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Designing Enterprise Internet of Things Systems

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ABSTRACT

Devices have been transmitting data automatically and in real-time without human involvement for years; the idea of the Internet of Things (IoT) is a new trend in technology that depends on smart devices, artificial intelligence (AI), and machine learning (ML). IoT is the capacity to create intelligent, connected objects out of commonplace products like machines, buildings, and cars that can communicate with users, apps, and each other. Businesses that understand how to link their devices and equipment can produce essential data, send it securely over numerous networks, and gather, store, and analyze it to turn it into usable information in real-time. The design of such a smart product, city, home, or service is challenging for software designers; it requires expert and professional personnel to benefit from IoT. This paper aims to present a theoretical model of the IoT characteristics and architecture and highlight the guidelines for the design process.

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INTRODUCTION

The use of connected devices, sensors, and applications in a professional or organizational setting is the deployment of Enterprise Internet of Things (IoT) systems. These series of disruptive technologies influence the daily lives of both individuals and companies (Santoro et al., 2017). These systems gather and analyze data to increase operational effectiveness, improve customer experience, and spur innovation. With the help of these systems, firms can connect, monitor, and manage various assets and activities, from supply chain management and industrial machinery to intelligent buildings and customer service interactions. The IoT concept was invented by one of the members of the Radio Frequency Identification (RFID) development community in 1999 (Lima et al., 2020). It recently became more relevant to the practical world mainly because of the popularity of mobile devices, embedded and ubiquitous communication, cloud computing, and data analytics. IoT is an evolutionary stage of the internet that connects physical objects with embedded systems to communicate, sense, or interact with their internal state or the external environment (Ramasamy & Kadry, 2021). An enterprise IoT system is a group of technologies that enables internet-connected products and devices to send and receive data explicitly intended for enterprise applications (Particle, 2024). It applies IoT techniques to identify and interact with all the elements such as machines, products, collaborators, suppliers, customers, and infrastructures (Chehri et al., 2021). IoT helps enterprises release new value from physical assets, using the information to promote product offerings, generate new revenue flows, and better manage physical assets (Particle, 2024). For example, a predictive maintenance system was developed by Microsoft and the automotive industry Rolls Royce using IoT solutions (Chehri et al., 2021). This system allows the manufacturer's managers to have a global view of the planes in real time.

IoT architecture is the system of multiple elements that range from sensors, protocols, and actuators, to cloud services and layers (Lima et al., 2020). For the enterprise to sell IoT products and ensure that customers will adopt this new technology, it needs to offer a smart product with a perfect design that covers all the features required by the customers and solves their problems. A good designer must consider the data flow between all entities, the network's stability, and data security and communicate with multiple service providers to include them in the design process. IoT's fundamental characteristics include safety, dynamic changes, heterogeneity, and services related to things.

Four key elements commonly make up enterprise IoT systems which are:

1. IoT Devices: Hardware or sensors that interact with each other and the Internet of Things platform to exchange data about the environment or assets. IoT devices include intelligent sensors, actuators, wearables, gateways, and other devices.
2. IoT Platform: This middleware or software layer permits IoT device administration, data processing, and communication. IoT platforms include features such as data ingestion, storage, device management, analytics, and integration with other business systems.
3. Connectivity: The network architecture linking IoT platforms and devices. It may also contain wired and wireless networks like Wi-Fi, Bluetooth, cellular networks, and other communication protocols to enable data flow between devices and the IoT platform.
4. Applications: These software programs or online services use the IoT platform's Processing of data gathered from IoT devices. Enterprise IoT applications include energy management, supply chain optimization, dashboards, analytics tools, and other sector-specific applications.

The key elements of IoT systems are illustrated in Figure 1.

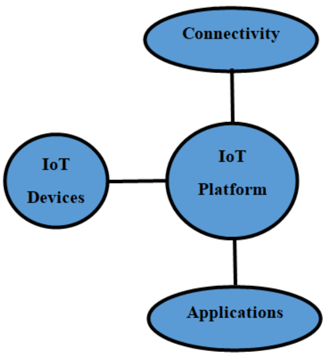

Figure 1: Key elements of IoT systems

Organizations may profit from enterprise IoT systems in several ways, including higher operational effectiveness, improved customer experiences, increased productivity, lower costs, and new revenue streams from cutting-edge goods and services. Data security, privacy issues, interoperability, scalability, and interaction with current enterprise systems are some difficulties they also bring. Enterprise IoT systems allow businesses to improve operations and provide value-added services using connected devices and data, ultimately fostering digital transformation and creativity across various industries. Next, IoT characteristics and architecture will be discussed followed by the design process, design factors, design guidelines, and recommended future work.

