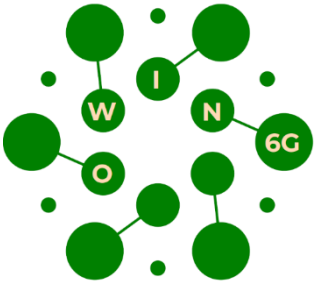
# HORIZON-MSCA-2022-DN-01

(Marie Skłodowska-Curie Actions Doctoral Networks)

**Project Number: 101119624**

**Acronym: OWIN6G**




**Project title: Optical and Wireless Sensors Networks for 6G Scenarios**

**Work Package 1: Devices and Subsystems**

**Deliverable 1.2: Prototype of a patch sensor**

**Northumbria University, Newcastle upon Tyne, UK**

**August 2025**

Funded by the European Union

## Contributors

| DC | Organization | Country | E-mail |
|---|---|---|---|
| Yiming Shen | Eblana Photonics | Ireland | D23130066@mytudublin.ie |
| Raul Zamorano-Illanes | Northumbria University | UK | raul.illanes@northumbria.ac.uk |
| Julian Solis Torrejon | Northumbria University | UK | julian.i.s.torrejon@northumbria.ac.uk |
| **Supervisors** | | | |
| Prof. Yuliya Semenova | Technological University Dublin | Ireland | yuliya.semenova@tudublin.ie |
| Prof. Zabih Ghassemlooy | Northumbria University | UK | z.ghassemlooy@northumbria.ac.uk |
| Dr Qiang Wu | Northumbria University | UK | qiang.wu@northumbria.ac.uk |

## Executive Summary

This document is the first report on Task 1.2 activities, summarising the work done on developing the fibre patch sensor and the associated sensor node (SN) for monitoring of human activity and health.

## Contents



Funded by the European Union

# Work package 1 (WP1) – T1.2 Prototype of the patch sensor

## 1. Main objectives

WP1 aims to develop devices and subsystems for sensing and data communications, focusing on the physical interaction between the optoelectronic components and the medium, and digitising the captured information for transmission wirelessly to the upper network layer. More, specifically, **Task 1.2** is focused on the development of the fibre-based patch sensor and its associated SNs for sensing human activities and health related issues. The information generated is transmitted using the visible light communication (VLC) [1] technology that utilises energy-efficient light-emitting diodes (LEDs) and offers inherent data security, which is highly critical in today's Internet-of-Things applications, especially for biometric data in Wireless Body Area Networks (WBAN) [2].

The summary of Task 1.2 and the related main objectives are presented in Tables I and II.

**Table I. Summary of T1.2**

| **Work Package Number** | WP1 | **Lead Beneficiary** | NU |
|---|---|---|---|
| **Task** | 1.2 | | |
| **Start Month** | 7 | **End Month** | 42 |
| **WP Name** | | Devices and Subsystems | |
| **Task Name** | | Portable electrical/optical sensor devices | |
| **Milestones addressed** | | No. 1 Implementation of sensor prototypes | |

**Table II. Main objectives of T1.2**

| **No.** | **Objectives** |
|---|---|
| 1 | Development of the patch-based optical and electrical sensor |
| 2 | Development of a VLC-based SN and its access point (AP) |
| 3 | Development of a collaborative framework for all other system layers |
| 4 | Present use cases for the monitoring system |
| 5 | Disseminate research outputs vis normal mediums |

## 2. Description

The development of the optical fibre-based sensing system was focused on two main technical challenges:

(i) The development of fibre sensors
(ii) The VLC technology for transmission of the real-time acquisition of data.

These challenges have been addressed by the collaboration between DCs 1, 9 and 10, based at EPL (Ireland) and NU (UK).

