IOP Conference Series: Materials Science and Engineering

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To cite this article: Kay Li Ng *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **495** 012022

IOP Conf. Series: Materials Science and Engineering **495** (2019) 012022 doi:10.1088/1757-899X/495/1/012022

Vehicle Recognition System using RFID Technology for Parking Management System

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Abstract. Technology is growing each day by leaps and bounds. The change in technology has done wonders to increase productivity in everyday life. However, drivers searching for parking contributed to traffic congestion especially in urban and suburban cities, while consuming their time and energy. Besides, traffic congestion in parking area is always an issue which contribute to traffic on the main road. The current approach to overcome this includes the implementation of parking ticket system, especially in busy area. The hour rate for busy area is elevated to promote liquidation of vehicles. However, this system requires patrol warden to manually inspect each vehicle for the parking ticket. The feasibility of the system decreases when the parking area is larger. RFID parking management system aims to bring automation into parking system. The use of passive UHF RFID which can read multiple tags from long distance can replace patrol warden and thus increase the effectiveness of the Vehicle Parking Management System (VPMS). Furthermore, the power consumption of RFID system is analyzed. A new method has been introduced to reduce the power consumption of RFID system which operates 24/7. Experimental results demonstrate the effectiveness of the proposed method in reducing the power consumption of the RFID system.

1. Introduction

Radio-frequency identification (RFID) is a combination of radio broadcast technology and radar. It was first developed in U.S in 1920s [1]. RFID was first used during World War II to identify aeroplanes. Aeroplanes radiate signal to read an identification number that is used to differentiate aircraft as allies or enemies [2]. In recent years, RFID is widely used by consumers and companies globally. It is adopted by many industries, such as product tracking, toll road payment, passports, libraries, shipping and other purposes. RFID system consists of interrogators such as RFID readers and antennas and transponders (RFID tags). RFID technology uses electromagnetic field or radio waves to identify objects or livestock attached with RFID tags automatically. It is able to read the tag without line of sight which improves the efficiency of processes and ease of use [3].

Vehicles have become the main transport in every country especially in cities. In 2017, approximate 73 million of cars were produced in the world [4]. In urban cities, buildings are rapidly developed. It is viewed that parking plays an important role for social and economy impacts in urban development. Therefore, an efficient parking system is required in enhancing the current transportation system. Parking is a location where vehicle transit for the next destination or reach its final destination and stop for a period of time. For example, an employee will park for long hours while some users will just park for short period of time to carry out some daily activities. Therefore, the convenience of car parks influences the effectiveness of the driver and at the same time prevent unnecessary traffic in busy area.

Most of the currently available parking systems use parking ticket for the collection of parking fees. The parking ticket can be in the form of prepaid scratch type which was mostly used in open parking spaces and the ticket dispenser machine type which was used mostly in shopping malls and underground/leveled parking. Parking system which utilized a ticket dispenser machine comes with a barrier to make sure every vehicle gets their own ticket before entering and the ticket was then reused for the exit trip [5]. The barrier slows the traffic and causing traffic congestion especially on peak periods. Prepaid scratch-type parking ticket prevented this issue where no barrier is required. This parking system has not been replaced as it collects the parking fees at minimal fees which comes from printing the ticket and warden hiring. However, this system requires users to change or update the ticket every half or one hour and there is coverage limit for using warden to manually check the ticket on every vehicle. Therefore, RFID technology ease the parking system with less workforce [6] and more efficient [7].

In existing market, passive UHF RFID is widely used in industries as assets management and personnel tracking in commercial buildings. The application of passive UHF RFID in Vehicle Parking Management System (VPMS) is not commonly available. The implementation of UHF RFID in an on-street parking management system might cause some problems, such as tag-to-tag interference, limitation on read range, environment conditions and high power consumption. The issue of tag-to-tag interference has been addressed by few researchers in [8]-[9]. Besides, the application of RFID reader in an open space parking area is varied but few methods had been proposed in [10]-[11] to improve the read range of RFID reader. Extreme environment condition such as high temperature during hot sunny day and rainy day might affect the RFID efficiency. The power consumption of the RFID system can also be a critical issue in implementing this technology in parking management system. This is a common issue for all other Internet of Things (IoT) systems that utilizes RFID reader. Therefore, power consumption of RFID reader is an important factor that has been overlooked which should be taken into account.

