Journal of Medical Devices Technology

jmeditec.utm.my

Original Research

Effect of Human Body to the Read Range of Radio Frequency Identification Devices Worn in Close Proximity

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ARTICLE INFO

Article History:
Received 6 December 2022
Accepted 28 February 2023
Available online 30 May 2023

Keywords:
Metamaterials,
Read range,
RFID

ABSTRACT

Radio Frequency Identification (RFID) is a wireless data collecting system which involves the use of radio frequency (RF) in the electromagnetic spectrum to transfer data between a reader and a tag. The read range is the working distance between the reader and tag that the RF signals can be delivered. This study aims to investigate the effect to the read range by placing the tag in close proximity to the human body compared to placing it in free-space. The results show that the read range diminished when the tag is worn by a human. The read range can be improved by incorporating metamaterials structure in the RFID devices.

INTRODUCTION

With the advance of Internet of Things (IoT), innovations in the healthcare sector today are often linked to contemporary technologies. The development of communication technology has produced various creative applications that benefited and transformed the healthcare sector by boosting productivity, cutting expenses, and improving patient care (Huarng et al., 2022). Wearable smart devices which can be adhered on the skin, implanted in the body or embedded in external accessories such as garment and clothing are used for collecting, sending data, and receiving the information (Verma et al., 2022). These smart devices are linked with other devices using IoT technology. This allows patients to share sensitive medical information or records wirelessly and securely through a trusted medical server. It maintains the data connected to the registered users. Name, sex, age, and a host of other information about the patient might be included (Shariq et al., 2021).

Radio Frequency Identification (RFID) is a wireless data collecting method that makes use of the RF portion of the electromagnetic spectrum. A transponder (tag), reader, and software make up RFID, which has the potential to collect data without the involvement of a human. The healthcare industry utilizes RFID to maintain the inventory of medical supplies, identify patients, and manage staff. The use of RFID technology has an influence on every employee working in the healthcare industry. This can decrease many problems including long-established paper-based processes, poor patient, staff, medical equipment, and data discernibility (Abugabah, 2020).

Getting trustworthy low power data from a passive RFID tag worn in close proximity to humans is still challenging as the read range from the reader to tag is considerably affected by its surrounding environment. The intensity of the transmitted signal is also affected by the phase difference of the signal. The radiation, efficiency, input impedance, radiation pattern, and radiation efficiency may be varied accordingly (Abdulghafor et al., 2021). Furthermore, when the RFID device runs parallel to the skin, the antenna will be negatively impacted by the body tissues to such an extent that its effectiveness will be reduced

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(Hughes, 2022). Therefore, understanding the effects of the human body to the performance of wireless RFID is required and hence this review particularly focused on the issue.

RADIO FREQUENCY IDENTIFICATION (RFID)

RFID Systems

RFID system generally consists of a reader, tags, and server for real-time communication and implementation of data tracking (Unhelkar et al., 2022). The RFID reader is equipped with scanning antenna to transmit and receive the radio waves signals. Each RFID tags is a combination of an electronic chip and an antenna for signal reception and transmission or backscattering (Luo et al., 2022). The RFID tags, each carries a univocal identification code using the electronic chip, send back the code to the RFID reader whenever they are interrogated. The tags can be passive or active. Passive tags retrieve the electromagnetic energy from the interrogating signals whereas active tags are powered by a battery. Passive tags are compact, light, low-cost, and easy to manufacture (Unhelkar et al., 2022). The frequency band that is allocated for ultra-high frequency (UHF) RFID applications ranges in between 860 MHz to 960 MHz. Due to the cheap price for UHF passive RFID tags, they can potentially replace the optical barcode reading for items. This RFID method also allow simultaneous reading of multiple tags and ease processes such as inventorying, identifying and tracking of items (Abdulghafor et al., 2021).

Read Range

The signals from an RFID tag are amplified by the reader and measured as received signal strength indicator (RSSI), which varies depending on the tag's orientation and position. The reader analyzes the RSSI of the signals and reports the tag's data to the user (Lee and Marsic, 2018). The read range or operating range is the distance between the reader and tag that the signals can be delivered. The read range for active tags is longer than that of passive tags as active tags are powered by a power source. The read range for passive tags depends on frequency of operations, type of reader and tags, interference, and surrounding environments (Tsalapati et al., 2021).

