Significant Applications of IoT in Covid Pandemic: A Systematic Review

SASEEKALA.M

Assistant Professor, Department of Computer Science, PSG College of Arts & Science, Coimbatore
saseekala@psgcas.ac.in

Abstract

Today the entire world is in the exigency state-COVID-19 quarantine days. We should stay home to live. To avoid a fight over the spread of corona, the governments of all the countries have enforced a nationwide lockdown. Though the lockdown may have helped to control the spread of COVID, it has had a devastating impact on numerous domains like health, agriculture, education, global supply chains, trade, and various industries like automotive, power – electronics, travel, aeronautical, tourism industry…etc, which are the basic roots of the growth of a nation. This censorious situation can be wielded with the eminent technology "IoT". Anytime, Anything, Anywhere"- this is the most significant feature of IoT. Any real-world object can be transformed into an intelligent object by the technology "IoT". Because of the affordability and availability of smart devices, the entire world is more connected with IoT than ever before. From this standpoint, the authors have chosen five real-time areas health, education, industry, agriculture, and society. This survey initiates from the impacts of COVID in the above-chosen areas, how it diminishes the day-to-day events of human life, the vitality of IoT, how it helps to tackle the COVID issues without any quality degradation in this quarantine period. This systematic review completely appraises the innovations and contributions of IoT used by various researchers to defend the impacts of COVID and concludes with the pros and cons. A detailed exploration has been done in this article particularly on "IoT in COVID pandemic". This will be more useful to the researchers to acquire clear-cut knowledge about the power of IoT, in particular how IoT plays a significant role in the period of COVID and further assists them to travel towards an innovative and serviceable direction in their research.

Keywords: IoT, COVID, PRISCA, IIoT, IoMT, IoHT

1. Introduction

On December 31, 2019, a large number of mystery pneumonia cases were recorded by Wuhan Municipal Health Commission, in Hubei Province, South China. On January 7, 2020, the Centres for Disease Control (CDC) declared the new disease to be novel coronavirus pneumonia (Lu et al., 2020). Scientifically, this disease is renamed SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2) by the International Committee on Taxonomy of Viruses (Huang et al., 2020; Lai et al., 2020). The World Health Organization declared this viral disease as COVID-19 on February 11, 2020. As COVID-19 spreads quickly across various countries of the world, the WHO officially declared the COVID-19 as a pandemic on March 11, 2020. Now the COVID-19 has spread to nearly 220 countries and territories, infected around 166.5 million people, and 3,425,017 deaths were reported to WHO as on 20 May 2021. COVID -19 has turned the condition of the entire world upside down. The scale and severity of this virus cannot be predicted.

The outbreak of the COVID-19 pandemic not only caused an adverse impact on the health of people all over the world but also affected the socio-economic activities of countries all over the world [2]. To avoid a fight over the spread of corona, all the governments have taken the decision "strict lockdown". All of us should stay home to live. This Halt in-activity has created various worst impacts across the world. COVID-19 is a public health emergency that threatens the civil, cultural, economic, political, and social rights of the people.

The major areas such as global supply chains, trade, agriculture industry, automotive industry, electronic industry, travel, transportation, and tourism industry, and so on have been severely disrupted because of COVID-19 [2]. It is wreaking havoc over the world, resulting in deaths, sicknesses, and economic hardship. It is estimated that 40-60 million people are being pushed into extreme poverty as a result of it. This pandemic has not yet left the agricultural sector. It has a significant impact on the food supply chain and agriculture at various levels. The COVID-19 pandemic has caused nationwide closures of schools and colleges around the world, disrupting the education of approximately 90% of the world's student population. From March 2020 onwards, global manufacturing has suffered a steady reduction in output growth due to the COVID-19 outbreak. One of the most important, pioneering technology that aids us in overcoming the effects of lockdown is the Internet of Things (IoT). It succours vitally in various domains to combat the pandemic's effects to the greatest extent feasible. Even amid CORONA disaster, creative IoT apps give a more participatory, easily available, reachable environment to all levels of people at an affordable cost." Anytime, Anything, Anywhere"- this is one of the most significant features of IoT.

IoT can be defined as "Things that are associated over the Internet."[1]. The term "IoT" has two parts: the Internet, Things. The term "Things" refers to smart devices, which can be identified uniquely, can communicate and interact with other heterogeneous devices, and can be accessed anytime, anywhere without any restrictions.
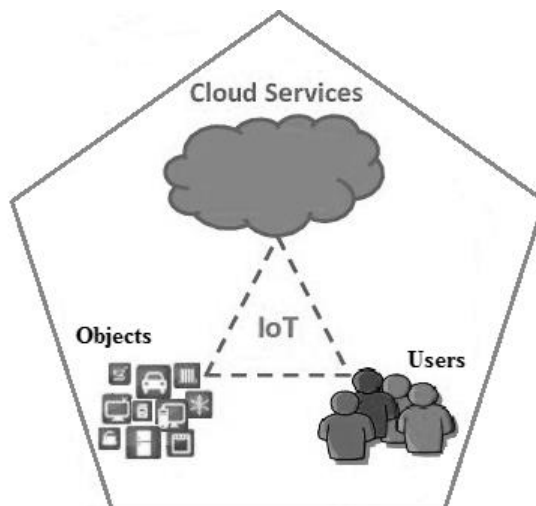

Figure: 1 – IoT

IoT is a sky-blasting, reliable technology that is commonly defined as follows:

Interconnection between living things like humans, animals, day-to-day non-living cyber-physical, digital, mechanical, electrical, and electronic things which are having unique identifiers, connected for data sharing based on standard, interoperable communication protocols with various application-specific software to communicate with the external environment without human intervention via the internet is called as IoT. The objects should be assigned with an Internet Protocol (IP) and able to transfer data over the network. IoT enables the connected objects to see, hear, think, observe the data and react intelligently based on the data they receive from one another.

