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Effects of IOT Devices on Human Health: A Comprehensive Survey

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ABSTRACT: IOT devices have varied domain specific applications. In this work, a comprehensive study is conducted to map IOT devices to its effect on human health via the radiations emitted. The short- and long-range radiations emitted by the IOT devices has the potential of affecting human health. A research protocol was developed to check the application areas of IOT devices, different radiations emitted from the IOT devices and how these radiations can potentially affect human health. The radiations emitted from IOT devices have several short- and long-term effects as show in the existing literature. The paper concludes with recommendations from the existing literature about IOT devices usage.

1. INTRODUCTION

IOT research has expanded multifold into various sectors and segments of everyday life. The transition is reportedly from Internet-Of-Things to Internet-Of-Everything (IOE) [1]. However, there has been slow growth in studying the effect of IOT devices on Human health. The effects of IOT devices based on short & long-term effects of radiation have been investigated by several researchers. Brain cancer cases have been on the rise since the last decade across the world [2].

As a significant result, there is general interest in investigating the effects of radiation on human health as there is a surge in the usage of wearable devices. There are newer research areas in which various frameworks are being proposed due to the integration of IOT with its satellite technologies and enabling technologies [1].

The existing literature provides information about the possible relationship between radiations and human health [14-20]. In this context, it is hence essential to find a relationship between radiations developed from IOT-based devices and human health as the infrastructure of IOT expands to include Body-Area-Network [3].

1.1 Goals Achieved

There were following different objectives completed after completion of this survey:-

1. The specific areas of IOT deployment were identified.
2. The radiations emitted from IOT devices were also identified.
3. The effects of radiation emitted by IOT devices on human health were also identified.

1.2 Specific Development Approach

The current work undertakes a mapping study of human health affected by IOT devices. The original aim of the authors was to carry out a Systematic Mapping Study (SMS) in order to access the effect of radiations emitted from IOT-based devices. However, due to the enormity of data from the initial search, it was decided to relegate the research to a comprehensive survey. The survey consisted of defining the research questions, conducting a search based on the search-string, defining the inclusion and exclusion criteria, extracting the necessary information for mapping to the research questions. The research questions were developed based on the motivating factors, and the search string was created according to the questions being addressed. The exclusion and inclusion criteria were defined using initial search. The exclusion principle was applied in order to exclude the irrelevant papers.

This research paper is organized in following sections. The section-1 gives the introduction of the research paper, section-2 defines the background for conducting this survey research. Section-3 discusses the research protocol used in conducting this survey. The three research questions answered in the result and discussion section numbered-4. The conclusion and future scope are given in section-5.

2. BACKGROUND

IOT technology has brought about path-breaking transformations in different fields of work. IOT embeds different devices within entities to accomplish various computational tasks. The IOT sensor and actuators are found to emit radiation ranging from short to long range [1].

The effect of radiation on human health has been under investigation for a long time. Human health deals with physical, mental and emotional well-being. There has been a consistent approach to developing better techniques for enhancing and restoring human health, which includes the usage of IOT sensors and actuators in achieving human health. However, how much these IOT sensors and actuators contribute to the degradation of human health, if any, needs a separate investigation.

The existing literature has not focused on conducting a comprehensive survey on the radiations emitted from IOT-devices and their subsequent effects on human health. The existing literatures mainly focus on effect of radiations in general only. The authors hence aim to complete this research gap by comprehensively surveying existing literature and finding linkages of IOT devices-based radiations to human health, if any.

2.1 Formulation of Research Protocol

The basic structure of the experimental setup included the following essential steps: -

1. Formulating the motivation for conducting research through research questions.
2. Choosing and creating the research string keywords using the research questions defined.
3. Selecting the inclusion and exclusion criteria for choosing the research papers.
4. Conducting data extraction by extracting specific information relevant to the research questions.
5. Answering the research questions by addressing the individual questions.

The above-mentioned steps needed defining the research protocol, registration on the online portals of dl.acm.org, sciencedirect.com and <https://pubmed.ncbi.nlm.nih.gov/> for the purpose of putting search string and getting the meta-data downloaded. The next step included defining and applying the inclusion and exclusion criteria, extracting the necessary data

from the selected studies. These steps will be useful for those prospective researchers who intend to replicate this comprehensive survey.