The following Friis transmission equation is used to calculate the RFID read range which P_t, G_t, and G_r are the reader's transmitted powers, the tag's antenna gain, the reader's gain, and the power transmission coefficient between the antenna and chip, P_{th} is the minimal RF power needed to transmit power and τ as a receiver (Jouali et al., 2022).

$$r = \frac{c}{2\pi f}\sqrt{\frac{P_t G_t}{P_{th}} G_r \tau} \qquad (1)$$

Human Body System

RFID tags may be included into clothing that experiences any unusual crumpling without having an impact on the structure of the tag when it returns to its original shape. It could impair the effectiveness of RFID tags as well as embroidered antennas. Operating near to the evaporative human body is convincing. The read range of the UHF-RFID tag antenna might be significantly impacted (El Bakkali et al., 2021). As a result, this study makes use of the human body's electrical characteristics, which were gathered from the datasheet and are displayed in Table 1 (Salem, 2022).

After examining the data that were taken from the journal articles and accessible datasheet, the chest was selected as the body component from the data for the human body model. Table 2 computes the average conductivity and permittivity values for the chest region. Prior to the body model being designed in CST and shown in Figure 1, it is also shown in Table 3 (Salem, 2022).

Effect on Human Body Tissues

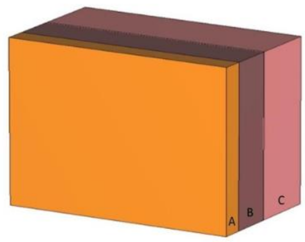


Fig 1 Average of Thickness, Permittivity, and Conductivity (Salem, 2022)

In most cases, electromagnetic energy cannot be effectively transferred from an in-body device to an outside transceiver. Antenna performance characteristics are influenced by human tissues' dielectric properties. Normal behaviour is for a living thing to absorb energy from the emitting source when it comes into contact with a static radio frequency field or non-radiating field. It is generally accepted that as frequency increases, the skin impact becomes more pronounced and pertinent to people (Yusri, 2022).

Pre-Read Range Analysis

To make sure the model is working properly, analyze the RFID tag on the human body first. Before moving on to the next analysis, an optimization utilizing the best value of S_{11} is required in order to get the RFID tag's optimal read range. Due to the hand measurement of the actual dimensions, the minimum and maximum values for the parametric sweep were set to be within tolerance. The finest and most ideal value in relation to Figure 2 can then be selected. At f = 920 MHz, the S_{11} slope is optimal and is less than -2.5 db (Salem, 2022).

Read Range Analysis

The simulation tests the read range of the model while the RFID tag is in open space without being disturbed by any nearby high loss items. The read range for the actual design of an RFID tag was stated to be between 4 and 8 meters, and with f = 920 MHz, it was 7.5 meters. In human body circumstances, the closer the tag is to the body, the more the read range is impacted by the characteristics of the body. It displays the read range while taking clothing and body movement into account as a spacing gap between the body and RFID tag model, and it provided various waves under the free space condition (Salem, 2022).

Table 1 Human Body Electrical Properties (Salem, 2022)

No	Body Part	Sub Body Part	Thickness (mm)	Permittivity (mm)	Conductivity (S/m)	Reference
1	Arm	Skin	1.5	41.32	0.8555	
		Fat	20	5.46	0.05	(Casula and Montisci, 2019)
		Muscle	30	54.97	0.934	
2	General	Skin	1.7	-	-	
		Fat	8	-	-	(Yalduz et al., 2020)
		Muscle	10	-	-	
3	Arm, Leg	Skin	2	37.95	1.49	
		Fat	5	5.27	0.11	(Nie et al., 2021)
		Muscle	20	52.67	1.77	
4	Chest/Belly	Skin	2	36.06	2.84	
		Fat	4	5.03	0.23	(Farahat, 2021)
		Muscle	5	49.84	3.93	
5	General	Skin	1	38.007	1.49	
		Fat	5	5.28	0.11	(Yin, 2021)
		Muscle	20	52.729	1.77	
6	Chest/Arm	Skin	2	35	3.8	
		Fat	5	4.95	0.3	(Keshwani, 2021)
		Muscle	20	48.4	5.12	
7	Chest, Leg, Arm	Skin (wet)	1	49.90	-	
		Fat	5	5.58	-	(El May, 2021)
		Muscle	40	57.13	-	
8	Wrist & Chest	Skin	2	37.95	1.45	
		Fat	5	5.27	0.11	(Du, 2021)
		Muscle	20	52.67	1.77	
9	Chest	Skin	2	37.95	1.49	
		Fat	5	5.27	0.11	(Roy and Chakraborty, 2019)
		Muscle	20	52.67	1.77	
10	Arm	Skin	2	31.29	5.0138	
		Fat	8	5.28	0.1	(Ali et al., 2017)
		Muscle	23	52.79	1.705	

The read range is more significantly impacted by human body characteristics when the tag is put near to the body than when it is farther away. In Figure 3, the read range is depicted while considering clothing and body movement as a gap between the body and RFID tag model. The slopes for both circumstances are also combined shown in Figure 4. The human body's dielectric biological matter and the object's high loss dielectric constants produce a variance in performance when an RFID tag is placed close to a human body, which reduces radiation efficiency and causes detuning of the tag (Salem, 2022).