Kevin Ashton, the Executive Director of Auto-ID Labs at MIT, who is honoured as the "Father of IoT" coined the term "Internet of Things (IoT)" in his presentation for Procter and Gamble, and now we all are using it. All the objects like mobile phones, heart monitors, lamps, washing machines, coffee makers, humans even animals that are having unique identifiers can be connected through the Internet.

According to a report of UNWTO (United Nations World Tourism Organization), border closures, travel bans, and quarantine procedures in many nations have a direct impact on the tourism business (1464 million to 850 millions) (CCSA report 2020). In addition to its immediate effects on health, jobs, and salaries, COVID is raising people's anxiety and stress, impacting their social relations, trust, personal security, and sense of belonging. COVID-19 has badly resulted in employment losses, affecting food security, housing, and shelter, and basic necessities access for over one billion people living in informal settlements and slum-like conditions. In 1990, John Romkey, a computer student of Massachusetts Institute Technology(MIT), Cambridge introduced a "Smart Toaster" at Auto-ID Labs which is the first IoT device. TCP/IP was used to link the Toaster to the Internet. Starting from 1990, various research innovations are persistently progressing in the IoT field till today. In the year 2020, approximately 31 billion IoT devices are installed. This may be increased by double the amount in the year 2025.This interconnection yields many astonishing advantages in various fields like Agriculture and Food services, Healthcare and Medicine, Education and Smart infrastructure, Banking and Insurance, Smart homes and cities, Security and surveillances, Vehicular and Non-vehicular transport systems, IT and Network services.........etc. Over the years, research efforts and breakthroughs in the field of IoT have steadily increased.

The Slogan of IoT is "Anytime-Anycontext-Anything-Anyone-Anybody-Anyservice-Any business-Any path-Any network-Anyplace-Anywhere".

How and Why this article
There are plenty of extensive surveys and reviews that have been already done in the field of IoT by various researchers thoroughly and effectively. But technology is growing day by day. "The growth of technology is still so much bigger than the past, it is part of our everyday life". Today the entire world is in a critical state - COVID-19 quarantined days. We can't think anything beyond human safety and can't predict the future accurately. To save our lives, we are staying in our houses. IoT plays a critical role in a variety of areas to prevent the pandemic's consequences to the greatest extent possible. So, progressing a detailed, systematic survey on various effective and efficient innovations that can be implemented in the domains of health, agriculture, education, society, and industry using IoT is reasonable cum more useful to researchers, academicians, industrialists, and numerous stakeholders.
The organization of this article is as follows: Section 2 covers the research questions, search strategy, inclusion and exclusion criteria, and study selection basics. Section 3 starts with the basics and structure of IoT, then it continues the IoT components and ends with the applications of IoT. Section 4 analyses the innovative researches and implementations that are done in the numerous significant domains using IoT, outlines the approaches to use IoT during this critical COVID-19 era and reviews the research questions' answers. Section 5 exhibits the challenges and future research directions of IoT and Section 6 concludes the article.
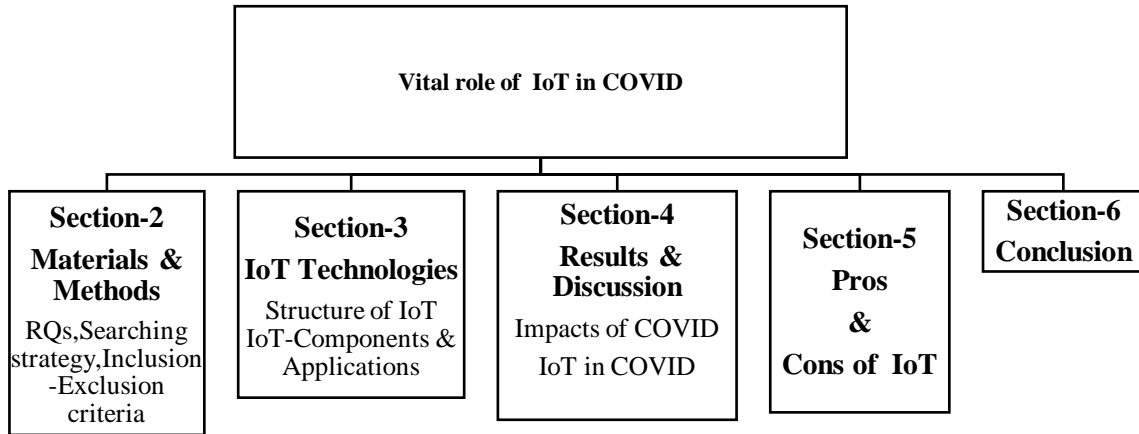
Figure: 2 - Organization structure of this article

Materials and Methods

In this section, the systematic methodology that is followed for this review is explained. As the authors are strongly believing the standard of systematic reviews, they followed the PRISCA (Preferred Reporting Items for Systematic Review and Critical-Analysis) methodology and successfully fulfilled the AMSTAR (Assessment of Multiple Systematic Reviews) checklist in every step of this survey. PRISCA is a systematic review approach for identifying, analyzing, evaluating, and synthesizing all related studies on a specific subject.