Figure 1 depicts the proposed SN system as part of the main project, outlining the main tasks associated with WP1. It is composed of the sensors, solar panel for energy harvesting, camera for optical detections, AP, RF-optical transceiver and distributed optical sensor. The SN captures the data and transmits it using an LED-based VLC link. Dual purpose photovoltaic (PV) cells (energy harvesting and optical receiver) and a camera are used for capturing the intensity modulated light signal for further analysis. A dedicated fibre interrogator is used for launching light into the fibre sensor and capturing the reflected light for further analysis. Using the spectral analysis, we have carried out real-time measurement of variables such as the temperature, mobility, electrocardiogram (ECG) signals, and biomarkers. At the network layer (i.e., local area network (LAN)), the sensing information is transmitted in real-time to a local edge server [3], enabling fast response and synchronisation with the on cloud servers via the wide area network. We have used an unmanned aerial vehicle (UAV) to activate and de-activate the SN in order to minimise the energy usage, thus prolonging the batteries lifetime [4].

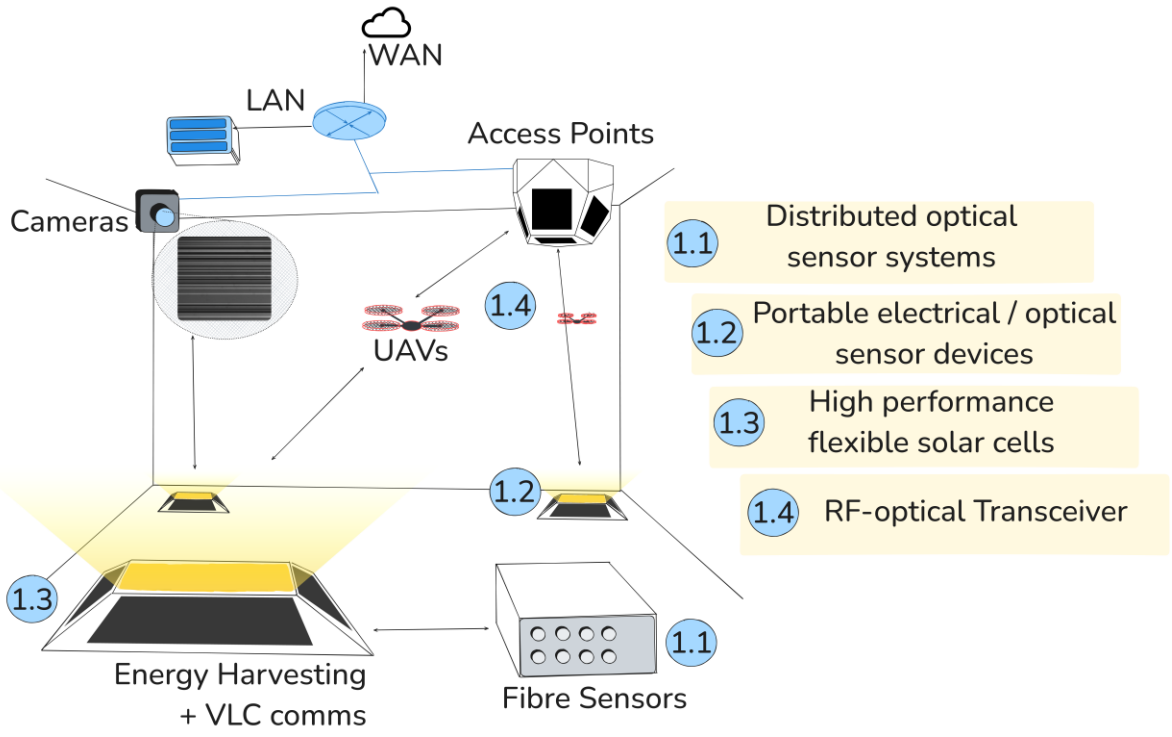



Fig. 1. Fibre-based sensing system using VLC.

# 3. Report on T1.2 activities

The system architecture is described in Fig. 2, where communications with the fibre Interrogator is performed via an RS232 interface, obtaining data over a range of wavelengths. A tunable laser source is divided into two channels for multiplexing purpose. Each channer supply light source to the fibre sensor to monitor surrounding environmental changes, including temperature, strain, vibration, acoustic signal and biomarkers for structural health monitoring, medical diagnostics, environmental pollution detection, etc. The SN is activated by an external Infra-red (IR) light, i.e., initiating information transmission via the VLC link. A PV cell is used as the receiver at the AP. Note that the AP transmits the information to the local server via TCP/IP to an MQTT server, which is synchronised with an on-cloud server for centralised access and post-processing of the data.

