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# The feasibility of motion sensor-based smart RFID system in improving the power saving

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## Abstract

RFID (radio frequency identification) implementation in large buildings requires setting up a grid that implies a lot of RFID readers. Although these readers are not power greedy, their usage can affect the electricity bill in the long run. In this paper, we study the worthiness of upgrading to a motion sensor-based smart RFID system, from a power-efficiency point of view. A decision-support protocol is developed for this purpose that considers the occupancy ratio of the environment where the system is implanted in deciding its feasibility, given that the energy drain depends on it. Moreover, we discuss the optimal way for integrating the motion sensor into the RFID system's architecture, as this insertion is able to highly reduce the power consumption in the standby mode, in exchange for slightly augmenting the drain during the reading mode. Finally, the developed decision-support protocol is demonstrated through an analogy on the studied upgrade to assess its overall feasibility. The overall results confirm the suitability of the upgrade for most environments.

### Keywords
Radio frequency identification, Microcontroller, Motion sensor, Power saving, Smart system.

## Nomenclature

| | |
|---|---|
| AC | alternative current |
| $C$ | the cumulative power consumed by the combination |
| $C1$ | the cumulative power consumed by the combination when no motion detected |
| $C2$ | the cumulative power consumed by the combination when motion detected |
| DC: | direct current |
| $K$ | the decision indicator |
| MCU | microcontroller unit |
| $r$ | the power consumption of the reader |
| $R$ | the cumulative power consumed by the reader |
| $R_C$ | the reliability of combination |
| $R_i$ | reliability of system component |
| $R_I$ | the reliability of intermediate |
| $R_R$ | the reliability of the reader |
| $R_{sys}$ | reliability of a system |
| RFID | radio frequency identification |
| $s$ | the power consumption of the sensor |
| $S$ | the cumulative power consumed by the sensor |
| PIR | pyroelectric infrared |

Radio frequency identification is a technology for collecting and diffusing information through radio waves, it is composed of four parts: tag, reader, database, and the backend, where the retrieved data are exploited in a planned action (Bing et al., 2017; Weinstein, 2005; Williams et al., 2019; Zumsteg and Qu, 2018). It can be classified according to the energy source of the tags: the active tags have an embedded

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battery; the passive tags are powered through electromagnetic waves of the reader, whereas the semi-active tags have an embedded power supply only for the integrated circuit, as the antenna gets the energy from the reader. RFID usage is very common, especially in big corporations with large facilities like shipping companies that have big storage units or even hospitals, which illustrates the effectiveness and easiness that this technology adds to tracking and managements.

Usually, electronic devices have two modes: the active or the 'in-use' mode, where they consume electricity while executing their main functions, and the non-active mode, where they are not in-use or unplugged and obviously they do not consume electric power. But there are devices that can be in a third mode besides the previous two, called the standby mode, in which the device is not in-use but it still consumes power at idle. Although there is no official definition from the International Standards Organization (ISO), the standby power can be defined as the power consumed by electronic devices while switched-off or not executing their primary role (McGarry, 2004).

In the case of the RFID reader, the three modes can be defined as follows: the active mode is when the reader is communicating with one or more tags, the non-active mode is when the reader is unplugged from the energy source, the third mode is when the reader is kept-running, drawing energy without being in communication with a tag (waiting state).

When the RFID reader is in any mode other than the unplugged, its electromagnetic waves cover all of its range. Since its work frequency, within the radio field, is classified under the category 2B (possibly carcinogenic) by the International Agency for Research on Cancer (IARC) (Fields et al., 1999; Costea et al., 2014), many disputes were raised about its health implications. Although these claims are unsettled yet, it is certain that the radio waves can result in electromagnetic interferences which may interrupt other equipment workflow (Cheng and Prabhu, 2009; Miclaus et al., 2009; Pous Solà et al., 2010; Van Der Togt et al., 2008; Astaneh and Gheisari, 2018). Therefore, in an environment preoccupied with electronic devices, optical-based motion sensing technology is visualized as a key solution against interference of other equipment during idle time.

Motion sensors are widely used in several indoor and outdoor activities like opening a door automatically or switching on/off public lights and surveillance cameras (Kroeger et al., 2012; Tan, 2019; Tsai et al., 2011; Hernandez and Sallis, 2019). All of these systems are called 'smart' because of their ability of automatically executing an intended task, triggered by a motion sensor. This can be extended to smart buildings and environments (Ling, 2015; Sovacool and Rio, 2020; Aman and Anitha, 2017).