The research questions were formulated in the first step by using PICO (Population, Intervention, comparison, Outcome) model, a standard framework used to form the research questions. A research protocol, which includes search strategy, inclusion/exclusion criteria, the data extraction process, and result dissemination, was defined based on the formed questions. Unique keywords and terms were used by the search strategy for searching. Inclusion and exclusion criteria were developed to choose the most important, related papers from the collected articles easily. Then, based on the pre-formulated research questions, data extraction was carried out. At last, the answers to the questions were given while emphasizing the field's challenges, opportunities, and limitations.

Research Questions

On one side, owing to COVID's severity, we should stay home to live. On the other hand, we need to figure out ways to combat the effects of lockdown. One of the most recent technologies, the Internet of Things, can mitigate the crisis's effects. As a result, the authors in this article have started a review on the topic of "IoT in Pandemic." In this systematic review, they defined crucial research issues and attempted to uncover appropriate solutions through a thorough investigation.

As a result, the following research questions are raised by the authors for this systematic review:

RQ.No	Research Question	Motivation
1.	Which domains are significant for human existence, national and global development?	The answer to this question identifies the most important domains for the human and global development
2.	Which domains are affected by COVID-19 and lockdown?	The answer to this question lists the various domains that are affected by COVID-19 and lockdown.
3.	What are the worldwide impacts of COVID-19 and lockdown?	The answer to this question clearly analyses and states the worldwide impacts of COVID-19 and lockdown.
4.	How IoT can be used in eradicating the impacts of COVID?	The answer to this question explains how the IoT can be used in eradicating the impacts of COVID.
5.	What are the IoT applications that have been developed and implemented to counteract the effects of COVID-19?	The answer to this question outlines the Internet of Things (IoT) applications that have been created and used to combat COVID-19's impacts.
6. `	What are the pros and cons of IoT applications?	The answer to this question highlights the benefits and drawbacks of the Internet of Things.

Table-1: Research Questions

These questions have been established by the authors to achieve the main contribution of this paper, which is to present a systematic review of the implications of COVID-19 crisis lockdown in a variety of important fields around the world and how IoT battles with the corona ramifications. This study outlines the IoT applications that have been developed and deployed to mitigate COVID-19's effects, evaluates the primary characteristics, benefits, and drawbacks of IoT applications. The final goal of performing a thorough study is to appropriately anticipate future IoT paths, and opportunities by incorporating the concerns of present IoT enthusiasts in this sector. This comprehensive review serves as a benchmark for new age researchers to learn the fundamentals of the domain clearly and concisely, allowing them to develop even further in this field.

Searching strategy
To address the research questions, initially, the authors have chosen a standard information source that includes many research databases, digital libraries, and search engines as listed in Table 3.

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INFORMATION SOURCE	URL
ACM Digital Library	http://dl.acm.org/dl.cfm
DBLP	https://dblp.org/
Google Scholar Search Engine	https://scholar.google.com/
IEEE Xplore	http://ieeexplore.ieee.org/Xplore/home.jsp
Researchgate Social Networking Site	https://www.researchgate.net/
Science Direct – Elsevier	http://www.sciencedirect.com/
Scopus Database	http://www.scopus.com/
Sensors Digital Library	http://www.mdpi.com/journal/sensors
Springer Digital Library	https://www.springer.com/
Web of Science	https://www.webofknowledge.com/
Wiley Online Digital Library	https://onlinelibrary.wiley.com/

Table 2: Information Sources

The next stage is to define the techniques for locating publications that are relevant to our perspective. Two key restrictions underpin the proposed procedure: (i) Articles published after January 2020 will only be considered for the study (ii) Search terms, keywords, and queries that are used to find the relevant articles. Using the search keywords specified in Table 4, vital literature was detected and extracted by querying scholarly information sources.

SEARCH QUERIES
IMPACTS OF COVID-19
IOT AND COVID-19
IOT SOLUTIONS FOR COVID-19
IOT IN DISTANCE LEARNING DURING THE COVID PANDEMIC
INTERNET OF THINGS IN POST-COVID ERA

Table 3: Search Queries

In total, 145 documents were identified, out of which 134 were obtained from standard research databases like IEEE, Science Direct, Scopus, Springer, Web of Science..etc, and 11 from other sources. The collected documents were further refined by using the inclusion and exclusion criteria.

