China-USA Business Review, Apr.-June 2024, Vol. 23, No. 2, 84-91
doi: 10.17265/1537-1514/2024.02.004

Implementing IoT-Based Solutions in Developing Countries for Achieving SDGs: A Case Study Analysis

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The 2030 Agenda considers Information and Communications Technology (ICT), and related technologies, as a tool capable of contributing to increasing progress in bridging the digital divide between communities. The main objective of this paper is to give an overview of the most promising application areas in order to successfully apply Internet of Things (IoT) to achieve SDGs in developing countries, also bringing out pros and cons of these applications and current challenges. A review of relevant literature and an analysis of key case studies of projects will be conducted in this research, with the aim of reducing inequalities in developing countries. This study seeks to highlight and classify some of the emerging IoT-based applications to reduce inequalities in developing countries, helping the achievement of SDGs.

Keywords: Internet of Things, innovation management, sustainability, SDGs, developing countries, SDG 2, SDG 3, SDG 4, SDG 6, SDG 7, SDG 9, SDG 13, SDG 14, SDG 15

Introduction

In the 2030 Agenda, Information and Communications Technology (ICT) and related technologies are referred to as a tool capable of contributing to increasing progress in bridging the digital divide between communities (Wu et al., 2018).

It follows that technology but also emerging technologies such as Internet of Things (IoT) can represent innovation accelerators capable of creating new products, processes, and industries and upsetting the ICT status quo.

However, despite the key role recognized for Science, Technology, and Innovation (STI) in achieving the SDGs by the 2030 Agenda itself, no explicit reference is made to new technologies and emerging technologies which are not mentioned in the SDGs.

Starting from these premises, we want to investigate the potential uses of IoT for Development (IoT4D) for achieving the SDGs, classifying the main areas of application, and providing emblematic examples of these applications.

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Literature Review and Research Questions

IoT represents a new paradigm shift in IT. This expression consists of two words: “Internet” and “Things” (Madakam, Ramaswamy, & Tripathi, 2015).

Relevant literature defines the Internet as a global system of interconnected computer networks, through the use of Internet protocols to reach users around the world. This system can also be seen as a network of networks. It is possible to identify different categories of networks, including: private, public, academic, corporate, and governmental (Nunberg, 2012).

The literature is not unanimous in the definition of the Internet of Things, despite the strong interest shown by academics, researchers, professionals, innovators, developers, and companies.

Ashton (2009) was one of the earliest to talk about IoT in reference to the possibility of adding sensors and radio frequency and object identification. According to Peña-López (2005), one of the first IoT applications is related to radio frequency identification (RFID). This application exploits the ability to have information about a tagged object, through the consultation of an Internet address or a database entry linked to an RFID or NFC (Want, 2006).

Over time, the concept came to incorporate a broader definition, namely a network of entities connected via sensors, for the localization, identification, and management of such objects (Ng & Wakenshaw, 2017). It is therefore possible to implement this technology in all situations in which the use of sensors is possible (De Villiers, Kuruppu, & Dissanayake, 2021).

Furthermore, IoT also represents a communication tool between human-human, human-things, and things-things, globally (Aggarwal & Das, 2012). Based on this definition, objects and tools, thanks to the use of IoT, can perceive and respond to user needs (De Villiers et al., 2021). This is possible thanks to the technology that allows the devices to receive the command, to carry out the requested operation, to communicate and coordinate with each other (Salman & Giain, 2017). In fact, according to Ouaddah, Elkalam, and Ouahman (2016), IoT, allowing objects to be connected to the Internet, has brought the digital world into real life.

As mentioned, IoT has attracted greater attention for the possibility of creating an infrastructure, at a global level, of physical objects that are connected in a network, allowing constant connectivity for any object in the network (Evangelos, Nikolaos, & Anthony, 2011).

These are just some of the definitions provided in the literature. All definitions share the fact that in the first phase the data were created by people, in the subsequent phase, however, the data are created by things.

It is therefore possible to identify the broadest and most complete definition. IoT is defined as an open network, characterized by the presence of intelligent objects. They are equipped with the ability to self-organize, share information, react and act when faced with situations and changes in the reference environment.

