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LIGHTING MAINTENANCE MANAGEMENT THROUGH IOT-BASED AUTOMATED FAULT DIAGNOSTICS

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Monitoring building assets is fundamental for preventing failures during building utilization. This practice is performed in predictive maintenance activities, which are based on asset monitoring using sensors to predict and avoid failures. Even if it has been demonstrated how asset monitoring can save costs, time and reduce breakdowns, it is still rarely used in common practice by facility managers. This paper proposes a framework for monitoring lighting systems to predict failures and intervene before their occurrence. The monitoring system is composed of sensors that capture temperature, voltage, electrical power and current data from lighting systems. The system can compare the data gathered with the expected value and, if anomalies are detected, it sends a maintenance request or, in case of an emergency, can actuate the shutdown of the device and schedule emergency maintenance. Furthermore, a fault detection diagram is illustrated based on the more common failures detected in lighting systems. The proposed framework provides the theoretical foundation for the development of a system for laboratory experiments.

Keywords: Lighting systems, Predictive maintenance, Facility management, Asset monitoring.

1 INTRODUCTION

The operation and maintenance (O&M) phase of buildings has the greatest quote of costs of the building life cycle, estimated to be up to 60% of the total building cost (Guillen *et al.* 2016). Even if huge economic efforts are required in the O&M phase, the facility management (FM) activities in this phase are far from efficient. Poor data management since the design phase is responsible for a rise in costs in the O&M phase, according to NIST (Gallaher *et al.* 2004). In fact, data are not rapidly available or stored in paper documents (IFMA 2013) that demand time to be found, affecting rising costs. Furthermore, reactive maintenance is the most popular method in cases of failure. It is based on the concept of intervention after a failure occurs and it has been shown how these costs are "three times greater than the same repairs made on a scheduled basis" (Ran *et al.* 2019). In this scenario, predictive maintenance (PM) is introduced, which is a type of maintenance based on asset monitoring through sensors and the collection of data that are successively processed and analyzed for the individuation of possible failures (Ran *et al.* 2019). According to Bousdekis *et al.* (2020), the application of PM involves various benefits such as maintenance costs, machine failure reduction and efficient use of resources. Even if the initial costs necessary for PM are higher than those required for reactive maintenance, PM is the best compromise between repair and prevention costs with respect to reactive and proactive maintenance (Ran *et al.* 2019). PM usage in the FM sector has been studied only for a few years, owing to the introduction of new technologies such as IoT systems, which include sensor networks that are able to communicate and send data in real time, leading to the creation of a Digital Twin (DT). Singh *et al.* (2021) defines it as a digital model of the physical counterpart, which is able to complete tasks like simulate the real condition of the physical object and, according to these data, predict future status of the physical object. These operations can be helpful in FM activities, particularly in the application of PM. Many studies have investigated the introduction of new technologies to FM practices in the construction sector; however, only a few have focused on indoor lighting systems. Many studies have been conducted on heating, ventilation, and air conditioning (HVAC) monitoring systems because they are responsible for a large part of the consumption of electrical energy in a building, followed by lighting systems (Wagiman *et al.* 2020). Because there is a gap in the scientific literature concerning indoor lighting system monitoring through IoT technologies and DT to support FM practice, this study proposes a first step towards its creation, beginning with the architecture of the monitoring lighting systems and a fault detection diagram (FDD). This study places itself in a wider research project started from Siccardi and Villa (2023) and before with the HVAC monitoring system implemented in Villa *et al.* (2021). In particular, the creation of a system for indoor lighting systems aims to add monitoring of another asset to open the way towards the creation of a DT of a building. In conclusion, the objective of this paper is the creation of a monitoring lighting system with a FDD integrated in it, in order to prevent failures in the system, and have a real time monitoring of the data coming from the device.

2 MONITORING LIGHTING SYSTEM

The first step was to individuate the parameters to be monitored. They are listed in Table 1.

Table 1. Data description with symbols and unit measures.

Description	Symbol	Unit measure	Symbol
Power	P	Watt	W
Temperature of the lamp	T1	Celsius	°C
Intensity of current	I	Ampere	A
Difference of potential	V	Volt	V

Once the parameters to be monitored have been defined, a scheme for monitoring the lighting system is shown in Figure 1. It is composed by:

- lighting system, which includes devices, sensors, and power supply;
- sensors that gather data regarding current, temperature, voltage and power, as listed in Table 1;
- Controller, whose task is to acquire data and compare it with the expected values.
- the actuator, which applies the command sent by the controller;
- the supervising system registers each warning sent by the controller and communicates the rate of unexpected failure.