Inclusion and exclusion criteria
        We deploy a set of inclusion criteria (IC) and exclusion criteria (EC) to refine our search results.
Inclusion criteria
(1) The paper should be indexed at least in one of the research databases
(2) The research article must be written in English and submitted for publication after 2020.
(3) The study must explore COVID-19's effects across multiple domains.
(4) Research studies that include the concepts "IoT in COVID" "IoT technology to alleviate the COVID crisis" are considered.
(5) The study includes IoT applications in the sectors of health, agriculture, education, society, and industry are mainly selected.
(6) The paper outlines how the IoT technology used is included.
(7) The paper should provide the answers to the research questions.
Exclusion criteria
(1) Duplicate papers
(2) Papers that are not written in a methodical, orderly manner
(3) Papers that are not relevant to the theme "IoT in COVID"
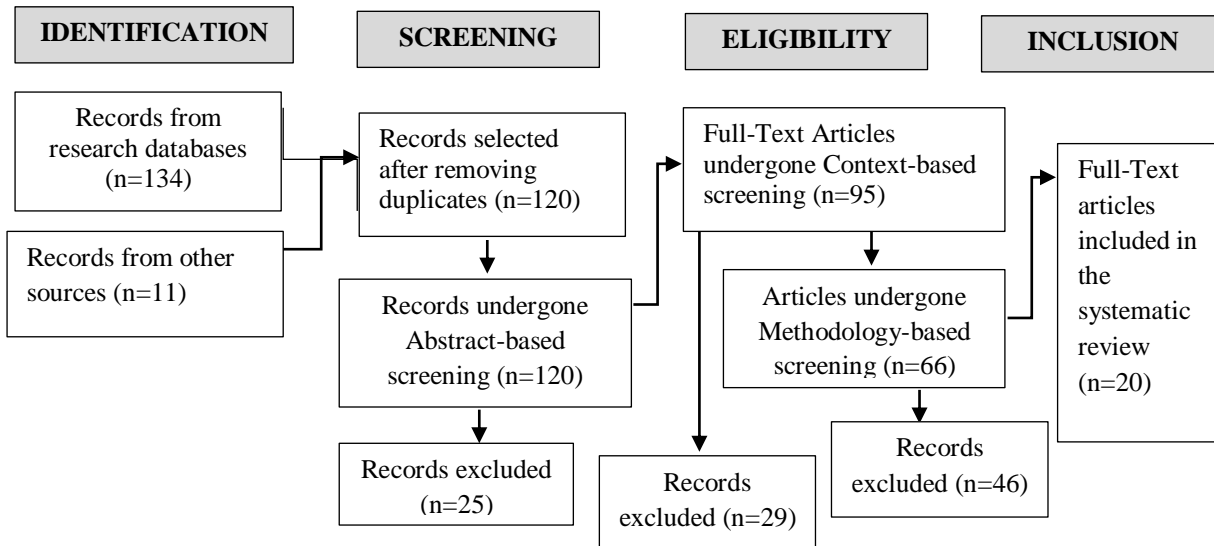

Study Selection

Figure 3: Selection Process

The following essential processes were used to choose relevant articles for this review, as per the PRISCA guidelines: identification, screening, eligibility, and inclusion. The systematic search-strategy method is depicted in Figure 4. Initially, we acquired 145 records from traditional research databases and other sources; first, the documents were analyzed for duplicate studies, and 25 publications were eliminated at this point. The remaining 120 papers were moved to the second step, which is a screening procedure for selecting publications that are relevant to our scenario. Three approaches are used in the screening process:

i) Abstract-based approach: we filter out irrelevant results using data and keywords from the abstract of the paper. For additional review, only the abstracts of papers that met at least 50% of the inclusion criteria were preserved.

ii) Context-based approach: Articles that do not answer our study questions are discarded.

iii) Methodology-based approach: The remaining findings are subjected to a quality examination, with those that do not meet any of the following criteria being removed:

- The paper follows the proper structure of a research article
- Research studies that have been written using a methodical technique
- The paper includes related works
- The paper includes an explanation of the findings.

Finally, the systematic review includes 20 standard full-text papers. These 20 papers were classified based on the domains and examined in order to find answers to the research questions defined at the beginning of this section. As a result, a thorough, comprehensive evaluation of all relevant literature was conducted, and this systematic review is clearly a vital contribution to the scientific community.

RQ1

In conjunction with more than 50 international organizations, the Sustainable Development Goals Report 2021 was prepared by the Department of Economic and Social Affairs, United Nations. Figure —— displays the

UN's 17 sustainable development goals, which aim to heal, secure, and strengthen our planet's existence, development, and peace.