It should not be forgotten that the implementation of this technology presents critical issues. In particular, we highlight the lack of a uniform architecture as various implementation solutions have been proposed, both by academics and professionals.

For the system to function, a large set of sensors, communications networks, and technologies must exist (Gigli & Koo, 2011).

In order to make the most of the IoT potential, three key elements have been identified (Gubbi, Buyya, Marusic, & Palaniswami, 2013): (1) hardware, (2) middleware, and (3) knowledge or semantic tools.

In particular, the first element includes sensors and communication technologies; the second includes archiving and computer processing; and the third element includes, for example, visualization tools.

According to other authors (Ouaddah et al., 2016), the potential of this technology can also be exploited in combination with blockchain technology. This solution could be a valid tool to comply with elements 2 and 3. In particular, this technology could be useful for providing a unifying and secure structure for storing and processing data and also for reporting.

Different models have been proposed in order to implement the blockchain for secure transaction management, leveraging smart contracts (Saghiri, HamlAbadi, & Vahdati, 2020).

Other authors have proposed combined applications of these two technologies to be able to record events such as temperature, humidity, or position, without the risk of manipulating the data themselves (Wang et al., 2019). This is made possible by guaranteeing access only to blockchain participants.

Christidis and Devetsikiotis (2016) believe that the joint potential of these two technologies is still underdeveloped, despite the innovative potential in the device-to-device services market.

Some promising areas of application (Wang et al., 2019) are related to transaction or data sharing systems related to the energy sector, property management; for identity management and access control.

One potential application is linked to the energy sector. Micro energy exchange between IoT devices can be managed by such solutions. In detail, energy is generated by solar panels. It is recorded on a blockchain and it is exchanged on the network (i.e. a peer-to-peer market), through smart contracts. As a matter of fact, this system allows recording, measurement, and energy management in a substantially autonomous way.

These elements may be interesting in reference to the possibility of using such innovative tools to measure the outcomes linked to the achievement of SDGs, also allowing confidential management of information between companies, governments, and other stakeholders.

Wang et al. (2019) highlight, however, some critical issues related to the integration of these two technologies due to network structures that are non-homogeneous and also due to insufficient computing power and Internet bandwidth.

As a matter of fact, the main goal of this research is to investigate the leading application areas and current challenges to be faced for successfully implementing IoT-based solutions in developing countries, taking into account pros and cons of these applications to achieve SDGs, promoted by Governments and International Organization. In particular, two main research questions have been formulated (RQs):

(1) What can be considered the main applications of IoT in developing countries for achieving the SDGs? (RQ1a); what are the main IoT-based projects implemented? (RQ1b)

(2) What are the strengths and weaknesses of these applications? (RQ2)

To provide a comprehensive answer to the first research question (RQ1), in the next section of the study, the relevant literature on this topic will be analyzed. To answer the second part of this first research question (RQ1b), the main case studies that emerged during the answer to RQ1a will be analyzed.

The last section will allow us to answer to RQ2 through the discussion of the main challenges to be faced.

IoT Solutions for Achieving SDGs

In industrialized countries, the use of IoT-based solutions is enjoying great success due to both high levels of efficiency and productivity. However, it should be underlined that in developing countries, this technology can represent a factor capable of accelerating development, in order to make it long-lasting and sustainable (López-Vargas, Fuentes, & Vivar, 2020). Consequently, implementing these IoT-based tools is also relevant for developing countries as it can overcome some of the challenges that these countries face.

Furthermore, it is worth specifying that these countries represent the most suitable environment for developing new innovative solutions capable of solving problems specific to these countries and not encountered by developed countries.

In this context, IoT4D can be seen as a solution to support growth not only economically but also in social and cultural terms (Barro, Degila, Zennaro, & Wamba, 2018).

Over the years, in developing countries, several IoT projects have been developed and implemented especially in sub-Saharan and southern Africa. The main areas of application of IoT technology in which it is possible to contribute to the achievement of the SDGs are the following (RQ1a).

Health, Water, and Sanitation (SDGs 3 and 6)

These tools are useful for a wealth of information of great importance about water resources and water management, as well as additional information on wastewater. In fact, projects have been developed for the management of water supplies for both healthcare and agricultural use (Zorn, 2018). In the healthcare sector, with reference to vaccines, this technology allows the monitoring of their cold chain (López-Vargas et al., 2020).