IOT CHARACTERISTICS AND ARCHITECTURE

IoT systems consist of numerous elements: physical objects like sensors, actuators, and interactive devices, the network connecting these objects, the data gathered from these devices and analyzed to create a significant meaning and the physical context in which the user interacts with the system. According to the literature, the fundamental characteristics of the IoT are:

1. Interconnectivity: With IoT, anything can be interconnected with the global communication and information infrastructure (Lima et al., 2020). Sensors, social networks, the Internet, and computer software are interconnected to generate, process, and deliver information with added value in real time (Chehri et al., 2021).
2. Things-related services: IoT can provide thing-related services like privacy protection and semantic consistency between physical things and their associated virtual things. This is to offer thing-related services within the constraints of things; the technologies in the physical and information worlds will change (Hossain et al., 2024; Lima et al., 2020).
3. Heterogeneity: The devices in the IoT Network are heterogeneous depending on different hardware platforms and networks. They interact with other devices or service platforms through various networks (Calderoni et al., 2019; Hossain et al., 2024; Lima et al., 2020).
4. Dynamic changes: The state of devices changes dynamically, e.g., connected and disconnected, including location and speed. Moreover, the number of devices can change dynamically (Lima et al., 2020).
5. Enormous scale: The number of devices that need to be managed and communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. Managing the data generated and their interpretation for application purposes will be even more critical. This relates to the semantics of data and efficient data handling(Calderoni et al., 2019; Chehri et al., 2021; Lima et al., 2020).
6. Safety: Safety must be prioritized. Safety must be designed to be used for both the creators and recipients of the IoT. The security of personal data and physical well-being must be included. Securing the endpoints, the networks, and the data moving across all of it means creating a security paradigm that will scale (Hossain et al., 2024; Lima et al., 2020).
7. Connectivity: Connectivity enables network accessibility and compatibility. Accessibility is getting on a network, while compatibility provides the standard ability to consume and produce data (Chehri et al., 2021; Hossain et al., 2024; Lima et al., 2020).

According to Lima et al. (2020), IoT architecture has different layers; the application layer, the service support and application layer, the network layer, the device layer, the management layer, and the security layer. First, the application layer contains IoT applications such as health monitoring, industrial automation control, or Smart Farm applications. Second, the service support and application layer consist of generic and specific support capabilities. These include support for developing applications and services by providing functions that use cloud computing infrastructure, data storage, and processing, providing interoperability between applications through APIs. Third, the network layer contains two types of capabilities: networking capabilities and transport capabilities. It addresses the communication protocols and technologies associated with the IoT connectivity between devices or elements of different technologies. It also includes different network infrastructures, such as a local network, a wide area network, a long-range network, and backhaul for long-distance connection.

Fourth, the device layer contains two types of capabilities: device and gateway capabilities. It includes sensors, actuators, wireless sensor networks composing a distributed sensor network, RFID, and near-field communications (NFC). Fifth, the management layer takes control of the IoT infrastructure management, in all its layers, to guarantee the reliability of this structure through the commissioning, monitoring, provisioning, and configuration of the sensor, actuator, and other devices, network elements, and computational infrastructure, supporting all the operation. Last, the security layer permeates all other layers, mapping the main technologies used to meet information security requirements such as privacy, integrity, availability, and access control. The IoT architecture is displayed in Figure 2.

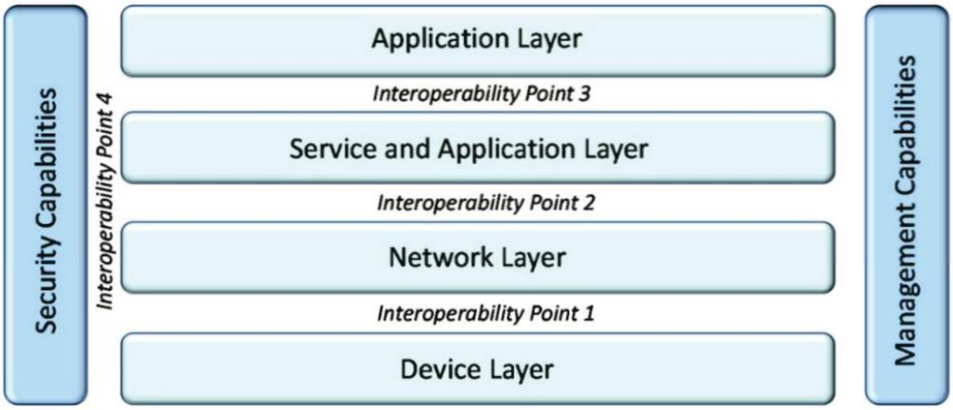

Figure 2: IoT architecture (Lima et al., 2020)

IOT DESIGN PROCESS

Like the design process of any Information Technology system, IoT design gathers data on various IoT systems and their interactions to create a meaningful user experience. IoT design takes a holistic look at the whole system and the role of each device and service and creates a conceptual model of how the user understands and perceives the entire IOT system (Calderoni et al., 2019; Sayar & Er, 2018). Although, different organizations or designers may have slightly different steps or approaches. The IoT design process is generally described in Table 1.

