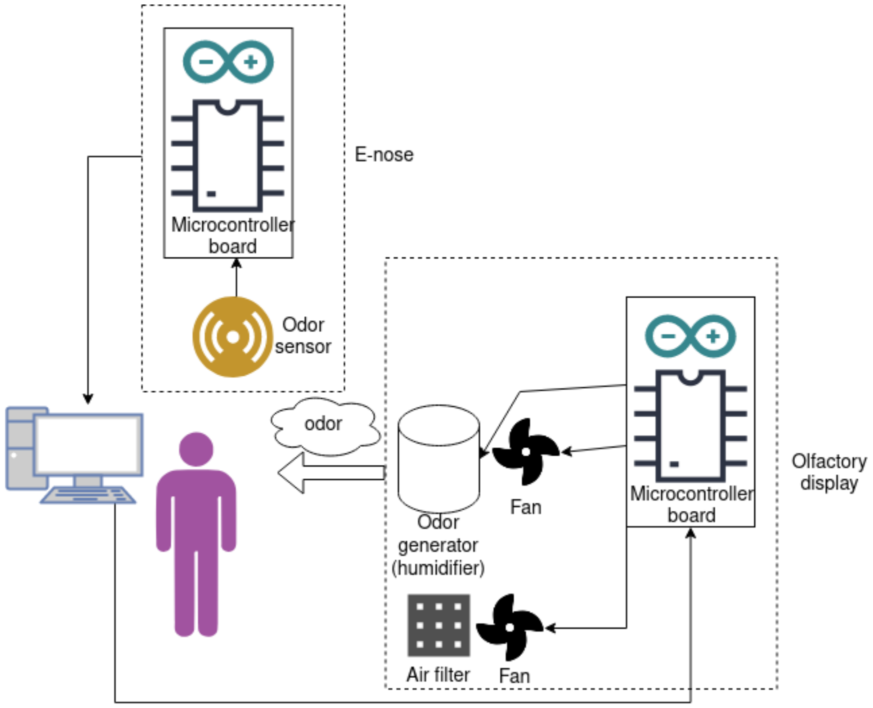

Fig. 1. Schematic diagram of the proposed olfactory display system with the e-nose.

The algorithm that runs on the laptop computer for activating the olfactory display and the e-nose is listed as follows:

1. If the virtual lemon is visualized on the computer screen, do the following:
   1a. Read the odor sensor data.
   1b. If the lemon odor is detected in the environment, do the following:
      1b.1 Do not activate the olfactory display.
      1b.2 Activate the air filter.
2. If the lemon odor is not detected in the environment do the following:
   2a. Activate the olfactory display (fan+humidifier) for some seconds.
   2b. Activate the air filter.
3. Go to step 1.

We coded the algorithm in a Python program, which access the Arduino microcontroller board through a laptop's USB port. In order to run the virtual environment more efficiently, all the e-nose data acquisition and processing is done on one of the microcontroller boards to free up computational processing power from the laptop computer. We developed and improved the olfactory display and the e-nose following an adaptation of the Evolutionary Prototyping methodology [28]. **Fig. 2** shows our prototype containing the olfactory display and the electronic nose.

