The Amalgamation of Internet of Things and Recommender Systems

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Abstract. The Internet of Things (IoT) has upgraded the things and regular devices around to smart devices that can interact, share information and collaborate. With the plethora of IoT products, solutions, and workflows available online, the consumer finds it challenging to find the most suitable one. IoT, when integrated with the recommender system, can extend its features to the new space of innovation, usability, viability, and success. Various recommendation techniques can be employed to support users to get the best fit services, applications, sensors, products, and IoT workflows. This article will steer via the basic introduction of the IoT, its building blocks, hardware, software, applications, and its challenges. It analysed scientific articles indexed in the Scopus database with help of biblioshiny tool based on Rstudio software. The analysis is directed on 260 articles to figure out the trending amalgamation of Recommender System with the Internet of Things. Results point to fact that personalized recommendations for IoT-based applications are the most worked on topic by the authors.

1. Introduction

In 1999, Kevin Ashton introduced the term ‘Internet of Things’ with the idea of ‘embedded internet’ or ‘pervasive computing’ enabling devices to manifest cloud interface [1,2]. Internet of Things (IoT) offers new possibilities like predictive maintenance, real-time remote monitoring, etc. [3].

Many new promising technologies like edge computing, fog computing, and IoT are interoperable with the cloud as shown in figure 1. Though they are adding complexity to cloud computing, still this integration is becoming a key player in reconstructing the world of enterprise computing. The Internet of things is the online interaction between the enormous network of heterogeneous devices [5]. Or, it can be explained as a guided association between the physical, digital and virtual worlds [6]. According to Margaret Rouse [7], A network of interrelated living beings or non-living objects with a unique id or identifier, that can exchange data with or without any interaction between machines or persons can be termed as IoT or Internet of Things.

IoT has transformed, the way things were viewed, rather they have evolved as a network of physical devices from smartphones, watches, home appliances, toys, vehicles, medical instruments, buildings to animals, people connecting then all where they can communicate and share information utilizing some restricted protocols [8]. IoT has turned almost everything smart.

A new revolution can be witnessed in all fields, be it a Professional arena such as automated business processes, logistics, industrial manufacturing, intelligent point of sale machines, and transportation, or personal space like an aided living, e-health, intelligent home appliance, etc.

IoT can be summarised into three forms [8]:

- People to People
- People to Machine/Things
- Machine/Things to Machine/Things
The key objective of the IoT is to empower anything so that it can send and receive information anytime, anywhere from, and to anyone using some service over the internet. It provides deeper integration of objects within a system by utilizing prevalent and emerging technologies like networking, robotics, sensing, etc.

1.1. IoT building blocks
Things that are part of IoT are equipped with a sensing element, communication elements, microcontrollers, data storage, and traversal feature, and a network protocol. The following are the basic building blocks of IoT: [9][10][11][8][12].

- **Devices/Sensors/actuators:** There are the endpoint or front end components of the IoT system, co-called Things. They bear a matchless IP address, used to be located over an enormous network. When they capture data from their surroundings in the form of electric pulses or analog signals like a temperature sensor or light sensor or RFID, etc they are called Sensors. On the contrary, when transmitting signals to the surroundings in form of actions known as Actuators. They are capable of gathering real-time data. And can be autonomous (self-directed) or can be dependent (user-controlled).

- **Gateways/Network Infrastructure:** Gateways provide strong connectivity between the devices and the cloud setup and act as an intermediary. Connectivity can be established via different mediums like cellular satellite, Bluetooth, Wi-Fi, or internet, etc. Network
Infrastructure that takes care of security and controls the data flow from things to cloud infrastructure. Devices used can be routers, repeaters, aggregators, and gateways.

- **Cloud Infrastructure:** This component comprises Data storage units and virtualized servers. The data acquired in the form of signals are then converted to artificial intelligence or Machine learning workable format.

- **Analytics/Processors:** The data capture is processed to mine valuable information or to make data intelligent. Applications control data on a real-time basis. It facilitates analytical, logical, and other advanced computing capabilities to leverage intelligent insights into processed data. Thus, assists actions to be taken.

- **User Interface:** It allows the user-cloud to interact. A platform through which the cloud can send notifications, emails, or messages to the user or vice versa. They are cloud-based applications, used to accomplish the actions taken based on the information extracted.

These building blocks ensure the proper working of the Internet of Things as shown in figure 2.

