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Internet of Behaviors : A literature review of an emerging technology

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***Abstract*—Nowadays, the evolution of the Internet of Things (IoT) and Artificial Intelligence (AI) has led to the emergence of an innovative technology called Internet of Behaviors (IoB). This technology aims to track, analyze, understand and interpret user attitudes in order to react effectively to human behavior. The IoB paradigm will become an essential marketing and distribution platform for businesses and organizations around the world. Several applications and research challenges related to IoB are fired in numerous fields during the last three years. This paper discusses the IoB concept and provides a statistical categorization and analysis of the proposed IoB approaches published between 2020 and 2022, and identifies the challenges and limitations of each approach. The contributions of this paper is the following: 1) Study the IoB paradigm, its benefits and highlights its application areas; 2) Discuss the proposed IoB approaches under different scenarios and compare them according to objectives, influence techniques, methods and used data; 3) Determine the research challenges and open IoB issues.**

***Index Terms*—Internet of Things, Internet of Behaviors, Artificial Intelligence, data analysis, tracking, influence.**

I. Introduction

Human behavior is the expression of physical, mental, and social actions associated with a person throughout his/her life. In recent years, the world has gone through many developments, phenomena and events that have caused upheavals in societies. The rise of digitalization (i.e., Web 2.0, media and social networks) has changed people's attitudes and behaviors. Behind this digital transformation has been a technological revolution, the emergence of the Internet of Things (IoT) and the evolution of Artificial Intelligence (AI). Today, the Internet of Things (IoT) plays an essential role in everyday life. The IoT is defined as a global infrastructure of interconnected services and smart objects intended to support humans in their daily life activities through sensing, computing and communication capabilities [1]. This infrastructure can be seen as a support of several technologies and research domains, such as industry, health, transportation, security and so on [2]. For instance, IoT can be used to increase the performance of production lines through introducing up-to-date data processing and exchange techniques. Furthermore, the protection and privacy technologies exploited in social networks can be deployed into IoT environments to enhance the security [3]. The IoT devices allow collecting data that provide valuable insights into the user behaviors, interests and preferences [4], [5].

Technology consumers and users are subject to multiple influences. Guiding human behavior toward better decisions is a major concern of today's professionals and scientists. Thus, it is very important to understand the decision-making process. Finding the sum of the factors that make a user click on one add-on and not another is a core research topic. In other words, what is the sum of the influences that a person will undergo to make a certain decision ? The Internet of Behaviors (IoB) can be seen as an extension of the IoT paradigm where digital traces of people's lives are collected from several sources to determine people's interests, attitudes and habits [6]. These traces could bring out crucial information and can therefore be used to impact the behavior of the peoples. According to Gartner, 40% of the world's population will be tracked via IoB by 2023, and more than half of the world's population will be subject to at least one IoB program, either governmental or commercial by the end of 2025 [6]. According to psychology professor Göte Nyman, the IoB attempts to understand the data collected from users' online activities and intends to answer the following question : *How to interpret data and how to use the corresponding knowledge to build and promote novel approaches ?* [4].

The IoB is seen as one of the major technology trends during the year 2021 in the sense where the COVID-19 pandemic is partly responsible for this trend [7]. The global IoB market has been estimated at USD 391.5 billion in 2021 and is expected to exceed USD 2,143.57 billion by 2030, expected to grow at a compound annual growth rate of 20.79% over the 2022-2030 period (see Fig. 1) [8]. The IoB attempts to understand the data on user's activity that is collected from multiple heterogeneous sources and seeks to deal with problems about how to analyze data and exploit the resulting information to offer new services based on human psychology, AI and IoT [9]. Furthermore, IoB brings together existing technologies that directly focus on humans, such as place tracking and facial recognition [10]. As shown in Fig. 2, IoT is responsible for transforming the signal generated by the IoT devices

Fig. 1. IoB market size, from 2021 to 2030 [8].

into data values, and IoB can translate the user's knowledge into real wisdom using various technologies, such as Data Analysis, Behavioral Science, and AI techniques [6]. These techniques, especially Machine Learning and Deep Learning methods, allow learning, reasoning and perceiving data to develop and predict new knowledge where the objective is to analyze, understand, and influence human behavior. For example, companies will use this knowledge to meet customer demands, create new products or boost existing ones, rethink the value chain, expand profits or reduce costs [2].