The global electricity consumption increased at a rapid pace due to economy growth and increased population. Energy efficiency has become an important measure in designing a device. According to Global Energy Statistical Yearbook, global electricity consumption in 2017 had strike a new record of 22,000 terawatt hours, therefore 2.6% of increment as compared to 2016 [12]. Coal is the main source of electricity. Burning of coal generated 37% of the global electricity [13]. For 1kWh of electricity produced from coal will produce 0.94kg of carbon dioxide emissions to the atmosphere, which equivalent to 7000 billion kilograms of carbon dioxide [14]. In addition, electricity generation has potential impact on the environment including air, water and land which indirectly affecting our health. The sustainability of an IoT device can be improved by having energy efficient design. Energy efficient IoT devices which can be powered by green energy improved the feasibility of the application of IoT systems.

In this paper, a one-off VPMS is proposed to centralize all parking ticketing system. This includes on-street and off-street parking. The proposed method is to integrate RFID tag into road tax, giving all vehicles their respective identities, which can be read easily using UHF-RFID reader. The hardware setup of the VPMS can be described as shown in Figure 1, where the reader is located at the entrance and exit of the parking area. When a vehicle enters the parking area, the reader will read the RFID tag built-in in the road tax sticker. The entrance and exit time of the vehicle into the parking area will be recorded and charged based on respective rates. The research covered in this paper will be focused on the power management of the VPMS. A power saving algorithm which utilizes duty cycle method is applied to optimize the performance of VPMS. LF-RFID system is used to simulate the VPMS UHF-RFID system. The application of this research does not limit to VPMS and can be applied to other RFID based applications.

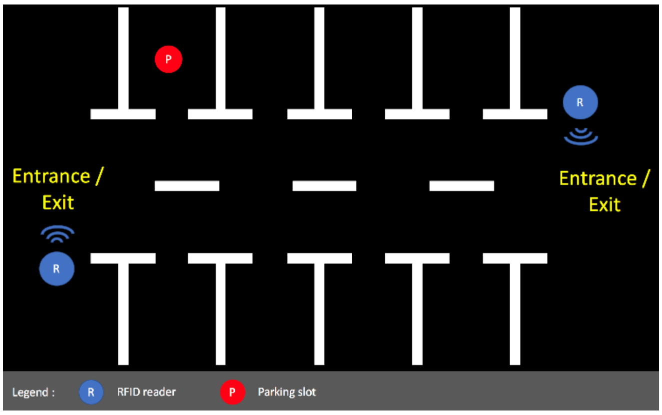

Figure 1. Overview of UHF RFID system in VPMS.

The remainder of the paper is organized as follows. In Section II, the methodology to carry out this research is described. Section III presents the experimental results and evaluate the performance of LF-RFID. In Section IV, relevant conclusions are drawn, and the future work are discussed in Section V.

2. Design Methodology

In this section, the design of proposed RFID system is described. The proposed RFID system is simulated using LF-RFID, RC522 module before the implementation on UHF RFID system. The proposed power saving algorithm is applied, and the power consumption of the RFID system is being monitored. The design methodology can be summarized into 4 stages as shown in Figure 2: Stage 1 describes the hardware design of the LF-RFID system. Stage 2 integrates the proposed algorithm into the RFID system. Stage 3 evaluates the performance of the proposed solution under different scenarios. Stage 4 deploys the solution onto UHF RFID system.

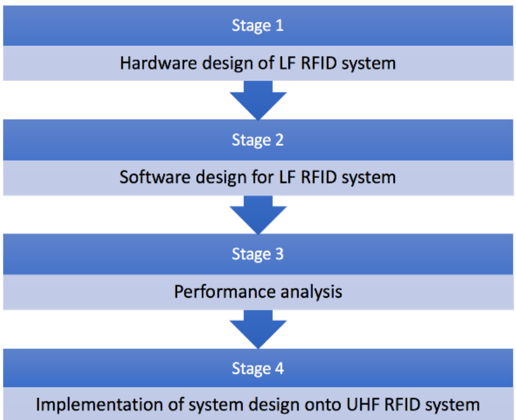

Figure 2. Overview of methodology.

