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INTRODUCTION TO THE IEEE P2520™ SERIES OF STANDARDS ON OLFACTION DEVICES AND SYSTEMS

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ACKNOWLEDGMENTS

Special thanks are given to the following reviewers of this paper:

Radislav Potyreilo, General Electric Research, Niskayuna, NY, USA

Krishna Persaud, Department of Chemical Engineering and Analytical Science, The University of Manchester, Manchester, UK

Artur Rydosz, Biomarkers Analysis Lab, Institute of Electronics, AGH University of Science and Technology, Krakow, Poland

John Saffell, Alphasense Ltd., Great Notley, Essex, UK

The Institute of Electrical and Electronics Engineers, Inc. 3 Park Avenue, New York, NY 10016-5997, USA

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PDF: STDVA25122 978-1-5044-8220-2

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INTRODUCTION TO THE IEEE P2520™ SERIES OF STANDARDS ON OLFACTION DEVICES AND SYSTEMS

ABSTRACT

A new series of international odor monitoring and analysis standards are being developed by the IEEE Sensors Council and the IEEE Industrial Electronics Society, in collaboration with the International Society for Olfaction and Chemical Sensing. The standards are designed for those developing and using odor analysis devices, electronic noses, and Volatile Organic Compounds (VOCs) analyzers. It is structured as a series of standards that target different, common, odor emission applications, such as outdoor air pollution and chemical processes. The hope is that by targeting specific applications more traction can be gained than during previous attempts at standards. This white paper gives a brief introduction to the series and solicits participation by individual scientists and engineers who see the importance of this work, by companies producing monitoring equipment, and by entities that set regulations that govern this field.

Keywords: artificial olfaction, electronic nose (e-Nose), machine olfaction, odor standards, VOC, Volatile Organic Compounds

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1. INTRODUCTION

Working groups sponsored by the IEEE Sensors Council/Standards Committee and cosponsored by the IEEE Industrial Electronics Society Standards Committee are currently in the process of developing standards for machine olfaction devices [often termed electronic noses (e-Noses), artificial olfaction or instrumental odor monitoring systems (IOMS)]. There has been a long-standing interest in instrumental measurement of olfaction within the IEEE community with special issues of the IEEE Sensors Journal devoted to the topic in 2002 (Nagle, et al. [27]), 2012 (Gardner, et al. [19]), and 2021 (Covington, et al. [14]). A recent focus has been the technical challenges associated with establishing performance standards (Nagle and Schiffman [26]) and selecting appropriate analytes for instrument evaluation (Schiffman and Nagle [28]). The absence of widely accepted performance standards for machine olfaction devices has been a barrier to their authoritative adoption for identifying, quantifying, and classifying odors in numerous applications including odor pollution and regulation, medical diagnostics, and quality assurance.

Current characterization of odor relies predominantly on three measurement techniques: (1) gas chromatography (GC) coupled with mass spectroscopy (MS), (2) compound-specific instruments that detect a single inorganic odorant such as hydrogen sulphide (H_2S) and ammonia (NH_3), and (3) human judgments. Performance standards and established protocols for these techniques are readily available. For example, standards for analysis of odorous samples by GC have been published by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). Examples of standards related to GC analysis of odorous samples include: sulphur compounds (ASTM D5504-20 [3]; ASTM D7011-15 [5]), cyclohexane (ASTM D7266-13 [6]), aromatic hydrocarbons (ASTM D5917-15 [4]) and volatile organic compounds in water (ISO 17943:2016 [21], ASTM D4128-18 [2]). Performance characteristics for instrumental analyzers of individual odorants such as H_2S (e.g., gold film sensors, SO_2 conversion, colorimetric gas detection tubes, electrochemical cells, fluorescence, and lead acetate cassette tape) can be assessed with calibration gases. Furthermore, data quality can be evaluated according to ISO/IEC 17025:2017 [22], which specifies the general requirements for the competence, impartiality, and consistent operation of laboratories. Standardized measurement practices for human assessment of odors are also available from ASTM, ISO, as well as the European Committee for Standardization (CEN). Examples include practices for determining odor thresholds (ASTM E679-04 [8], ASTM E679-19 [9], ISO 13301:2018 [20], and EN 13725:2003 [16]), referencing suprathreshold odor intensity (ASTM E544-18 [7]), sensory perception of odor (ISO 16000-30:2014 [22]), and determination of odor in ambient air by field inspection (EN 16481-1:2016 [17] and EN 16481-2:2016[18]). Dispersion modeling is often used in tandem with these measurement types for odor legislation and regulation (Bokowa, et al., [11]). Concentrations of individual odorants (e.g., H_2S) or odor (odor units) are quantified

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on-site to model and predict levels off-site by dispersion modeling.

Although, these three techniques and their associated standards can provide useful information about odor, each has limitations. It is not possible to predict human sensory quality from the characteristic GC signature of odor samples because the location and amplitude of the peaks is not consistent with sensory relevance. Large peaks may represent compounds with no odor at all, but small peaks can correspond to potent odorants with low sensory thresholds. Chemical characterization of individual gases does not predict the odor quality or intensity of complex odorous mixtures (Bax, et al. [10]; Jiang, et al. [24]). Human assessments can be affected by sensory fatigue, bias, and lack of availability when a plume is present. Furthermore, dispersion modeling suffers from limitations in accurate prediction of short-term odor concentrations (Brancher, et al[12]).