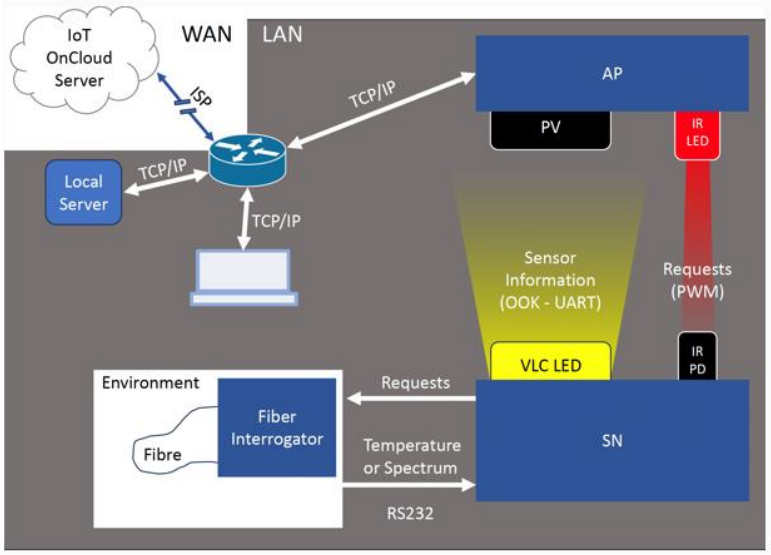



Fig. 2. Architecture of the developed system.

## 3.1. Development of the patch-based optical and electrical sensor

A skin patch sensor enables real-time, non-invasive detection of biomarkers by monitoring biochemical signals from the skin or its secretions. Functionalised fibre optic sensor (FOS) [5] can be a promising solution for skin patch sensors. The development of microfluidic patches allows FOS to be integrated into a skin patch, which is wearable and enables continuous monitoring of biomarkers. We have developed a soft polymer-based skin patch to act as a matrix for fibre sensors embedding with high body compliance, allowing fibre cleaning through a microfluidic circuitry, and easy connection of the fibre sensor to an optical read-out system (see Fig. 3 and Fig. 4).

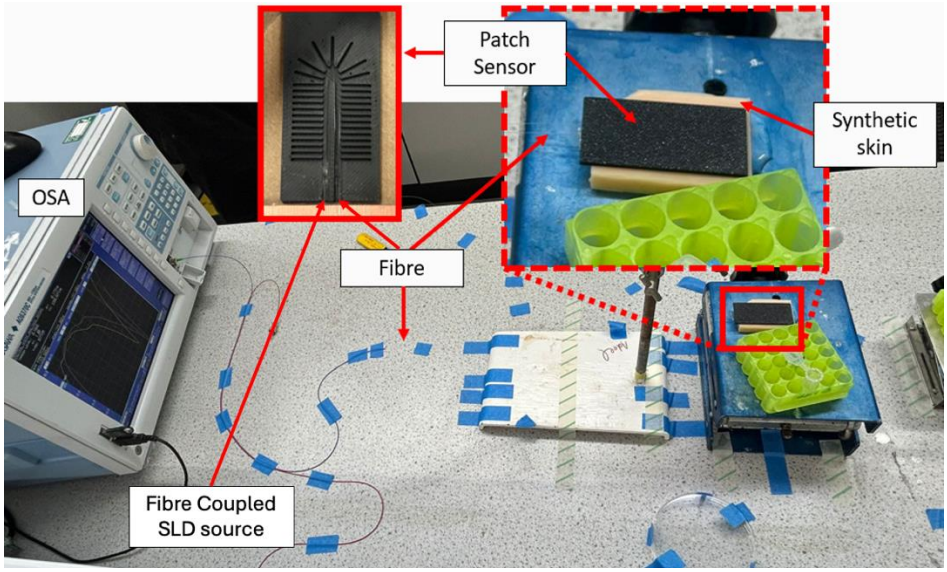



Fig. 3. Testbed for the testing of the fibre samples.