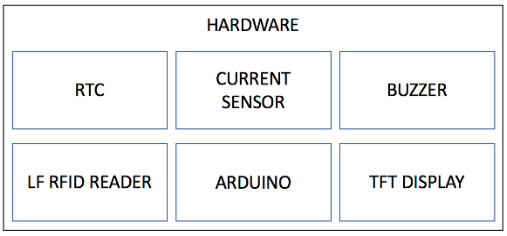

Figure 3. The hardware components of LF RFID system.

Stage 1 – Hardware design of LF RFID system

The block diagram as shown in Figure 3 describes the hardware design of LF RFID system. Arduino Nano is used as the microcontroller for this system. LF RFID reader, RC522 module has been used in LF RFID system to simulate the UHF RFID. INA219 module is used for current sensing. Real time clock (RTC) module is used for time logging purpose. The buzzer can be included for alerting every successive scan and Thin Film Transistor Liquid Crystal Display (TFT LCD) can be used to display the info from tag scanned. The TFT LCD comes with capacitive touch feature which accommodates control interface.

Stage 2 – Software design for LF RFID system

Arduino IDE is used to program the operation of the RFID system. The software of the proposed RFID can be categorized into three section:

1. Reader algorithm
2. Display and control
3. Data management

RFID system consistently consumes power all the time, however, the RFID reader applied in VPMS is in idle state most of the time. The power consumption of RFID reader in VPMS is simulated using LF RFID system in this paper. Two power saving algorithms are proposed, namely constant duty cycle and variable duty cycle techniques. The proposed power saving algorithm utilizes duty cycle control over the RFID reader module. The duty cycle can be reduced while maintaining the optimal operation performance of the entire RFID parking management system. Duty cycle is applied to the transmission antenna by switching on and off the antenna at intervals. The TFT LCD is used to ease the prototyping and calibration purpose, where user can do the fine tuning easily. The data or identification of the RFID tags is stored locally in the reader before sending to the cloud.

Stage 3 – Performance Analysis

The power consumption of the RFID reader module is measured using current sensor, INA 219 module. The power consumption is measured and recorded for four different situations:

1. During peaks hours, tag always present, reader always on
2. Tag always absent, reader always on
3. During peaks hours, tag always present, with duty cycle
4. Tag always absent, with duty cycle

Analysis is carried out between the power consumption of RFID system for power saving algorithm on constant duty cycle and variable duty cycle. Therefore, the most suitable power saving algorithm method will be chosen to be implemented in RFID system in VPMS.

Stage 4 – Implementation of system design onto UHF RFID system

Once the performance of the proposed algorithm has been proven, the RFID system will be duplicated using UHF RFID reader. The performance of the algorithm on UHF RFID system will be verified by doing field test.

2.1. Power Saving Algorithm – Constant Duty Cycle

For constant duty cycle, the scanning frequency will be fixed at 1 Hz. The duty cycle used can be calculated using Equation 1.

$$\text{Duty Cycle} = \frac{required\ read\ speed}{minimum\ read\ speed} \times 100\% \quad (1)$$

From the actual performance of the LF-RFID reader, the minimum read speed of the RFID tag is approximately 10 tags per second. In this case, to ensure that every vehicle that passed through the entrance/exit are recorded, the minimum read speed required is 2 tags per second. Table 1 shows the actual number of tags detected when duty cycle is applied. Thus, from Table 1, 20% is the optimum duty cycle to be applied in VPMS with more than 2 tags detected in 1Hz.

Table 1. The number of tags detected in a second with different duty cycle.