Figure 1 provides the basic steps used in this survey. The research proposal started with defining the contours of the research definition. The research definition included defining the context of searches to be conducted on different databases. The research definition led to defining the research questions, which formed the basis for formulating the search string. The search strings were then passed across different publishing and indexing databases. The inclusion and exclusion criteria were decided based on the research questions that were formulated.



Fig. 1. Basic Research Protocol

3 RESEARCH PROTOCOL EXECUTION

3.1 Research Question Formulation

The scope of the current work is on IOT devices and how their functioning and usage affect human health. The focus of the research was to study the relationship between IOT devices and their effect on human health. There were no specific IOT devices that were focused while defining the research questions.

In order to achieve this objective, the following research questions defined: -

Research question 1: What are the different areas where IoT systems are deployed?

Research question 2: What are the different types of radiation emitted from IoT systems?

Research question 3: What are the effects of radiation emitted from IoT devices on human health?

Search strings were formulated based on the different research questions. Table 1 provides the research questions and the corresponding search string that is formulated. The research question 1 has a search string with keywords IOT, Deployment, Thrust, Areas. AND operator ensured that both the keywords must be found in the search string. The research question-2 has search string with the keywords IOT, Device, and radiation.

The research question 3 has a search string with the keywords Radiation, Human Health, device. AND operator ensured that both keywords must be found in the search string. The motivation for search string 1 was to know the locations and infrastructure where IOT devices were deployed. The motivation for search string 2 was to know the type of radiation (long-range and short-range) emitted from the IOT devices to study its effect on humans. The motivation for search string 3 was to study the radiation-based effect on human health.

Table 1. Research Questions mapped to search strings and motivation

Research Question	Search Strings formulated	Motivation
1	Iot AND Deployment, Iot AND Thrust AND Areas	The IOT devices and their deployment areas are necessary to study understand its effect on human health

2	Iot AND Device AND Radiation	The radiations emitted by IOT devices must be known before studying effects on human health.
3	Radiation AND Human Health AND IOT	The effects of radiations on human health must be studied and connected with IOT devices.

3.2 Database Selection and Research Conduction

The area of research was interdisciplinary. Therefore, it was decided that one publishing house or database specific to computing will be chosen, while another publishing house that publishes articles in both the computing and medical domains will be chosen. ACM Digital Library, which indexes IOT-based researchers, and ScienceDirect, which indexes both computing and the medical area of research, were chosen. In order to make the list of research papers more exhaustive, the third database, PubMed was chosen, which publishes research papers and articles in the medical domain. PubMed is an amalgamation of several biomedical journals that publish papers in the domain of radiation as well. In the case of ACM, only a full text collection was used to pass the search string. The search strings presented in Table-1 were passed to the following databases and publishing houses:

1. ScienceDirect (Scencedirect.com)
2. ACM (dl.acm.org)
3. PubMed (<https://pubmed.ncbi.nlm.nih.gov/>)

Table 2 gives the result of passing the search strings to the chosen databases and publication houses. The databases and publication houses were passed along with the search string. The results obtained after passing the search string are given herein. The search string Iot AND Deployment gave the highest number of papers from ScienceDirect and the lowest from ACM digital library. The search string Iot AND Device AND Radiation gave the highest number of papers again from ScienceDirect and the lowest from the PubMed database. The search string Radiation, Human Health, AND IOT gave the highest number of papers from the ACM digital library and the lowest from PubMed.

Table 2. Results Obtained By Passing Search Strings Across Different Databases

Search String given in Title	Name of the Database/Publishing House	Results Obtained
Iot AND Deployment	ScienceDirect	1680
	ACM(In the title)	128
	PubMed	496
Iot AND Device AND Radiation	ScienceDirect	4410
	ACM	894
	PubMed	86
Radiation AND Human Health AND IOT	ScienceDirect	7800
	ACM(In the title)	1420
	PubMed	24

The exclusion criterion was used to exclude papers not related to the research questions. The exclusion criteria were mainly the presence of IOT or radiation or human health in the related in the reference section. This is given in table 3.