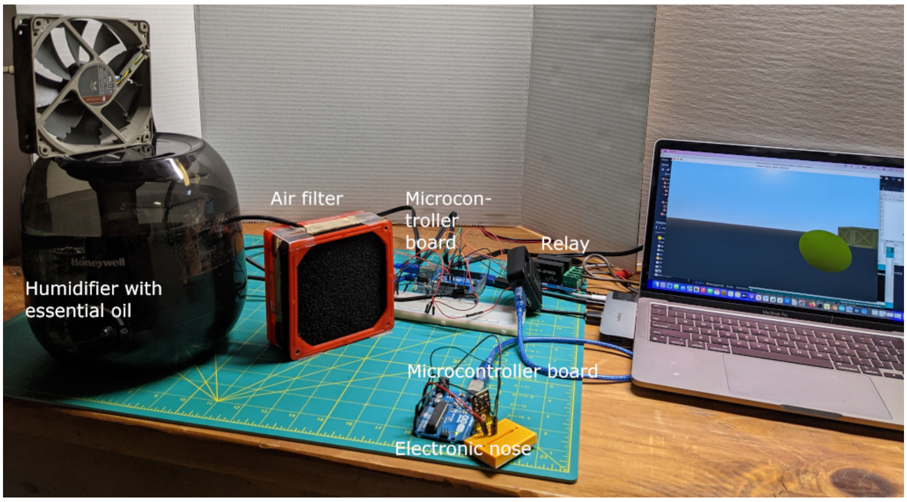

Fig 2. The complete olfactory display+electronic nose set up.

As **Fig. 2** shows, A solid-state relay was used for turning the humidifier on and off with one of the Arduino Uno microcontroller boards. The PC fan (also controlled by the microcontroller board) placed on top the humidifier diffused the odor towards the user.

4 The 3D Virtual Environment

We developed a 3D virtual environment made in Godot [29, 30], a popular video game engine. A Godot script from the virtual environment sends a digital signal to the Python program. This program activates the microcontroller board that controls the humidifier and the fan when a virtual lemon is displayed on the center of the computer screen, generating and diffusing the lemon odor by turning on the humidifier containing the essential oil. **Fig. 2** shows the virtual environment that we developed for our proof of concept, running on the laptop computer. The lemon 3D model that is displayed on the virtual environment was downloaded from [31]. We also created and displayed more than 200 virtual crates in the virtual environment to give the illusion of perspective and to show 3D models other than the virtual lemon to deactivate the olfactory display when the virtual crates were displayed. The crates were procedurally generated in Godot and placed randomly in the virtual environment.

5 Preliminary Results

We informally tested the virtual environment, the olfactory display and the electronic nose a number of times, navigating in the virtual environment in 3D using the computer's arrow keys. As expected, our olfactory display was activated every time the virtual lemon appeared at the center of the computer screen, while we captured the electronic nose data for 45.5 seconds. **Fig. 3** shows the data that we sampled from the SEN-CCS811 odor sensor module once every 0.5 seconds. According to the sensor manufacturer, this is the minimum time required for reading data from the odor sensor. The sensor data was obtained through the Arduino IDE's Serial Monitor.

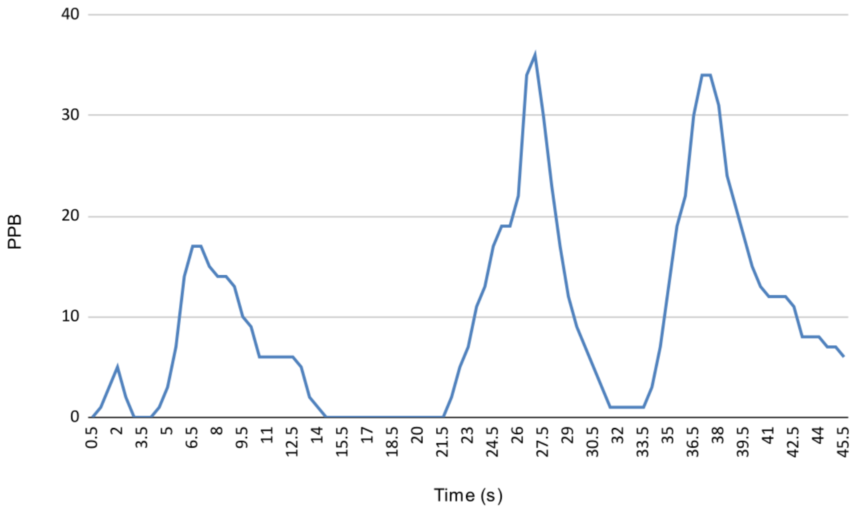

Fig. 3. Data obtained from the electronic nose.

