Design of a portable radio-frequency-identification reader capable to reading a user memory bank for smart-building energy management

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ABSTRACT

Communication is an important factor in smart-building energy management (SBEM). Many communications technologies have been applied to SBEM, including radio-frequency identification (RFID). RFID has been used not only for identification but also for carrying information, which is stored in a user memory bank attached to the tag. To access the user memory bank, an RFID reader should comply with ISO 18000-6C standards. The greatest challenge of RFID-reader technology is its short communication range, which limits the sensing area. To overcome this problem, this paper proposes a portable RFID reader built to an ISO 18000-6C standard to extend the sensing area due to its moveability. The reader is designed using low-cost devices widely available on the market for ease of duplication and assembly by researchers, educators, and startups. The proposed RFID reader can read passive tags with distances up to 12 and 5.5 m for line-of-sight (LOS) and non-line-of-sight (NLOS) communication, respectively. The minimum received-signal-strength indicators (RSSIs) for LOS and NLOS are found to be −63.75 and −59.66 dBm, respectively. These results are comparable with those of non-portable RFID readers on the market.

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1. INTRODUCTION

Smart-building energy management (SBEM) aims to achieve maximum energy efficiency by monitoring and controlling all uses of electricity. Monitoring and control requires communication between the sensor and the master control, and several communications technologies have been investigated for this purpose, including low-energy Bluetooth [1], Zigbee [2], and radio-frequency identification (RFID) [3]. RFID has superior advantages because a passive RFID tag, as a sensor, does not require a dedicated power source to communicate with an RFID reader. The tag harvests the power emitted by the RFID reader and uses that to transmit a signal. RFID has been widely used for many applications such as: toll card [4], entry system [5], monitoring system [6] sensory system [7], smart cards [8], agriculture [9], and parking [10].

Research and development is underway to adapt RFID for use as an information carrier. RFID uses noncontact wireless radio-frequency (RF) waves to transfer data [11]. In general, RFID tags can be divided into active and passive types depending on their power source. A passive RFID tag does not have an internal power source, whereas an active RFID tag does [12]. The RFID system consists of two components: a tag and a reader. The tag is placed on the object for identification, while the reader is a device to read/write information on the tag [13]. The tag contains an antenna and an application-specific integrated circuit containing a memory in which data are stored. The reader consists of an antenna, an RF module for communication with tags, and a control module for communication with external interfaces such as personal computers to process information exchanged from the reader [14]. The tag acts as a transponder and the reader as an interrogator. The reader-antenna area is divided into two main parts: the near and far field. The near field uses the principle of inductive coupling, while the far field uses backscattering coupling [15]. The RFID reader communicates with the tag via an RF channel. The reader also performs anti-collision protocols to ensure that no communication conflict occurs between the tags [16].

A temperature monitoring system has been investigated using RFID-based communication carrier [17]. As a part of the system, a lightweight UHF RFID reader has been developed with sensing range up to 0.31 m. A slightly improvement, a UHF RFID reader for inventory and tracking of surgical equipment has been designed with reading distance up to 0.4 m in [18]. With improvement in reading distance up to 1.3 m, Vera *et al.* designed a UHF RFID reader for detecting goods or people [19]. This improvement has been achieved by using double-antenna sensor tag. A UHF RFID reader for tracking patients' location with multiple tags has been implemented with sensing range up to 3.8 m [20]. This system uses multiple RFID tags as bracelets to locate the patients. The reading distance was improved up to 1.3 m. Moreover, a UHF RFID reader with passive sensor tag system for new born monitoring achieved the read range 8.25 m [21]. However, those RFID readers do not comply with ISO 18000-6C for accessing user memory bank. Compliant with the ISO standard is important for wide range device compatibility. Moreover, capability for accessing user memory bank is necessary feature for tag-sensory system.

RFID tags that comply with the ISO 18000-6C standard are marketed under the name electronic product code (EPC) Gen 2 tag. This tag consists of four memory banks: an EPC, a tag identifier (TID), a reserve memory, and a user memory. The EPC bank stores EPC binary encoding; the TID bank stores information about the tag, such as the type of physical object to which it is attached; the reserve bank contains a password; and the user memory bank provides a variable memory size for storing additional data. The user memory bank is not always available in the tag [22]; hence, there are only a limited number of RFID readers capable of reading the user memory bank [23], [24]. Moreover, a well-known RFID problem is its short sensing distance. For a larger sensing distance, RFID uses the active tag, which needs regular battery replacement. Another solution is to use a portable RFID reader to increase the sensing distance using its mobility.