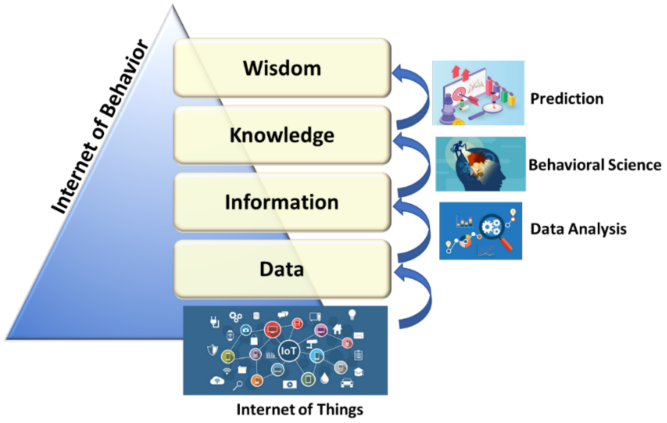

Fig. 2. IoT versus IoB [10].

The aim of this research is to conduct an in depth study to provide a systematic review of the IoB technology. More specifically, this research work presents the state-of-the-art on the IoB paradigm. Firstly, this study discusses the IoB concept, its goals and benefits for companies and organizations worldwide. Secondly, it summarises the approaches proposed for IoB applications by classifying them into two categories. A comparison between these approaches is carried out in terms of applications, influence techniques, methods and used data. Furthermore, to identify several application scenarios, this study focuses on the challenges and open questions facing IoB technology. The contributions of this paper can be summarized as follows:

- Study the IoB paradigm, its workflow, benefits and application areas.
- Describe the research methodology.
- Discuss the proposed IoB approaches under different scenarios and compare them according to applications, used methods, used data and influence techniques.
- Determine the research challenges and open IoB issues that need to be addressed by the research community.

The remainder of the manuscript is organized as follows. Section II introduces the IoB paradigm, its workflow, its benefits and its application areas. Section III gives the research methodology used to carried out this study. Section IV summarizes the proposed IoB-based approaches with a classification into two categories. Section V presents a discussion of the proposed approaches and the open challenges in the scope of IoB. Section VI concludes the paper.

II. IoB PARADIGM

IoB is a new and evolving paradigm that takes place in many areas to help businesses and public institutions understand and influence the user's behavior. IoB uses data that can be collected from different sources: IoT devices, wearable technologies, individual online activities and household electrical appliances, which provide valuable information about user behavior and interest. IoB was first introduced in 2012 by Professor Göte Nyman from the University of Helsinki. It was motivated by a lack of understanding of individual behavior and behavioral patterns. Thus, he proposed a solution that borrowed ideas from the IoT, Behavioral Science, Behavioral Analysis, Data Mining, Technology and Psychology [11], [12]. As shown in Fig. 3, IoB can be seen as a link between technology and human psychology that gives IoB the power to understand the structure and function of human mental activity and behaviors. Furthermore, IoB interacts with all aspects of behavioral sciences to effectively use the data collected by IoT devices and provide behavioral data analysis to get a final prediction.

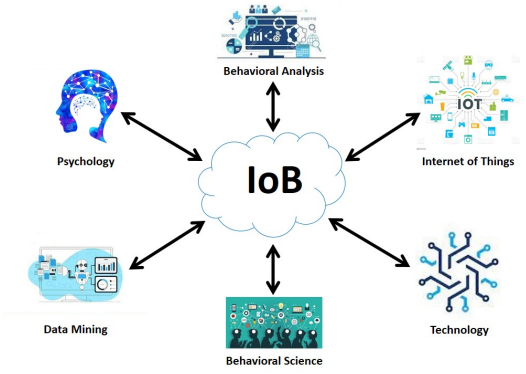

Fig. 3. The interaction between the IoB related domains.

