Application of IoT in Civil Engineering and Geodesy

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SUMMARY

IoT (*Internet of Things*) represents an advanced connection of devices, systems, and services. Sensor networks, software systems, and numerous industrial and open protocols enable the functioning of many IoT systems. In combination with artificial intelligence and cloud computing, IoT offers new opportunities for smart applications in many industries including civil engineering and geodesy. Some of the benefits of using this system include improvements in industrial processes, products, and services, greater dependability, and lower operational costs. The significance of IoT concept is proven also by the *Fourth Industrial Revolution* (4IR or Industry 4.0) which describes the digital transformation and blurs the boundaries between the physical, digital, and biological worlds. 4IR includes the usage of technologies that have become even more accessible and less costly in the last few years, among which is IoT. The paper presents IoT concept, constituent elements, and its way of functioning. The emphasis in the paper is given on the analysis and presentation of possible application of this modern concept in the field of geodesy and civil engineering. IoT and its application in general in these areas is still in development, but it is also of great importance and interest. Some of the applications analyzed in the paper are smart building and city concept and SHM (*Structural Health Monitoring*).

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1. INTRODUCTION

IoT is a new field of information technology that is developing very quickly and allows connection of large number of users, devices, services and applications on the internet. The term IoT was proposed by Kevin Ashton in 1999, as a system that connects physical world on the internet with the help of sensors (Ashton, 2009). All components within the IoT system are interconnected, communicate and exchange data. All collected data can be processed locally or can be sent for processing at remote locations. End users can access data via various mobile and online applications, perform additional data analysis and adjust settings of sensors and devices in order to maintain IoT systems (Radenković et al., 2017), (Tan & Wang, 2010), (Wu, Lu, Ling, Sun, & Du, 2010). An overview of significant areas of IoT application is given in Figure 1. Main IoT characteristics applicable to every application and system are shown on Figure 2.

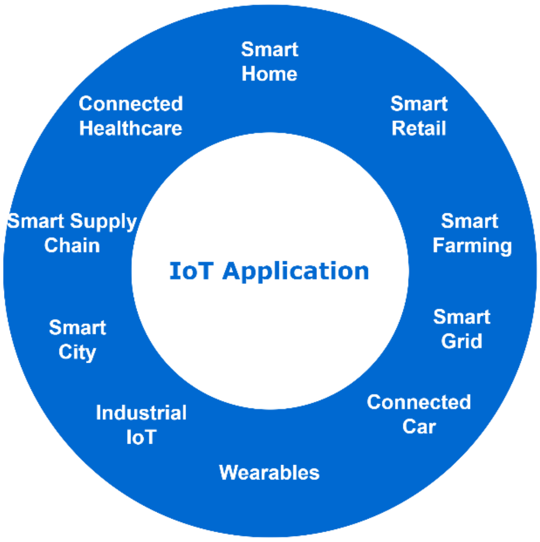

Figure 1. IoT Application

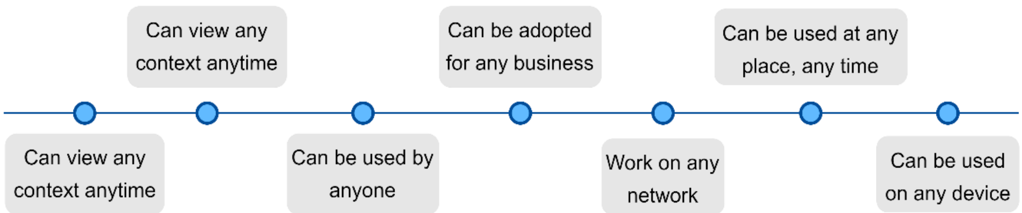

Figure 2. IoT characteristics

Many papers deal with IoT, its structure, way of functioning and applications. This corresponds to the fact that there is world-wide rapidly growing interest for developing in this area and its application. Papers (Kumar, Tiwari, & Zymbler, 2019), (Gada & Sayed, 2021), (Khan, Alhazmi, Javed, Ghandorh, & Aloufi, 2021) discuss different challenges and key issues of IoT, architecture and important application domains. Latest security trends in IoT domain are analysed in (Rachit, Bhatt, & Ragiri, 2021).

2. INTERNET OF THINGS

The Internet of Things has come to the fore in the past decade. It is considered the destructive technology of this century that has so far attracted the attention of society, industry, and academic community as a way to improve everyday activities, create new business models, products and services, and as a source of research topics and ideas. Several associations, institutions, companies, and even the government have recognised the importance of this technology and the potential benefits that can result from it, leading them to take on strategic projects and initiatives in order to develop in this field and make a profit (Ibarra-Esquer, González-Navarro, Flores-Rios, Burtseva, & Astorga-Vargas, 2017).