As **Fig. 3** shows, the valleys are the periods where the virtual lemon was not displayed on the screen, and no lemon odor was present or it was barely present in the environment, when the sensor read very low odor concentrations from the environment. In addition, the low PPB readings indicated that the air filter was operating effectively during those periods. The peaks happened during the olfactory display activation, where two of them are values greater than 30 PPB. During the peaks, the lemon odor was distinctive. We will need to conduct further user studies to confirm this. There is a small peak at the beginning of the readings. We believe that it happened because the sensor required an initial self-calibration adjustment, according to the sensor module's specifications [23]. We found in a number of trials that TVOC concentrations of the lemon odor of less than 20 PPB were barely noticeable, but we will need to confirm that in further user testing. We then set up the program for stopping the olfactory display when the electronic nose obtained values of 20 PPB or less.

A video recording showcasing the olfactory display, the electronic nose data and the virtual environment is shown in [32].

6 Conclusions

This paper presented an olfactory display system and an e-nose, with the objective of diffusing the right amount of odor to a user, avoiding an excess of odor production in the user's environment that may affect user's odor perception. Both the olfactory display and the e-nose were interfaced to a laptop computer using microcontroller boards. A 3D virtual environment running on the laptop computer activated the olfactory display system when a 3D model of a lemon was displayed on the screen. The Evolutionary Prototyping methodology was very useful for developing our olfactory display system and our e-nose.

Our paper demonstrated the application of easy-to-use electronic components, and a low-cost yet capable microcontroller board for developing a rapid prototype of an olfactory display and an e-nose. In addition, the Godot game engine facilitated the virtual environment prototyping. We found that the SEN-CCS811 odor sensor module was effective for measuring the concentration of the essential oil odor in the environment. Our informal prototype tests shown that it is technically possible to use an e-nose to measure the odor concentration generated by an olfactory display, thus avoiding generating an excess of odor that may produce a negative user experience. Further user studies are needed to corroborate this.

For future work, we will adapt the virtual environment made in Godot to run on a virtual reality headset. We are planning to send the activation data from the virtual reality environment to the microcontroller board controlling our olfactory display using the Message Queuing Telemetry Transport MQTT protocol [33]. In addition, we plan to develop and test an array of two or more VOC odor sensors connected to the virtual environment and the olfactory display. The array should provide more sensor data accuracy [34], since individual e-noses performance and data results may have false or unreliable odor classifications, provided that an optimal classification pattern algorithm is applied to them. The array may be needed because sensors sometimes present an inherent problem of sensor signal drift and other technical issues. In addition, environmental factors such as humidity and temperature may affect sensor's performance [35]. These problems should be minimized by getting data from an array of sensors, where one or more sensors will compensate for any affected odor sensor.

References

1. Kaye, J.N.: Symbolic olfactory display, https://dspace.mit.edu/handle/1721.1/16788, (2001).
2. Kaye, J. "Jofish": Making Scents: aromatic output for HCI. interactions. 11, 48–61 (2004). https://doi.org/10.1145/962342.964333.