The IoB tries to understand the data that can be used to create new products, promote existing products and increase profits or reduce costs. According to the IoB workflow (see Fig. 4), the user's behavior is first monitored to collect data using IoT devices. These data will then be analyzed using

data analytics and machine learning algorithms. Afterwards, the information obtained during the analysis phase must be understood based on behavioral science. Finally, the knowledge gained from the workflow are employed to set-up business strategies and influence the user's behavior.

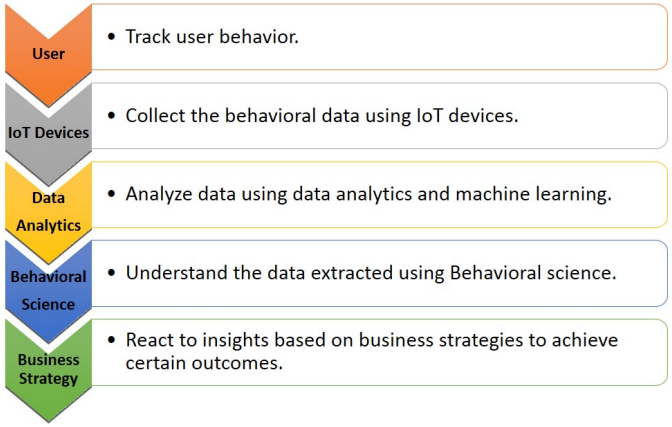

Fig. 4. IoB Workflow.

A. Benefits of IoB

Behavioral analysis and psychology have opened up new perspectives on data collected through the IoT. All human behavior is a massive and diverse set of attitudes and actions, so the discussion will focus on common business benefits for sales, marketing, production, services and customer experience. IoB is a technique that is going to prove beneficial in several ways. IoB makes it simple to study the way users are interact with products and devices, gain more insight into where the customer is in the purchasing process, and analyze their behavior, needs, and pattern of purchase across all platforms. In addition, IoB allows businesses to provide real-time notifications to customers about any latest offer, point of sale or even targeted advertising [12].

Companies are currently using this technology to track employee behaviors and improve their employer-employee relationships. It is also used to monitor client and staff behavior in order to improve public health and safety. For example, we can use computer vision to determine whether or not employees are adhering to mask protocols. Similarly, we can exploit loud speakers within the environment to alert people to violations of the protocol. [11], [13].

B. Applications of IoB

IoB can be useful in a variety of industries, including:

1) Digital Marketing : IoB will emerge as a new powerful marketing and business tool for companies and organizations around the world. In this context, marketers are able to analyze customer buying patterns across platforms, access previously inaccessible data, and even provide real-time point-of-sale notifications and targeted advertising. This allows companies to increase their revenue and keep their customers happy [12], [14].

2) Business : Companies can benefit enormously from IoB by analyzing customer activities and helping them to make strategic decisions. IoB provides companies with advanced means to market products and services, while influencing the behaviour of users and employees. Businesses can better focus on commercial and real-time notifications to improve sales by having all the data they need about their customers. IoB also gives the company a unique way to reach customers [5].

3) COVID-19 pandemic : The COVID-19 pandemic is partly responsible for making IoB the latest trend since several IoB applications have been proposed to facilitate social distancing and ensure safety [14], [15]. Using RFID sensors and tags, health officials can determine if there are inconsistencies in compliance with safety standards [5].

4) Health Industry : IoB can help patients with certain applications. For example, a health application that can alert the user if any of these values need attention: diet, exercise and weight, heart rate, stress level, blood sugar level of a person [5], [14].

III. Research Methodology

Given that IoB paradigm is an emerging research area, an exploratory process is carried out in this study to understand how the current literature defines, describes and discusses this paradigm. Accordingly, the research questions RQ_1 and RQ_2 have been introduced:

- RQ_1: What are the IoB-based influence techniques proposed to change human behavior?
- RQ_2: What are the open challenges for the IoB approaches?