The concept of IoT deals with the presence and wired or wireless connection of things and objects in the environment. A smart world where real, digital, and virtual cooperate is being developed in order to perform various activities more efficiently. In it, each object has its own address, objects communicate and cooperate with each other and thus realise applications and services to achieve common goals. Thus, as a general definition of IoT, it can be said that it is a network of physical objects with nested technology to communicate, monitor, and interact with their internal states or environment (Drajić, 2017).

IoT World Forum adopted IoT reference layered model shown on Figure 3 which depicts main components and their role in IoT architecture. This reference model is based on the premise that: DEVICES send and receive data interacting with the NETWORK where the data is transmitted, normalised, and filtered using EDGE COMPUTING before landing in DATA STORAGE/DATABASES accessible by APPLICATIONS which process it and provide it to people who will ACT AND COLLABORATE (Sánchez, Mallorqui, Briones, Zaballos, & Corral, 2020).

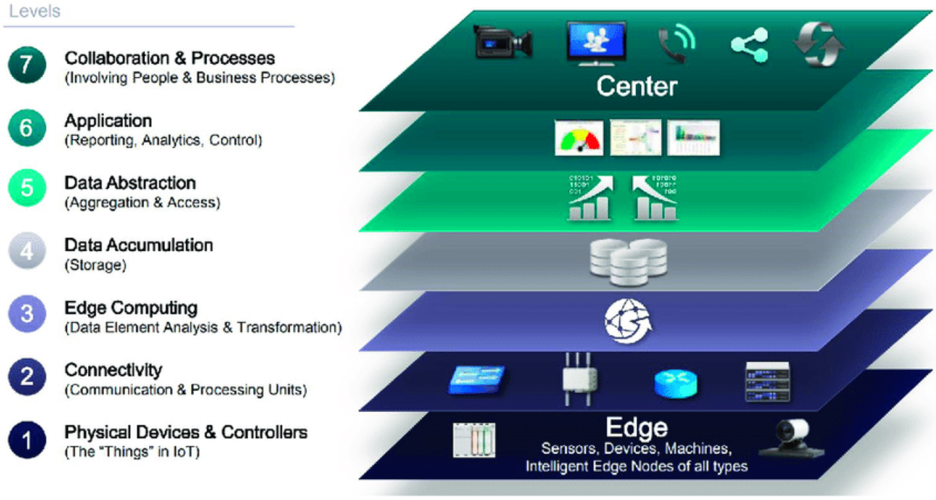

Figure 3. IoT World Forum Reference Model (Sánchez et al., 2020)

Physical Devices and Controllers are basically "things" of IoT, i.e. different type of sensors and devices managed by IoT architecture. Connectivity layer represents different technologies implemented in order to distribute data through system architecture. Edge computing is actually a cloud layer that enables protocol conversion, routing to higher layer software functions "fast path" logic for low latency decision making. Data Accumulation is a storage system that keeps data for later processing, analysis, and different applications. Data Abstraction layer "makes sense" of the data – it organizes data streams into appropriate flows for upstream processing. Application layer represents the purpose of the IoT system – it enables monitoring, process optimisation, alarm management, statistical analysis, etc. At Collaboration and Processes layer data and their processing results are presented to users in appropriate business applications (Sánchez et al., 2020). Inner system communication with data transfer and analysis communication is shown on Figure 4.

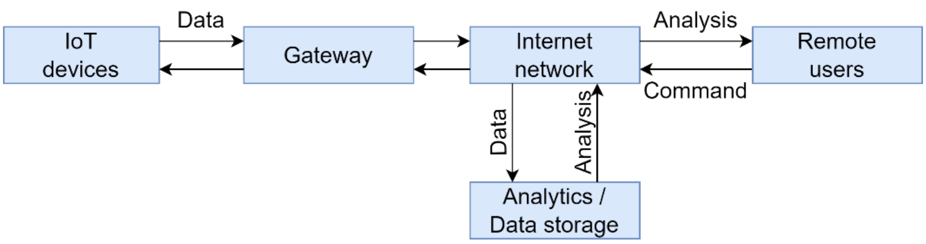

Figure 4. Inner communication system in IoT

The IoT concept consists of uniquely identifiable elements that have their own virtual representation in a structure similar to the Internet, which has a number of components (Vermesan & Friess, 2014):

- Module for communication with local IoT devices (e.g., nested in a mobile phone or located in the immediate vicinity and accessible via short-range wireless connection).

