Instrumental Odour Monitoring System Optimized for Drone Applications

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Abstract—**In this contribution, a novel design for an Instrumental Odour Monitoring System (IOMS) is presented. This evolution of the IOMS concept is designed to be mounted on a drone, enabling the generation of 3D maps of gas concentrations and odour levels during flight. It features fast-response gas chambers, a rapid data acquisition architecture, a modular design, and fast GPS RTK tracking. The performance of this innovative design has been tested under controlled conditions, comparing its performance with existing designs. The results show that the time for the gas concentration inside the IOMS to reach the limit of detection of the sensors is approximately 3-7 seconds faster than that observed in traditional IOMS designs. Additionally, measurements taken during test flights with a conventional IOMS are compared with those obtained using the new design. In every flight, the new IOMS produces results tenths of seconds faster than the conventional designs. These results, both in the laboratory and in the field, indicate that the modifications in the new IOMS design enable it to respond rapidly to changes caused by the drone's swift movements. This fast response and rapid tracking make the novel design more suitable for fast 3D map of gas concentrations and odour levelthan conventional IOMS designs.**

Index Terms—**IOMS; Drone-based odour monitoring; 3D odour mapping; Gas concentration mapping; Fast-response gas chambers; Electronic nose; Malodours; Machine learning; Odour intensity prediction**

I. INTRODUCTION

INSTRUMENTAL Odour Monitoring Systems (IOMS) have been deployed in Wastewater Treatment Plants (WWTPs) over the past decade [1]–[4]. These systems are used for odour quantification and monitoring due to their effectiveness in measuring gases such as H_2S, NH_3, and others producing malodorous [5], [6]. Consequently, in recent years, they have become commercial products and are being installed at WWTP fences and critical points across Europe [4], [7]–[9]. However, these deployments are time-consuming, requiring extensive and costly calibration procedures. Furthermore, they lack flexibility in case of plant changes and cannot produce a comprehensive map of the plant unless multiple IOMS units are deployed around and inside the facility [10].

In recent years, drone-based IOMS have emerged for rapid gas concentration characterization and odour mapping in the industrial landscape [11]–[13]. Their applications include methane leak control [14], fire detection with source location [15], and air quality monitoring [16]. In particular, studies on WWTPs have shown that these systems can produce 3D maps of gas concentration results much faster than commercial IOMS for the entire plant [17], enabling data scientists to develop odour quantification models [18], [19].

Despite these results, experience has shown that drone-mounted designs struggle to follow rapid variations of its surrounding air [12], [13], [19]. Consequently, the drone's speed (typically ~ 10 m/s) when moving around the plant for 3D mapping is limited by the response time of the measuring system. Also, windy conditions produce plumes of odour and the conventional IOMSs struggle to work in these conditions (wind speed ≤ 10 km/h). This limitation reduces the applicability of IOMSs to quantify static sources and operate in favorable conditions.

Recent studies have shown that a careful design of the gas chambers containing the sensors in an IOMS significantly reduces the time needed to reach the sensors' limit of detection [20]. This reduction in response time impacts on the requirements of sensor data and GPS location data acquisition architectures of the IOMS. Consequently, the traditional IOMS design, even in its drone-mounted version [12], requires a substantial review.

This work presents the mentioned review of the conventional IOMS design, featuring a very fast response time, rapid data acquisition architecture, and centimeter-precise RTK GPS location. This platform is capable of tracking rapid changes in the surrounding air, addressing the limitations of conventional IOMSs when mounted on drones (such as drone speed and windy weather conditions). During laboratory tests, the novel design has shown faster response (in the tenths of seconds) to an odorous step than a conventional IOMS and fast plume tracking. This behavior has been confirmed during test flights (at UPC facilities droneLab, Castelldefels, Spain).