To answer these questions, the following search terms are used: "Internet of Behavior" AND "IoB" OR "Internet of Behavior" OR "IoB" OR "Behavior" OR "Influence" OR "Influence of Behavior" OR "Psychology" OR "Behavioral Science" OR "Internet of Behavior" AND "Internet of Things" OR "Human Behavior". Lising these terms, we performed a broad search on Google Scholar and several databases, such as Science Direct, IEEE Xplorer, Springer Link, and ACM Digital Library. After the search process, a large number of articles were found. We applied the inclusion/exclusion criteria shown in Table I to select the appropriate papers. Fig. 5 shows the distribution of resulting papers considered in this study according to some scientific publishers, such as IEEE, Elsevier, ACM, Taylor & Francis, etc.

TABLE I
Inclusion and Exclusion Criteria for Papers Selection Process.

Inclusion	Exclusion
• Studies in the domain of IoB . • Studies in the domain of human behavior. • Research papers that explicitly propose IoB-based approaches.	• Books, Book Chapters and Thesis. • Studies not presented in an English context. • All papers that do not have quality.

IV. Related Works

The potentialities offered by the IoB make possible the development of a large number of applications, of which only

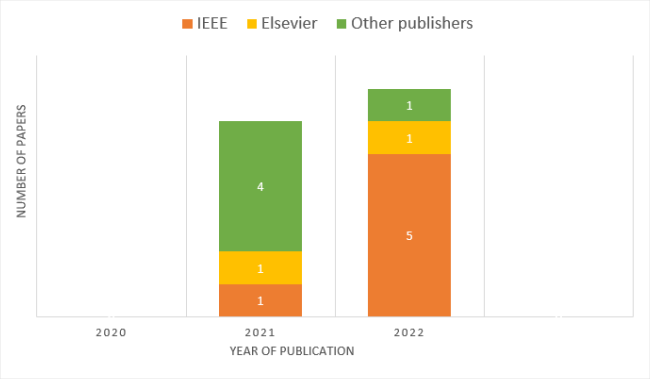

Fig. 5. Distribution of studied papers by Publisher.

a very small part is currently available to our society. There are many areas and environments where novel technologies would likely improve the human quality of life such as, at home, while traveling, in case of illness, at work, etc. Several companies realize its main advantages and consequently use it for different marketing strategies, for example, Google and Facebook use behavioral data to deliver ads to users on their sites. Similarly, Youtube uses behavioral analysis to enhance the experience of the viewer through recommending or highlighting only subjects and videos that interest them. A number of approaches have been proposed for IoB applications and can be grouped into the following two categories:

A. IoB approaches for improving service

IoB aims to understand human behavior through data aggregated from different sources. IoB technologies will soon be used to provide people with a better quality of life. Several IoB approaches have been proposed in the literature to improve services in smart cities, education, marketing, tourism, etc. In [7], the authors discuss important IoB applications to improve customer service. Companies use data in ways that they like to monitor customers' purchasing patterns and influence their behavior in order to market large quantities of products. IoB is employed to monitor compliance by employees with COVID-19 security rules.

In [5], the authors presented an overview of IoB technology, highlighted its application domains and give some open IoB issues. However, they did not identify IoB-based work and only describe one use case. While our paper presents a literature review of proposed IoB-based approaches with a classification into two categories. In addition, a comparison between these approaches is carried out in terms of applications, year of publication, used methods, used data and influence techniques.

In [16], the author proposed an android application powered by a managed fog-to-cloud software engine. This application has been deployed in the Cagliari Airport, including an recommendation advisor and a indoor navigator, piloted by machine learning algorithms, offering a more enjoyable and less stressful experience for passengers on the field. While authors of [15] developed a framework to advance research on assisted driving. This framework considers the input of heterogeneous sensor data that are processed using three models of deep learning: Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM) and Graph Convolution Neural Network (GCNN). To evaluate the proposed framework, they used four benchmark connected vehicle datasets. Results clearly demonstrate that the proposed framework outperforms other baseline approaches in terms of prediction rate and execution time.

The authors in [17] proposed an IoB model based on the literature and the results of semi structured interviews conducted with 20 top rated scientists. This IoB model is applied to the queuing system at the Uffizi galleries in Florence, Italy. For that, they replaced the previous box office system with a dynamic behavioral tracking system, modeled them and used the behavior to make predictions by exploiting Radio Frequency Identification system, Closed-Circuit Television cameras and person meters to obtain more accurate data. The proposed IoB system allows for flexible and convenient reservation and also addresses Quality of Service issues related to human behavior.