3. Yanagida, Y., Tomono, A.: Basics for Olfactory Display. In: Human Olfactory Displays and Interfaces: Odor Sensing and Presentation. pp. 60–85. IGI Global, Hershey, PA, U.S.A. (2013). https://doi.org/10.4018/978-1-4666-2521-1.ch003.
4. Barfield, W., Danas, E.: Comments on the use of olfactory displays for virtual environments. Presence: Teleoper. Virtual Environ. 5, 109–121 (1996). https://doi.org/10.1162/pres.1996.5.1.109.
5. Cater, J.P.: Smell/taste: odors in reality. In: Proceedings of IEEE International Conference on Systems, Man and Cybernetics. p. 1781 vols.2-. IEEE (1994). https://doi.org/10.1109/ICSMC.1994.400108.
6. Howell, M.J., Herrera, N.S., Moore, A.G., McMahan, R.P.: A reproducible olfactory display for exploring olfaction in immersive media experiences. Multimed Tools Appl. 75, 12311–12330 (2016). https://doi.org/10.1007/s11042-015-2971-0.
7. Serrano, B., Baños, R.M., Botella, C.: Virtual reality and stimulation of touch and smell for inducing relaxation: A randomized controlled trial. Computers in Human Behavior. 55, 1–8 (2016). https://doi.org/10.1016/j.chb.2015.08.007.
8. Garcia-Ruiz, M.A., Kapralos, B., Rebolledo-Mendez, G.: An Overview of Olfactory Displays in Education and Training. MTI. 5, 64 (2021). https://doi.org/10.3390/mti5100064.
9. Yanagida, Yasuyuki: A survey of olfactory displays: Making and delivering scents. Presented at the Sensors , Taipei, Taiwan (2012).
10. Batch, A., Patnaik, B., Akazue, M., Elmqvist, N.: Scents and Sensibility: Evaluating Information Olfactation. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. pp. 1–14. Association for Computing Machinery, New York, NY, USA (2020).
11. Tsaramirsis, G., Papoutsidakis, M., Derbali, M., Khan, F.Q., Michailidis, F.: Towards Smart Gaming Olfactory Displays. Sensors. 20, 1002 (2020). https://doi.org/10.3390/s20041002.
12. Kato, S., Nakamoto, T.: Wearable Olfactory Display with Less Residual Odor. In: 2019 IEEE International Symposium on Olfaction and Electronic Nose (ISOEN). pp. 1–3 (2019). https://doi.org/10.1109/ISOEN.2019.8823231.
13. Sugimoto, S., Okada, K.: Olfactory Display Based on Ink Jet Printer Mechanism and Its Presentation Techniques. In: Human Olfactory Displays and Interfaces: Odor Sensing and Presentation. pp. 401–414. IGI Global, Hershey, PA, U.S.A. (2013). https://doi.org/10.4018/978-1-4666-2521-1.ch020.
14. Kadowaki, A., Sato, J., Bannai, Y., Okada, K.: Presentation Technique of Scent to Avoid Olfactory Adaptation. In: 17th International Conference on Artificial Reality and Telexistence (ICAT 2007). pp. 97–104 (2007). https://doi.org/10.1109/ICAT.2007.8.
15. Davide, F., Holmberg, M., Lundstrm, I.: Virtual Olfactory Interfaces: Electronic Noses and Olfactory Displays. In: Communications Through Virtual Technology: Identity, Community and Technology in the Internet Age. pp. 193–220. IOS Press, Amsterdam, The Netherlands (2004).
16. Kauer, J.S., White, J.: Electronic Nose. In: Squire, L.R. (ed.) Encyclopedia of Neuroscience. pp. 871–877. Academic Press, Oxford (2009). https://doi.org/10.1016/B978-008045046-9.01694-6.