Several phenomena are exploited in detecting motion such as the optical, microwave, and acoustic (Khan et al., 2019; Micko, 2008; Lvov et al., 2018; Bakhsheshi et al., 2019; Moghavvemi and Seng, 2004). One of the very commonly used sensors is the pyroelectric infrared-based motion detector (PIR sensor), which is a passive sensor, its technology mainly based on detecting the heat energy emitted from the moving object in form of radiations, as this heat energy varies following the moving object' temperature. So, basically the PIR sensor-based devices identify this temperature' difference as a detected motion, which is exploited then, in triggering actions or for recording purposes.

In general, the RFID system is not power greedy, but in big facilities with large buildings, deploying a network of multiple readers can significantly affect the electricity bill in the long run. The literature shows a remarkable lack of research in this aspect, the only proposal addressing this issue was made by T. B. Austin et al. (Moghavvemi and Seng, 2004), through an integrated motion sensor-based RFID reader design. However, despite the fact that the phenomenon-based operating mechanism of the motion sensor is not specified, there are some exposed challenges obstructing the adoption of this reader, raising mainly from being a built-in design. First, its set-up cost is significantly high for the firms already running a network of RFID systems, as they need to replace all the existing readers with the new ones. Moreover, it has a higher maintenance complexity degree, meaning that any potential sensor failure, which will cause the reader to stop working, needs to be repaired by qualified maintenance personnel. This can result in an important inconvenience for the institutions that does not have an internal maintenance department, as they have to search for a specialized external servicing, which may even increase the downtime due to the associated procedural arrangements. Besides, it is obvious that upgrading to this reader is not always profitable, as it might have a reverse effect on power saving in heavily busy work spaces, due to the sensor and the reader being both constantly active rather than the reader alone, which leads to ask the question: How busy can an environment be while still being worthy of the upgrade? This remains a quite intractable question in the absence of clear indices reflecting the upgrade power effectiveness in relation to the busyness of the environment, especially that the literature provides no guidelines in this regard. Therefore, in this work, first, we attempt to address this matter through the development of a reliable decision support protocol to assess the upgrade' feasibility in terms of power efficiency. Next, we investigate the different possibilities for inserting a motion sensor, in an RFID system, with the aim of identifying the optimal integration structure, in order to bypass the previously discussed adoptability challenges. Then, we conduct an empirical study to evaluate the energy consumption of the identified integration options compared to the regular RFID system, before finally, executing the developed decision support protocol to demonstrate its applicability. The flowchart of the proposed methodology is illustrated in Figure 1.

This paper is organized as follows: in the second section, we explain the proposed decision-support protocol along with the proposed structure of incorporating a motion sensor into the RFID system, after discussing the different integration possibilities. In the third section, we reveal and discuss the result of an empirical study, reviewing the power-efficiency of the identified motion sensor-based RFID systems, compared to the ordinary RFID system. Finally, we present our concluding remarks along with some research perspectives.

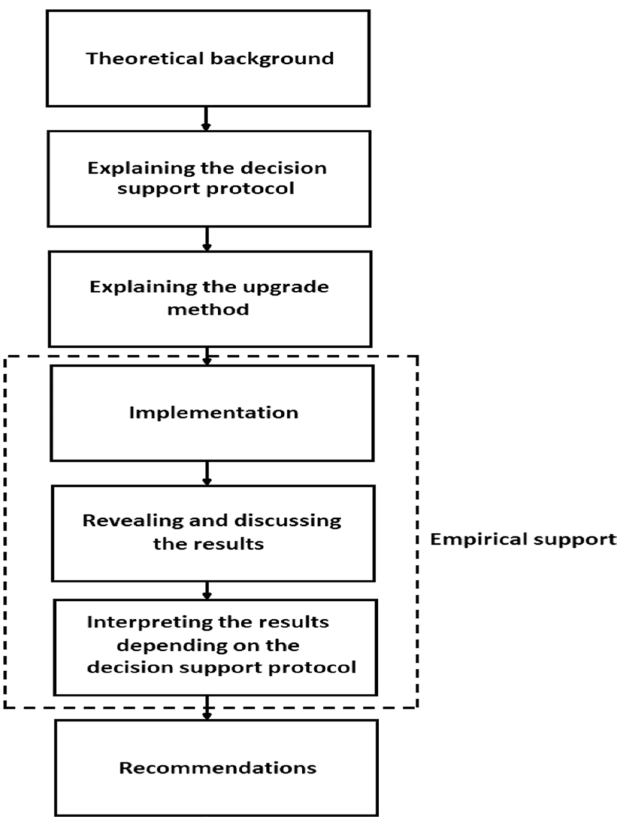


Figure 1: Research methodology flowchart.