In [9], the author proposed a new paradigm based on the IoB technologies and Explainable AI (XAI) to analyze students' actions to analyze students' actions to affect and influence their behaviors and attitudes in the interest of their education. For this, they used data that describing the personal abilities and social skills of 41 students to determine patterns of learner behavior that explain the machine learning predictions. To evaluate the proposed system, Each student's performance was calculated before and after using the system. As a result, they found that after the advice sent by the system to the students, significant improvements in their performance were obtained.

In [18], the authors proposed an intelligent monitoring system for IoB based on an adaptive relational attention network for person re-identification that works well on global relational information extraction. The objective of this system is to analyze the behavioral state of the pedestrian at different places and times. To do this, the researchers used three reference databases, each containing numerous images of people. These images were analyzed by the CNN algorithm.

In [19], the authors used the methodology of Natural Language Processing (NLP) and Clusturing to treated the problem of increasing productivity in cinema. For this, they investigated if and to what extent emotions are shaping consumers' preferences for entertainment media and content, using the emotional arcs of movies.

In [20], the authors defined a processing model including multivariate linear regression and fixed effect models study the impact of air pollution on people's everyday activities, using the density distribution of people in different urban areas. For this, they used Detailed Call Records (CDRs) data and hourly concentration data of major air pollutants.

B. IoB approaches to reducing costs

The IoB technology is employed in some applications to the cost reduction that is characterized by a set of techniques designed to reduce expenses significantly. In [13], the authors

proposed a model based on XAI and IoB, to change consumer behavior into economic behavior by monitoring the amount of global active power. The objective of this system is to minimize the consumption of energy, reducing therefore the cost and waste of potentially used energy. For this, a LSTM algorithm was used to build an energy consumption prediction model. They used a multivariate time series consisting of 34,589 samples that describe the hourly electrical energy consumption measurements of an individual household (located in Sceaux, France). The results of the scenario showed that the proposed system managed to reduce 522.2 kilowatts of wasted energy in the house over a period of 200 hours and saved 95.04 €.

The authors in [21] have used the same database and approach are used in [13], to propose a decentralized IoB framework to achieve sustainable energy and control excessive energy consumption by tracking, analyzing, and influencing the behavior of smart electrical IoT devices. The results indicate that the decentralized system is more precise than the centralized system proposed in [13].

In [22], the authors proposed an approach that combines Game Theory, Simulated Annealing (SA) and Deep Q-Network (DQN) to solve the computational overhead problem in multi-user scenarios. The main objective is to reduce the system cost, task completion time and energy consumption. This system is implemented in a scenario related to the Internet of Medical Things where they used physiological data that will need to be processed and computed in real-time.

V. Discussions and open challenges

In this section, a statistical analysis of the proposed approaches is reviewed according to the two research questions.

- RQ_1: What are the IoB-based influence techniques proposed to change human behavior?

The IoB approaches presented in related work were classified, according to their objectives, into two categorizations namely IoB approaches for improving service and IoB approaches to reducing costs. Table II summarizes these approaches and compares them in terms of applications, year of publication, used methods, used data and influence techniques. The proposed studies have some weaknesses. For example, most solutions only process time series data using LSTM, but sensors can capture a variety of data types, including images, videos and graphs, and using these different data formats can help provide more reliable and understandable solutions for tracking, analyzing and influencing behavior. In another aspect, the use of other machine learning techniques helps provides better results and therefore to improve the learning and prediction of the AI model and the overall system in [13], [21].

- RQ_2: What are the open challenges in the IoB approaches?

The related work section show that the IoB technology has a number of open challenges. The most important ones are security, privacy, and ethical concerns [13], [15]. In this context, organizations need to be aware of the responsibility of using IoB since processing sensitive and real-time data always creates security issues for any service user. Data sensitivity encourages cybercriminals to access, disclose, collect, and profit with their use. IoT devices are one of the most targeted devices by cybercriminals that can access the network by exploiting the vulnerabilities present in these devices. The integrity of the collected data is therefore not guaranteed and IoB analysis can be compromised due to the compromised data integrity [5], [13].