Considering the range of wavelengths adopted, sampling rates, and measurement resolutions, which can vary, we have used an OSA that offers an important reference when using other hardware for real-time implementation as shown in Fig. 4(a). Note that a previously tested patch sensor is connected to a fibre interrogator with a tunable laser over a range of 1520 to 1560 nm once every second, enabling the real time display of the spectrum and tracking of wavelength peaks and dips, see Fig. 4(b). Finally, a spectrum waterfall graph is presented in Fig. 4(c), showing the shift in the wavelength due to the change of the surrounding environment.

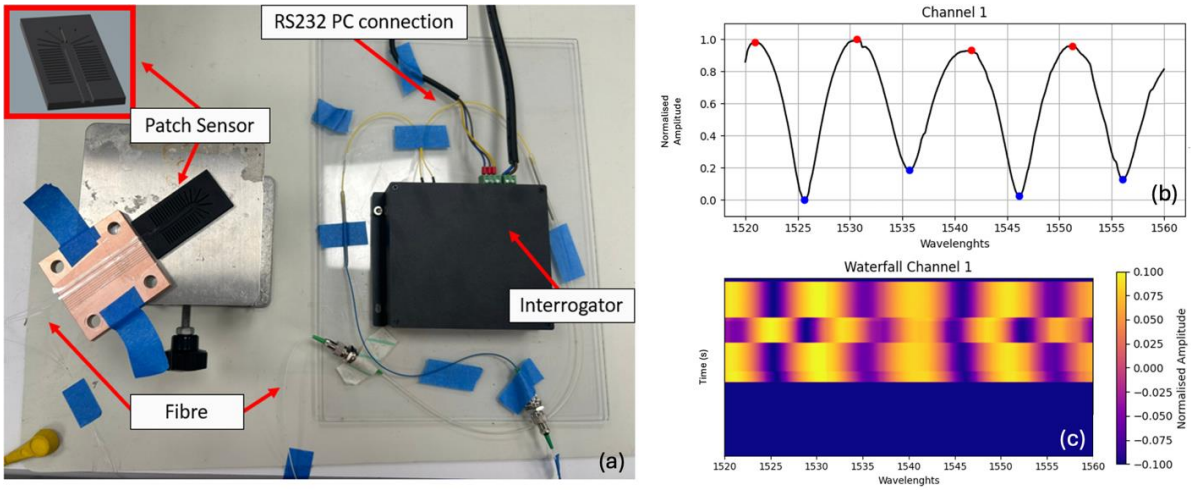



Fig. 4. (a) Patch-based sensor connected to the fibre interrogator, (b) optical spectrum and the peaks and valleys recognition, and (c) the waterfall graph along the time registering a temporal wavelength shift.

Funded by
the European Union

As depicted in Fig. 5, a patch sensor is used to obtain the ECG signals from a person, transmitting the sensing data by visible light over the free space channel. An LED and a PV are used as the transmitter and the receiver, respectively, enabling the display of the sensing data in real time in a local area network server.

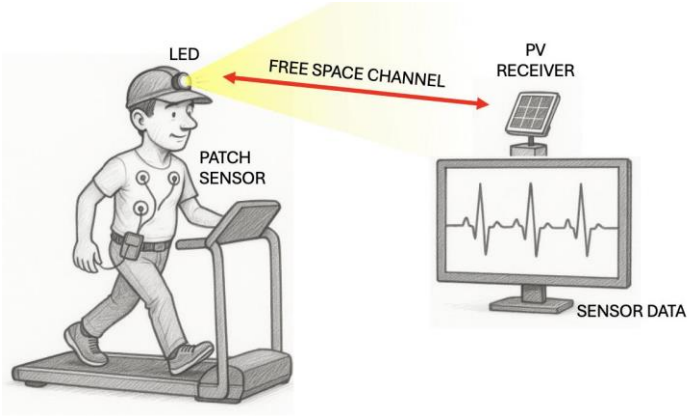



Fig. 5. Graphical representation of the portable VLC-based system developed.