Electronic nose devices have the potential to overcome the limitations of these three techniques. As instruments designed to replicate the biological olfactory system, they typically comprise of a diverse array of discrete chemicals sensors coupled with a pattern recognition technique. The pattern across the sensor array induced by a complex odorous mixture attempts to relate directly to the odor quality and intensity. Furthermore, an e-Nose can provide responses in real time during odor events at specific locations and is available when human odor panellists are not. Properly placed instruments can also eliminate the need for dispersion modeling.

Although assessment of odors by machine would meet market needs in many application areas, e-Nose devices can show performance issues related, for example, to nonlinearity, repeatability, drift, and stability. For this reason, technical standards for these devices need to be developed to help ensure their reliability and safety (Marco [25]). Several approaches have been undertaken to date. These include UNI 1605848 (2019) from Italy, VDI 3518-3 (2018) from Germany, and CEN TC/264 WG41 (2015 to present) from the EU (see Cipriano and Capelli [13] for a review). The IEEE Standards Association (IEEE SA), in collaboration with the International Society for Olfaction and Chemical Sensing (ISOCS), is expanding upon these early standardization approaches.

After standards are in place, conformity assessment by independent third parties will be needed to build trust in commercially available odor monitoring and assessment equipment. The IEEE Conformity Assessment Program (ICAP) has been developed to satisfy this market demand (ICAP, 2021). The IEEE P2520™ Standards will be included in ICAP.

In summary, companies provide odor-monitoring systems to meet market needs, divided into dozens of application areas. For each targeted application, specific performance standards are needed to demonstrate to customers that the odor monitoring system being purchased provides results. Conformity assessment processes should be provided with each of our new standards in the IEEE P2520™ series.

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2. WORKING GROUPS STRUCTURE

During the period from August 2019 to August 2020, the IEEE P2520™ Working Group (WG) formulated a numbering system for our odor equipment performance standards. At the highest level, general application areas for initial focus were classified as follows:

- **2520.1**—Baseline Performance
- **2520.2**—Outdoor Odor Nuisances and Pollutants
- **2520.3**—Indoor Odor Nuisances and Pollutants
- **2520.4**—Industrial Application Odors and Quality Control
- **2520.5**—Personal Health and Hygiene
- **2520.6**—Safety Protection
- **2520.7**—Medical Odor Applications

Within each of these general classes, further subclasses were defined. For example, the IEEE 2520.2 Outdoor Odor Nuisances and Pollutants class has been subdivided as follows:

a) <u>2520.2.1 General Outdoor Air Odor:</u> Odor nuisance is a recurring complaint in urban and industrial areas. Perception of noxious smell in the air decreases quality of life and sense of wellbeing among community members. Moreover, offensive odors can be a warning sign of potential risks to human health. Machine olfaction can be deployed remotely to track spatial and temporal fluctuations in odor intensities in real time. However, the performance of such devices can be significantly influenced by varying environmental conditions (e.g., temperature and humidity) and the presence of non-odorous cross-interfering gases. Hence, there is a need for standardized test protocols for performance verification of these measurement systems.

b) <u>2520.2.2 Landfill Odor</u>: Odorous emissions from the working face of municipal solid waste landfills are a major global problem. Instrumental assessment of odors onsite will enable operators to aggressively apply appropriate treatments to mitigate odor. Placement of e-Nose devices in the surrounding communities can monitor the intensity and frequency of exposure to landfill odor experienced by neighbors.

c) <u>2520.2.3 Residential Water Supply</u>: Chlorine-generated residential water odor can be perceived as bleach, chemical, or medicinal. Bacteria can generate sulphurous or sewage-like odors and can combine with decaying organic matter to generate musty, moldy, earthy, grassy, or fishy odors. Solvent-like odors can be produced by petroleum, gasoline, or turpentine leaks. Pesticides, septic tanks, and methane from landfills can also be odor sources. Odor monitors that can detect, classify, and quantify these odors will be the focus of this standard (Jiang, et, al. [24]).

d) <u>2520.2.4 Sewage Treatment (outdoor and downwind)</u>: Odor emissions from sewers and wastewater treatment plants (WWTPs) are a persistent problem around the world. H_2S as well as VOCs are

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commonly released from sewers. The odor remediation processes in the WWTPs also generate odors that can be detrimental to the plant personnel and local residents. Odor control and abatement at the WWTP must be carefully monitored and regulated. The focus on this standard will be to develop testing and conformity assessment protocols for this class on odor analysis and monitoring equipment (Jiang, et al. [24]).

e) 2520.2.5 Animal Confinement (outdoor and downwind): Confined animal feeding operations (CAFOs) house thousands of animals at a single facility. Aerial emissions from CAFOs generate odor complaints downwind. Monitoring odor onsite and downwind will provide information on odor dispersion and facilitate development of techniques for odor control.

