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IoT for Urban Sustainability in Smart Cities

By

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I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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IoT for Urban Sustainability in Smart Cities

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In the highly interconnected world of today, new technologies that allow for the digitalization of the physical world are brought to the forefront of discussion. The Internet of Things (IoT) and mature Information and Communication Technologies (ICT) have driven various digital and industrial transformation processes (Industry 4.0). Meanwhile, humanity faces emerging challenges that threaten its well-being and the environment, with recent issues like pandemics and climate emergencies capturing the attention of governments and scientific communities.

In this context, IoT and ICT gain significance as an emerging solution for diagnosing and making decisions regarding problems that threaten city sustainability. The implementation of these technologies as robust infrastructure has given rise to the concept of smart cities or intelligent societies. However, the real value does not lie in the technologies themselves, but in the ***data*** they generate. Deploying IoT solutions is not trivial, as designing both an IoT device and a system that collects valuable information involves careful consideration from multiple perspectives.

In IoT, the tasks of device deployment and data acquisition, storage, and analysis each present their own challenges. The state-of-the-art is rich in solutions seeking to contribute to each of these issues. This thesis report aims to undertake a comprehensive analysis covering the main problems that a solution could encounter. From studying the scenario and technical feasibility of the task at hand; designing a flexible device that allows adaptability to various types of measurements; determining the correct frequency of data sampling and efficient use of device resources; the type of communication and network deployment needed to define the solution's coverage; and ensuring the quality, credibility, and coherence of data generated by devices, as well as protecting it from potential alterations.

The analysis conducted in this thesis has also opened up new questions about tangential scenarios related to certain dynamics, such as the use of architectures that merge IoT with emerging technologies like blockchain. This is relevant not only to the subject of interest but also as an alternative for issues like identity theft and citizen impersonation. Moreover, considering the constraints and challenges faced during the pandemic in education, an exploratory scenario is proposed where IoT

could serve as a supportive tool for teaching. This would facilitate the quantification of parameters such as student attention.

Summarizing, the main contributions of this thesis are the following:

- *IoT system for the quantification of human well-being parameters in indoor and outdoor environments of a building.*
  The subject matter of this research focuses on outdoor air quality measurement, indoor building comfort, and attention levels. Different IoT solutions are proposed for each application and evaluated as proofs of concept for the initial quantification of these phenomena.

- *Optimal sampling in terms of energy and data quantity for particulate matter pollution variables in low-cost sensors*.
  This work examines the frequency dynamics of particulate matter pollution in urban environments, defining optimal sampling frequencies and studying the effects of applying duty-cycling techniques to reduce sensor power consumption. The impact of these techniques on sensor precision is also assessed.

- *An architecture for hybrid deployments using various wireless technologies.*
  Various deployment topologies and different wireless transmission technologies for transmitting particulate matter pollution data are explored. Each technology's unique constraints are considered with the aim of enhancing spatio-temporal resolution of measurements within a city.

- *A process for generating scientifically valid data for low-cost sensors.*
  This topic investigates numerous algorithms encapsulated within a framework designed to achieve precise measurements, comparable with reference measurement equipment, using low-cost sensors known for their noisy behavior and high failure rates.

- *Integration of IoT and blockchain for data integrity protection.*
  The study further analyzes two use cases of Distributed Ledger Technology (DLT) as a solution for the protection of both personal and public data, as well as city measurement data. Hybrid models are utilized to minimize resources.