Therefore, this contribution is organized as follows: Section II provides a description of the novel IOMS, including its gas chambers, data acquisition architecture, communications, and GPS data management. Section III presents a comprehensive performance characterization of the IOMS by comparing its response in various experiments with that of a conventional design. Section IV summarizes the flying tests assessing the IOMS performance. Finally, Section V summarizes the achievements of this design, outlining the potential applications of this optimized IOMS.

II. IOMS Description

The templates are intended to **approximate the final look and page length of the articles/papers**. **They are NOT intended to be the final produced work that is displayed in print or on IEEEXplore®**. They will help to give the authors an approximation of the number of pages that will be in the final version. The structure of the LaTeX files, as designed, enable easy conversion to XML for the composition systems used by the IEEE. The XML files are used to produce the final print/IEEEXplore pdf and then converted to HTML for IEEEXplore.

III. IOMS Performance Characterization

The following online groups are helpful to beginning and experienced LaTeX users. A search through their archives can provide many answers to common questions.

http://www.latex-community.org/
https://tex.stackexchange.com/

IV. Drone-mounted IOMS and Flight Performance

See [**?**], [**?**], [**?**], [**?**], [**?**] for resources on formatting math into text and additional help in working with LaTeX.

V. Conclusions

For some of the remainer of this sample we will use dummy text to fill out paragraphs rather than use live text that may violate a copyright.

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$$x = \sum_{i=0}^{n} 2iQ. \tag{1}$$

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VI. Some Common Elements

A. Sections and Subsections

Enumeration of section headings is desirable, but not required. When numbered, please be consistent throughout the article, that is, all headings and all levels of section headings in the article should be enumerated. Primary headings are designated with Roman numerals, secondary with capital letters, tertiary with Arabic numbers; and quaternary with lowercase letters. Reference and Acknowledgment headings are unlike all other section headings in text. They are never enumerated. They are simply primary headings without labels, regardless of whether the other headings in the article are enumerated.

B. Citations to the Bibliography

The coding for the citations is made with the LaTeX `\cite` command. This will display as: see [**?**].

For multiple citations code as follows: `\cite{ref1,ref2,ref3}` which will produce [**?**], [**?**], [**?**]. For reference ranges that are not consecutive code as `\cite{ref1,ref2,ref3,ref9}` which will produce [**?**], [**?**], [**?**], [**?**]

C. Lists

In this section, we will consider three types of lists: simple unnumbered, numbered, and bulleted. There have been many options added to IEEEtran to enhance the creation of lists. If your lists are more complex than those shown below, please refer to the original "IEEEtran_HOWTO.pdf" for additional options.

Fig. 1: Simulation results for the network.

A plain unnumbered list:

bare_jrnl.tex
bare_conf.tex
bare_jrnl_compsoc.tex
bare_conf_compsoc.tex
bare_jrnl_comsoc.tex

A simple numbered list:

1) bare_jrnl.tex
2) bare_conf.tex
3) bare_jrnl_compsoc.tex
4) bare_conf_compsoc.tex
5) bare_jrnl_comsoc.tex

A simple bulleted list:

- bare_jrnl.tex
- bare_conf.tex
- bare_jrnl_compsoc.tex
- bare_conf_compsoc.tex
- bare_jrnl_comsoc.tex

D. Figures

Fig. 1 is an example of a floating figure using the graphicx package. Note that \label must occur AFTER (or within) \caption. For figures, \caption should occur after the \includegraphics.

Fig. 2(a) and 2(b) is an example of a double column floating figure using two subfigures. (The subfig.sty package must be loaded for this to work.) The subfigure \label commands are set within each subfloat command, and the \label for the overall figure must come after \caption. \hfil is used as a separator to get equal spacing. The combined width of all the parts of the figure should do not exceed the text width or a line break will occur.

Note that often IEEE papers with multi-part figures do not place the labels within the image itself (using the optional argument to \subfloat[]), but instead will reference/describe all of them (a), (b), etc., within the main caption. Be aware that for subfig.sty to generate the (a), (b), etc., subfigure labels, the optional argument to \subfloat must be present. If a subcaption is not desired, leave its contents blank, e.g.,\subfloat[].