Duty Cycle	Number of tags detected in 1s
5%	0-1
10%	1-2
20%	3-5
30%	7-8
40%	9-10
50%	12-13

2.2. Self-Learning Power Saving Algorithm – Variable Duty Cycle

In this section, a self-learning power saving algorithm is proposed where the duty cycle is manipulated and varied based on the previous conditions or past data to minimize the power consumption of the RFID reader. Figure 4 and 5 show the flow diagram of the proposed self-learning power saving algorithm, with variable duty cycle. In this case, the duty cycle will be updated every hour depending on the past traffic condition. Traffic pattern will be slightly different every day in a week and depends on the location. The total number of tags detected every hour in each day of a week will be collected as a reference to determine the duty cycle for next week or future.

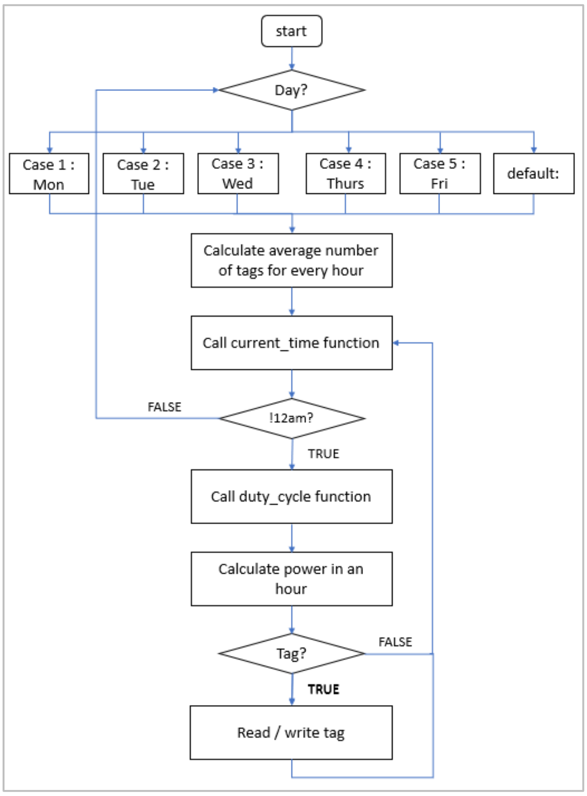

Figure 4. The flow diagram of self-learning algorithm.

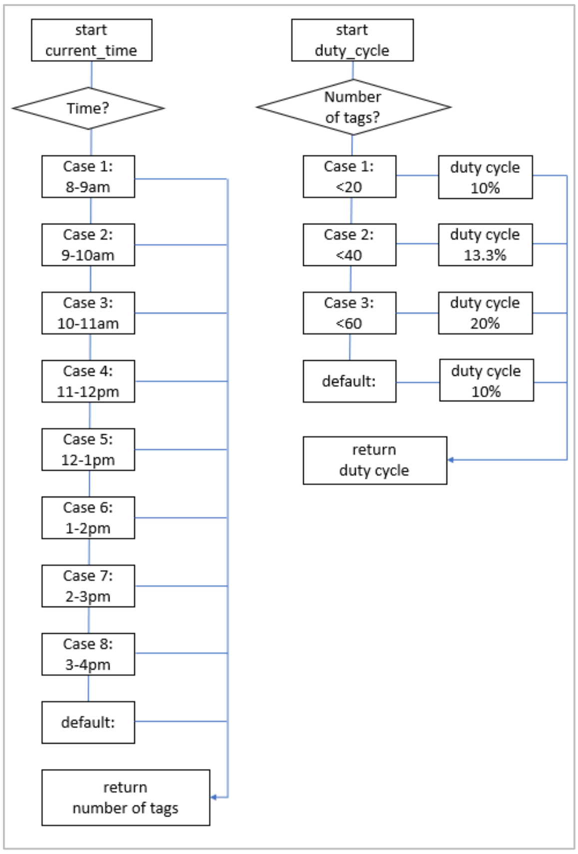

Figure 5. The flow diagram of current_time and duty_cycle function.