Figure 4: UNs - Sustainable Development Goals 2021

Obviously, the following are the key domains that must be prioritized in order to achieve the goals:

GOAL NO.	UNDER THE DOMAIN
3,6	HEALTH
1,2,15	AGRICULTURE
4,5,8,10	EDUCATION
7,8,9,11,12	INDUSTRY
5,6,7,10,11,12,13,14,16	SOCIETY
17	ALL THE ABOVE

Table 4: Sustainable Development Goals 2021

RQ2

The COVID-19 pandemic is a public health emergency impacting civil, cultural, economic, political, and social domains. The United Nations and all member organizations of the Committee for the Coordination of Statistical Activities (CCSA) have assessed the multifaceted impacts of the pandemic thoroughly. The summary of the report says that the major areas such as global supply chains, trade, education, agriculture industry, automotive industry, electronic industry, travel, transportation, sports, entertainment and tourism industry, and so on have been severely troubled all over the world due to lockdown.
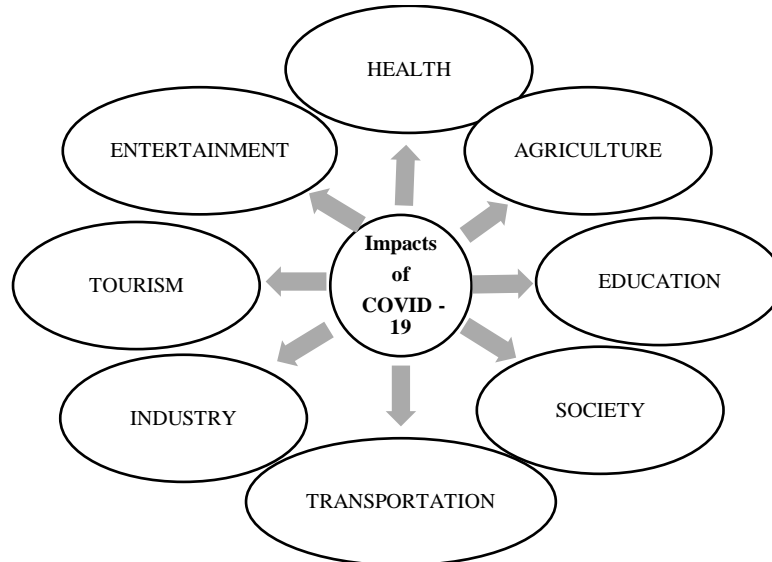
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Figure 5: Impacts of COVID-19

RQ3

- The impacts of COVID-19 have exacerbated 144 million employment losses and pushed 40-60 million people into extreme poverty. Over one billion people living in informal settlements and slum-like conditions are struggling for their food, shelter, and basic needs.
- According to a study (FAO et al, 2019), 820 million citizens are currently facing severe hunger, while 113 million citizens face acute uncertainty. More than 10 million children in India rely on school-provided noon meals to meet their nutritional needs. However, due to the lockdown, children are not receiving their meals, which may reduce their ability to deal with the pandemic (FAO, 2020b).
- Covid-19 has a major impact on the education industry and its sub-sectors. Nationwide closures of educational institutions in 192 countries have hampered the education of nearly 1.6 billion learners or 90% of the world's student population. Overall, domestic closures affect over 155 million pre-primary school children, 691 million pupils of primary school, 537 million secondary school students, and 191 million post-secondary students. Production, supply, and demand for different educational products were clogged and several employees have therefore been financially affected. (Janmenjoy et al. 2020).
- Most countries have taken precautionary measures such as home quarantine, traffic restrictions, and business cessation to control the spread of corona. The world's manufacturing industry saw a steady drop in production growth from March 2020. COVID-19 affected automobile new vehicle sales very badly. In China new sales of vehicles have fallen by 92%, in European countries total vehicle sales were dropped by 7.4%, Sales in USA are anticipated to refuse by 15%, in India, many automobile industries such as TVS, Mahindra have stopped their production sales due to lockdown and likewise, many sectors have been affected.
- The closure of country margins, travel bans, and measures for quarantine have affected the tourist sector directly in many countries (1464 million to 850 million), and international tourism plummets almost 78 percent. Passenger transport in air transport has fallen by 60% while freight has dropped by about 10%.
- Though public transports such as rails, metro, flights, taxis, and buses are the real carriers of inventories, they are the major causes for the spreading of Corona. Therefore, they are forcefully claimed by unwavering social distance laws.