This paper proposes a portable RFID reader capable for reading and writing a user memory bank. The proposed RFID reader is designed to use low-cost devices widely available on the market for easy reproduction by researchers, educators, and developers, even in developing countries. This paper is organized as follows: Section 2 presents the RFID-reader design; Section 3 describes the experimental scenarios; Section 4 presents the results and discussion; and Section 5 presents the conclusion.

2. RFID READER DESIGN

The RFID-reader design consists of RFID workflow, hardware, and software components. The RFID workflow explains how the RFID reader performs its sensing, processing, and displaying tasks; the RFID workflow is implemented by assembling the hardware components and developing the software.

2.1. RFID workflow

The RFID reader must perform three functions: sensing, processing, and displaying. Sensing aims to detect the presence of tags within reach of the reader. The presence of tags is indicated by reading the EPC, TID, reserved, and user-memory-bank data. Processing refers to the processing of binary data from the RFID module to the Arduino module. Binary data processing includes conversion of binary data into hexadecimal, reading mode (continuous or discrete), data selection, and reading duration. Displaying is the act of presenting the data processed by the Arduino module on the liquid-crystal display (LCD) screen. LCD-screen operation can be used to select the type and number of tags to be displayed.

The reader begins to work when the tag is in the reader's far field; then, the reader can detect changes in the field. The antenna on the reader propagates the electromagnetic waves, which are then caught by the tag's antenna, inducing an alternating voltage that is then rectified by the diode component. Thereafter, the capacitor component stores the voltage as a power source for the tag. A load modulation then modulates EPC, TID, reserved, and user memory data when the tag is powered. This load modulation is dependent on the receiver side. If the load is large, the circuit will open and there will be no current flow on the receiver antenna, such that there is no backscatter. When the load is small, the current flows to the receiver antenna to perform backscattering. After backscattering, the reader receives the tag data. All data are expressed in binary code and sent to the Arduino UNO for further decoding. The Arduino can decode hexadecimal or binary code based on what has been written and uploaded by the Arduino. Then, the Arduino UNO only needs to run the code, after which the resulting data displayed on the LCD, thus completing the reading process.

2.2. Hardware component

Figure 1 shows the main and auxiliary hardware components. The main components are inside of the rectangle and comprise the interrogator, processor, interface, and power supply. The interrogator uses an ultra-high-frequency RFID module employing backscattering modulation. Thereafter, backscattering-modulation process occurs, and the UHF RFID module receives the tag's data, which are forwarded to the processor or control section. The RFID-reader module used is the SparkFun Simultaneous RFID Tag Reader, which complies with the EPC Global Gen 2 (ISO 18000-6C) standard with a nominal backscatter rate of 250 kbps and a maximum power of 27 dBm. In addition, this module is also equipped with antenna-selection features by which users can choose to employ an on-board or external antenna [25]. This module was chosen due to its ISO 18000-6C standard performance, allowing it to access user memory banks, and because it can be easily found on the market. Moreover, this module is equipped with an on-board antenna without any specification; thus, it can be installed using an external antenna. The component used as a processor is the Arduino UNO, namely, the SparkFun RedBoard. The Arduino UNO processes the code in the form of binary encoding sent by the interrogator; by running the code written and uploaded by the host component, the laptop, which contains the Arduino IDE software, will finish data processing. The host component is connecting via a serial port. We select Arduino-based components for rapid development and prototyping of new systems. There are two options for displaying the reading data: using a serial monitor or using an LCD. Both options depend upon the reading mode selected by the user. If the user chooses a continuous reading mode, the reading is only to be displayed on the serial monitor. By contrast, if the user selects a noncontinuous reading mode, the reading results can be seen on the serial monitor and LCD. The button on the LCD makes this tool more interactive with the user. We used an LCD module with a keypad [26]. An intermediate device called an I2C backpack is used to connect the LCD and the Arduino [27]. The RFID-reader's power supply uses a power bank of 10,000 mAh.

The auxiliary components outside of the rectangle consist of a tag and a host. In this paper, we used two types of tags: standardized and nonstandardized ISO 18,000-6C. The host is a laptop running Microsoft Windows Operating System. The host is used for software development and deployment. For operation itself, the host is not used.