TABLE I: An Example of a Table

One	Two
Three	Four

VII. TABLES

Note that, for IEEE-style tables, the \caption command should come BEFORE the table. Table captions use title case. Articles (a, an, the), coordinating conjunctions (and, but, for, or, nor), and most short prepositions are lowercase unless they are the first or last word. Table text will default to \footnotesize as the IEEE normally uses this smaller font for tables. The \label must come after \caption as always.

VIII. ALGORITHMS

Algorithms should be numbered and include a short title. They are set off from the text with rules above and below the title and after the last line.

Algorithm 1 Weighted Tanimoto ELM.

TRAIN($\mathbf{XT}$)
    select randomly $W \subset \mathbf{X}$
    $N_{\mathbf{t}} \leftarrow |\{i : \mathbf{t}_i = \mathbf{t}\}|$ **for** $\mathbf{t} = -1, +1$
    $B_i \leftarrow \sqrt{\text{MAX}(N_{-1}, N_{+1})/N_{\mathbf{t}_i}}$ **for** $i = 1, ..., N$
    $\hat{\mathbf{H}} \leftarrow B \cdot (\mathbf{X}^T\mathbf{W})/(\mathbb{1}\!\!\mathbb{X} + \mathbb{1}\!\!\mathbb{W} - \mathbf{X}^T\mathbf{W})$
    $\beta \leftarrow \left(I/C + \hat{\mathbf{H}}^T\hat{\mathbf{H}}\right)^{-1}(\hat{\mathbf{H}}^TB \cdot \mathbf{T})$
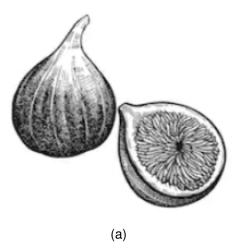   **return** $\mathbf{W}, \beta$

PREDICT($\mathbf{X}$)
    $\mathbf{H} \leftarrow (\mathbf{X}^T\mathbf{W})/(\mathbb{1}\!\!\mathbb{X} + \mathbb{1}\!\!\mathbb{W} - \mathbf{X}^T\mathbf{W})$
    return SIGN($\mathbf{H}\beta$)

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IX. MATHEMATICAL TYPOGRAPHY AND WHY IT MATTERS

Typographical conventions for mathematical formulas have been developed to **provide uniformity and clarity of presentation across mathematical texts**. This enables the readers of those texts to both understand the author's ideas and to grasp new concepts quickly. While software such as LaTeX and MathType® can produce aesthetically pleasing math when used properly, it is also very easy to misuse the software, potentially resulting in incorrect math display.

IEEE aims to provide authors with the proper guidance on mathematical typesetting style and assist them in writing the best possible article. As such, IEEE has assembled a set of examples of good and bad mathematical typesetting [**?**], [**?**], [**?**], [**?**], [**?**].
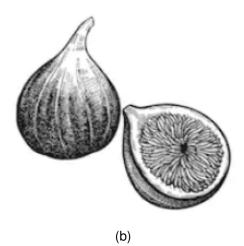
(a)   (b)

Fig. 2: Dae. Ad quatur autat ut porepel itemoles dolor autem fuga. Bus quia con nessunti as remo di quatus non perum que nimus. (a) Case I. (b) Case II.

Further examples can be found at http://journals. ieeeauthorcenter.ieee.org/wp-content/uploads/sites/7/ IEEE-Math-Typesetting-Guide-for-LaTeX-Users.pdf

A. Display Equations

The simple display equation example shown below uses the "equation" environment. To number the equations, use the \label macro to create an identifier for the equation. LaTeX will automatically number the equation for you.

$$x = \sum_{i=0}^{n} 2iQ. \tag{2}$$

is coded as follows:

```
\begin{equation}
\label{deqn_ex1}
x = \sum_{i=0}^{n} 2{i} Q.
\end{equation}
```

To reference this equation in the text use the \ref macro. Please see (2)
is coded as follows:

```
Please see (\ref{deqn_ex1})
```

B. Equation Numbering

Consecutive Numbering: Equations within an article are numbered consecutively from the beginning of the article to the end, i.e., (1), (2), (3), (4), (5), etc. Do not use roman numerals or section numbers for equation numbering.
Appendix Equations: The continuation of consecutively numbered equations is best in the Appendix, but numbering as (A1), (A2), etc., is permissible.