- Agricultural sectors and sub-sectors such as agriculture mechanization, soil and water conservation, agricultural marketing, food manufacturing, agricultural entrepreneurship, and many others have been affected due to a severe pandemic, and the chain of value in agriculture differed between divisions. The agricultural and food organization (FAO, 2020) described that COVID-19 infection has greatly distressed various aspects like food supply, food demand, food security, markets and farm prices, farmers' health, the farm workforce, worker safety, and other disruptions.
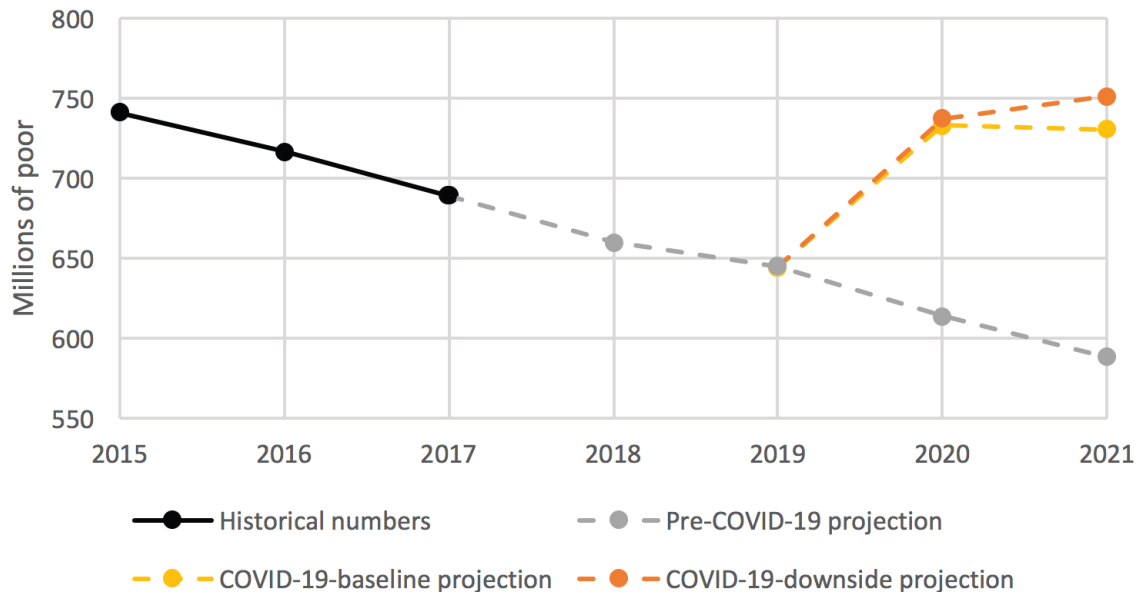

Figure 6: Poverty prediction and reality during COVID

RQ4

IoT is an innovative, vital technology that incorporates technological, social prospects which enhance our lives in specific during this COVID-19 period. It has been used in many fields such as healthcare, agriculture, education, transportation, distribution, and energy production, etc., and provides better healthcare services, enables clinical choices, improves the quality of services, and fulfils significant challenges during the pandemic. IoT devices such as Smart Helmets, drones, robots, IoT buttons, Smart Glasses, Bands, and Smart watches... etc., and applications like social monitoring, Selfie App, Civitas…etc. assist patients and healthcare authorities by its features like internet-connected hospitals, smart diagnosis, remote health monitoring, and tele-health consultation..etc. The rapid growth of IoT in healthcare is expected to rise from USD 70 billion in 2020 to USD 190 billion in 2025. IoT wearable devices that can perform biometric measurements like blood pressure, heartbeat, oxygen level, and activity tracking, can help the patients consistently in monitoring their health remotely. Elderly people are also monitored by their family members by using IoT devices wherever they are.

Internet of Medical things (IoMT), telemedicine, telehealth, Internet of Health things (IoHT) are various subfields of IoT where the medical devices, healthcare IT systems, and medicinal software applications are combined to offer efficient, quick healthcare services to the patients and reduce the workload pressure of the healthcare people. Medical people working in ambulances are usually handling highly critical patients, that too in this COVID period the situations faced by them are tenser and worse. In IoT-aided ambulances, the medical experts will remotely monitor the patients from the initial stage and keep on providing the necessary instructions to the medical people on how to handle the patients effectively in the ambulance. Various COVID

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alerting applications like Aarogya setu, COVIDSafe, COVID Defense, COVIDWISE….are released to alert the users when they come into the surrounding of COVID affected persons.

The current pathetic situation radically altered the traditional academic system, ie., on-campus education. Academic stakeholders' students, teachers, and learners are utilizing modern technologies such as IoT to gain or share their knowledge even in this pandemic situation. IoT is made up of a large number of hyper-connected objects that communicate with one another. It enhances the safety of academicians, offers communication channels for global students, and assists disabled pupils. It changes the teaching-learning process completely. In COVID-19, many universities and educational institutions have changed the traditional education processes. Books and papers are replaced by electronic gadgets. This helps students and teachers to teach/learn from the places at which they are comfortable. Students are getting a similar learning experience at both home and college. In comparison to traditional educational methods, IoT-based education is extremely useful and effective.

The next important domain affected by COVID-19 is industries. Due to lockdown, all the transportations are stopped and as a result, significant areas like production, supply chains, warehouses, sales, and marketing ...etc are stricken badly. IoT-based intelligent applications remit the negative effects of this pandemic, improve the process of importing and exporting goods and save the business world from a tremendous downfall. Industrial Internet of Things (IIoT) is a subfield of IoT that automates all industrial activities directly through machine-to-machine (M2M) communication without human intervention. The field of IoT provides various innovative, technical, remote applications and plays a vital in improving the economic growth of the entire globe.

Smart Grid is another application of IoT which fulfils the necessity of continuous power supply in this pandemic. Even a single minute of power interruption may affect a patient's condition more pathetic in today's critical situation. Various sensors, transducers, metering infrastructures have been combined with the traditional power grids and provided reliable, uninterrupted power supply at affordable cost.

As COVID-19, the entire world is struggling for human survival. Human is a social animal, we are emotionally dependent on one another, but CORONA isolated us. All the entertainment sectors like stadiums, tourist spots, malls..etc. are closed due to lockdown. No other way, we should conquer these critical days and live our regular life. It is really difficult but possible with the use of IoT. Smart applications of IoT are providing various features to enrich the mental health and psychological thoughts of humans.