Table 3. Exclusion Criteria's Mapped To Research

Sr. No.	Exclusion Criteria	Research Question Addressed
EC1	Paper's referring to IOT and satellite technologies in the reference section	RQ-1
EC2	Papers referring to IOT and wireless, frequency, Bluetooth devices in the reference section.	RQ-2
EC3	Papers referring to IOT and wireless, frequency, Bluetooth devices in the reference section	RQ-3

The duplicate entries were also removed from as many papers as appeared in ScienceDirect, ACM, and PubMed. The duplicate entries appeared in either two databases or all three of them. The results obtained after applying the inclusion and exclusion criteria are given in Table 4. The inclusion and exclusion criteria were applied to papers from all the publishing houses corresponding to the search strings.

The data extraction process included extracting data for answering research questions. The count of papers selected for each research question is given in Table-5.

Table 4. Results Obtained After Applying Inclusion and Exclusion Criteria

Search String given in Title	Name of the Database/Publishing House	Count of Included
Iot AND Deployment	Sciencedirect	202
	ACM(In the title)	97
	PubMed	4410
Iot AND Device AND Radiation	Sciencedirect	968
	ACM	88
	PubMed	1250
Radiation AND Human Health AND IOT	Sciencedirect	4320

3 Mapping and Data Extraction

The data extraction process included extracting data for answering research questions. The count of papers selected for each research question is given in Table-5.

Table 5. Research Question and Corresponding Count of Research Papers Studied

Research Questions	Count of Paper Studied
RQ-1	30
RQ-2	20
RQ-3	27

The data extracted included information specific to the research question being addressed. The data extracted also included following general information of each research paper:-

1. Title of Paper
2. Names of the authors
3. Year of publication
4. Source of publication
5. List of authors
6. Type of authors
7. Summary of research findings

Data Extraction Strategy for Research Question-1

The research papers that did not follow the exclusion criteria were removed from the data extraction process. In order to answer research questions, a data extraction strategy was formulated.

The data items extracted from each research paper are shown in Table 6. The data extracted had two components. The basic information consisted of the index, title of publication, year of publication, the venue of paper published, author's details such as name and type of author (researcher or practitioner), and summary of the paper. The information focusing on research question 1 was also extracted, which consisted of IOT device deployment details and the location of deployment.

Table 6. Exclusion Criteria's Mapped To Research Questions

Sr. No.	Main Information Extracted	Detail about Information	Research Question Focused
D1	The ID of the study.	RQ-1	Basic Information
D2	Title	The title of study	Basic Information
D3	year	The published year of the study.	Basic Information
D4	Publication Venue	The place where the paper published.	Basic Information
D5	Authors	The names of authors	Basic Information
D6	Authors' type	Researcher or practitioner or both.	Basic Information
D7	Summary	The main theme of the paper	Basic Information
D8	IOT deployment	What are the specific deployment areas where IOT devices are used	RQ1
D9	Location of deployment	Precise location of deployment	RQ-2

Data Extraction Strategy for Research Question-2

The data extraction strategy for research question 2 dealt with extracting information pertaining to different short and long-range radiations that are emitted by the IOT devices. The data items extracted from each research paper are shown in Table 7. The data items extracted from each research paper are shown in Table 7. The data extracted had two components. Basic information consisted of the index, title of publication, year of publication, venue of the paper published, author's details such as name and type of author (researcher or practitioner), and summary of the paper. The information focusing on research question 1 was also extracted, which consisted of IOT device deployment details and the location of deployment.