This module is in charge of collecting observations and sending them to a remote server for analysis and permanent storage;
- Module for local analysis and processing of observations collected by IoT devices;
- Module for interaction with remote IoT devices, directly via the Internet or more likely, through proxies;
- Module for special data processing. This module runs on the application server serving all clients. It retrieves requests from mobile and web clients and relevant IoT observations as input, executes appropriate processing algorithms and generates output in the form of knowledge that is later presented to users;
- Module for integration of IoT generated information into business processes of the company. This module will gain in importance with the increased use of IoT data by enterprises as one of the important factors in the daily definition of business strategy;
- User interface (web or mobile) that performs visual representation of measurements in a given context (for example, on a map) and interaction with the user, i.e. the definition of user searches.

3. IOT APPLICATION IN CIVIL ENGINEERING

IoT applications are numerous, but here will be emphasized only those that relate to civil engineering and geodesy.

3.1 Smart building and city concept

Development of modern technologies, sensors and software solutions has greatly changed the way buildings and cities function today. This is exactly what the development of smart cities and buildings means. Smart city is concept that considers connected, intelligent and optimised environment with aim to reduce costs, increase safety, attract investment, be sustainable, and enhance livability. To get there requires smart governance, the education of a smart workforce and smart citizens, the digital transformation of assets, and the deployment of sensor networks with ubiquitous multimodal connectivity. Main areas in which smart city concept is applied is given on Figure 5. With the emergence of IoT and a new generation of intelligent edge devices, concept of smart cities has taken on an entirely new meaning for building automation. Buildings of all sizes and functions, residential or commercial, are becoming connected smart ecosystems in which systems monitor and maintain much more than climate control and lighting. Smart sensors are deployed for purpose of gathering, aggregating, analysing, and sending different kind of data to edge computing where advanced predictive analytic engines will enable new levels of control, security, and alarming, while significantly improving the overall user experience in the building environment.

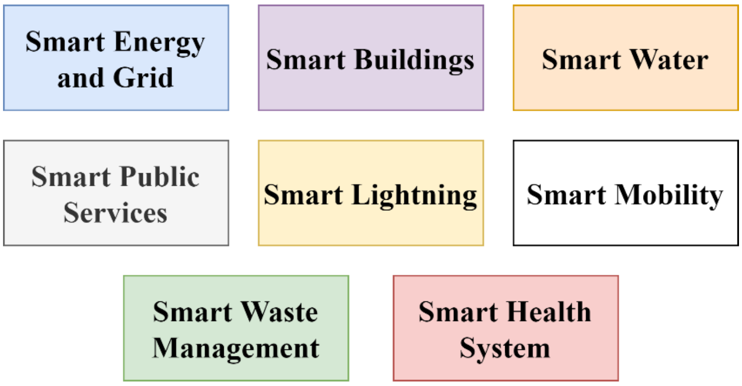

Figure 5. Smart city areas

Paper (Elvas, Mataloto, Martins, & Ferreira, 2021) proposes an integrated resilience system linking interconnected critical infrastructures in a smart city to improve disaster resilience. A data-driven approach is considered, using artificial intelligence and methods to minimize cascading effects and the destruction of failing critical infrastructures and their components (at a city level). The proposed approach allows rapid recovery of infrastructures' service performance levels after disasters while keeping the coverage of the assessment of risks, prevention, detection, response, and mitigation of consequences. The city of Lisbon (Portugal) is used as a case to show the practical application of the approach. The IoT technologies and projects implemented in New York City of the USA to make it a smart city are explained in paper (Shah, Kothari, & Doshi, 2019). The topics covered in this paper are waste management, water management, air quality control, lightning in the city, improvement in parks, LinkNYC program, NYCDot. Paper (Sankaran & Chopra, 2020) gives detailed explanation on how Masdar City (Abu Dhabi) can position itself as a sustainable, smart city for others to follow based on IoT application.

3.2 IoT in construction industry

Applying IoT concept in construction industry can significantly contribute to more efficient and economical use of resources, technology, and employees. Application of the IoT concept in this industry can be divided into several phases (Katiyar & Kumar, 2021):

- Planning and Control;
- Quality Management;
- Safety Management;
- Equipment Management;
- Procurement Management;
- Execution.