f) 2520.2.6 Travel-Based Air Pollution (automotive/rail/planes): Aircraft cabin air is commonly circulated through the aircraft engine, so exposure to oil and hydraulic fume is possible. Other odor sources include human bodies, traveling pets, de-icing fluid, cleaning fluid residues, perfumes, and shaving lotions (AFA-CWA). Airlines and other means of public conveyance should maintain these odor levels near or below human detection thresholds. The focus of this standard will be to develop standards for specific modes of transportation, including automobiles, buses, trains, and airplanes.

g) 2520.2.7 Workplace Satisfaction: Odors in the workplace have great impact on employee and customer satisfaction (de Luca [15]). Fragrance allergies, food odor problems, moldy HVAC, employee hygiene, building materials, and the like can be a detriment to employee satisfaction and workload efficiency. Techniques to measure and control these problems will be addressed in this standard.

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3. DISCUSSION

After much deliberation and discussion, the IEEE P2520 WG decided to initiate five new IEEE SA approved WGs on the following specific topics:

a) P2520.1™ Baseline Performance for Odor Analysis Devices and Systems (James Covington, WG Chair): The goal is to provide testing methods and conformance processes to help ensure that odor analysis devices and systems achieve reliable and reproducible baseline performance appropriate for general VOC/odor monitoring and assessment applications. All instruments shall pass this standard before moving onto a more specific standard.

b) P2520.2.1™ Machine Olfaction Devices and Systems Used for General Outdoor Odor Monitoring (Ehsan Danesh, WG Chair): WG meetings officially kicked-off in February 2021 and since then, members have focused on identifying gaseous chemicals responsible for outdoor malodorous events and their relevant concentrations. The focus has been to understand past and on-going international efforts in standardizing odor measurement.

c) P2520.2.2™ Landfill Odor Monitoring Devices and Systems (Susan Schiffman, WG Chair): IEEE P2520.2.2 will build upon IEEE P2520.1 and IEEE P2520.2.1. Therefore, participants interested in the new IEEE P2520.2.2 WG are meeting informally with IEEE P2520.1 and IEEE P2520.2.1. IEEE P2520.2.2 will formally kick off and work independently once the scopes of those two foundational standards have been defined.

d) P2520.3.1™ Machine Olfaction Devices and Systems Used for General Indoor Odor Monitoring: (Ehsan Danesh, WG Chair): The focus of this standard is devices that are designed to monitor nuisance odors in indoor environments such as commercial and residential buildings, sport venues, car parks, kitchens, and food storage facilities, where VOCs may produce noxious smells and/or impose health risks. A Project Authorization Request (PAR) for this WG has been approved by IEEE SA, and the first meeting was held in June 2021.

b) P2520.4.1™ Performance of Machine Olfaction Devices and Systems for Chemical Manufacture: (Susana Palma, WG Chair): This WG initiated its work in February 2021 and aims to develop performance testing protocols for artificial olfaction instruments employed to monitor odors from chemical manufacture plants (e.g., pharma, biotech, paints, solvents, chemicals). IEEE P2520.4.1 gathers a multidisciplinary group of academic researchers, sensor manufacturers, and odor monitoring experts. IEEE P2520.4.1 will build upon IEEE P2520.1. Therefore, most IEEE P2520.4.1 WG participants are meeting also with the IEEE P2520.1 WG. The current focus of the IEEE P2520.4.1 WG is in understanding the specific requirements of chemical manufacture plant odor monitoring, selecting test chemicals, and testing setups. The goal is to have a draft standard outline early in 2022.

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4. CONCLUSIONS

The new Working Groups began operations in early 2021. Collaborations among the working groups have been initiated. The groups contain researchers from across Europe, the Americas and Asia and consist of people from both industry and academics. Members of the groups develop sensors, systems, and applications. We are at the early stages in our standards drafting effort. If you are interested in joining in one or more of these efforts, please contact:

P2520™ Testing Machine Olfaction Devices and Systems (https://sagroups.ieee.org/2520-1/)
(https://sagroups.ieee.org/2520/)
Susan Schiffman, WG Chair (s.schiffman@ieee.org)

P2520.1™ Baseline Performance for Odor Analysis Devices and Systems (https://sagroups.ieee.org/2520-1/)
(https://sagroups.ieee.org/2520-1/)
James Covington, WG Chair (j.a.covington@ieee.org)

P2520.2.1™ Machine Olfaction Devices and Systems Used for General Outdoor Odor Monitoring
(https://sagroups.ieee.org/2520-2-1/)
Ehsan Danesh, WG Chair (e.danesh@ieee.org)

P2520.3.1™ Machine Olfaction Devices and Systems Used for General Indoor Odor Monitoring
(https://sagroups.ieee.org/2520-3-1/)
Ehsan Danesh, WG Chair (e.danesh@ieee.org)

P2520.4.1™ Performance of Machine Olfaction Devices and Systems for Chemical Manufacture
(https://sagroups.ieee.org/2520-4-1/)
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[5] ASTM D7011-15(2019), Standard Test Method for Determination of Trace Thiophene in Refined Benzene by Gas Chromatography and Sulphur Selective Detection.

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