The duty cycle is separated into 3 cases, 0-19 tags with 20% duty cycle at 1Hz, 20-39 tags with 13% duty cycle at 0.67Hz and 40-60 tags with 10% duty cycle at 0.5Hz. For example, to determine the current duty cycle to be used at 10am on Monday, the number of tags detected for the past Monday at 10am will be retrieve and calculate the average. If the number of tags detected in an hour is less than 20 tags, the duty cycle for this hour will be 20% at 1Hz.

3. Results and Discussion

Stage 1 is completed as shown in Figure 6. The components labelled are as followed, (1) current sensor, (2) real time clock, (3) Arduino Nano, (4) RFID reader and (5) RFID tag.

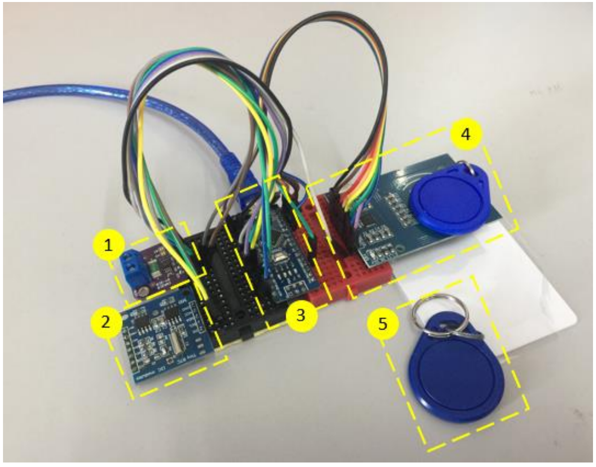

Figure 6. The hardware set-up for LF RFID system.

There are two common methods in measuring current, namely D'Arsonval Meter which is based on electromagnetics and shunt resistive method, and also based on theory of electricity, Ohm's Law [15]. Shunt resistive current sensing method is used in this research. INA219 shunt resistive current sensor with its high precision amplifier provides high sensitivity and high precision in sensing small current. According the specification of INA219 module, it can be calibrated to measure a maximum of 400mA with 0.1mA resolution. The power consumption improvement of the reader is analyzed. Simulation of before and after implementation of power saving algorithm are carried out and the difference in performance are discussed in simulation.

The power consumption characteristics of RFID reader without and with the implementation of power saving algorithm (constant 20% duty cycle) are shown in Figure 7 and 8, respectively. From Figure 7, the average power consumption is constantly above 50mW. The peaks in the power consumption graphs are due to the presence of RFID tag. From Figure 8, the peak power is approximately 60mW when RFID tag is present, while the peak power is around 50mW when the RFID reader is in standby mode.

By applying the power saving algorithm, the power consumption of the reader can be reduced. This algorithm lowers the read rate of the RFID reader as the application of RFID system in VPMS does not required high read rate. Moreover, the read rate can be increased by adjusting the switching frequency or the duty cycle.

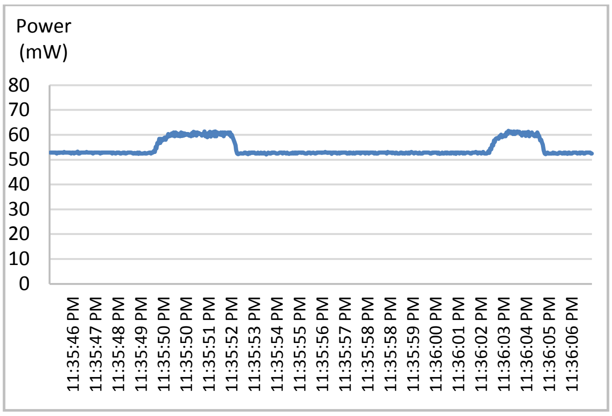

Figure 7. The power consumption of a typical LF RFID reader.