Construction material arriving at the construction site can be marked with RFID (*Radio Frequency IDentification*) tags and in this way provide information at any time on the amount of available individual construction materials. In addition, alarms can be generated when the amount of available material falls below the defined minimum value. In this way, the future lack of necessary material will be noticed in time and idle time on the construction site will be reduced, because the material will always be available. It is possible to place appropriate GNSS (*Global Navigation Satellite System*) sensors on construction machines that will monitor their movement and location in real time. In this way, construction managers can know exact machines' location at any time and manage their movement in a more economical and efficient way. In addition, IoT-enabled sensors tracking indicators like excessive vibration or temperature allow identifying the most appropriate time for servicing equipment. During the construction, IoT-enabled devices allow obtaining reports on different changes in materials or environment conditions; tracking separate parts, details, or items; and updating BIM (*Building Information Model*) models in real-time. Therefore, when the problem is detected by an IoT-enabled sensor, a BIM model connected with this IoT device will analyse and diagnose this issue.

IoT platform based on cloud for prefabricated construction works is presented in paper (G. Xu, Li, Chen, & Wei, 2018). This platform is beneficial for small and medium enterprises and will help process automation. The principle on which platform works is explained and implemented in actual prefabricated construction project in Hong Kong. Paper (Kim, Ryu, & Kang, 2018) proposes an IoT-based construction site safety management system. A prototype for the proposed system has been developed to monitor field workers and outsiders approaching the hazard zones at all times. The prototype system provides danger alarm to safety managers in construction sites and at remote sites. Paper (J. Xu & Lu, 2018) aims to develop a closed-loop lifecycle management system that can enable a consistent stream of information for use and reuse of all stakeholders. The framework integrates the state-of-the-art smart construction, construction automation and IoT technologies to help fragmented practitioners access and manage the information via a standardised interface among various applications throughout the whole lifecycle. Within the closed-loop lifecycle management system for IoT-based smart construction, digital technologies such as 3D laser scanner, drone, BIM, AR (*Augmented Reality*), Auto-ID, GPS (*Global Positioning System*), WSN (*Wireless Sensor Network*), robotics, mobile digital devices, and web-based applications are used to collect proactive data from different stages. Further, the data are stored, shared, processed, and utilised in one unified platform for all stakeholders to support better decision-making and interaction throughout a project lifecycle. Research presented in (Tabatabaee et al., 2022) aims to identify and analyze the barriers impeding the use of IoT technology in the CSSM (*Construction Site Safety Management*) context.

3.3 Structural Health Monitoring

SHM involves the observation and analysis of a system, i.e. engineering object over time using periodical measurements in order to monitor changes to the material and geometric properties of objects such as bridges, buildings, dams, towers, etc. Parameters that are usually measured in this field are stress, strain, vibrations, displacements, and environmental parameters such as temperature, humidity, precipitation, wind speed and direction, traffic quantities. The emergence of IoT has simplified laborious and manual data collection which is inefficient and slow. The collection of real time data of structures state and condition can be easily done by installing sensors and actuators in the structures in order to improve the overall performance

(Gunturi, 2021). Moreover, the combination of SHM, cloud computing, and the IoT enabled ubiquitous services and powerful processing of sensing data streams beyond the capability of traditional SHM system. Cloud platform allows the SHM data to be stored and used intelligently for smart monitoring and actuation with smart devices.

First of all, in order to monitor the structure, it is necessary to choose the appropriate sensors. Each sensor measures a certain characteristic, i.e. type of structure deformation. During the last decades, various sensors have been created and used in the implementation of SHM systems. Examples of these sensors include temperature sensors, strain gauges, accelerometers, anemometers, seismometers, load cells, GPS sensors, etc. Regarding the needs and requirement of SHM systems, potential parameters that can be measured to detect corrosion, fatigue, or crack in structures, are summarised in Table 1.

Table 1. Potential parameter measured to access structure status (Tokognon, Gao, Tian, & Yan, 2017)

Parameters	***Measurements***	***Sensors***
Mechanical	Strain, displacement, rotations, curvature, distortions, forces, etc.	Fiber Bragg Grating Sensor (FBG), Strain Gauges, GPS, Piezoelectric sensors
Optical	Light, photon, etc.	Fiber optical sensors, Phototube sensors
Chemical	pH value, Sulfate, chlorine, etc.	RFID sensors
Environmental/ Physical	Temperature, humidity, precipitation, wind speed and direction, solar irradiation, velocity, etc.	Accelerometers, Temperature sensors, Anemometers, seismometer
Loads	Cable Load, etc.	Load cells

With the recent developments in micro and nanotechnologies, most of the sensors used in SHM are miniaturised and can be easily packed in any small devices. In addition to the choice of the sensor type and model, it is of great importance to choose the number of sensors that will be placed on the structure as well as the selection of the appropriate location on the structure. Great attention needs to be paid to all this in order to gather accurate and timely information on the structure status. The application of the IoT concept in SHM enables the use of so-called smart sensors that have the ability to connect to the internet and send data to a remote cloud server (Figure 6). In this way, engineers and other professionals can access the measurement data on the structure at any time and conduct appropriate analyses. In addition, there is the possibility of creating automatic alarms in case the value of a measurement exceeds a certain limit. In this way, the responsible persons are informed about such events in close real time and can take the necessary actions in time.