## Material and method

### The proposed decision support protocol

This proposed decision support protocol is set to be considered when adopting any combination involving a motion sensor, aimed at reducing power consumption, in order to assure that, during a defined period (usually 24 hr), the cumulative power consumed by the combination is less than the power consumed by the reader used alone, which reflects the feasibility of the combination in saving energy.

The protocol is divided into two parts:

- Part one: determining the power consumption, during a defined period for each of the reader, the motion detector and their combination.
- Part two: verifying the set condition to check the upgrade worthiness.

#### *Part one*

We denote *r*, *s*, and *c*, corresponding to the power consumption (expressed in watt) of the RFID reader, the motion detector, and their combination, respectively (Figure 2).

During a period of time [$t1$;$t2$], the power consumed by the PIR sensor ($S$) is (Austin et al., 2014):

$$S = \int_{t1}^{t2} s \, dt, \quad (1)$$

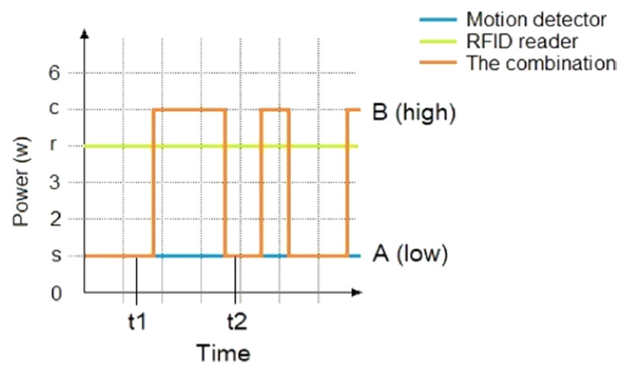


Figure 2: Illustrative representation of power consumed by RFID reader, motion detector, and their combination.

and the power consumed by the RFID reader ($R$) is (Austin et al., 2014):

$$R = \int_{t1}^{t2} r\, dt. \quad (2)$$

The power consumed by their combination ($C$) is identified following two states: low (A) and high (B) (Figure 2). The first state (A) refers to 'no motion detected', which means only the PIR sensor is consuming power. This can be modeled, according to Equation (1), by:

$$C = C1 = S = \int_{t1}^{t2} s\, dt. \quad (3)$$

The second state (B) refers to 'motion detected', which means both the PIR sensor and the RFID reader are consuming electric power. This can be modeled by combining Equations (1) and (2) such as:

$$C = C2 = S + R = \int_{t1}^{t2} s\, dt + \int_{t1}^{t2} r\, dt. \quad (4)$$

Each of the above states can occur only independently and never simultaneously, i.e. at the same moment we have either $C = C1$ or $C = C2$, exclusively.

Thus, during a period of time [$t1$;$t2$] implying both states, the power consumed by the combination can be deduced from Equations (3) and (4) such as:

$$C = C1 + C2. \quad (5)$$

### Part two

After determining the power consumed by both the reader alone and the combination involving a PIR sensor, we can calculate the decision indicator ($K$) by using Equation (6) and referring to Equations (2) and (5), which allows us to identify the best option in terms of power efficiency such as:

$$K = R - C. \quad (6)$$

- If $K > 0$, the combination is worthy for improving the power consumption.
- If $K = 0$, the combination is not worthy for power saving, but it might be dedicated for other tasks; such as reducing electromagnetic interferences possibility.
- If $K < 0$, the combination is onerous and wasteful.

The above protocol was initially designed for the case above (motion sensor and reader). However, it can be generalized later for any motion sensor-based device that aims to reduce power consumption.

## The motion sensor-based smart RFID system

Since this combination is aimed at saving energy, the PIR sensor is the first option to consider, as it provides the lowest standby power consumption compared to other motion sensors, and it is, therefore, widely deployed.

The combination has two parts hardware and framework, described as follows.

### Hardware

This motion sensor-based smart system can be achieved in two ways, as shown in Figure 3. The first way (Type A) is the built-in way, as applied in Shenkman (2006), whereas the second way (Type B) suggests using an external intermediate to trigger the RFID reader. This intermediate can be a simple relay or a thyristor-based or mostly an MCU (microcontroller unit). The PIR sensor detects whether a possible tag carrier is approaching or not. Based on that, the MCU turns the reader on/off, through the relay.