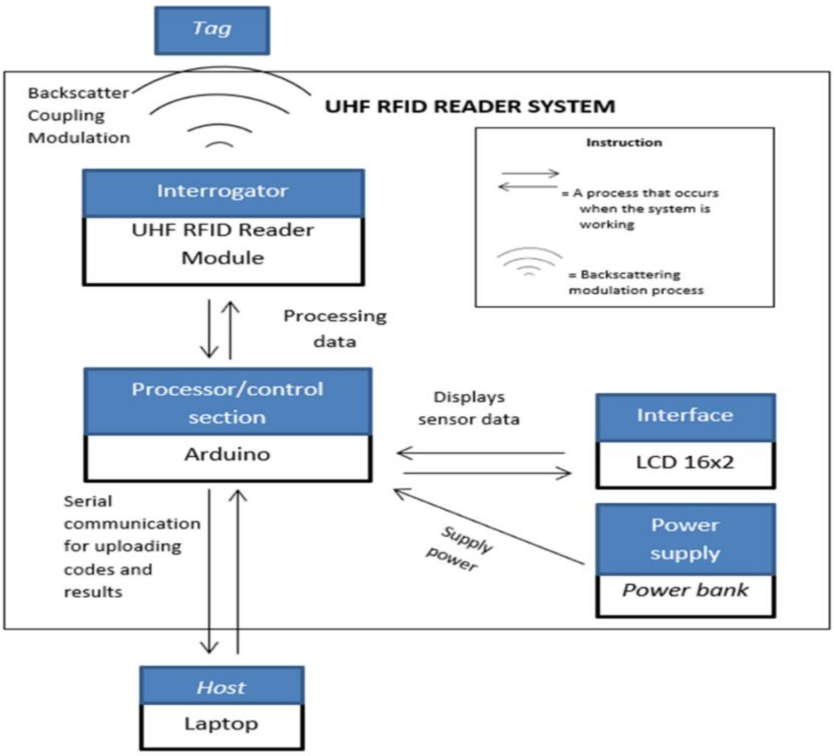


Figure 1. Hardware component

2.3. Software design

Figure 2 presents the software workflow for the RFID reader. When starting the program, the user may choose between two reader working modes: continuous or noncontinuous. If the user does not define the reading mode, then the reader defaults to the noncontinuous mode. If the user selects the continuous mode, the reader reads the RSSI, frequency, and EPC during the tag-reading duration. The data are then displayed on a serial monitor with a predetermined baud rate of 115,200 bps. Both processes continue until a predetermined time. If the program keeps reading beyond this time, then the reader will stop reading. The LCD does not support this mode, such that when this mode takes place, the LCD switches off to minimize the power consumed.