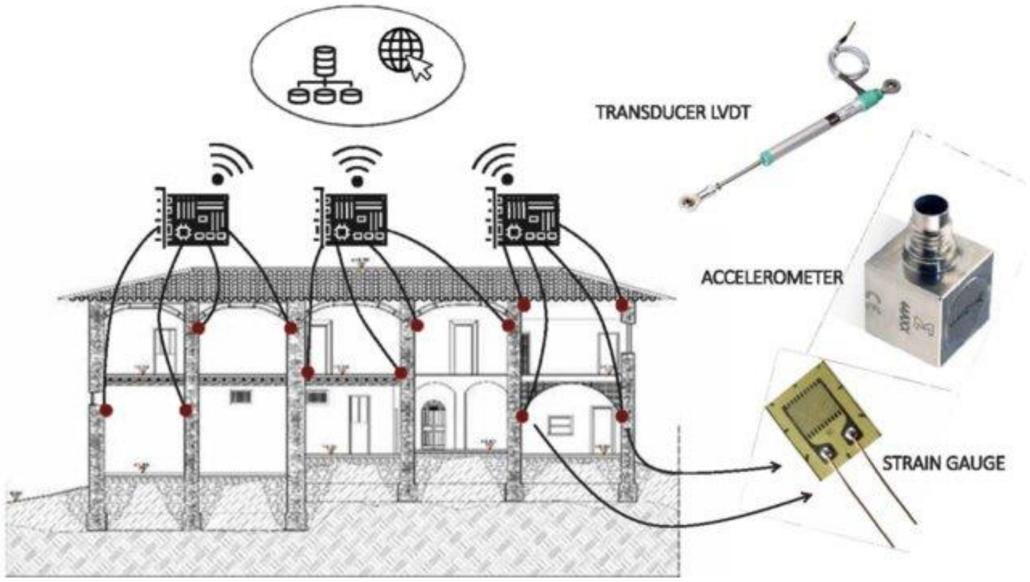

Figure 6. Future of SHM – IoT application (Abruzzese et al., 2020)

A low cost bridge health monitoring system is proposed in paper (Pandey, Haider, & Uddin, 2016). Arduino, an open-source hardware platform reads vibration data from an accelerometer and transmits this information on web-based Application Programming Interface (API). The IoT has been used to connect the accelerometer to the internet thereby enabling the computation and analysis of real time data at base station. IoT system for SHM is designed in paper (Muttillo et al., 2020). For this purpose, a customized data logger and nodes have been designed. Data logger has an internal memory to allow for the post-processing of the collected data. The nodes are composed of a digital triaxial accelerometer, a general-purpose microcontroller, and an external memory for storage measures. The system has been characterised and the damage indicator has been evaluated on a testing structure. Experimental results show that the estimated damage indicator increases when the structure is perturbed - the damage indicator increased by a maximum value of 24.65 when the structure is perturbed by a 2.5 mm engraving. SHM system of a long-span arch bridge - the Jiubao bridge in China is systematically incorporated and presented in paper (Chen, Zhou, Wang, Dong, & Qian, 2017). Multidisciplinary approach of merging BIM methodology with real-time monitoring, using low-cost IoT sensors is explained in paper (Scianna, Gaglio, & Guardia, 2022). This solution gives the possibility to remotely monitor, in real time, the behaviour of the structure visualised in the BIM model.

4. CONCLUSION

What can be concluded from presented in the paper is that IoT is a powerful modern technology with great potential. Countries with a high development rate and economic capabilities have already begun to apply this concept in many spheres of work, life, and business – managing energy, water, waste, transportation, buildings, etc. The aim of this paper is to bring the IoT concept, its role, and the way of functioning closer to people, especially experts in the field of geodesy and civil engineering and how they can use it. IoT is the technology of the future that is already being applied and used, but further it will become an indispensable part of every segment of people's lives, it is only a matter of time before that happens.

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