Table 7. Information Extracted From Research Papers For RQ2

Sr. No.	Main Information Extracted	Detail about Information	Research Question Focused
D1	Index	The ID of the study.	Basic Information
D2	Title	The title of the study.	Basic Information
D3	Year	The published year of the study.	Basic Information
D4	Source	The published venue of the paper.	Basic Information
D5	Author list	The full names of all the authors.	Basic Information
D6	Authors' type	Researcher or practitioner or both.	Basic Information
D7	Summary	The main theme of the study.	Basic Information
D8	Types of Radiation	What specific types of radiations emitted by IOT devices.	RQ2
D9	Range of Radiations Emitted	What is the range of radiations emitted by IOT devices	RQ2

The data specific to research question-1 that was extracted from each research article included the following: -

1. Types of Radiation
2. Range of radiation Emitted
3. Frequency of radiation emitted

Data Extraction Strategy for Research Question-3

The search string for research question 3 was modified after getting the results of research question 2. The modified search string was as shown in Table 8.

Table 8. Modified Search String Based on Research Question-2's Results

Older Search String given in Title	Newer Search String Based On Research Question-2 Results
Radiation AND Human Health AND IOT	Infra-Red Radiation and Human Health
	Broadband Wireless and Human exposure
	Bluetooth Radiation and Human exposure

The results produced from the modified strings were very large; hence only first 100 entries against each search string, from Scienedirect.com, were used in data extraction.

The data extraction for research question-3 involved extracting the basic information and RQ-3 specific information. The extracted information dealt with extracting the effect of radiations identified in RQ-2 on human health. This is shown in table-9. The basic information extracted was index, title, year, source, author list, authors type, summary. The extracted information related to research question-3 included radiations and human health relationships and radiation effect on humans.

Table 9. Information Extracted From Research Papers For RQ3

Sr. No.	Main Information Extracted	Detail about Information	Research Question Focused
D1	Index	The ID of the study.	Basic Information
D2	Title	The title of the study.	Basic Information
D3	Year	The published year of the study.	Basic Information
D4	Source	The published venue of the paper.	Basic Information
D5	Author list	The full names of all the authors.	Basic Information
D6	Authors' type	Researcher or practitioner or both.	Basic Information
D7	Summary	The main theme of the study.	Basic Information
D8	Types of Radiation	What specific types of radiations emitted by IOT devices.	RQ2
D9	Range of Radiations Emitted	What is the range of radiations emitted by IOT devices	RQ2

The data specific to research question-1 that was extracted from each research article included the following: -

1. Types of Radiation
2. Range of radiation Emitted
3. Frequency of radiation emitted

4. RESULTS AND DISCUSSION

In this section, the results obtained and the findings for each research questions are provided. The findings for each research question helped in answering them.

Findings for Research Question-1

The first research question dealt with the applicability of IOT across different fields. The scope of this answer was expanded to include different sectors where IOT is applied. IOT has been applied in various settings, including commercial and industrial. The industrial setup includes processes as well as product development levels. Many of the applications are actually overlapping, as IIoT and Intelligent Manufacturing have similar deployment strategies. The scope of IOT has increased to include the Internet-Of-Everything (IOE).

The various areas in which IOT is deployed are as follows:

1. Health
2. Transport
3. Energy

4. Security
5. Communication
6. Infotainment
7. Smart Parks
8. Video Surveillance
9. Industrial IOT (IIOT)
10. Intelligent Manufacturing
11. Smart Home
12. Smart City [3]
13. Medical IOT (IOT-M)
14. Construction

Findings for Research Question-2

The second research question dealt with the type of radiation being emitted by IOT devices. The different types of devices being emitted from IOT devices are as follows:

1. Infra-Red (IR)
2. Bluetooth
3. Broadband Wi-Fi
4. Zigbee Networks
5. GPS radiation

The different radiations emitted by the IOT devices and their corresponding frequencies are given in table-10. The radiations identified were infrared, Bluetooth and broadband wireless. The operating frequencies are short ranged i.e. 10^{11} - 10^{14} Hz, Bluetooth and broadband wireless are long ranged 300–3000 Mhz. The existing literature provides the duration of exposure to these radiations along with their effects on humans health.