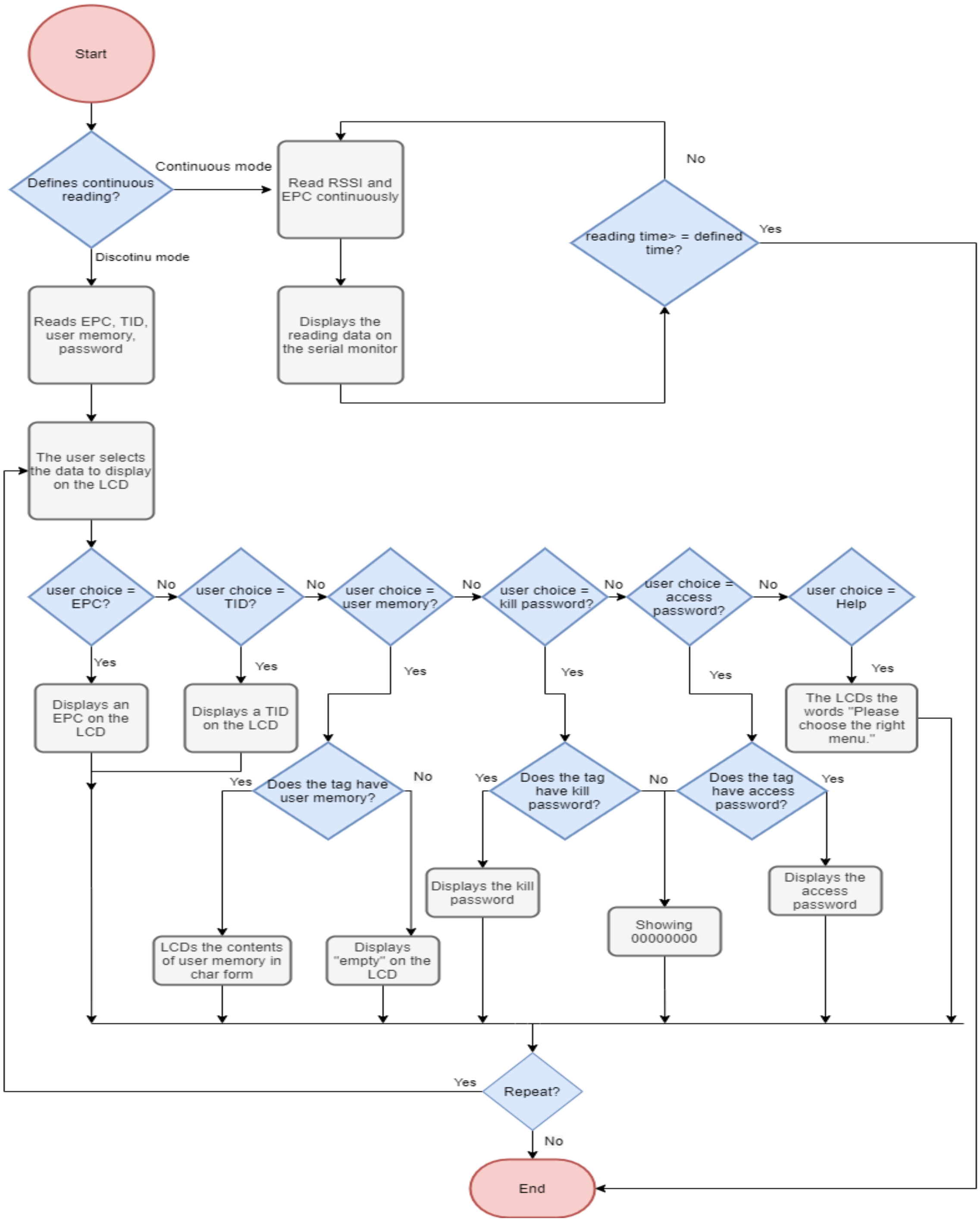


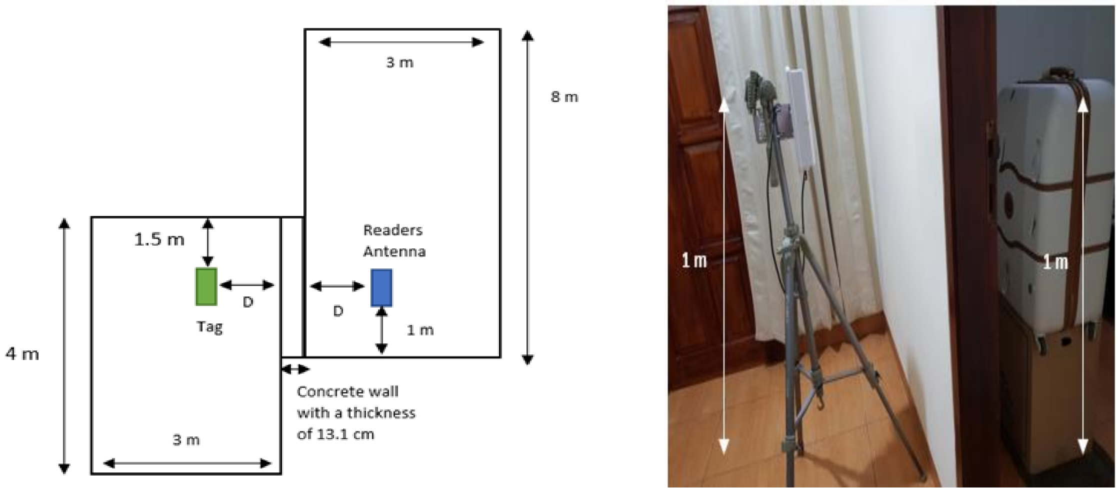
Figure 2. Software workflow

Meanwhile, if the user selects the noncontinuous mode, the reader reads the EPC, TID, user memory, kill password, and access password from the tag within its reading range. Afterward, the user can choose which data they want to display on the LCD. The reading process can be repeated if the user wants to read another tag; otherwise, the reader terminates the reading.

3. EXPERIMENTAL SCENARIOS

To determine the performance of the RFID reader, we measured it experimentally in terms of parameters including RRSI, sensing range, output power, and ability to detect a number of tags simultaneously. Its performance was measured for a variety of different antennas and tags. The antennas included the on-board antenna, an omnidirectional antenna with 2-dBi gain, and a microstrip antenna with 6-dBi gain. Measurements were carried out under two conditions: LOS and NLOS. In the LOS condition, we ensure that there are no obstructions between the reader and the tag; both are installed at a height of 1 m above level ground, as shown in Figure 3. Measurements are made using a sparse variation of 1 m and a closest distance of 1 m. Furthermore, in NLOS conditions, measurements were made indoors with a wall of thickness 13.1 cm acting as a barrier between the reader and the tag. The reader and tag are placed such that they are the same distance from the wall. The distance between the two is varied from 1 m to 6 m with an increment of 1 m. The reader and tag are placed at a height of 1 m; the plan and realization of reader-and-tag placement can be seen in Figures 4(a) and (b), respectively.