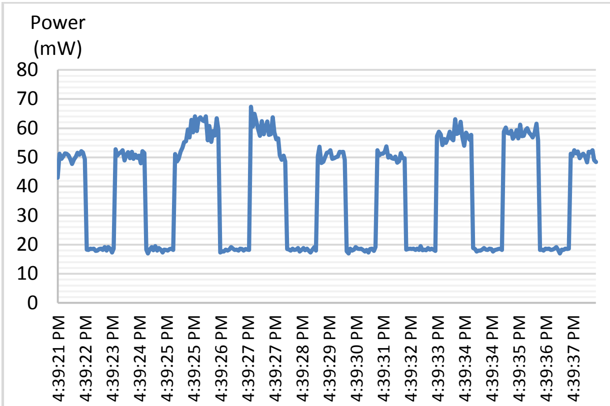

Figure 8. The power consumption of LF RFID reader with power saving algorithm.

Figure 9 shows the average power consumption of RFID reader without the power saving algorithm in an hour while Figure 10 shows the average power consumption of RFID reader in an hour when the power saving algorithm with a duty cycle of 20% is applied. The power consumption of RFID reader is higher when the tag is present. The absent of tag indicates the best-case scenario where the power consumption is at minimum while the present of tag implies the worst case scenario as the power consumption is at maximum. It can be seen from Figure 9 and 10 that the implementation of power saving algorithm with constant duty cycle reduces the power consumption of the RFID reader by 50%, where the power consumption is reduced from 60mWhr to 30mWhr.

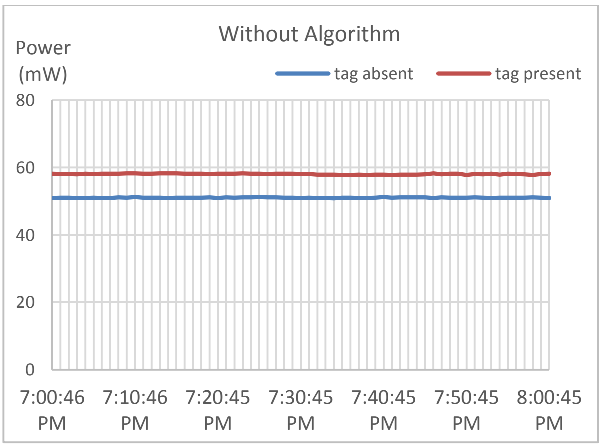

Figure 9. The average power consumption of a typical LF RFID reader in an hour.

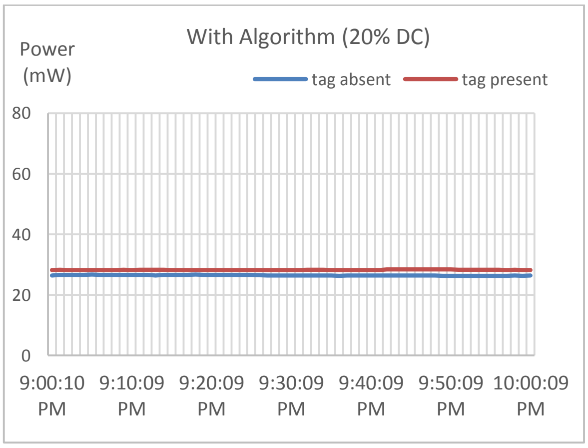

Figure 10. The average power consumption of LF RFID reader in an hour with 20% duty cycle.

Figure 11 shows the effect of duty cycle percentage on the average power consumption of the RFID reader over an hour. The duty cycle is varied from 10% to 100% with an increment of 10%, and is based on the frequency of 1Hz. It can be seen from Figure 11 that when the duty cycle increases, the power consumption increases as well. Duty cycle of 100% is equivalent to LF RFID system without implementing power saving algorithm. Although the power consumption for duty cycle of 10% is lowest, it is not recommended to be applied in VPMS. This is because the read and write of the RFID reader into tag took approximately 10% of duty cycle with 1Hz. Therefore, to complete the process of interrogation between reader and tag, the safe zone is within 20% duty cycle.