Figure 4 describes the combination that includes the MCU. This enhanced smart system is adapted for large facilities, so they can mount the upgrade directly on the top of their existing ordinary RFID management system without having to replace any component.

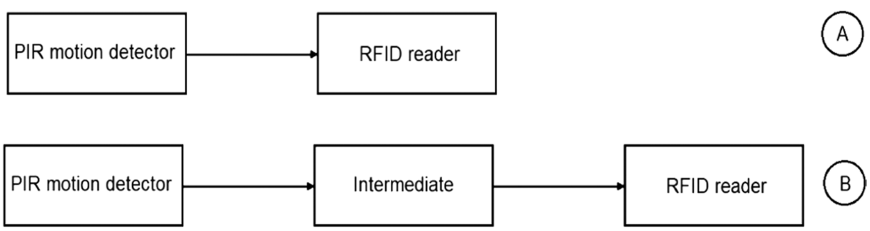


Figure 3: The options of integrating the motion detector.

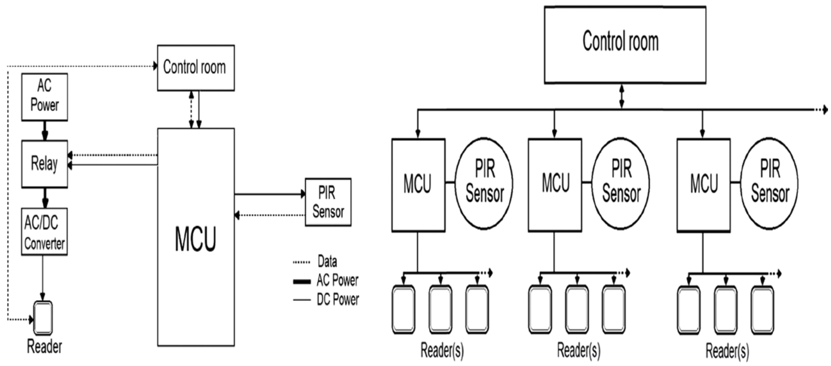


Figure 4: Block diagram of smart RFID system and a grid of smart RFID systems.

The inner AC/DC converter acts as a power supply for the RFID reader, as it requires DC voltage input; therefore, in large facilities with a grid of multiple RFID readers, the use of numerous converters can be very wasteful, given that they drain more power than the main devices, at low currents (Tan, 2019). Therefore, it is much worthier to power the MCUs by linking them to the server in the control room, rather than adding external converters, whereas the PIR sensor and the relay are powered by connecting them to the MCU. Thus, avoiding the converters' onerous power consumption.

As illustrated in Figure 4, in a grid that contains a number of PIR sensors-based RFID systems, we have two levels (Fig. 5).

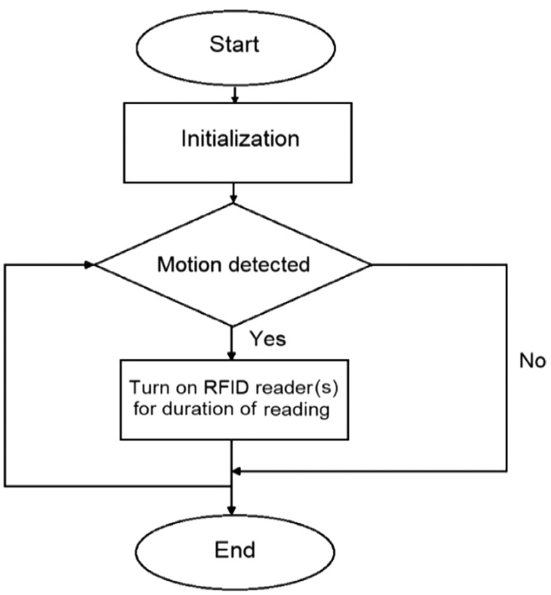


Figure 5: Program flowchart of PIR sensor-based RFID system.

In the first level, the PIR sensor controls the state off/on of the RFID reader, while being monitored by the server so that the latter can easily detect any potential sensor failure.

In the second level, the server can control the state off/on of the reader regardless of the information collected from the PIR sensor. This can be useful in the case of a sensor failure, as it allows to easily switch to the ordinary RFID system, while pending repair.

### *Framework*

The framework mainly is an endless loop, where the MCU triggers the reader (s) after checking the PIR motion detector.

At first, the combination of PIR sensor and the reader (s) are in the state 'low', which implies that the RFID reader is turned off. Once a movement is detected, the output signal of the motion detector automatically switches on the RFID reader (s), turning the system into the state 'high' throughout the presence of motion.