Table 2 Electrical Properties of Human Body Chest (Salem, 2022)

No	Body Part	Sub Body Part	Thickness (mm)	Permittivity (mm)	Conductivity (S/m)	Reference
1	Chest/Belly	Skin	2	36.06	2.84	
		Fat	4	5.03	0.23	(Balanis, 2015)
		Muscle	5	49.84	3.93	
2	Chest	Skin	2	35	3.8	
		Fat	5	4.95	0.3	(De Vita Iannaccon, 2005)
		Muscle	20	48.40	5.12	
3	Chest	Skin (wet)	2	37.95	1.49	
		Fat	5	5.27	0.11	(Kurokawa)
		Muscle	20	52.67	1.77	
4	Chest/Arm	Skin	2	37.95	1.45	
		Fat	5	5.27	0.11	(Nikolayev et al., 2018)
		Muscle	20	52.67	1.77	
5	Chest/Arm	Skin	2	37.95	1.49	
		Fat	5	5.27	0.11	(Ali et al., 2017)
		Muscle	20	52.67	1.77	
		Bone	13	18.49	0.82	
6	General	Skin	1	38.007	1.49	
		Fat	5	5.28	0.11	(Li et al., 2017)
		Muscle	20	52.729	1.77	
7	Chest, Leg, Arm	Skin	1	49.90	-	
		Fat	5	5.58	-	(Ung and Karacolak, 2012)
		Muscle	40	57.13	-	
		Bone	1	49.9	-	
8	Chest	Skin	2	14	0.25	
		Fat	4	55.1	0.93	(Chen et al., 2017)
		Muscle	54	20.8	0.33	
9	Chest	Skin	0.1cm	54.5	0.10	
		Fat	1.0cm	5.64	0.10	(Loktongbam et al., 2019)
		Muscle	6.0cm	54.50	0.60	

METAMATERIAL

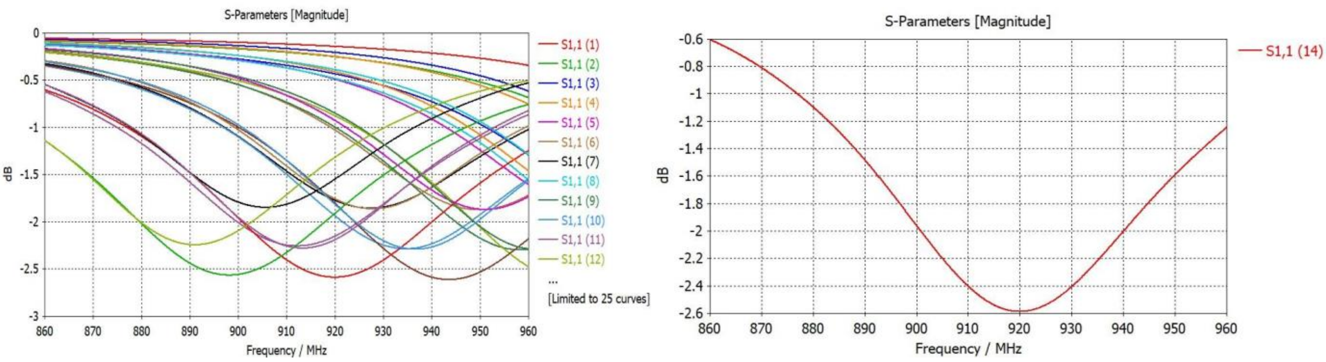
Metamaterials are structures which exhibit properties not found in natural materials such as negative permittivity and negative permeability. Metamaterials have been research interest in the past decade due to their functionalities and potential applications in various fields. The inclusion of metamaterials in RFID devices enhances the performance of the devices (Abdullah, 2021). In this section, metamaterials loaded to the RFID devices are discussed.

Metamaterial-based RFID Devices

The integration or incorporation of metamaterial structure on RFID antennas can realize size reduction, gain enhancement, and even chip-less tag. A typical RFID tag consists of an integrated circuit (or a chip) and an antenna printed on a substrate. The impedance matching between the chip and the tag-antenna is essential to maximize the power transfer between the reader and the chip. Planar printed monopole or dipole antenna are commonly used as the tag-antenna on the RFID tag.