Hyphens and Periods: Hyphens and periods should not be used in equation numbers, i.e., use (1a) rather than (1-a) and (2a) rather than (2.a) for subequations. This should be consistent throughout the article.

C. Multi-Line Equations and Alignment

Here we show several examples of multi-line equations and proper alignments.
A single equation that must break over multiple lines due to length with no specific alignment.

The first line of this example
The second line of this example
The third line of this example   (3)

is coded as:

```
\begin{multline}
\text{The first line of this example}\\
\text{The second line of this example}\\
\text{The third line of this example}
\end{multline}
```

A single equation with multiple lines aligned at the = signs

$$a = c + d \tag{4}$$
$$b = e + f \tag{5}$$

is coded as:

```
\begin{align}
a &= c+d \\
b &= e+f
\end{align}
```

The align environment can align on multiple points as shown in the following example:

$$x = y \qquad X = Y \qquad a = bc \tag{6}$$
$$x' = y' \qquad X' = Y' \qquad a' = bz \tag{7}$$

is coded as:

```
\begin{align}
x &= y & X & =Y & a &=bc\\
x' &= y' & X' &=Y' &a' &=bz
\end{align}
```

D. Subnumbering

The amsmath package provides a `subequations` environment to facilitate subnumbering. An example:

$$f = g \tag{8a}$$
$$f' = g' \tag{8b}$$
$$\mathcal{L}f = \mathcal{L}g \tag{8c}$$

is coded as:

```
\begin{subequations}\label{eq:2}
\begin{align}
f&=g \label{eq:2A}\\
f' &=g' \label{eq:2B}\\
\mathcal{L}f &= \mathcal{L}g \label{eq:2c}
\end{align}
\end{subequations}
```

E. Matrices

There are several useful matrix environments that can save you some keystrokes. See the example coding below and the output.

A simple matrix:

$$\begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix} \tag{9}$$

is coded as:

```
\begin{equation}
\begin{matrix}  0 &  1 \\
1 &  0 \end{matrix}
\end{equation}
```

A matrix with parenthesis

$$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \tag{10}$$

is coded as:

```
\begin{equation}
\begin{pmatrix} 0 & -i \\
 i &  0 \end{pmatrix}
\end{equation}
```

A matrix with square brackets

$$\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{11}$$

is coded as:

```
\begin{equation}
\begin{bmatrix} 0 & -1 \\
1 &  0 \end{bmatrix}
\end{equation}
```

A matrix with curly braces

$$\begin{Bmatrix} 1 & 0 \\ 0 & -1 \end{Bmatrix} \tag{12}$$

is coded as:

```
\begin{equation}
\begin{Bmatrix} 1 &  0 \\
0 & -1 \end{Bmatrix}
\end{equation}
```

A matrix with single verticals

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} \tag{13}$$

is coded as:

```
\begin{equation}
\begin{vmatrix} a &  b \\
c &  d \end{vmatrix}
\end{equation}
```

A matrix with double verticals

$$\begin{Vmatrix} i & 0 \\ 0 & -i \end{Vmatrix} \tag{14}$$

is coded as:

```
\begin{equation}
\begin{Vmatrix} i &  0 \\
0 & -i \end{Vmatrix}
\end{equation}
```

F. Arrays

The `array` environment allows you some options for matrix-like equations. You will have to manually key the fences, but there are other options for alignment of the columns and for setting horizontal and vertical rules. The argument to `array` controls alignment and placement of vertical rules.