## Results and discussion

In this section, we reveal, evaluate and discuss the results of an empirical study reviewing the power efficiency of the ordinary RFID system compared to the smart RFID system, including both designs: Type A and Type B.

Figure 6 depicts the implementation of the smart RFID system, as illustrated in the diagram.

Although it is possible to operate multiple readers with a single wide range (or well placed) motion sensor, we use, in this experiment, only one reader per sensor. Table 1 shows the power consumption of the smart RFID system compared to an ordinary

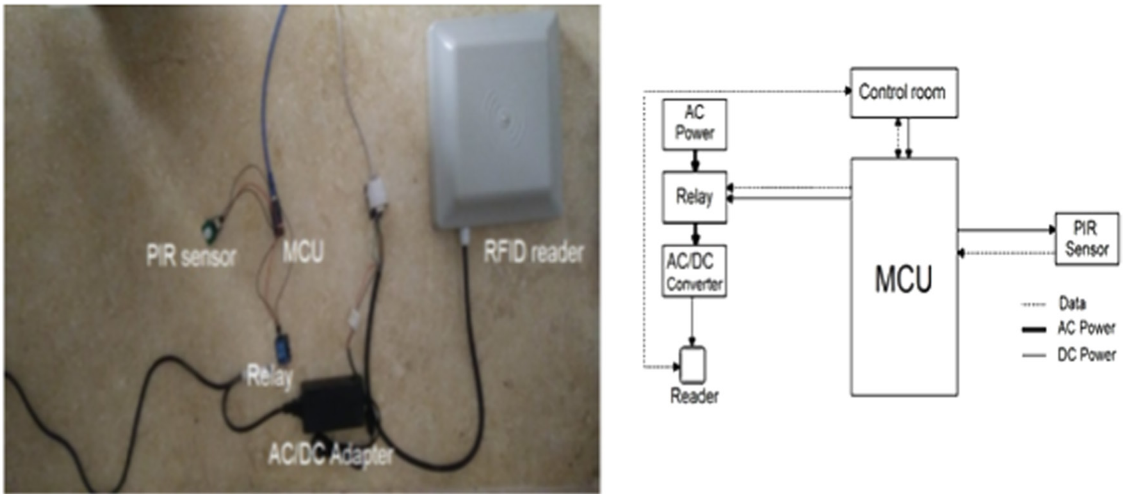


Figure 6: Implementation of the optimal motion sensor-based smart RFID system.

## Table 1. The power consumption of smart and ordinary RFID systems.

| Module | Ordinary system | | Smart RFID system (Type B) | | Smart RFID system (Type A) | |
|---|---|---|---|---|---|---|
| | Standby mode | Reading mode | Standby mode | Reading mode | Standby mode | Reading mode |
| MCU | / | / | 232.5 mw | 232.5 mw | / | / |
| PIR sensor | / | / | 170 µw | 170 µw | 170 µw | 170 µw |
| AC/DC converter | 455 mw | 455 mw | 0 | 455 mw | 455 mw | 455 mw |
| RFID reader | 3.15 w | 3.15 w | 0 | 3.15 w | 0 w | 3.15 w |
| Total | 3.605 w | 3.605 w | 232.7 mw | 3.838 w | 455.2 mw | 3.6052 w |

RFID system, in both of the standby and the reading modes. The power consumption values were obtained from the datasheets of the components.

The obtained results show that when adopting the smart RFID system type B, the power consumption can be reduced to 232.7 mw in the standby mode, given that, in this mode, only the MCU and the PIR sensor consume power, that is a gain of 3.3723 w in power, which means 93.94% of energy saving. On the contrary, the power drain rises to 3.838 w in the reading mode, which means 6.46% of energy wasted compared to the ordinary RFID system, as, in this mode, all of the MCU, the PIR sensor and the reader are in use.

On the contrary, using the built-in design (Type A), the drain can be reduced to 455.2 mw in the standby mode, since the power is consumed only by the PIR sensor and the AC/DC converter in this mode, that is a 3.15 w gain of power, which means 87.37% of energy saving, whereas, in the reading mode, the power consumption augments slightly by 0.01%.

These results show the privilege of the upgrade using Type B design, in the standby mode, whereas the Type A design is privileged in the reading mode. Therefore, the design adoption decision should consider the busyness of the environment in which the system is implemented.