Other healthcare applications are related to remote patient monitoring, personal healthcare, and the integration of medical devices.

Agriculture and Livelihoods (SDG 2)

The use of these tools is useful for achieving better optimization of resources, for reducing production costs, and for reducing the risks of crop loss. Unfortunately, lack of user awareness and lack of adequate infrastructure (internet connection) make it difficult for many farmers to use such tools. Despite this, as we will see in the next section, several projects have been implemented with notable results in developing countries. It must also be remembered that SDG 2, the promotion of sustainable agriculture, also contributes to the fight for poverty reduction (SDG 1) and to the achievement of inclusive and sustainable economic growth (SDG 8).

Education (SDG 4)

The potential of technology can be harnessed to enable personalized and exploratory learning for students from the most disadvantaged areas.

Environment (SDGs 13, 14, and 15)

It is possible to exploit these IoT-based tools for several promising environmental applications. The main ones are identified below: contributing to the reduction of greenhouse gas emissions; contributing to slowing the rise in global temperatures; possibility of mitigating the effects deriving from emergency situations such as natural disasters (for example, the early detection of tsunamis/hurricanes/typhoons allows timely warnings to be issued, reducing the number of deaths and injuries as well as damage to infrastructure).

Resilience, Infrastructure, and Energy Sector (SDGs 7 and 9)

IoT4D can contribute to the provision of clean energy solutions, to monitor and manage the energy resources, to the creation of smarter energy markets and the optimization of existing tools (Ramanathan et al., 2017). As will be seen in the next section, some of these projects have succeeded in improving the people's well-being in developing countries. In addition, it should not be forgotten that, in these countries, women have limited access to resources. Consequently, these solutions also impact other SDGs (1, 4, and 5).

Case Studies

As shown in the previous paragraph, IoT technology can contribute to achieving the SDGs (RQ1a). In particular, we highlight the following projects related to these IoT application areas in order to answer to RQ1b.

Health, Water, and Sanitation

In Bangladesh, 48 arsenic sensors have been installed in order to monitor water quality and prevent pollution. In China (Jiangsu), the quality of the water supply is monitored with IoT sensors installed in the distribution network. Furthermore, in developing countries IoT can be useful to monitor the cold chain of vaccines. In Haiti, smart thermometers are used to monitor the delivery and the storage of vaccines. In addition, IoT can also be a valid tool for addressing immediate humanitarian challenges, such as in West Africa for the Ebola epidemic.

Agriculture and Livelihood

Nano Ganesh e-Irrigation was designed to allow Indian farmers to remotely control micro-irrigation pumps. To use this tool, all you need is a cell phone. This tool also allows you to check the availability of the water supply.

In Sri Lanka and Rwanda, a project has been designed for tea plantations so that soil moisture and nutrient content can be monitored.

In Kenya, however, the Kilimo Salama project was created to help small landowners safeguard their crops from drought and floods.

Education

In Burkina Faso, a project has been designed to establish a virtual university. In China, the Guangdong Compulsory Education Project uses these tools to develop digital teaching materials.

Environment

IBM's China in partnership with the Environmental Protection Bureau in Beijing has developed a project to monitor and predict air quality. In Beijing, IoT sensors have been installed to have increasingly precise pollution predictions. In countries such as India, Iran, Pakistan, and Oman, tsunami early warning systems have been installed.

Resilience, Infrastructure, and Energy Sector

In Kenya, the M-Kopa project was designed to guarantee energy, produced by photovoltaic systems, at prices accessible to all citizens. This system allows using the energy produced and monitoring remote usage levels and possible faults.

Implementation Challenges

With the emergence of IoT, several works have been conducted to analyze IoT applications for developing countries, highlighting the challenges for implementing such technology in these countries, in order to promote social development. The main challenges (RQ2) are related to the following.

Technical Challenges

Design requirements. IoT4D solutions require different design requirements and technological frameworks. This is due to the fact that information requirements in developing countries may be substantially different from those for industrialized countries (Miazi et al., 2016).

Poor level of research on the IoT topic and lack of IoT skills in the territory. In addition to the poor research activity conducted on these innovative topics, a challenge that should not be underestimated in developing countries is the lack of expert technical personnel who can deal with IoT systems that require regular maintenance, updates, and operational testing (Fuentes et al., 2018).