The experimental testbed and the prototype for the portable patch-based sensor are illustrated in Fig. 6(a), where ECG signals are digitised, encoded in an on-off keying (OOK) data format using a microcontroller unit (MCU) for intensity modulation of the LED via a drive circuit. The PV-based receiver filters and amplifies the signal prior to transmitting the regenerated signal to a computer via an MCU. The example of acquired ECG signal obtained at the receiver side is shown in Fig. 6(b), and the received signal captured by an oscilloscope is presented in Fig. 6(c).

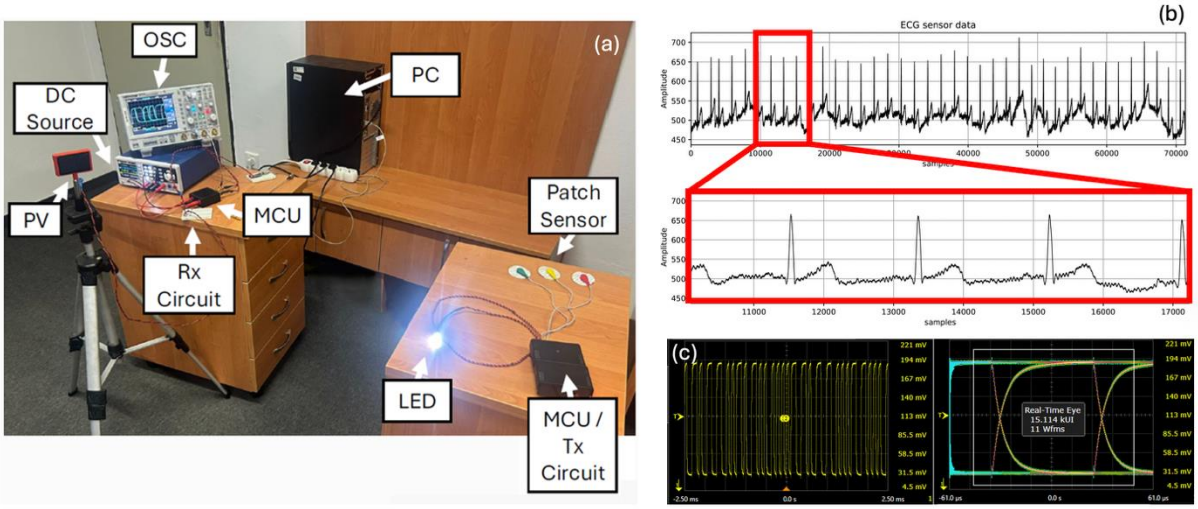



Fig. 6. (a) Testbed for the VLC-based portable ECG sensor, (b) ECG digital signals received at the PC, and (c) an Eye diagram for the OOK signal.

Funded by
the European Union

### 3.2. Demonstration system and dissemination

During the first year of the OWIN6G project, the team members attended the Smart Buildings and Sustainability Leaders' Forum (SBS), which was held at Birmingham (UK) in September 2024, with many companies working in the field of Smart Infrastructure to showcase their products and promoting sustainability, innovation, and collaboration. The presented system, focused on biomedical measurements and real-time display of the sensing process, sparked interests of companies in the sanitary health and health sector, due to its high sensitivity in water quality monitoring for targets as Staphylococcus aureus, Listeria monocytogenes, Salmonella Typhimurum, Escherichia coli, etc; with a detection limit of 1 Colony Forming Unit per milliliter (CFU/mL).