As the converter plays the role of a power supply for the RFID reader, which is very wasteful at low power rates. The same issue applies for the MCU and the PIR detector, as they require a DC voltage input. This can be solved by inserting a battery in the case of upgrading one reader. However, in case of a grid of readers, the MCU should be connected and powered by the server in the control room, which is always running, whereas the relay is placed before the reader's AC/DC converter unit. Hence, any kind of onerous wasting caused by the converter in the standby mode is avoided without worrying about recharging or replacing the batteries.

Moreover, since the RFID reader is turned off in the standby mode, the electromagnetic emanation is reduced up to 0 w/m, which reduces the possibilities of electromagnetic interferences with other devices.

Based on the proposed decision support protocol, the evaluation of the worthiness of this combination, in terms of energy saving, can be interpreted from the angle of the busyness of the environment, in which the system is installed, as follows.

Assume that we have the following power consumption' values, obtained during a 24 hr horizon: 3.838 w, 3.6052 w, and 3.605 w, which correspond to the RFID system types B, A and the ordinary RFID, respectively (Figure 7).

By referring to the decision-support protocol, we find that the cumulative electric power consumed by the ordinary reader during 24 hr is equal to the cumulative power consumed by the smart RFID system Type B in 22 hr 43 min, and it is equal to the cumulative power consumed using the type A during 23 hr 58 min. This means that the upgrade using Type B design is power efficient for an environment that is busy for up to 22 hr 43 min/24 hr (94.65% of the day), and the upgrade using Type A is power efficient for an environment busyness of up to 23 hr 58 min/24 hr (99.86% of the day).

Moreover, these results show that, if the environment in which the system is installed is busy less than 22 hr 43 min a day, which is the case for most environments, the privileged upgrade is Type B. Otherwise, the upgrade using Type A is preferred.

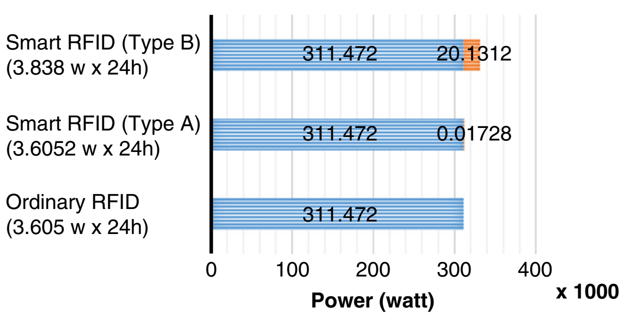


Figure 7: The cumulative power drain in 24 hr of the studied RFID systems.

Although there are no data about the reliability of the components of this system, we can say that upgrading to type A is relatively more reliable than type B. We explain this below:

As known (Fussell, 1975):

$$R_{sys} = \prod_{i=n}^{i=0} R_i, \tag{7}$$

where $R_{sys}$ refers to the reliability of a system, and $R_i$ refers to the reliability of the system's components. From (7), we obtain for the combination with an intermediate (Type B):

$$R_C = R_S.R_I.R_R. \tag{8}$$

However, for the case of the built-in design (Type A):

$$R_C = R_S.R_R. \tag{9}$$

This means that the combination reduces the reliability by the ratio of $R_S.R_I$ or $R_S$.

Therefore, in the case of an issue or failure of a PIR sensor, by dint of the connection of MCUs to the readers, sensors and the server, a 'hard reading', can be launched remotely, by updating the software of the MCU linked to the failed PIR sensor, in order to permanently turn on the matching reader(s) regardless of the information received from the sensor, while pending repair. This can prevent missing the tags passing by, during the failure period, which shows the reliability of this upgrade. This fix cannot be applied in the case of type A upgrade, where a failed PIR sensor means a failed RFID reader. Moreover, even when replacing a faulty sensor, the type B has a better maintainability, as this can be achieved easily without taking off the reader or going through complex disassembly tasks.

Apart from the gain in power, we can say that the upgrading to type B is more advantageous than type A, due to its ease of adoption even in environments where an existing RFID system is in use, and its ability to avoid the interruptions of the workflow of the system, especially in busy networks. In addition, its flexible structure allows the possibility of using only one PIR motion detector for multiple RFID readers, depending on the optimal emplacement of the readers i.e. if a PIR sensor is well positioned and it is possible to place optimally multiple readers within its range, we can both reduce the adoption cost and improve the power conservation. On the contrary, when using one sensor per reader, nearby sensors can be used to monitor the failures of each other, in real-time, and act as a backup motion detector, if needed, which increases the overall reliability of the system.