**Figure 2:** Major Components of IoT [13]

1.2. How IoT Works

In IoT systems, smart web-enabled devices are embedded with inbuilt sensors that assemble data from their surroundings. They are tagged with a unique ID with the use of technologies like Radio-Frequency Identification (RFID), actuators, wireless sensors [14], and satellite positioning. Sometimes devices may interconnect to collect related data. This data is then routed to a cloud infrastructure using IoT Gateways. Gateways manage the smooth data flow and security over the movement of data. Cloud applications process that data into intelligent information using AI or ML-based models. An analysis is performed on this extracted data and outcomes derive the actions to be taken [8][9]. Action may be automated handling the sensors or devices without any human intervention. For e.g., if the temperature sensor, senses the increase in temperature, after analysis, the AC is automatically turned on. User interface devices or applications receive the directions to proceed further in the forms of notifications, alerts, etc to notify the user or in case use inputs are required to finalize the action to be taken. Thus, take intelligent moves to control the physical entities.

IoT is a combination of various hardware, software, and connecting technologies, that are required to support the complete IoT solution. Some of the basic hardware, software, and technologies used are discussed in the next sections.
1.3. Hardware

Hardware plays a vital role in the IoT solution. IoT hardware is the smart devices that incorporate sensors, unique ID, display, and capability of capturing information from surroundings and responding to the environment [15]. According to Paul Jacobs in the coming time, everything will be a smart thing, internet-enabled and smartphones will play as IoT hubs [16]. IoT hardware can be broadly categorized into I) wearable devices and gadgets and II) embedded systems and boards [15].

- **Sensors**: They are the base component of the system. Their work comprises primarily these modules: A power management module, a sensing module, an RF (radio-frequency) module, and an energy module. RF takes care of communication signals through Wi-Fi, Bluetooth, Ethernet, ZigBee, etc [15][17][18]. Humidity sensors (micro flow sensor), light sensors (acoustic sensor), temperature sensors (accelerometers) are examples of sensors.
- **Actuators**: It works in the reverse direction of sensors, receives signals from the cloud, and renders the physical action required. Electric motor, a pneumatic system, solenoids, comb drives, and a hydraulic system are examples of Actuators [18].
- **Standard Devices**: Generally used devices like desktops, tablets, smartphones, routers, and switches were always an integral part of the IoT system. Settings can be made in these devices to make them remote or command centers [17][18].
- **Wearable gadgets**: Electronic devices that can be carried on the wrist, head, neck, arms, etc can act as a smart device too [15][17].

1.4. Software

To perform activities like collection of data, its storage, and data analysis set of instructions are employed known as IoT software. They support the smooth functioning of the complete IoT system. It may be an operating system, applications, firmware or middleware, etc. [15][17][18]. The following are the tasks performed by IoT software.

- **Data Collection**: It involves the collection of data from various sources with help of built-in sensors, its filtrations, a compilation of the information in real-time, and, then forwarding the same to the other devices in the IoT. The reverse flow of information to render analytical actions is also supported.
- **Device Integration**: they are the programs that integrate different components of IoT infrastructure so that they can operate as a system. It directs the protocols, limitations, and various applications of every device to be capable of communicating.
- **Real-Time Analytics**: The data collected from various IoT devices gets processed and analytics is performed to identify clear patterns to take actions automatically or provide information to humans to take the required action.
- **Application Extensions**: They enhances the capabilities of existing software, systems, and infrastructure to make an effective IoT system.

On the ground of tasks mentioned above IoT software can be broadly categorized as [15].

- **Connectivity/ M2M platform**: Focuses on the inter-connectivity of Machines using identification modules.
- **Infrastructure as a service platform**: It provides the hosting and processing power for IoT applications.
• **Hardware-Specific platforms**: Software built to supports varied hardware platform devices to get incorporated in the IoT system.

• **Software extensions**: Consumer or enterprise-specific extensions that offer software packages and IoT integration modules.

1.5. **IoT Technologies**

To make objects think and act smart, a blend of different existing and new technologies is required. These technologies enable software and hardware to act as an IoT component.

• **RFID (Radio-frequency Identification) and NFC (near-field communication)**: RFID and NFC facilitate simple, versatile, and low-energy technology to make devices uniquely identifiable over the network. RFID chip creates a short-range electromagnetic field through which it identifies the tags attached to the devices that operate in a two-way direction. The tags hold the data about the devices and the chip sends and receives from the receiver. NFC employs protocols for electronic devices to be able to communicate. RFID can be active with a built-in power supply or Passive not battery powered.