RQ5

In Table 4, the selected papers are grouped based on the domains of health, Agriculture, Education, Society, and Industry. It presents various applications proposed in the COVID period, technologies used, and the purpose of the proposed applications clearly.

Domain	Citation Reference	Application	Technology Used	Purpose
Health	Barroca et al. (2021)	IoT-based healthcare platform	Sensors, Raspberry Pi , Cloud Computing	Monitor the home-care COVID patients in critical situations
	Vedaei et al. (2020)	COVID-SAFE, An IoT-Based System for Automated Health Monitoring and Surveillance in Post-Pandemic Life	IoT node, Fog-based Machine Learning tools for data analysis and diagnosis	To Monitor the participants' health condition, notify them to maintain physical distancing and minimize the risk of exposure to the Coronavirus.

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	Mukhtar et al. (2021)	An IoT Framework for Screening of COVID-19 Using Real-Time Data from Wearable Sensors	Wearable sensors integrated using the Arduino interfacing, rule-based decision making, and a smartphone application.	To examine the patients without the need for physical direct contact with them to reduce the possibility of infection.
	Mukherjee et al. (2021)	IoT-cloud based healthcare model for COVID-19 detection	Enhanced-KNN with feature selection using ACO	To perform predictive analytics regarding the disease, and for IoT-cloud-based COVID detection.
	Karmore et al. (2021)	IoT-based Humanoid s/w for identification and diagnosis of Covid-19 Suspects	AI for medical science, humanoid uses the concept of real-time data sensing and machine learning	A cost-effective, safety-critical mobile robotic system, Medical Diagnosis Humanoid (MDH), tests to check whether a person is infected by Covid-19 or not.
	Abdulkareem et al. (2021)	Effective COVID-19 Diagnosis System Based on Machine Learning and IoT in Smart Hospital Environment	Machine Learning models, NB, RF, and SVM diagnosis based on original and normalized datasets	To diagnose patients with COVID-19 in smart hospitals.
	Mashrur et al. (2020)	IoT based Health Monitoring & Automated Predictive system to Confront COVID-19	'Internet of Things (IoT) and machine learning (ML) Supervised learning algorithms	To monitor the health status, detect the severity of coronavirus in a human, to provide healthcare and emergency medical support to the patients.
	Bai et al. (2020)	Chinese experts' consensus on the Internet of Things-aided diagnosis and treatment of coronavirus	IoT plus Cloud-based technology	Early identification, diagnosis, treatment, and management of COVID epidemic, especially for outpatients
	Lalit et al. (2020)	Anonymity preserving IoT-Based COVID-19 and other Infectious Disease Contact Tracing Model	RFID, Blockchain for data storage, DApp - frontend, DLT -back end	To identify the clusters of infected contacts, deliver a notification for mass isolation, and control the spread of COVID-19

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Agriculture	Sanjeev et al. (2020)	IoT-based coordination system in Agri-food supply chain: development of an efficient framework using DEMATEL-ISM	ISM methodology, DEMATEL technique, IoT based AFSC and Cleveland theory	IoT-based efficient, supportive system for enhancing the coordinating mechanism in AFSC under natural outbreaks.
	Abhishek et al. (2020)	Deep Learning and Internet of Things integrated Farming during COVID-19 in India	IoT-based agriculture framework, Deep learning	To monitor and analyze crop health, the future advanced farm management systems, and to solve the various problem faced by Indian farmers during the COVID-19 pandemic.
Education	Eswaramoorthy et al. (2021)	Transformation of normal Education Rooms into Smart Environments in Post Pandemic Period using IoT	Temperature sensor, Sensor-based sanitizer, Social distancing detector module, Conditional decision making using fuzzy logic	Proficient methodology during post Covid period to conduct classroom teaching through new tracking methods.
	Muhammad et al. (2021)	LSTM based Emotion Detection using physiological Signals: IoT framework for Healthcare and Distance Learning in COVID-19	Proposed IoT protocols (TS-MAC and R-MAC)	Real-time communication and recognition of emotions which enables health monitoring and distance learning to improve the reliability and high-level performance (f-score) of 95%
	Galina et al. (2020)	IoT in Distance Learning during the COVID-19 Pandemic	5G Networks, Cloud computing, and IoT	To make interactive smart classrooms and smart labs, to realize personalized interactive models of education, to stimulate learners' creativity, boost operational efficiency in the online learning environment.
	Kobchai et al. (2020)	A blended learning model with IoT-based technology: when the COVID-19 pandemic	IoT, Blended learning, Content analysis	To provide an uninterrupted, effective learning environment to the academicians