Also, compared to type A, the use of type B can keep the ability of exploiting the PIR sensor for tasks other than launching the readers, such as security purposes, triggering an alarm, mapping the occupancy, etc.

The MCU provides a real-time interfacing with the sensors and devices, which permits to monitor the workflow and detect possible issues. Moreover, it facilitates the potential exploitation' changes over the time and diversifies its options, as it does not require any physical intervention and can be programed remotely by simply updating the code.

Given the above, we can say that the proposed upgrade can be an ideal solution to reduce the electricity bill, especially in institutions with large facilities, as they can benefit from the efficiency of the RFID system in management with the minimum cost. In addition, the base structure of the upgrade takes into consideration the avoidance of interrupting the workflow and the ability of monitoring the working sensors state, which guarantees a smooth deployment in an environment with an existing RFID system, along with an improved reaction to any potential issue.

## Conclusion

In this paper, we studied the worthiness of upgrading an ordinary RFID system into a smart system, in terms of improving power-saving. In this context, we discussed the optimal way of integrating a motion sensor into the RFID system's architecture. The upgrade using the separate block design is privileged, as it is flexible and it maximizes the exploitation of the system components, in addition to its ease of implementation. We also addressed the issue of the wasted energy by the AC/DC adapter, in the standby mode, and most importantly, we suggested a decision-support protocol that takes into account the busyness of the environment in deciding the adoptability of the upgrade. This protocol can be later generalized for any motion sensor-based device, aimed at improving the power efficiency.

Provided that the proposed motion sensor upgrade is applied, the conducted analysis shows that the power consumption may decrease by more than 93% in the standby mode, while it augments by 7% in the reading mode. This is where the role of the suggested protocol shows up, as it assists the decision maker in assessing the upgrade' feasibility, according to the busyness of the implementation environment. The results illustrate that the upgrade is suitable for most environments, as it shows an improved power efficiency for environments that are busy 94.65% of the day. However, this upgrade can be blamed for its dependability to the PIR sensor and the MCU, which affects slightly its reliability; thus, an effective maintenance plan is important to keep the system in a fully working state by taking timely effective actions such as temporarily switching to the 'Ordinary' mode, upon a sensor failure.

Overall, the upgrade has the ability to reduce the electricity bill remarkably in the long run, especially in big facilities. Moreover, it reduces the electromagnetic interferences possibilities, thus, providing important benefits on both the economical and operational aspects. Future work should address the reliability issues of the proposed combination by developing a communication way between the other smart systems in the network that implies logical resolving like analyzing the route constraints, or smart grids.

## Literature Cited

Aman, F. and Anitha, C. 2017. Motion sensing and image capturing based smart door system on android platform. 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), 2346–2350, available at: https://doi.org/10.1109/ICECDS.2017.8389871.

Astaneh, A. A. and Gheisari, S. 2018. Review and comparison of routing metrics in cognitive radio networks. *Emerging Science Journal* 2: 191–201, available at: https://doi.org/10.28991/esj-2018-01143.

Austin, T. B., Duron, M. W., Stern, M. and Wulff, T. E. 2014. RFID reader with motion detection. Google Patents, available at: https://patents.google.com/patent/US8681005B2/en.

Bakhsheshi, M. F., Ho, M., Keenliside, L. and Lee, T. -Y. 2019. Non-invasive monitoring of brain temperature during rapid selective brain cooling by zero-heat-flux thermometry. *Emerging Science Journal* 3: 1–9, available at: https://doi.org/10.28991/esj-2019-01163.

Bing, Y., Baolong, L. and Hua, C. 2017. Review on RFID identity authentication protocols based on hash function. 2017 International Conference on Computer Network, Electronic and Automation (ICCNEA), 20–27, available at: https://doi.org/10.1109/ICCNEA.2017.20.

Cheng, C. -Y. and Prabhu, V. 2009. Experimental investigation of EMI on RFID in manufacturing facilities. 2009 IEEE International Conference on Automation Science and Engineering, 241–245, available at: https://doi.org/10.1109/COASE.2009.5234152.

Costea, M., Golovanov, N., Grintescu, I. M., Stanciulescu, E. -L. and Gheorghe, S. 2014. Human exposure to electromagnetic fields produced by distribution electric power installations. *Advances in Electrical and Computer Engineering* 14: 29–36, available at: https://doi.org/10.4316/AECE.2014.01005.

Fields, E., Cleveland, R. F. and Ulcek, J. L. 1999. Questions and answers about biological effects and potential hazards of radiofrequency electromagnetic fields. OET Bulletin, available at: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.704.6054.