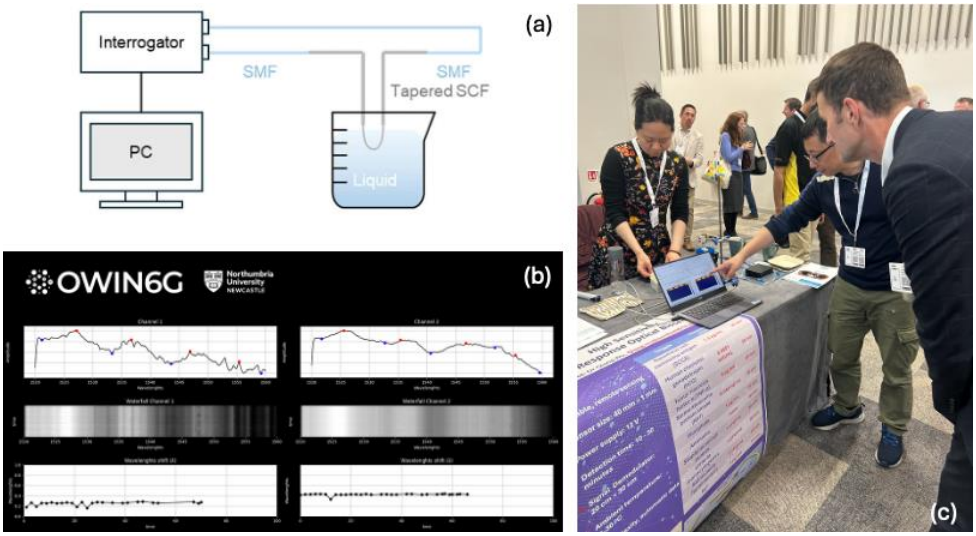



Fig. 7. (a) The system diagram for the demonstration system, (b) a screenshot of the last version of the software, and (c) a photo of our stand SBS 2024.

**Impact on Industry:** See the list of invitations of further associate partners below:

- Eblana Photonics.
- Integrated System Technologies (ISTL).

**Impact on Research:** The research led to the following publications:

1) Y. Shen, Z. Wang, Z. Wang, et al. "Enhanced Force Sensing Utilizing a Glass-Supported WGM Microbubble Resonator". Journal of Lightwave Technology, 2025. (DOI: 10.1109/JLT.2025.3556857)
2) Y. Shen, et al. "Two-dimensional force-sensing whisker based on a WGM microbubble resonator." 29th International Conference on Optical Fiber Sensors. Vol. 13639. SPIE, 2025. (DOI: 10.1117/12.3060356)
3) A. Aslanidis, T. Kamalakis, S. Zvanovec, R. Zamorano-Illanes, and Z. Ghassemlooy. "Modeling of an Energy Harvesting Hybrid Radio Frequency Optical Wireless Sensor Network". Applied Optics, OPTICA Publishing Group, accepted 2025. (DOI: 10.1364/AO.564969).

**Lectures/seminar at universities:** The research work led to the followings:

- Yuliya Semenova, "Fibre optic sensors and distributed sensing", OWIN6G 1st Training school and mid-term check, September 18th - 20th, 2024, Prague, Czech Republic.
- Yuliya Semenova, "Whispering Gallery Mode Fibre Resonators and Applications",10th Asia-Pacific Optical Sensors Conference, APOS-2024, September 27- 29, 2024, Chengdu, China.
- Yuliya Semenova, "Recent advances in sensing with optical fibre microresonators", Optical Nanofibre Applications: From Quantum to Biotechnologies ONNA2025, Physikzentrum Bad Honnef, Germany, 16 - 21 March 2025.
- Yuliya Semenova, "Novel Fibre Micro- and Nanostructures for Ultrasensitive Sensors and Photonic Devices", OFC: Optical Fibre Communications Conference and Exhibition, 30 Mar - 03 Apr 2025, Moscone Convention Center, San Francisco, California, USA.
- Invited lectures by Z Ghassemlooy, as part of the IEEE Distinguished Lecture series, at three universities in UAE in December 2025.
- Invited talk, Qiang Wu, “Bent optical microfibre sensor and its application for nanonewton force measurement”, The 23rd International Conference on Optical Communications and Networks, 28-31 July 2025, Zhangjiajie, China
- Invited talk, Qiang Wu, “Optical microfibre sensor and its biochemical application”, The 16th International Conference on Information Optics and Photonics (CIOP2025), 10-14 August 2025, Xi’an, China

## 4. Summary

During the first year of the project, the team have succeeded in the development of prototypes of soft polymer-based patch integrated with fibre sensors focused on the real time measurement of biological markers, as well as environmental variables, transmitting the sensing information via VLC, founding a strong framework for the physical layer of the project, generating a demonstration system, obtaining direct feedback from the industry due the attendance to dissemination events.