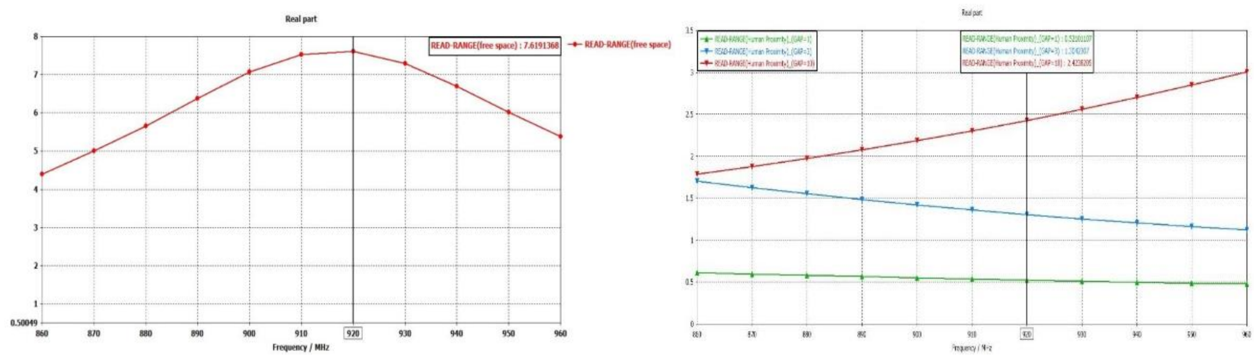
Table 3 Average of Thickness, Permittivity, and Conductivity (Salem, 2022)

Body Part	Sub Body Part	Thickness (mm)	Permittivity (mm)	Conductivity (S/m)
A	Skin	2	37.95	1.49
B	Fat	5	5.27	0.11
C	Muscle	20	52.27	1.77



(a) (b)

Fig 2 S_{11} parametric sweep (Salem, 2022)



(a) (b)

Fig 3 Read range at free space condition and proximity to human body (Salem, 2022)

Therefore, meandered line antennas are widely used due to their miniaturized size and omnidirectional radiation pattern. A smaller size is required to save production cost and ease the integration of the tag as wearable tag. Metamaterial structures including split ring resonators (SRRs) (El Yassini et al., 2021), meander lines (Bhaskar, 2021), and fractal (Sultan and Sabaawi, 2021) are used.

Split-Ring Resonator Structures on RFID

In RF microwave devices, the split-ring resonator (SRR) is intended to provide the best surface wave suppression, selectivity, and size miniaturization properties. The resonance frequency (fr) of an SRR-loaded planar device is affected by the effective dielectric constant (εeff), where εr is the relative permittivity of the substrate, and h is the height of the substrate, and w is the width of line (Wajid et al, 2022).

$$\varepsilon eff = = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \tag{2}$$

Metamaterial Surface as Ground Plane

A form of metamaterial that may be used with antennas is the artificial magnetic conductor (AMC). It offered a small size and a high gain increase. For 5G applications, it works in the 3.5 GHz band (Abdulbari et at., 2022). AMC structures are used to enhance an antenna's radiation properties, such as effectiveness, and to operate as a Perfect Magnetic Conductor (PMC), which is necessary for operating in a certain frequency range.

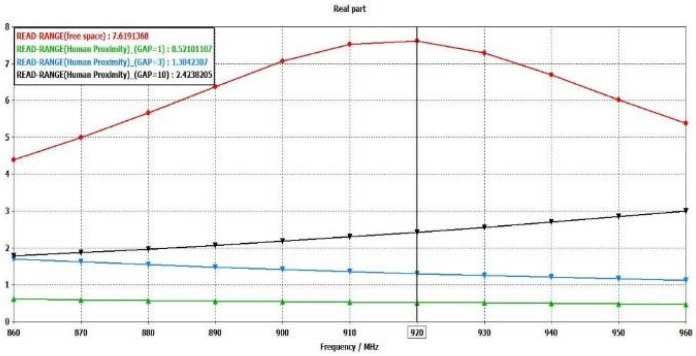


Fig 4 Comparison of read range for free space and proximity to human body (Salem, 2022)

Additionally, it also aims to increase read range (Bansal et al., 2019).

CONCLUSION

The results of this investigation allow us to draw the conclusion that an RFID tag's read range will be lowered when it is near a person. This paper also discusses the features of RFID, and a simulation of an RFID tag shows the read range under both free-space conditions and when it is linked to a human body. As a result, when an RFID tag is attached to a person, the clothing that will be in contact with the person's skin must also include the tag. It is hoped that a human experiment in the open field would enable the study to be more broadly based in the future.

Acknowledgment

The authors would like to thank the Ministry of Higher Education (MOHE), School of Postgraduate Studies (SPS), Research Management Centre, Advanced Diagnostics and Progressive Human Care Research Group, Faculty of Electrical Engineering and Universiti Teknologi Malaysia (UTM), Johor Bahru, for the support of the research under UTM Encouragement Research Grant Q.J130000.3851.20J74.

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