• **Wireless Sensor Network (WSN)**: They are bi-directional, low-power integrated circuits, low cost, and efficient devices that can be incorporated in remote sensing applications. WSN forms a wirelessly connected network of sensors. Several smart sensors gather raw data like temperature, speed, humidity, etc, processes it into valuable information, and then disseminate it. A lower-end WSN can be equated to an active RFID with limited storage and processing capabilities.

• **Cloud Computing**: Cloud computing provides a robust support platform for the IoT system. Cloud computing enhances processing capabilities and provides an effective solution to the software, hardware, storage, and firmware limitations. Services proposed by cloud computing service providers can be classified into three standard service models as states by NIST [19][4] as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

• **Networking Technologies**: networking plays a vital role in IoT infrastructure. For IoT components to stay connected a fast and efficient network is required. 3G, 4G, etc used for wide-range communication whereas, short-range Bluetooth, wi-fi, etc can be utilized. These technologies are strong pillars of ubiquitous computing.

2. **IoT Application Areas**

With an increase in internet-enabled smart devices, there are a plethora of IoT applications emerging every day in almost all areas. IoT has raised life quality. Applications with autonomous features connect with associated devices and share information and thus give way to many innovations like Google Car, a self-driving with real-time information exchange of road, traffic, and weather conditions [21][7]. The following are a few applications of IoT [21][22][7].

• **Smart Traffic System**: Traffic is a fundamental part of everyone's day-to-day life and its issues impact society, therefore they must be addressed. IoT technology contributes potentially in accessing the prior information on traffics jams, road conditions, an optimal route, etc, and assist in making timely decisions. An intelligent traffic monitoring system avails features like accident reporting, toll collection and, theft detection, etc. A weather adaptive traffic lighting
system saves energy and proves to be cost-effective. Smart city incorporates a smart parking space system keeping track of their availability and status.

- **Smart Environment**: Weather forecast and natural calamities like floods, earthquakes, thunderstorms, and cloud bursting, etc can be timely predicted by IoT applications. Preventive measures like the evacuation of people from the affected area, or triggering rescue operations there can be taken well in time. Water quality monitoring can also be accomplished by IoT, its sensors that measure critical water parameters to ensure quality water supply.

- **Smart Home**: Home appliances like A.C, refrigerators, televisions and washing machines, etc can be upgraded to be smart and allow efficient energy management. A home monitoring solution for the elderly, a power consumption monitoring system for a cost-effective solution, and a home guard system for protection against theft and encroachment can be developed by integrating with IoT.

- **Smart Healthcare**: Smart wearable devices can be associated with the patients that can sense and report the medical parameters related to patients like temperature, pulse, blood pressure, and heartbeat, etc to the nurses and doctors. Drone ambulances are an IoT example already in markets that can facilitate emergency kits before the doctors could reach the scene.

- **Smart Agriculture**: IoT application monitors the nutrition levels of soil, light, and humidity, etc, and can adjust the temperature to create the desired greenhouse effect, precise watering, and fertilization, thus improves production.

- **Supply chains logistics IoT**: With the use of IoT applications and RFID technology products in the Retail Market can be easily tracked. Retailers get assisted with the management of the stock levels and automated reordering when products go out of stock and can spot shoplifting. Also, IoT applications can empower businesses with features like a sales forecast, reports, charts, and graphs which can help to make effective marketing strategies.

Besides various prevailing applications of IoT, there are many challenges that it encountered. These issues must be addressed to advance the growth and comfortable adoption of IoT.

### 3. Challenges of IoT Application

IoT has immense potential to transform the way lives are lived. But before hiring future changing technology IoT at a mass scale few challenges must be worked on [23][24][25][8].

- **Privacy and Security**: User Data is the base of the IoT system, its privacy, and security is a critical concern and is a major roadblock in the intended adoption and growth of IoT. The diversity of devices and technologies used increases the IoT system’s vulnerability to security threats. The measure is being worked on to provide a safe and secure communication IoT platform.

- **Cost**: The support components of IoT infrastructure like sensors, networking, and control mechanism, etc must be cost-effective to promote effortless acceptance of IoT.