Figure 3. Measurement of the line of sight (LOS) scenario



(a) (b)

Figure 4. Non line of sight (NLOS) scenario: (a) Placement of the tag and the reader and (b) Realization

4. RESULTS AND DISCUSSION
4.1. RFID-reader specification

Figure 5 shows the RFID reader that we constructed. The Arduino microcontroller uses a Sparkfun Simultaneous RFID module; this RFID reader is equipped with an LCD keypad shield with buttons for operation and a mode for supporting mobile work that does not need personal computer or laptop. The LCD can display list of observed RFID tags, access types of memories including, EPC, TID, user memory, and password. The RFID-reader's packaging is equipped with a transparent acrylic box of compact shape to support portability.

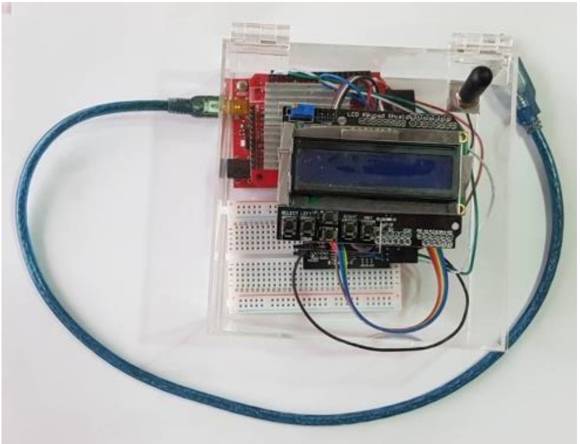


Figure 5. Realization of RFID reader

Table 1 shows the proposed RFID-reader's specifications. The reader has dimensions of 129 × 129 × 60 mm and an antenna of 223 × 200 × 60 mm. The reader is separated from the antenna, making it easier to place the antenna for maximum sensitivity. The protocol used by the reader is ISO 18000-6C. This reader can operate in several countries, such as America, Europe, China, India, South Korea, Australia, Japan, Indonesia, and many others. The frequency can be adjusted from 860 to 960 MHz by the user. The reader also has an output power of 5–27 dBm with an increment of 1 dBm. Furthermore, 12 m is the farthest reading distance achieved by the reader during LOS conditions. The antenna has a gain of 6 dBi. Based on the RFID module's datasheet, this reader has a receiving sensitivity of −59 dBm [28] and can read multiple tags at once, owing to its anti-collision protocol. This reader is also equipped with LCD to show the sensing tags. The program is written in the Arduino language. The reader can read partitions from the user memory bank by directly addressing the data and its length.

Table 1 also compares the proposed RFID reader with others available on the market, including the RFD7206E RAIN UHF Integrated Reader Writer [23] and the Miniature Integrated RFID Reader CL7206B7A with RJ45 [24]. Several specifications are compared, including dimensions, protocol, working frequency, output power, reading distance, antenna gain, working mode, and the ability to read user memory with a particular address. These comparisons show that even though the proposed RFID reader remains separated from the antenna, it is still less compact than the two readers on the market that fuse the reader circuit with the antenna. The protocol used by the three RFID readers is the same, namely, ISO 18000-6C, while the proposed RFID reader has a broader working-frequency coverage, allowing it to be used in more countries. The two RFID readers [23], [24] have output powers ranging from 0 to 30 dBm, while the proposed RFID reader produces a smaller range of power from 5 dBm to 27 dBm. The incremental powers of the three readers is the same, namely, 1 dBm. The two readers have reading distances up to 8 m, while the proposed RFID reader, even though it uses less power (25 dBm), can achieve reading distances as large as 12 m. The antenna gain of the proposed RFID reader is 6 dBi, while the others [23], [24] have gains of 6 dBi and 5 dBi, respectively. Sensitivity is an important parameter for RFID, and knowing the reader's sensitivity can allow the reading distance to be estimated. The proposed RFID-reader's sensitivity is −64 dBm, while the other two readers do not include this parameter on the datasheet.