A simple array

$$\left(\begin{array}{cccc} a+b+c & uv & x-y & 27 \\ a+b & u+v & z & 134 \end{array} \right) \tag{15}$$

is coded as:

```
\begin{equation}
\left(
\begin{array}{cccc}
a+b+c & uv & x-y & 27\\
a+b & u+v & z & 134
\end{array} \right)
\end{equation}
```

A slight variation on this to better align the numbers in the last column

$$\left(\begin{array}{cccr} a+b+c & uv & x-y & 27 \\ a+b & u+v & z & 134 \end{array} \right) \tag{16}$$

is coded as:

```
\begin{equation}
\left(
\begin{array}{cccr}
a+b+c & uv & x-y & 27\\
a+b & u+v & z & 134
\end{array} \right)
\end{equation}
```

An array with vertical and horizontal rules

$$\left(\begin{array}{c|c|c|r} a+b+c & uv & x-y & 27 \\ \hline a+b & u+v & z & 134 \end{array} \right) \tag{17}$$

is coded as:

```
\begin{equation}
\left(
\begin{array}{c|c|c|r}
a+b+c & uv & x-y & 27\\
a+b & u+v & z & 134
\end{array} \right)
\end{equation}
```

Note the argument now has the pipe "|" included to indicate the placement of the vertical rules.

G. Cases Structures

Many times cases can be miscoded using the wrong environment, i.e., `array`. Using the `cases` environment will save keystrokes (from not having to type the `\left\lbrace`) and automatically provide the correct column alignment.

$$z_m(t) = \begin{cases} 1, & \text{if } \beta_m(t) \\ 0, & \text{otherwise.} \end{cases}$$

is coded as follows:

```
\begin{equation*}
{z_m(t)} =
\begin{cases}
1,&{\text{if}}\ {\beta }_m(t),\\
{0,}&{\text{otherwise.}}
\end{cases}
\end{equation*}
```

Note that the "&" is used to mark the tabular alignment. This is important to get proper column alignment. Do not use `\quad` or other fixed spaces to try and align the columns. Also, note the use of the `\text` macro for text elements such as "if" and "otherwise."

H. Function Formatting in Equations

Often, there is an easy way to properly format most common functions. Use of the `\` in front of the function name will in most cases, provide the correct formatting. When this does not work, the following example provides a solution using the `\text` macro:

$$d_R^{KM} = \underset{d_l^{KM}}{\arg\min}\{d_1^{KM}, \ldots, d_6^{KM}\}.$$

is coded as follows:

```
\begin{equation*}
d_{R}^{KM} = \underset {d_{l}^{KM}}
{\text{arg min}} \{ d_{1}^{KM},
\ldots,d_{6}^{KM}\}.
\end{equation*}
```

I. Text Acronyms Inside Equations

This example shows where the acronym "MSE" is coded using `\text{}` to match how it appears in the text.

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$$

```
\begin{equation*}
\text{MSE} = \frac {1}{n}\sum _{i=1}^{n}
(Y_{i} - \hat {Y_{i}})^{2}
\end{equation*}
```

X. Conclusion

The conclusion goes here.

Acknowledgments

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XI. Biographies

Javier Alonso-Valdesueiro was born in Madrid, Spain, in 1980. He received his Telecommunications Engineering degree from the University of Alcalá, Madrid, in 2006, and his Ph.D. degree from the Polytechnic University of Catalonia, Barcelona, in 2011. From 2012 to 2020, he worked on developing electronic instrumentation for NMR experiments, initially at the C.E.A Center in France, followed by the University of Southampton in the UK, and later as a Marie Skłodowska-Curie Fellow at the University of the Basque Country (UPV/EHU). Over the past four years, he has advanced his career as an RF and instrumentation engineer in both private companies and public research centers, including TECNALIA Innovation Foundation and the Institute of Biomedical Engineering of Catalonia. Recently, he has been appointed as Assistant Professor in the Department of Electronic and Biomedical Engineering at the University of Barcelona.