- **Interoperability**: Different industries are accommodating support to IoT within their applications. Some standard interfaces must be incorporated to facilitate high-level interoperability of heterogeneous devices and varied data sources. Applications to be Cross organizational and operate as a part of diverse infrastructure must follow some standard protocols and encodings.
• **Data Management**: With an interconnected network of smart devices, constantly generating and exchanging heterogeneous data types in massive volume, data management is very crucial.

• **Training data sets**: To generate decisions/outcomes accurately, a deep learning model needs large training data sets, the availability of which is again a noticeable challenge.

• **User Tailored IoT**: In the modern era, everyone is jumping to IoT solutions personally or professionally with diverse requirements and expectations concerning varied factors like location, class, age, or profession. The same thing cannot satisfy the needs of all. IoT has a bigger challenge to customize itself according to the range of dissimilar users.

• **Lack of Knowledge**: Even many users intend to switch to IoT applications, but owing to insufficient knowledge or lack of time to locate and evaluate various IoT apps or devices available, they face hindrances to easy adoption of IoT.

The Recommender system can provide a viable resolution to handle issues like Huge data management, cost, customization, and unawareness. An overview of the significant role that the recommender system can play in supporting and establishing the growth and advancement of the Internet of things with easy approachable solutions to everyone is discussed below.

4. **Recommender System in IoT**

Internet of Things is a budding communication paradigm that has reformed the internet into a network of a massive number of smart devices. Whereby objects to object communication and exchange of information is leveraged. IoT has marked its presence in almost all the domains viz. healthcare, personal care, businesses, smart transportation, sports, and smart homes, etc. An extensive range of innovative IoT applications and artifacts compete with each other and they are expected to grow exponentially in the coming future. With an enormous variety of products to choose from, lack of concerning knowledge, and scarcity of time, it becomes a tedious task for users to find suitable IoT applications for them. It demands proper surveys based on various criteria such as cost, user context, product specifications, and capabilities, etc. The recommender system can assist in selecting the most relevant IoT application. A recommender system can help to save time and reduce the cost involved in implementing the IoT solution by proactively providing a list of components according to the user’s situations and preferences. This way, the user can find products or items which can't be otherwise located. Data management in large datasets can be made quick and efficient with the use of RS, which can filter the huge data, based on the three key factors users, devices, and services. Thus, recommendation technologies can take the future of IoT to new heights.

A recommender system can be included as additional functionality in IoT gateways, thus supporting the user with the configuration and selection of useful apps based on the interaction protocols and gateways settings used by the user. For example, a medical sensor like an oximeter, glucometer, or BP monitor can sense the personal readings of a user and communicate to the IoT gateway. Where it can be assimilated with cloud platforms like Google Fit [26] and Fitbit [27]. This personalized information of the user can be utilized by the recommendation algorithms like Collaborative filtering, where users' preferences can be listed based on the similarity between K nearest neighbors or a list of recommendations based on the user’s own past experiences using content-based filtering. Or, an RFID tag attached to the refrigerator can sense the food items available in it, clubbed with one’s diet plan can provide a recommendation list of recipes. User’s context and demographic pieces of information can also be considered while suggesting in many IoT use-cases [28][29].

4.1. **Literature Review**

I. Mashal, O. Alsaryrah, and T. Y. Chung [29] introduced a hybrid multi-criteria decision-making recommendation system. The proposed system was based on an analytical hierarchy process and simple additive weight methods and is formulated to address the issue of selecting the most appropriate IoT
application. They compared the model on three criteria wiz. objects, applications, and providers. Results support application criteria more than the other two.

S. P. Erdeniz et al [30], amalgamated the IoT and Recommender systems for Quantified-Self (QS) applications. Authors proposed three new approaches for Recommendations in QS applications namely Virtual Coach, Virtual Nurse, and Virtual Sleep Regulator which assists QS users to track their health conditions. They explain how their proposed approaches provide qualitative recommendations in the field of Quantified-Self applications.

Lye, Guang Xing et al [31], proposed a novel architecture based on a framework that provides personalized recommendations. The recommendation engine works on the knowledge-desire-intention model to improve service discovery and composition. The algorithm claims to eliminate the cold start issue and provide high satisfaction. The experiments indicate a 28% higher F-score than other approaches.