Simple and cheap technology. Since resources are scarce, some simpler and cheaper technological tool may be more suitable for developing countries (López-Vargas et al., 2020).

Lack of infrastructure. It is quite difficult to have widespread stable and reliable energy systems in developing countries (López-Vargas et al., 2020).

Internet connection. This is a key issue to be resolved in order to enable IoT-based solutions (Hong et al., 2014).

Energy supply. Reliable energy is a significant challenge in enabling these innovative tools. Photovoltaic and wind power is seen as the best solution to implement in developing countries (Miazi et al., 2016). IoT solutions should be based on an energy source that can be self-sufficient (Masinde, 2014).

Environmental Conditions

Harsh environmental conditions in developing countries. These IoT tools should be configured in such a way that they can withstand extremely adverse weather conditions.

Social Differences

It is possible to identify significant differences between rural and urban areas in developing countries. This aspect is essential as it impacts the infrastructures (for example, communication networks or electrical grid) that can be used in the implementation of IoT tools.

Policy Aspects

Problems related to security and privacy. These tools are not always designed in such a way as to overcome these critical issues.

Lack of standards. Developments without adequate standardization can lead to tools that work in an overly disruptive manner (E. P. Yadav, Mittal, & H. Yadav, 2018).

Government regulations. A clear regulatory framework could be a further support for a rapid acceleration of the implementation of IoT-based tools, giving the possibility to exploit its potential (Abunohaiah & Al-Haija, 2019). As mentioned above, privacy issues may arise. This implies a decrease in the level of user trust towards these tools. This implies the need for government regulations to regulate these controversial aspects (Tzafestas, 2018).

Aspects Related to the Financial Sector

Lack of adequate financial systems. Unfortunately, even today, in developing countries, access to basic banking services is not guaranteed to everyone. To make up for the lack of financial inclusion, various business models are taking hold (López-Vargas et al., 2020), such as Pay-As-You-Go (PAYG), also in combination with IoT-based solutions.

Discussions of Results and Conclusions

In this paper, we identified the main applications of IoT technology (RQ1) and we also highlighted the critical issues for the implementation of IoT in developing countries (RQ2).

Recently, the trend that has emerged in developing countries has been a mix of IoT and seamless digital-payments or innovations in business models (such as, for example, PAYG). As a matter of fact, thanks to the analysis of the main successful IoT-based projects, we can consider IoT4D as a mix of two fundamental elements: (1) low-cost IoT; and (2) PAYG.

These solutions have become necessary to reach an ever-increasing number of end users in order to help them improve their living conditions. The possibility of using low-cost IoT solutions therefore allows us to provide users with products that were previously inaccessible to them, also contributing to the achievement of financial inclusion.

Previous studies have shown that approximately 85% of IoT solutions could help achieve the SDGs (López-Vargas et al., 2020). The great potential of this technology could, therefore, have a more persistent impact in developing countries than in industrialized ones.

It should be noted that the implementation of IoT solutions in developed countries and developing countries is different. Some critical issues can be found in developing countries. Among these, the main ones worth mentioning are: infrastructural problems, poor connectivity, lack of technical knowledge, unfavorable environmental conditions, and the characteristics of financial systems where inclusion is lacking.

As mentioned, one of the main challenges is connectivity. In many cases, by integrating the various IoT solutions with open source tools, the costs related to the technology are substantially reduced.

These projects generally do not require high initial investments, allowing a higher level of diffusion and making them more attractive and economically advantageous for the scientific community, contributing to the achievement of sustainable development objectives.

As a result, we can argue that the combination of IoT technologies is a trend in developing countries that has achieved outstanding results. This technological combination represents the best scenario to disseminate IoT4D in the most useful way in order to promote the achievement of the SDGs.

In addition, the critical issues found in developing countries can open up new fields of scientific investigation, leaving room for the possibility of new technological solutions and new fields of application.

This research will be of interest to academia, with particular reference to scholars investigating the intersection between innovation management and sustainability. This research will also be useful for policymakers to understand how to better integrate new technologies into their action plans, with particular reference to sustainability actions.

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