Table 1: The IoT design process.

Step	Description
1. Define Requirements	Determine what problem the IoT device is solving, what features it requires, and what performance is expected.
2. Identify Sensors and Actuators	Choose sensors that will gather data needed to solve the problem and actuators that can act upon the environment or trigger actions based on the data collected.
3. Determine Network Connectivity	Decide how to connect the device to the Internet or other networks, such as cellular, Wi-Fi, or WAN.
4. Choose a Platform	Select a platform to host the IoT solution, whether a cloud service, a local server, or an edge device.
5. Develop Firmware	Develop the software on the device, including the operating system, drivers, and middleware.
6. Develop Backend Software	Develop the software that will run on the platform to receive data from the device, store it, and perform analytics.
7. Develop a User Interface	Please create a user interface for the device that allows users to interact with it, view data, and manage settings.
8. Test and Validate	Test the device and software to ensure it meets performance requirements and solves the problem it was designed for.
9. Deploy and Monitor	Deploy the device and software to users, and monitor its performance to ensure it continues to meet expectations.
10. Maintain and Update	Maintained the device and software, including updating firmware and backend software and fixing bugs and issues that arose over time.

DESIGN FACTORS AND GUIDELINES

One of the most critical phases at the start of the enterprise IoT journey is designing the overall system and architecture. Designing IoT systems for designers of software services and screen-based interfaces or physical products creates new design challenges. Designers need to do multiple types of design, from industrial product design to service and business design. Smart product design needs to consolidate IoT technology from the beginning. It is a way to create an effective connected solution (Sniderman et al., 2016). Several design factors and guidelines are derived from the literature to ensure that an enterprise IoT system provides the required benefits. It is necessary to consider several design factors listed below:

1. Data Management: Enterprises must develop systems to handle and analyze massive amounts of IoT-generated data efficiently. This entails deciding on scalable data storage options, developing data pipelines to manage massive volumes of data, sharing data, and putting data analytics tools in place to conclude the data (Calderoni et al., 2019; Camatti et al., 2020).
2. Power Management: IoT devices are frequently battery-powered. Therefore, businesses must create systems to manage power consumption efficiently. This entails choosing low-power consumption equipment, designing systems to maximize power utilization, and implementing power management techniques to increase battery life (Prasad & Chawda, 2018).
3. Regulatory Compliance: Enterprise IoT systems must be built to adhere to legal standards. This entails choosing hardware and sensors that adhere to industry standards, putting security and privacy measures in place to safeguard sensitive data, and following data protection laws (Lata & Kumar, 2021).
4. User Experience: End-users must be considered while designing enterprise IoT systems. This entails developing user interfaces that are clear and simple to use, putting in place feedback mechanisms that let users offer suggestions, and designing systems that can change to suit the preferences and requirements of the user (Hacid et al., 2023).
5. Technology Stack and Future Ready: A significant aspect that frequently goes unnoticed is choosing mature technology that will maintain the program for 5–10 years without reworking essential components. The network architecture, cloud technology preferences, team strengths, the state of technology, and the system's functional requirements are other elements that can affect the technological stack (Sailaja & P, 2021).
6. Cost: The cost is quite essential, when creating enterprise IoT systems. Businesses must weigh the expense of IoT devices and sensors against the benefits that they might provide. This entails choosing technology that offers the most value for the money, developing systems to minimize operational costs, and putting cost-cutting measures in place to lower ownership costs (Lee, 2019).

The essential guidelines that designers should consider before and during the designing process of an IoT system are:

1. Do the research: The essential step in the design process is understanding the product features and customers' needs. The designer must do deep research about the targeted audience and the product features and determine how this product will meet customer needs (Fattahi, 2023). Talking to customer support teams to hear from end users and discuss with the sales team to find out what potential customers ask about before purchasing. Industry conferences also uncover what end users are interested in, what they may look for in an IoT product, and how this product makes their lives easier.
2. Align features with user value: The IoT system must offer a valuable product to the end users. IoT users usually do not know the device's actual value, how it can service them, and how it can solve their problems. Also, customers' needs frequently change, so the IoT product should adapt to unforeseen updates (Sniderman et al., 2016). When the designer knows the customer's issues, they can align the value of IoT products with customer needs, which means selling the appropriate product that solves end-user problems quickly and saves time. If the end user is aware of and understands the value of an IoT product, they will buy it and feel comfortable using it.
3. Look at the entire picture: The excellent design must offer a holistic system ceremony. All parts, including devices, services, and applications, should work perfectly to provide smart products with exclusive properties. IoT device is not just standalone hardware; it is connected to other devices, systems, and applications. The IoT product interacts with multiple destinations; the end user, company, and other linked devices (Sniderman et al., 2016). The designer should consider the data flow between different entities in the cycle. The interaction between the user and devices is an important point that