Table 10. Data Items Extracted From Each Selected Study For Rq-2

Radiations	Frequency of Operating	Range
Infra-Red (IR) [4]	10^{11} - 10^{14} Hz	Short
Bluetooth [5]	300–3000 MHz	Long
Broadband Wireless [5]	300–3000 MHz	Long

Findings for Research Question-3

The third research question is being answered in this section. The third question relates to the effect of radiation on human health. We considered the existing literature in finding effects of radiation emitted from IOT devices. The search string was modified to include IR, Bluetooth and Broadband wireless only. The other radiations, such as GPS and Zigbee networks, were excluded from the search. The search string for research question 3 was modified after getting the results of research question 2. The modified search string is as shown in Table 11.

Table 11. Modified Search String Based on Research Question-2's Results

Older Search String given in Title	Newer Search String Based On Research Question-2 Results
Radiation AND Human Health AND IOT	Infra-Red Radiation and Human Health
	Bluetooth Radiation and Human exposure
	Broadband Wireless and Human exposure

Short-Term Effect of IOT-Device Based Radiations

The short-term effects of IOT device radiations are as follows: -

1. Pain in the head
2. Short-term stress
3. Oxidative degeneration of body organs [14] [17-20]

Long-Term Effect of IOT-Device Based Radiations

The long-term effect of IOT device radiations are as follows: -

1. Brain tumor
2. Cancer
3. Hormone imbalance [17]
4. Sperm count reduction [18]-[26]
5. Heart Beat interference [16].

The findings given in sections 4.3.1 and 4.3.2 are countered to state that there is little to limited evidence suggesting linkage between radiations and human health [16] due to lack of proper measurement approaches.

Recommendations By International Health Organization

The World Health Organization (WHO) has declared the radiation emitted from Cell Phones/Mobile as possibly cardiogenic in 2011. This is just one step below the level of direct linkage that causes diseases [5]. All these network technologies form the backbone of IOT devices and infrastructure. Several other international organizations have also issued similar directions and recommendations in line with the WHO's declarations.

Recommendations Based on Literature Review

The present work endeavours to study the effects of radiation emitted from IOT devices on human health. The following are the recommendations from this study:

1. Energy audit of the building and the whole infrastructure [8].
2. Radiation audit of the building and the whole IOT device-based infrastructure [9].
3. Monitor and review radiation and energy audits at micro and macro areas where IOT devices are deployed [8] [11-15].
4. Sensitizing the people, workers, officials, and managers working in the areas about the radiation effects where IOT devices are deployed [6].
5. The different health organizations at national and international levels must facilitate disseminating information about the radiation effects where IOT devices are deployed [7]. The recommendations made by such organizations must be in conformance to the latest research work done in this field.

6. Different types of metrics and measures must be developed in order to assess the short- and long-term effects of radiation from IOT devices.
7. Different types of protocols must be developed in order to limit exposure to devices emitting high amounts of radiation.
8. Barring movement of living entities, including humans, into areas of that require constant contact with IOT device-based radiation.
9. Conducting a holistic review of all the medical treatments involving radiation and verifying the recurrence of the different diseases.
10. Incentivizing the usage of wired networks over wireless networks.
11. Increasing the infrastructure of wired networks to cater for different IOT applications.
12. Creation of different infrastructure's to study the effect of radiation on human health.

General Discussion on the Literature Review Observations

The existing literature had research papers as well as survey papers studying the effect of Electromagnetic Field (EMF) radiations on human health. However, there was no direct study that mapped human health to radiation from IOT devices on the three online portals. The present work therefore holds significance as IOT devices have started to be embedded even within the human body in form of Body- Area Network (BAN) [3] which constitute a branch of wearable devices and IOT-Medical (IOT-M).

The unwanted radiation related to Electromagnetic Field (EMF) is known as EMF pollution [15]. IOT devices also contribute a significant amount to this pollution. There is a lack of standardization and clarity with respect to EMF radiation measurement [16]. However, evidence in literature also indicates the effects of radiation in terms of brain tumors, cancer [17], low sperm count [12], and changing sleeping patterns [17]. Hence, the human right to not be exposed to radiation must be upheld. Authors insist on making states obligatory to ensure that European citizens' rights get protected [16].