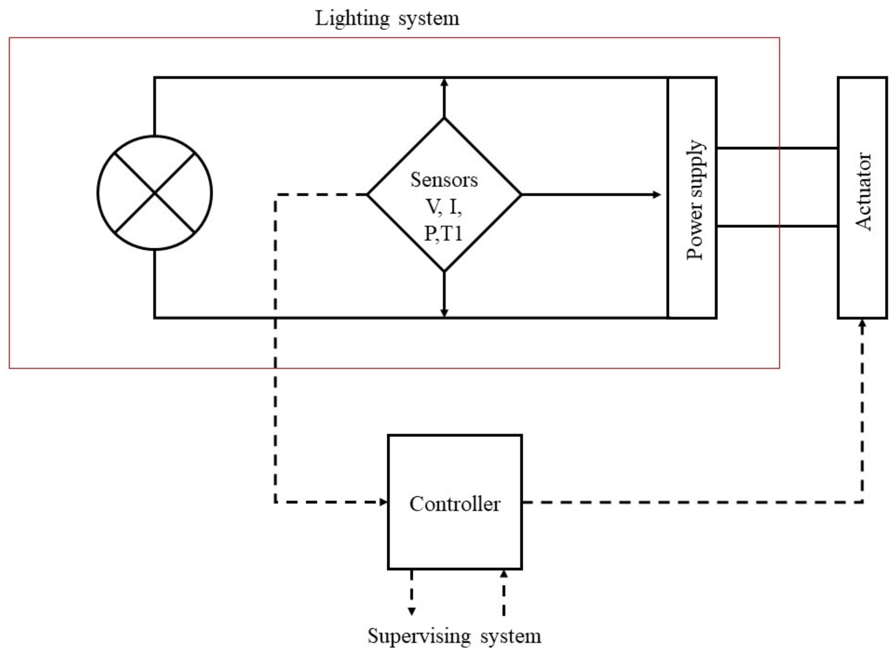

Figure 1. Scheme of monitoring lighting system.

In the monitoring system, the controller acquires and registers data at defined time intervals and compares them with the expected values based on the percentage of lighting set by the supervising controller. If anomalies are detected at different time intervals, the controller sends a maintenance request. In addition, if risk conditions occur, the controller can dispose the switch off of the device and send an emergency maintenance request to the system. The data registered from the supervising system can be analyzed to calculate the failure percentage with respect to the operating time, in order to exclude the supplier of the component from future purchases.

3 FDD

According to Isermann (2005), fault detection methods are used to complete tasks, such as early fault detection, fault diagnosis in sensors, actuators or components and remote fault detection. Defining the terminology adopted in this field can be useful. A fault is identified as a non-permitted deviation of at least one feature of the system, and it can be divided into failure, which is a permanent interruption, or malfunction, which is a non-permanent irregularity of the system (Isermann 2005, Miljković 2011). Once the terminology is defined, fault detection is introduced as a framework that can identify the occurrence of a fault in a monitored system (Miljković 2011).

In this case, the FDD for the lighting system is shown in Figure 2. The design of the diagram is based on typical faults that can affect lighting systems. The first part of the diagram indicates whether the parameters obtained from the sensor are normal. Particularly, if the voltage or current or electrical power are too high the lamp could start to dim or flicker or not turn on at all, so the controller disposes the turn-off of the device and sends a maintenance request. If the current is too low and does not reach the minimum value for turning on the light a maintenance request is sent. In addition, lamp temperature of the device is monitored. The controller turns off the lighting system when the temperature is too high in order to avoid worst damages to the device.