Table 1. Comparison of RFID-reader specs

Specs	The proposed RFID reader	RFD7206E RAIN UHF Integrated Reader Writer [23]	Miniature Integrated RFID-reader CL7206B7A with RJ45 [24]
Dimensions (length × width × hight) in mm	Reader: (129 × 129 × 60) antenna: (223 × 200 × 60)	Reader and antenna: 164 × 164 × 49.6	Reader and antenna: 164 × 164 × 49.6
Protocol	ISO 18000-6C	ISO 18000-6C	ISO 18000-6C
Frequency	FCC (NA, SA) 917.4–927.2 MHz; 865.6–867.6 MHz; TRAI (India) 865–867 MHz; KCC (Korea) 917–923.5 MHz; ACMA (Australia) 920–926 MHz; SRRC-MII (P.R. China) 920.1–924.9 MHz; MIC (Japan) 916.8–922.2 MHz; “Open” (customizable channel plan; 859–873, 915–930 MHz)	USA: 902 MHz–928 MHz (FCC part 15) EU: 865–868 MHz (ETSI EN 302208) CN: 920–925 MHz (CMIIT)	920 MHz～923 MHz, 840 MHz～845 MHz and FCC, 902 MHz～928 MHz and ETSI, 865 MHz ~ 868 MHz
Output power	5–27 dBm	0–33 dBm	0–33 dBm
Power adjustment	±1 dBm	±1 dBm	±1 dBm
Reading distance in LOS conditions	Up to 12 m	Up to 8 m	Up to 8 m
Antenna gain	6 dBi	6 dBi	5 dBi
Reader sensitivity	−64 dBm	Not available on the datasheet	Not available on the datasheet
Anti-collision	Yes	Yes	Yes
Working mode	*Fixed/Mobile*	*Fixed*	*Fixed*
Equipped with LCD	Yes	No	No
Programming language	Arduino	.NET/C/C#	.NET/.NET Core/C++/Java SDK Android platform
Has the ability to read memory users by special addresses	Yes	Yes	Yes
Price (IDR)	4,916,659	19,000,000	10,000,000

Meanwhile, the two readers on the market have a fixed working mode or depend upon the laptop for operation. In contrast, the proposed RFID reader can work both when connected and when not connected to the laptop, because it is equipped with an LCD to display the reading results. The three readers have an anti-collision protocol, which allows them to read multiple tags at a time. All three readers can read the user memory bank with a specific address. The proposed RFID reader can be programmed using the Arduino programming language, while the RFD7206E RAIN UHF Integrated Reader Writer can be programmed using languages such as .NET, C, and C#, and the Miniature Integrated RFID-reader CL7206B7A with RJ45 can use .NET, .NET Core, C++, or Java SDK Android platforms.

The RFD7206E RAIN UHF Integrated Reader Writer has the highest price of the three (IDR 19,000,000), while the Miniature Integrated RFID-reader CL7206B7A with RJ45 costs IDR 10,000,000. Meanwhile, the cost spent on manufacturing the proposed RFID reader is only IDR 4,916,659; however, this does not consider the software-development cost.

4.2. RSSI versus distance in a LOS scenario

Figure 6 shows the RSSI measurements in a LOS scenario. The RSSI value can be seen to decrease as the distance between the reader and the tag increases. RSSI data were obtained from six different tags that can be classified into two groups: ISO and non-ISO. The ISO tags consist of passive contactless tags and windshield-sticker tags, whereas the non-ISO tags consist of a jewelry-label tag, a passive on-metal tag, an Impinj Monza tag, and a laudry tag. At a maximum distance of 4 m, almost all types of tags can be detected by the reader and only two types of tags can be detected at a distance of 11 m, both of them ISO 18000-6C-standardized. These results confirm that the choice of tag type can affect the operational distance of the reader. The interesting thing about this measurement is the reader’s ability to detect tags up to RSSI −63.75 dBm.

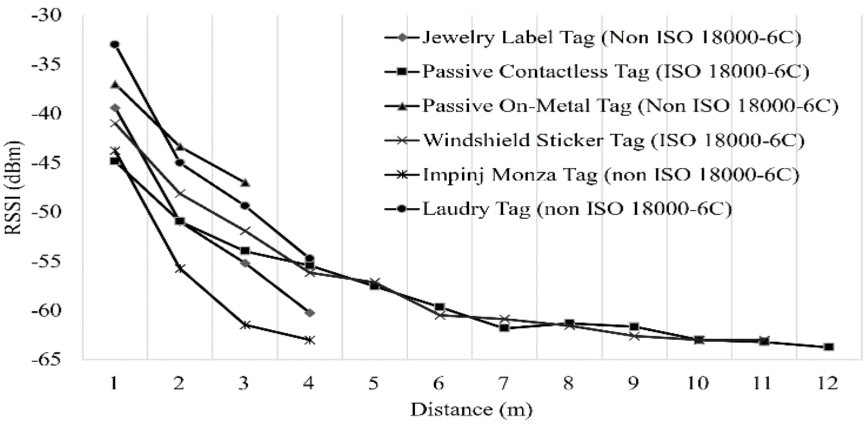


Figure 6. RSSI versus distance in a LOS scenario with tag variation

4.3. RSSI versus distance in a NLOS scenario

Figure 7 shows the results of RSSI measurements in the NLOS scenario. RSSI is observed to decrease when the distance between the reader and the tag increases. Here, there are only three tags that can be detected at a distance of more than 1 m, with the greatest detection distance being 5.5 m. The maximum detection distance is less than 50% that in LOS scenarios.