5. LIMITATIONS OF CURRENT WORK

This work did not consider aspects of mapping studies in the form of snowballing. Future research can focus on searching for primary, secondary and tertiary literature based on the citations found through snowballing. The secondary and tertiary source of literature was not included while undertaking this mapping study. The prospective researchers can do complete snowballing in order to get more research papers [10].

6. FUTURE SCOPE

The type of IOT-devices and the duration of their exposure to humans essentially determine their effects on human health. There can be different research directions for future work specific establishing relationship between IOT devices and human health: -

1. This work can be extended to perform a Systematic Literature Review (SLR) on the effects of IOT devices on human health.
2. The context of the present study did not include any specific IOT device to study its corresponding radiation effects. Hence, researchers can focus on specific IOT devices and study their long-term and short-term radiation effects.
3. The radiation from the IOT devices can be studied according to the domain of their deployment, combined with the cumulative effect of other radiations on human health. The more specific studies can focus on the range of different types of radiation and their cumulative effects on human health which can assessed whenever a radiation audit is done.
4. An infrastructure-based study can also be conducted to study radiations effect on human health. This infrastructure can include any area of IOT deployment along with the duration of exposure.
5. The current work also did not focus on studying the accumulative effects of multiple radiations and their effects on a specific human population for both short-range and long-range radiations. The effects of radiation, as outlined in Section 4.3, may vary according to the age of the person who has been exposed to the radiations as the body develops until a certain age [14].

6. Further extension may also include the creation of measures, metrics, equipment, standards, and necessary infrastructure to assess the long- and short-term effects of radiation exposure [9].
7. National and international organizations, state governments, and national governments may also conduct independent studies about the effects of IOT-device-based radiation on human health.
8. The patients who are already suffering from diseases may further be investigated for checking if their recovery rate gets affected by IOT-based devices usage and recurrence of diseases takes place or not.
9. The current work did not focus specifically on the 2G to 6G radiations that are emitted by mobile-based IOT devices. The prospective researchers can carry out this investigation.
10. Employees as well as employers are subject to varying degrees of radiation exposure. An investigation can be conducted to assess the effect of radiation on their health as well.
11. The current survey did not include other scientific databases such as IEEE or, more specifically medical databases such as MEDLINE, the EMF portal, Embase [12], which may have additional research papers related to IOT based radiations and its effect on human health. Therefore, future prospective researchers can include IEEE, MEDLINE, EMF portal, Embase while conducting a survey, SMS, SLR or further research. More exhaustive research can, however, be conducted using Scopus and Web Of Science scientific databases.
12. The focus of research can also be different areas of a state or country to study the effect of radiation due to IOT devices [7] [13-16].
13. The specific radiations whose effects on human health were not covered in this survey are GPS and Zigbee networks. Hence, prospective researchers can carry out separate investigations in the form of a survey, SMS, SLR or research to study their effect on human health.
14. A feasibility study may be carried out to make research related to radiation effects free for all to view and download. The open access fee may be funded by an international organization or the governments.
15. An assessment on IOT-based industrialization in cities, towns, villages and its long-term and short-term effect to human health can also be done.

CONCLUSION

This study tries to connect the effects of IOT device-based radiations on human health. The research protocol outlined different steps needed to complete this survey, which consisted of the creation of research questions to be addressed, string creation, the conduct of searches on standard online publishing and indexing sites, and conducting meta-analysis on the selected studies. Three research questions related to IOT device-based radiation were answered. The IOT devices were found to emit short-range and long-range radiation. These radiations are also suspected to cause different diseases in form of brain tumors and cancer, besides creating diseases of the reproductive organs. There were also studies that cited a lack of measurement approaches to justify no linkage between IOT device-based radiation and human health. However, the funding agency and methodology adopted by such studies also need independent investigations.

AUTHOR CONTRIBUTIONS

Nakul Sharma: Conceptualization, Investigation.

Vishnu Suryawanshi: Methodology, Laboratory Analysis.

Amar Buchade: Data Curation, Formal Analysis.

Jagannath Nalavade: Supervision, Writing—Review & Editing.

Mandar Diwakar: Data Curation, Formal Analysis.

Nandkishor P Karlekar: Methodology, Writing—Review & Editing

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required for this study.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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