Overall, the acquisition of a methodology of work interconnecting the different areas involved in the design of the optical fibre sensors, optoelectronic devices, and its integration into the optical wireless communication (OWC) environment, enabling the collaboration of the DCs and the knowledge transfer in between institutions and fields of research have been accomplished.

## 5. Future works

The development of a patch-based fibre sensor for Body Area Networks based on OWC, for real-time monitoring of biometric parameters and movement in a controlled environment. Implementing Machine Learning methodologies to identify body movement patterns and characterise the behaviour of new environments.

The development of a patch-based fibre sensor for the monitoring of Unmanned Aerial Vehicles components. The implementation of UAVs for activating SNs and acquiring sensing information over the monitored environment.

Unification of the sensors in an on-edge platform, allowing the real-time application of the trained models and its visualisation.

## 6. References


[1] Ghassemlooy, Z., Alves, L.N., Zvanovec, S., & Khalighi, M.-A. (Eds.). (2017). Visible Light Communications: Theory and Applications (1st ed.). CRC Press. https://doi.org/10.1201/9781315367330

[2] D. M. G. Preethichandra, L. Piyathilaka, U. Izhar, R. Samarasinghe and L. C. De Silva, "Wireless Body Area Networks and Their Applications—A Review," in IEEE Access, vol. 11, pp. 9202-9220, 2023, doi: 10.1109/ACCESS.2023.3239008

[3] S. Lu, J. Lu, K. An, X. Wang and Q. He, "Edge Computing on IoT for Machine Signal Processing and Fault Diagnosis: A Review," in IEEE Internet of Things Journal, vol. 10, no. 13, pp. 11093-11116, 1 July1, 2023, doi: 10.1109/JIOT.2023.3239944

[4] G. Pan, H. Lei, Z. Ding and Q. Ni, "3-D Hybrid VLC-RF Indoor IoT Systems With Light Energy Harvesting," in IEEE Transactions on Green Communications and Networking, vol. 3, no. 3, pp. 853-865, Sept. 2019, doi: 10.1109/TGCN.2019.2908839.

[5] B. Li, Y. Zhao, Y. Zhang, A. Zhang, X. Li, J. Gu, S. Xi, and G. Zhou, "Functionalized Micro Structured Optical Fibers and Devices for Sensing Applications: A Review," J. Lightwave Technol. 39, 3812-3823 (2021).

# Annex A. ACRONYMS

| | |
|---|---|
| AP | Access Point |
| CTU | Czech Technical University |
| DB | Database |
| DC | Doctoral Candidate |
| Di.i | Deliverable i.i |
| ECG | Electrocardiogram |
| EPL | Eblana Photonics |
| FBG | Fibre Bragg Grating |
| HUA | Harokopio University |
| IR | Infrared |
| IT | Instituto de Telecomunicações |
| LAN | Local Area Network |
| LED | Light Emitting Diode |
| MCU | Microcontroller Unit |
| MQTT | Message Queuing Telemetry Transport |
| NU | Northumbria University |
| OOK | On-Off Keying |
| OSA | Optical Spectrum Analyzer |
| OWC | Optical Wireless Communications |
| SN | Sensor Node |
| Ti.i | Task i.i |
| UAV | Unmanned Aerial Vehicle |
| UV | Universitat de Valencia |
| VLC | Visible Light Communication |
| WGM | Whispering Gallery Mode |
| WPi | Work Package i |
| WSN | Wireless Sensor Network |