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	Mathews et al. (2020)	Solution Integration Approach using IoT in Education System	IoT, Cloud Computing and Machine Learning	Centralized system to address e-learning, student tracking, security and student management.
Society	Xiangjie et al. (2021)	Real-time Mask Identification for COVID-19: An Edge Computing-based Deep Learning Framework	Deep learning, including video restoration, face detection, mask identification	An edge computing-based mask identification framework (ECMask) to help public health precautions
	Gupta et al. (2021)	Future Smart Connected Communities to fight COVID-19 Outbreak	IoT, synergistic applications and technology, cloud-enabled Amazon Web Services, and E-Health RPM	Intelligent monitoring, proactive prevention, and control, mitigation of COVID-19 to develop 'pandemic-proof' future smart communities.
	Baskaran et al. (2020)	IoT Based COVID Preventive System for working Environment	Thermal detection, Facial recognizer, Infrared sensor for temperature	A novel system for preventing the people from Covid-19
	Md. Rahman et al. (2021)	The architectural design of smart blind assistant using IoT with deep learning paradigm	IoT embedded Deep Learning	The workable and handy proposed system will be helpful in the daily activities of a blind person.
	Nenad Petrović et al. (2021)	IoT-based System for COVID-19 Indoor Safety and Monitoring	IoT technologies	An affordable IoT-based solution to increase COVID indoor safety
	Seda et al. (2021)	IoT-based GPS assisted surveillance system with inter-WBAN geographic routing for pandemic situations	Proposed IoT software (Node-RED, InfluxDB, and Grafana)	To protect persons from the pandemic situation and to detect the mask status

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Industry	Shashank et al. (2020)	Applications of Industry 4.0 to overcome the COVID-19 operational challenges	IoT-Embedded software	Smart Campus with epidemic control, supply chain, and disaster management
	Ayoub et al. (2020)	Advanced metameric dimension framework for heterogeneous industrial Internet of things	IoT technologies	To identify the real-time resembling and continuous monitoring of metameric dimension of the machines
	Xingyu Li et al. (2020)	Intelligent Manufacturing Systems in COVID Pandemic and Beyond	Automated manufacturing assets, Networked sensors, and Intelligent decision-making algorithms	To allocate the IM resources according to the mutual market demands and the severity of the pandemic, to evaluate and schedule the IM technologies.
	Shohin et al. (2020)	IoT-enabled smart appliances under industry 4.0	Industry 4.0 and IoT technologies	To turn conventional appliances into smart products and systems (SPS)

Table 5: IoT applications on various domains

RQ6

Though IoT has attained a tremendous rise over the past few years, there are several technical and conceptual challenges are existing in this field. Proper efforts and researches have to be done to address these challenges to make the applications of IoT, a tremendous success. The key challenges are:

- Lack of standard architecture – IoT systems are evolving continuously and the IoT environment is heterogeneous, designing a standard, accurate architecture or framework for IoT is a big challenge. Various Layer-based, service-based, middle-ware-based, technology-based architectures are already proposed. As a complete IoT implemented world has not yet been fully achieved, a standard, sufficient architecture is still needed.
- Heterogeneous communication technologies – An IoT system is a critical, heterogeneous environment. It consists of a connection between various types of networks through various communication technologies. We need a flexible, common communication technology to manage the incompatibility between the resources and services.
- Security and privacy – In the field of IoT systems, most of the devices are portable, working under wireless technology, and may be placed at any place. So security to the IoT objects and personal privacy to the data collected from those objects are serious threats in the domain of IoT. Objects identity management, data encryption and security, proper maintenance of the IoT data ownership are the various major issues that need to be addressed clearly in IoT.
- Scalability – Though the number of objects is increasing, the quality and services of an IoT system should never be compromised. But scalability will become an issue at different levels of an IoT application. Identification, addressing, and administering the devices are difficult. As the number of objects is high, a large amount of data may be transmitted, which will be resulted in heavy latency,

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data loss, a lot of work in data analysis, and various communication conflicts. So a holistic IoT system should be designed to manage and maintain the quality of services in all circumstances.

- Various open challenges like Physical safety of the IoT objects, Insufficient network bandwidth, Data analysis and mining complexity, Data confidentiality, Uninterrupted services are still unresolvable in the field of IoT.

Conclusion

In this timely study, a systematic review was done on the IoT applications developed during the outbreak of COVID-19 in the health, agriculture, education, society, and industrial-related domains. By following the PRISMA approach, 145 papers were identified, screened, based on the inclusion and exclusion criteria, they were filtered and finally, 25 articles were selected based on their relevance to the six research questions we developed. Distinguished from other IoT survey papers, the vital contribution of this review paper is that it focused on the newly developed applications of IoT which are helping us to face the crisis of COVID. This may be used as a fundamental article to the researchers who are in the initial stage of their research. The future of IoT is very bright. Everything would be connected in our day-to-day life and IoT would provide us with a better lifestyle and make us live our life meaningfully even in this pandemic situation.

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A Brief Author Biography

Dr. M.SASEEKALA is currently an Assistant Professor in the Department of Computer Science in PSG College of Arts & Science, Coimbatore. Her educational qualification is M.C.A., M.Phil., Ph.D. she completed Ph.D. in Bharathiar University, Coimbatore in the year of March 2019. She did M.C.A in Bishop Her College, Trichy in 2005 and started her career. Now she is having more than 15 years of teaching experience. She cleared SET (State Eligibility Test) and (NET) National Eligibility Test for Professors. She published a number of papers in preferred Journals and chapters in books, and participated in a range of forums on Wireless Networks. She also presented various academic as well as research-based papers at several national and international conferences. Her research area is Mobile Adhoc Networks and IoT.