IoB relies on data collected by various IoT devices and other sources that the user may have. This raises the issue of privacy, especially when IoT devices are used in sensitive domains, such as healthcare, insurance and defense. However, connected devices collect a tremendous amount of personal data and can pose a potential security risk. Cybercriminals can use these devices to gain backdoor access to the user's network and steal valuable data, such as credit card information, bank account and social security card numbers [5].

The collection, storage and analysis of data must be accompanied by transparent and ethical use due to the fact that behavioral data are sensitive and personal. The collected data can provide a direct description of the user (e.g. videos, images or sound recording) who is allowed to be informed of this procedure, as well as to know that his/her privacy is preserved and protected against abuse. Furthermore, to be entitled to privacy requires specific protections. For instance, non-disclosure of that person's personal information, non-disclosure of that person's images, and so on, without their free and informed consent [7], [13].

VI. Conclusion

To understand the decision-making process, otherwise the human behavior of an individual, it is necessary to track him in his development, in his growth and his history. Data collected by IoT devices provide valuable insights into user behavior, interests and preferences. IoB is a new concept that aims to understand the data collected on human behavior and use this understanding to achieve certain goals. For now, companies primarily use IoT and IoB to track, collect, understand and try to influence user behavior to meet customer needs. This paper can be useful for researchers and readers interested in the field of IoB, as this survey deals with the history of the IoB, its various proposed approaches, its research challenges and open problems that must be addressed by the research community. In terms of future work, it is essential to consider data security and confidentiality mechanisms to improve the external validity of the proposed studies.

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TABLE II
SUMMARY OF THE STUDIED IOB-BASED APPROACHES.

Ref	Year of publication	Applications	Methods	Datasets	Influence techniques
[16]	2021	Demonstrate the IoB capabilities of tracking and engaging interested people in the airport area	• Machine Learning • Fog-to-cloud	Airport information like: detailed map of the area, list of available services represented by points of interest, such as toilets, stores, etc	Android application
[15]	2022	Improve research on assisted driving	• LSTM • CNN • GCNN	Heterogeneous sensor data: images, videos, time series and graphs that determine artificial and natural landmarks, accidents, etc	Framework
[17]	2022	Dynamically capture and predict visitors' mobility behavior to facilitate ticket booking and eliminate long queues	Semi structured interviews	Time series that describes the mobility of people at the Uffizi Museum, Italy (number of visitors and duration of visits)	Update the queue management system
[13]	2021	Affect the electricity consumption behavior by automatically controlling the amount of energy	• LSTM • XAI	Multivariate time series that describe the electrical energy consumption measurements of an individual household for approximately 4 years between December 2006 and November 2010	Warning
[21]	2022	Control excessive energy consumption by tracking, analyzing and influencing the behavior of smart electrical IoT devices	• LSTM • XAI	Multivariate time series that describe the electrical energy consumption measurements of an individual household for approximately 4 years between December 2006 and November 2010	Alerts
[9]	2022	Analyze students' actions in order to influence and change their habits and behaviors for the sake of their education	Machine learning	Behavioral data from 41 students in two primary abilities: personal and social skills	E-mail
[18]	2022	Monitoring and analyzing the behavioral state of the pedestrian at different times and places for person re-identification	CNN	Three large person re-identification datasets, consisting of images of people taken by different cameras	No influence
[22]	2022	Improve the basic algorithm to minimize the system cost, task execution time and energy consumption	• DQN • Game Theory • SA	Physiological data in real time	Update basic algorithm
[20]	2021	Study the influence of air pollution on the daily activities of the population	• Fixed effect model • Multivariate Linear Regression	Datasets on Call Detail Records from Monday 2 February to Sunday 22 February 2015 and the hourly concentrations of the major air pollutants	No influence
[19]	2021	Improve productivity in the film industry by analyzing the emotional content of film scripts	• NLP • Clusturing	Dataset containing 6174 English subtitle files, selected according to various criteria : length, download count, users rank, etc	No influence

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