In [32], S. S. Basa et al. introduced a new trust-based recommender system grounded on three major areas IoT (Internet of Things), blockchain, and Cognitive Systems. In the system, the cognitive engine gathers the status of all the IoT things and takes the desired action using actuators and sensors. Blockchain technology is then used to verify any payment process involving any kind of cryptocurrency. The authors tested the proposed system on a shopping centre and found their approach novel with more secure and potentially high additional benefits.

A novel recommendation system is projected for travel routes by C. Bin et al. [33]. The candidate system tracks tourist's travel behavior via smartphone and the IoT embedded technology with regards to a specific point of interest. The authors developed an Android app that takes parameters like duration of visit, pictures were taken, etc. Tourist behavior and travel behavior sequential algorithms are designed to generate frequent potential routes. Afterward, a route ranking method constructed on a tourist’s profile and route constraints generates tangible routes. Experiments determine that the proposed system is effective and efficient for generating recommendations.

R. M. Frey, R. Xu, and A. Ilic [34] proposed a new recommendation system that explores apps on user’s mobile devices automatically and infers user's physical objects from these apps. A digital inventory is built from these physical objects, which is then used to make user’s personalized recommendations. The system enables new opportunities for business and marketing strategies. Using user’s data might raise privacy concerns. However, the authors suggested taking prior consent from the user before employing their personal information.

5. Analysis and Discussions

Internet of Things has continued to be the most trending topic from past decades. Its amalgamation with the recommender system has given new horizons to its growth rate. To back this fact, a bibliometric investigation of Scientific articles indexed in Scopus was done with help of different metrics. With parameters of academics like authors, sources, keywords, and affiliations, a quantitative study called bibliometric analysis is performed. Overall, 260 publications were identified. Personalized recommendations in web-based applications using collaborative filtering are key trends in the year 2019 in the field of IoT shown in figure 3 and figure 4.
Out of 260 publications, 113 are conference papers followed by 85 articles, 61 conference reviews, and 1 book chapter from different sources as shown in figure 5.
In figure 6 the three-fields plot by Keywords, Country, and Affiliations is displayed, which shows a major share is contributed by China and India with keywords Internet of Things, Recommender systems, Collaborative filtering and Personalized recommendations from varied affiliations with maximum publications from North China University of Science and Technology.

Further figure 7 shows the most relevant source of publications from a total of 260 documents, approximately 8% are from Advances in Intelligent Systems and Computing and 7% from Lecture Notes in Computer Science.
Information extracted from the analysis illustrates an annual growth rate of 31.95% of articles based on IoT and Recommender systems, out of total Scientific Production done annually till the year 2020 as rolled out by figure 8.

It can be clinched from the analysis done above that Recommender Systems has gradually gained focus in the field of the Internet of Things since the last decade. Collaborative filtering-based personalized recommendations in IoT are the topmost preferences of the authors and extensively trending in the years 2016 to 2019. China and India have given maximum contributions to the topic.
6. Conclusion
The Internet of things has advanced as an extension of cloud-based technologies and has brought a new revolution in the field. IoT has turned every object into a smart device with the capabilities of sensing data from the surroundings and transmitting it to the cloud. Data processing and analytics direct to the actions in the real world either automatically or by sending signals to humans. IoT has influenced every sphere of today's world from smart cities to smart businesses and smart health care to smart homes. With possible prospects of the technologies, many limitations and challenges come in the way that needs to be taken care of. Employment of proper data management and analytical models to engender effective outcomes and to enable secure and pocket-friendly IoT solutions will be a challenge and pathway to new research in this direction.

With the furtherance of the Internet of Things, a rapid proliferation in the artifacts available online has occurred. It is quite a cumbersome task for the user to pick or traverse the IoT solution, one is looking for. IoT, when integrated with the recommender system, not only makes this task simple for the user but also an added advantage for businesses online. Recommenders can extend IoT’s features to the new dimensions of innovation, usability, viability, and success. Various recommendation techniques can be employed to support users to get the best fit services, applications, sensors, products, and IoT workflows.

Bibliometric indicators point to the trending increase number of publications on an amalgamation of Recommenders with the Internet of Things. Analysis output is dominated by keywords as the Internet of Things, Recommender System, Collaborative Filtering, and Personalized Recommendations. It has been realized that recommender systems’ benefits extend beyond just the selection of the right IoT solution but, as a tool to provide a helpful, enjoyable, and personalized experience that leads to user satisfaction and hassle-free adoption of IoT.

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