17. Al-Dayyeni, W.S., Al-Yousif, S., Taher, M.M., Al-Faouri, A.W., Tahir, N.M., Jaber, M.M., Ghabban, F., Najm, I.A., Alfadli, I.M., Ameerbakhsh, O.Z., Mnati, M.J., Al-Shareefi, N.A., Saleh, A.H.: A Review on Electronic Nose: Coherent Taxonomy, Classification, Motivations, Challenges, Recommendations and Datasets. IEEE Access. 9, 88535–88551 (2021). https://doi.org/10.1109/ACCESS.2021.3090165.
18. Hu, Y.-Y., Jan, Y.-F., Tseng, K.-W., Tsai, Y.-S., Sung, H.-M., Lin, J.-Y., Hung, Y.-P.: aBio: Active Bi-Olfactory Display Using Subwoofers for Virtual Reality. In: Proceedings of the 29th ACM International Conference on Multimedia. pp. 2065–2073. Association for Computing Machinery, New York, NY, USA (2021).
19. Covington, J.A., Agbroko, S.O., Tiele, A.: Development of a Portable, Multichannel Olfactory Display Transducer. IEEE Sensors Journal. 18, 4969–4974 (2018). https://doi.org/10.1109/JSEN.2018.2832284.
20. Herrera, N.S., McMahan, R.P.: Development of a Simple and Low-Cost Olfactory Display for Immersive Media Experiences. In: Proceedings of the 2nd ACM International Workshop on Immersive Media Experiences. pp. 1–6. Association for Computing Machinery, New York, NY, USA (2014). https://doi.org/10.1145/2660579.2660584.
21. UNO R3 | Arduino Documentation, https://docs.arduino.cc/hardware/uno-rev3, last accessed 2022/05/20.
22. Mini Cool Mist Humidifier, https://www.honeywellpluggedin.com/mini-cool-mist-humidifier-hul525, last accessed 2022/05/20.
23. KS0457 keyestudio CCS811 Carbon Dioxide Air Quality Sensor - Keyestudio Wiki, https://wiki.keyestudio.com/KS0457_keyestudio_CCS811_Carbon_Dioxide_Air_Quality_Sensor, last accessed 2022/03/23.
24. Nematollahi, N., Weinberg, J.L., Flattery, J., Goodman, N., Kolev, S.D., Steinemann, A.: Volatile chemical emissions from essential oils with therapeutic claims. Air Qual Atmos Health. 14, 365–369 (2021). https://doi.org/10.1007/s11869-020-00941-4.
25. Vivaldo, G., Masi, E., Taiti, C., Caldarelli, G., Mancuso, S.: The network of plants volatile organic compounds. Sci Rep. 7, 11050 (2017). https://doi.org/10.1038/s41598-017-10975-x.
26. Ellia Lemon Essential Oil, https://www.homedics.ca/lemon-essential-oil/, last accessed 2022/05/20.
27. Berna, A.: Metal Oxide Sensors for Electronic Noses and Their Application to Food Analysis. Sensors. 10, 3882–3910 (2010). https://doi.org/10.3390/s100403882.
28. Garcia-Ruiz, M., Santana, P.: Design, evaluation and impact of educational olfactory interfaces. In: 19th Americas Conference on Information Systems, AMCIS 2013 - Hyperconnected World: Anything, Anywhere, Anytime. pp. 1053–1059. AMCIS, Chicago, IL, USA (2013).
29. Godot Engine - Free and open source 2D and 3D game engine, https://godotengine.org/, last accessed 2022/03/28.
30. Dhule, M.: Getting Started with Godot. In: Dhule, M. (ed.) Beginning Game Development with Godot: Learn to Create and Publish Your First 2D Platform Game.

pp. 17–33. Apress, Berkeley, CA (2022). https://doi.org/10.1007/978-1-4842-7455-2_2.
31. Lemon Free 3D Model - .blend - Free3D, https://free3d.com/3d-model/lemon-72357.html, last accessed 2022/05/20.
32. Miguel Garcia-Ruiz: New video by Miguel Garcia, https://photos.google.com/share/AF1QipOE3A_H2GWV644ZksnaYD8sHDWQvQBM2oywd6gIvRRmB-b9LXp6PeznvDxsKC-SBBQ?key=Q2RTdmozbTdDQmpncXQzN2R0bXZpU-Go5YWNMNWln, last accessed 2022/04/21.
33. Al Enany, M.O., Harb, H.M., Attiya, G.: A Comparative analysis of MQTT and IoT application protocols. In: 2021 International Conference on Electronic Engineering (ICEEM). pp. 1–6 (2021). https://doi.org/10.1109/ICEEM52022.2021.9480384.
34. He, J., Xu, L., Wang, P., Wang, Q.: A high precise E-nose for daily indoor air quality monitoring in living environment. Integration. 58, 286–294 (2017). https://doi.org/10.1016/j.vlsi.2016.12.010.
35. Goodner, K.L., Dreher, J.G., Rouseff, R.L.: The dangers of creating false classifications due to noise in electronic nose and similar multivariate analyses. Sensors and Actuators B: Chemical. 80, 261–266 (2001). https://doi.org/10.1016/S0925-4005(01)00917-0.