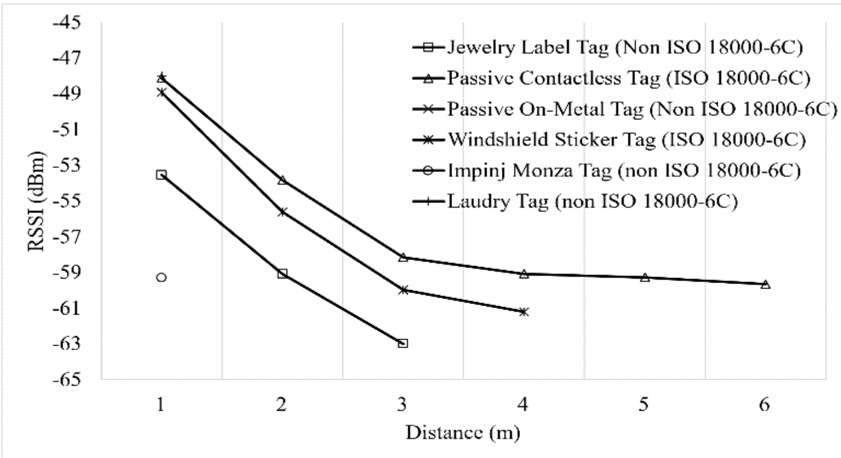


Figure 7. RSSI versus distance in a NLOS scenario with tag variation

4.4. Number of tags read versus distance

Figure 8 shows that, at a distance of 1 m, the reader can read all 14 of 14 tags in the LOS condition; in the NLOS condition, the maximum number of tags read was only 11. At a distance of 12 m, only one tag responded, and beyond this distance, the reader cannot read any tags at all in LOS condition. In both conditions, the graph exhibits decrease with increasing distance. The relationship between the distance and the maximum number of tags that was read was inversely proportional to the distance increase—the greater the distance, the fewer tags can be read.

Distance affects the RSSI value because the reader's electromagnetic waves will attenuate their way into the tag. The greater this distance and the greater the transmitted wave's attenuation, the less energy that the tag will receive. If the distance is too great, the energy received by the tag will be too small; in such a case, the energy will not be sufficient for the tag to transmit data in the form of reflected waves to the reader. Under other conditions, the tag will still reflect waves but with less power; therefore, the RSSI value reads lower. The reader will still be able to read tags with a high RSSI value at a reading distance of 11 to 12 m, while those with a smaller RSSI value will not be legible. Therefore, there is a reduction in the maximum number of tags read as distance increases.

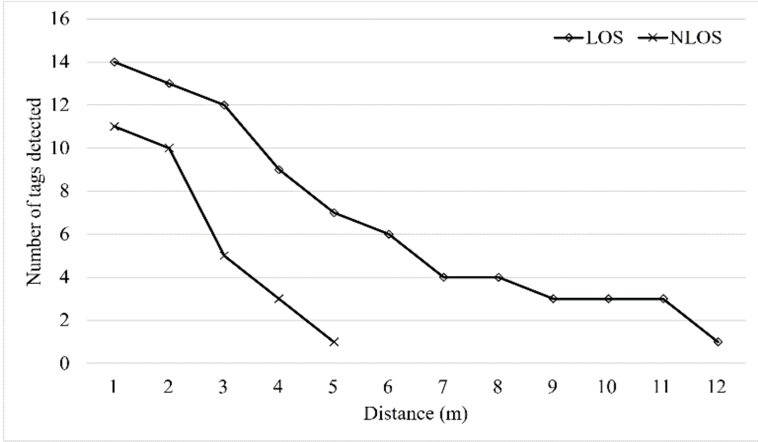


Figure 8. The number of tags detected in the LOS and NLOS scenarios

4.5. Distance versus power and antenna types

Figure 9 shows the effect of the reader-antenna type upon its detection ability. There are three types of antennas, namely, on-board, omnidirectional, and microstrip. LOS and NLOS measurements were performed by varying the transmission power over 5–25 dBm. LOS-measurement results marked with a solid line show that the microstrip antenna provides the best results with a greatest detection distance of 12 m. Meanwhile, on-board and omnidirectional antennas result in a detection-distance performance of less than 1 m, even though the reader is set to 25 dBm of output power. Closer to the NLOS marked by a dashed line, the microstrip antenna still has the greatest detection distance. These results confirm that the choice of reader-antenna type can affect the detection-distance performance.