should be considered within the design process. Connectivity components must always be on, secure, and reliable (Sniderman et al., 2016). During the design, designers should consider every object that could connect to, communicate, or control, then design accordingly. When the designers understand the whole picture, they will develop the required system to achieve its goal.

4. Consider the operating settings: An effective design depends on how well IoT product designers merge digital and physical components; one can affect the other. IoT system combines physical (sensors, devices) and digital (data) worlds (Sniderman et al., 2016). The devices interact with data when sent by the sensors. A device that can function on low power differs from one that must be weatherproof or another that hosts many end users. The device with the right feature sets lets customers know how IoT products are valuable. The context for IoT devices means developing convenient and dedicated features for the considered use case that can give the user value. When developers deliver contextually proper IoT experiences with suitable device feature sets, they offer clients the knowledge of how IoT can solve their problems. Context builds long-term demand for IoT devices and products because end users better understand IoT use cases and how IoT can work within various settings.
5. Include security early: Data security and privacy are essential components of any IoT device design, especially if the devices are in remote or insecure places (Hossain et al., 2024). Clients must ensure that their data is safe so they can purchase products comfortably. Incorporating privacy and security standards from the beginning is the only way to build user trust.
6. Deploy effective data management: Designers must know how the device generates data to develop suitable systems and efficiently gather, store, and transmit the data. Collect and store only relevant data that would complement the IoT system. This method makes IoT systems faster and quickly deploy devices with low latency, memory, and battery concerns (Rupareliya, 2021).
7. Prepare for different use cases: The IoT system includes hundreds of connected devices, all of which should be appropriately connected and work together through well-defined gateways (Borgini, 2022).
8. Prototype early: Align the design of the Hardware and software. IoT systems are hard to expand after deployment because all objects are connected. Prototyping hardware and software early saves cost, time, and change.
9. Build a strong brand: Designing a product with a distinct design builds a wide range of loyal customers (Rupareliya, 2021). Those end users will forgive the enterprise in an unexpected situation. Therefore, it is recommended to work on product brandings like logos, messaging, principles, core beliefs, style, and language, and use all of these to connect with the clients.
10. Include scalability: IoT product designers should expect end users' scenarios while using the product. Using case-flexible IoT devices may succeed more as customers can scale the product's use and reach (Lee, 2019; Sailaja & P, 2021). Designers can track user-generated ideas and consolidate them into future device versions or retroactively support those new use cases.

FUTURE WORK

Future IoT applications will allow humans to interact with each other and machines in real time over great distances. New opportunities within remote learning, surgery, and repair will increase. Immersive mixed reality applications would become the next platform after mobile. There is a potential to enable billions of devices simultaneously and leverage the huge volumes of actionable data that can automate diverse business processes. Therefore, designing enterprise IoT systems needs to consider increased network agility, integrated AI, and the capacity to deploy, automate, organize, and secure diverse use cases at hyper scale. Furthermore, the design evaluation of the enterprise IoT systems, which are not discussed in this paper, needs to be explored further and included in future work. Several existing design evaluation methods need to be investigated thoroughly to ensure that the proposed design guidelines are efficient and effective. This could also be done with an actual case study from the industry.

CONCLUSIONS

The Internet of Things (IoT) is an essential platform for businesses looking to change their processes. Businesses adopt IoT technologies more frequently to streamline operations, cut costs, and enhance customer satisfaction. The paper presented IoT characteristics and architecture, the design process, and the design factors. The design guidelines are recommended to be followed by software designers. The design process or phase is a very critical stage in product development. If the designers miss any object, connectivity, or feature, it will be hard and costly to repeat the processes from the start. The IoT solution should be flexible and scalable to provide a high-quality product. Understanding the target audience's requirements and the relationship between all objects is essential. Also, crucial points are the preparation for unexpected issues and the predictable changes in the future that require a system update.

As a result, several variables must be carefully considered while developing an enterprise IoT system, including data management, power management, regulatory compliance, user experience, and cost. By considering these factors, enterprises may develop IoT solutions that deliver the intended benefits and give them a competitive advantage. To ensure that the IoT system satisfies their demands and offers value, it is also crucial to have a clear strategy, set clear goals, and interact with stakeholders.

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