Fussell, J. 1975. How to hand-calculate system reliability and safety characteristics. *IEEE Transactions on Reliability* 24: 169–174, available at: https://doi.org/10.1109/TR.1975.5215142.

Hernandez, S. and Sallis, P. 2019. Robust single target tracking using determinantal point process observations, available at: https://doi.org/10.21307/ijssis-2020-001.

Khan, S. A., Ahmad, I., Shufian, A. and Ahmed, M. S. 2019. A smart intruder alert system based on microprocessor and motion detection. 2019 International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), 335–339, available at: https://doi.org/10.1109/ICREST.2019.8644109.

Kroeger, S., Drake, G. M., Crist, R., Fleig, T., Dallas, M., Siegel, N. et al. 2012. Doppler radar motion detector for an outdoor light fixture. Google Patents, available at: https://patents.google.com/patent/US8232909B2/en.

Ling, Y. 2015. Automatic human daily activity segmentation applying smart sensing technology. *International Journal on Smart Sensing & Intelligent Systems* 8: 1624–1640, available at: https://doi.org/10.21307/ijssis-2017-822.

Lvov, N., Khabarov, S., Todorov, A. and Barabanov, A. 2018. Versions of fiber-optic sensors for monitoring the technical condition of aircraft structures. *Civil Engineering Journal* 4: 2895–2902, available at: https://doi.org/10.28991/cej-03091206.

McGarry, L. 2004. Standby power challenge. Proceedings of 2004 International IEEE Conference on the Asian Green Electronics (AGEC), IEEE, 56–62, available at: https://doi.org/10.1109/AGEC.2004.1290867.

Micko, E. S. 2008. PIR motion sensor. Google Patents, available at: https://patents.google.com/patent/US7399970B2/en.

Miclaus, S., Bechet, P., Bouleanu, I. and Helbet, R. 2009. Radiofrequency field distribution assessment in indoor areas covered by wireless local area networks. *Advances in Electrical and Computer Engineering* 9: 52–55, available at: https://doi.org/10.4316/aece.2009.01009.

Moghavvemi, M. and Seng, L. C. 2004. Pyroelectric infrared sensor for intruder detection. 2004 IEEE Region 10 Conference TENCON, 656–659, available at: https://doi.org/10.1109/TENCON.2004.1415018.

Pous Solà, M., Fernández Chimeno, M. and Silva Martínez, F. 2010. RFID system evaluation against radiated transient noise. EMC Europe 2010 9th International Symposium on EMC Joint with 20th International Wroclaw Symposium on EMC, 625–628, available at: https://upcommons.upc.edu/handle/2117/11256.

Shenkman, A. L. 2006. *Transient Analysis of Electric Power Circuits Handbook*, Holon: Springer Science & Business Media.

Sovacool, B. K. and Del Rio, D. D. F. 2020. Smart home technologies in Europe: a critical review of concepts, benefits, risks and policies. *Renewable and Sustainable Energy Reviews* 120: 109663, available at: https://doi.org/10.1016/j.rser.2019.109663.

Tan, B. 2019. Motion sensor light. Google Patents, available at: https://patents.google.com/patent/USD866035S1/en.

Tsai, C. -H., Bai, Y. -W., Chu, C. -A., Chung, C. -Y. and Lin, M. -B. 2011. PIR-sensor-based lighting device with ultra-low standby power consumption. *IEEE Transactions on Consumer Electronics* 57: 1157–1164, available at: https://doi.org/10.1109/TCE.2011.6018869.

Van Der Togt, R., van Lieshout, E. J., Hensbroek, R., Beinat, E., Binnekade, J. M. and Bakker, P. 2008. Electromagnetic interference from radio frequency identification inducing potentially hazardous incidents in critical care medical equipment. *JAMA* 299: 2884–2890, available at: https://doi.org/10.1001/jama.299.24.2884.

Weinstein, R. 2005. RFID: a technical overview and its application to the enterprise. *IT Professional* 7: 27–33, available at: https://doi.org/10.1109/MITP.2005.69.

Williams, L. R., Fox, D. R., Bishop-Hurley, G. J. and Swain, D. L. 2019. Use of radio frequency identification (RFID) technology to record grazing beef cattle water point use. *Computers and Electronics in Agriculture* 156: 193–202, available at: https://doi.org/10.1016/j.compag.2018.11.025.

Zumsteg, P. and Qu, H. 2018. Reading RFID tags in defined spatial locations. Google Patents, available at: https://patents.google.com/patent/US9892289B2/en.