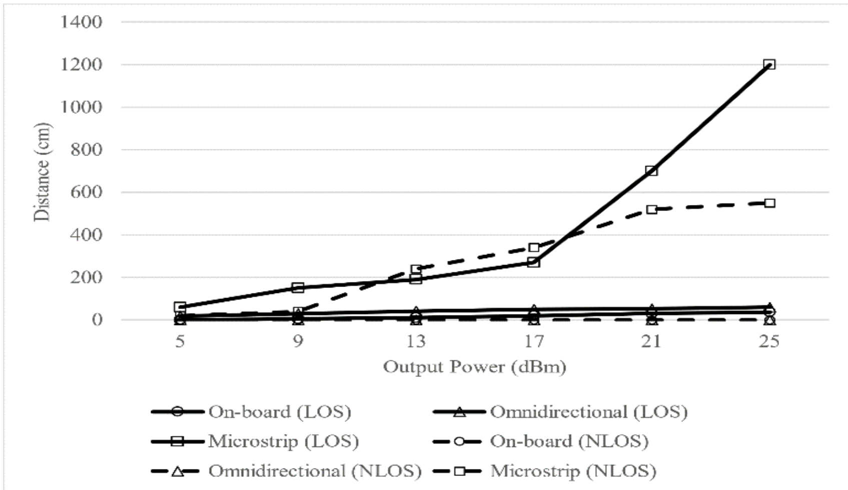


Figure 9. Performance detection of an RFID reader by antenna type

4.6. Memory reading

We show a serial communication interface that represents how the RFID reader accesses all memory banks, as shown in Figure 10. We can see the read arrow that there is a user memory bank read.

4.7. Discussion

A portable RFID reader may be a good solution for sensing over a large area while maintaining a low power consumption. Moreover, an RFID reader that can access a user memory bank obtains more information from a tag; however, such RFID readers do not tend to be mobile [23], [24]. This paper has therefore proposed a portable RFID reader capable of accessing user memory banks.

We have designed the proposed RFID reader with a comparable specification as shown in Table 2. Our RFID reader outperforms its competitors in terms of several parameters, such as radius range (which is 2 m longer) and cost-effectiveness with improvement being 25% and -50%, respectively. However, we should note that this price does not include research.

Since the RFID operates in unlicensed spectrum, we should consider interference from technologies that use same spectrum such as LoRa and Zigbee. These interferers can deteriorate performance of RFID reader. However, the performance of the proposed RFID reader can even be improved using the high-gain antenna and standardized tag. These results have been investigated through measurements under the LOS and NLOS scenarios. There can be no doubt that the performance of the RFID reader with the NLOS scenario decreased due to harder propagation of the signals. However, the performance results and characteristics point to a new level of RFID-reader technology.

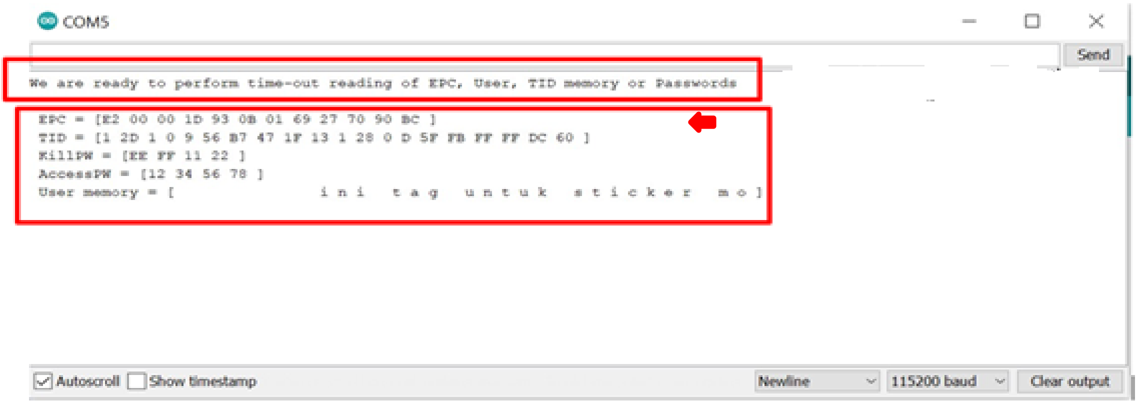


Figure 10. RFID reads all memory banks

Table. 2 Percentage of improvement

Parameter	RFID [24]	Proposed RFID	% Improvement
Max. LOS Reading Distance (m)	8	12	**25**
Price (IDR)	10,000,000	4,916,659	**-50.8334**

5. CONCLUSION

This paper proposed a portable RFID reader capable of accessing user memory banks on RFID tags. The reader was designed using low-cost devices widely available on the market, such as Arduino-based microcontrollers. We showed that the performance of our proposed reader outperformed that of the reference RFID reader with a reading distance up to 12 m. The proposed reader could read and write all memory banks well, including EPC, TID, reserved memory, and user memory. The proposed design of the RFID reader can be applied in communications technology for SBEM, particularly where data collection is required. Moreover, the proposed reader can collect data over a large area due to its mobility.

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