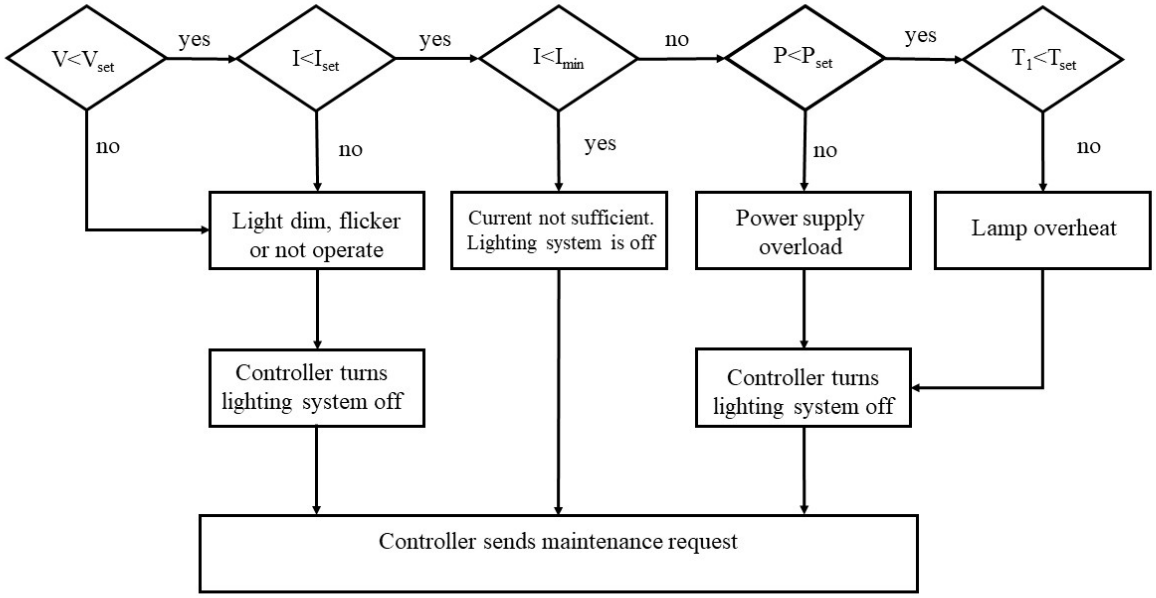

Figure 2. FDD of the lighting system.

Once the data are acquired, they will be displayed on a dashboard in order to be analyzed from the facility mangers. The dashboard will be useful to directly have an insight on the data gathered in real time from the lighting system, like showed in Figure 3.

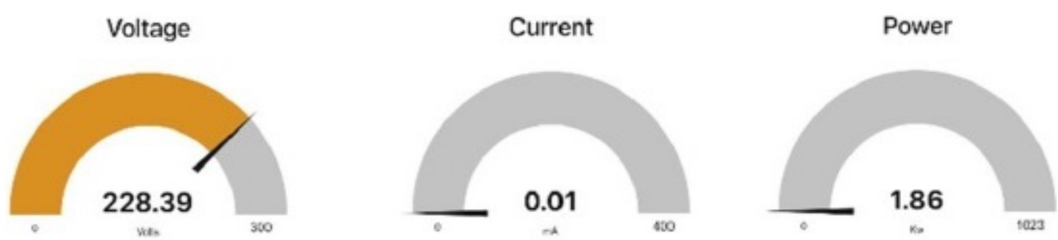

Figure 3. Dashboard for data visualization.

4 CONCLUSION

PM maintenance is far from daily usage in the FM sector. Even if it can bring many benefits, its application remains difficult, since the architecture behind it is complex and requires an important initial economic investment, although it returns optimal results in terms of maintenance and usage of the buildings, since breakdowns are avoided. In this context, this study aims to introduce PM and its principles for monitoring lighting systems. A scheme was provided with the structure of the monitoring system and an FDD to detect potential failure of the system parts. In particular, the proposed monitoring systems and the FDD aims to paving the way towards the application of PM. In particular, this paper places itself as a theoretical base on which future experiments will be based. The purchase of sensors that can be placed in an IoT system, with automated fault detection, can lead to the creation of a DT of a building. This research also revealed a lack of studies regarding the monitoring of indoor lights. Because it is an important part of the buildings' energy consumption, their monitoring is important not only for energy saving, but also for avoiding interruption of service of some parts of the building.

5 FUTURE WORKS

IoT, smart sensors, and information and communication technologies (ICT) can be promisingly integrated into the building and advantageously implemented in the facility management system, very often without additional costs that cannot be repaid through the benefits of improved performance toward facility users. This is the case of lighting systems. They are particularly important for facility managers, because they usually use a large number of lamps distributed widely throughout the building and often related to safety and security issues. Manual and continuous monitoring of their status requires a lot of time and resources and can benefit greatly from automated diagnostics systems with distributed intelligence duly integrated in the BIM model. An intelligent sensor system is considered to be realized in the future to be implemented in a lighting system, and then the automatic fault detection and diagnostics system is designed in its IoT components and operational logic till the integration in the BIM modelling. Eventually, a field test of the distributed intelligence system is conducted to verify its effectiveness under real-world conditions: the experimentation proved the framework's competence to detect anomalies in the lighting system; the automated lamp diagnostics, its implementation on the BIM model, and the effectiveness of intelligent sensors were also demonstrated.

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