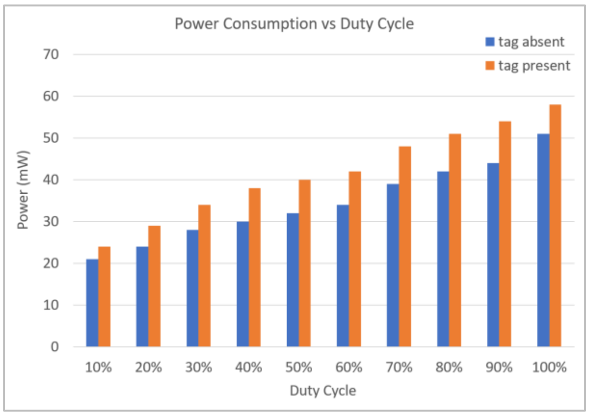

Figure 11. The overview of average power consumption of LF RFID reader in an hour with various duty cycle while tag absent and tag present.

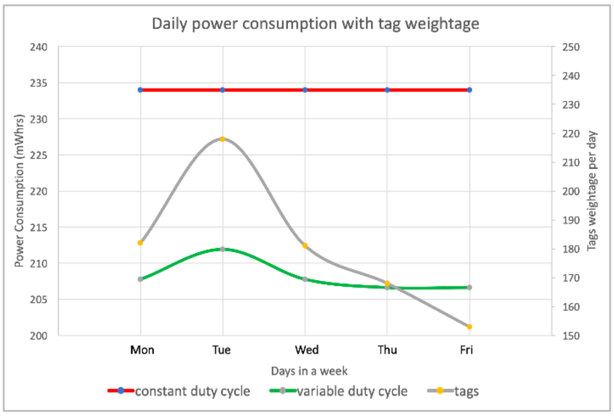

Figure 12. Graph of power consumption comparison between constant and variable duty cycle.

In the next example, we investigate the performance of the proposed self-learning power saving algorithm method, with variable duty cycle. A test condition is formulated, where the number of tags detected for different hours in a particular day are different. Figure 12 compares the power consumption between proposed constant duty cycle (20%) algorithm and self-learning variable duty cycle method for the formulated test condition. The daily power consumption (from 8am-4pm) without power saving algorithm is rated at 490mWhr, while the power consumption is reduced by 52% to 230mWhr when the power saving algorithm with constant 20% duty cycle is applied. By implementing the self-learning method, the duty cycle is tuned according to the traffic condition and it can be observed that the power efficiency is further improved by 9-12% to 207mWhr. Figure 12 also shows that the power consumption of the self-learning method is proportional to the weightage of tags detected.

The implementation of power saving algorithm for constant 20% duty cycle has proven a 50% reduction in power consumption. The same concept can be applied to UHF-RFID VPMS. From the datasheet of ThingMagic M6E Nano, the power consumption of the reader with 27dBm antenna is 3.2W [16]. Further improvement can be made by introducing self-learning method which can reduce up to 57% of the original power consumption. The power consumption of the reader in full operating mode is expected to be 1.4Whr after implementing the power saving algorithm. The improvement in power efficiency for RFID system allows the possibility of battery powered or solar powered system. The UHF-RFID parking management system improves the ticketing system as well as parking management system

4. Conclusion and Future Work

In this paper, passive UHF RFID system has been introduced into Vehicle Parking Management System. The implementation of constant duty cycle in this research has effectively reduced the power consumption of the RFID reader by 50%, whereas the introduction of self-learning method with variable duty cycle can improve the efficiency by 57%. This result is proven to be an effective power saving solution in RFID system. The power saving will be significant with large number of RFID devices continuously powering up for a long period of time. By implementing UHF RFID in VPMS, the efficiency of parking management and ticketing system can be improved. Besides, this method also helps in improving the road safety by tracking the vehicles, ensure smooth traffic especially around parking areas and upgrades the convenient of the road users as well as parking management authorities with automation.

The implementation of duty cycle power saving algorithm can also be applied to other RFID applications for power saving purpose. An e efficient UHF RFID VPMS can be powered up by using renewable energy. This will improve the feasibility of installing the system on a large scale. The implementation of UHF RFID on every vehicle enables the tracking and localizing of vehicles. This feature allows centralized traffic monitoring, thus provides useful data for security purposes as well as in city planning. The optimization in power consumption will be critical for the rapid growth of smart technology which relies on IoT. This research is crucial as conservation of depleting energy is equally important in the effort of sourcing new alternative energy.

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