Live Data Visualization of IoT Sensors Using Augmented Reality (AR) and BIM

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Abstract –

Recently, the integration of Building Information Modeling (BIM) technology and Virtual and Augmented Reality (VR/AR) technologies during the operation and maintenance phase has been increasingly adopted. There has also been a surge of interest in the exploitation of Internet of Things (IoT) for constructed facilities, in the form of wireless networks connecting physical objects (e.g., sensing devices, facility assets, equipment, etc.). Recent IoT systems offer data management and visualization solutions. However, to improve issues such as safety and indoor comfort conditions for facilities, most of the existing IoT deployment do not benefit from the enriched digital representations of BIM and its graphical visualization capabilities. Although the integration of sensor data with BIM models has been investigated in academia, storing such real-time data in a standard and structured manner remains to be further investigated. This research aims to visualize live environmental data collected by IoT agents in the AR environment built upon existing BIM models. In our case study, the environmental data, such as indoor air temperature, light intensity, and humidity are captured by sensors connected to Arduino microcontrollers. Sensor reading are then stored in the BIM model and visualized in both the BIM platform and the AR application in a real-time manner.

Keywords –

BIM; sensors; thermal comfort; Augmented Reality; Arduino; Internet of Things (IoT); Visualization

1 Introduction

Since the emergence of Internet of Things (IoT) paradigm, numerous IoT architectures have been deployed to support indoor environmental monitoring and management. Many of those architectures are deployed and used for maintaining optimal comfort conditions with the aid of live streams of sensor data. IoT sensors can provide real-time feedback to building occupants about their surrounding physical environments. This information will be of great value since indoor conditions have a huge influence on the quality of their well-being.

Choosing an appropriate method for sensor data visualization is important as it may help users to intuitively understand and work with the data faster and easier [1]. Conventionally, static visualization techniques are used to interpret the meaning of captured data by turning data into various graphical forms (e.g., line graphs, charts, bar graphs, scatter plots, and maps). However, such static visualization techniques have certain constraints. For example, they can only allow certain data types to be presented and they are unable to present the real-time sensor data, such as indoor/outdoor air temperature, relative humidity, and air-flow rate. Provision of such information will be of essential importance for making prompt decisions for tackling building problems more proactively. As the complexity of relationships between various sources of data increases and the size of datasets continues to grow, 2D static visualization methods become less helpful and such methods need to be improved [2, 3]. In addition, static visualizations significantly suffer from the lack of the capability for representing live data interactively, thereby prohibiting interactive tasks [2].

A number of previous studies have proposed the development of various visualization methods, which allow for faster and more interactive data representation. Kim et al. (2017) [2], developed VisAR system which offers interactivity with static data visualization using Augmented Reality (AR). Sicat et al. (2018) [4] developed data visualization applications for extended reality (DXR), a toolkit for immersive visualization of building data based on Unity development platform. An immersive data visualization embedded in DXR system was developed to present data with interactive 2D or 3D visualizations. Hosokawa et al. (2016) [5] developed a virtual reality (VR) system to visualize the air flow rate and temperature for an HVAC system by integrating BIM, Computational Fluid Dynamics (CFD) software (i.e., OpenFOAM) data, and VR.

In addition, other methods have been proposed to improve data visualization and facilitate decision-making throughout building lifecycle. For example, Motamedi et al. (2014) [6] investigated a knowledge-assisted BIM-based visual analytics approach for failure root-cause detection. In the mentioned study, BIM is integrated with other sources of FM knowledge (such as fault-tress) and inspection data to provide customized visualizations. Such visualizations assist technicians to utilize their cognitive and perceptual reasoning for problem-solving purposes. In an another study, Natephra et al. (2017) [7] proposed a method to integrate BIM and thermographic images together with environment sensing data in order to visualize spatio-temporal thermal data of building surfaces to support the assessment of indoor thermal comfort. Based on the previous studies, preprocessing of data is a crucial step before proceeding to incorporate digital models into virtual environments. To the best of our knowledge, effective methods for generating visualizations of live data streams for immersive environments are currently missing within the existing body of knowledge.

On the other hand, IoT and real-time sensing technologies are being increasingly used and applied in various platforms to enhance quality of life [8]. Vaccari (2015) [9] stated that IoT enables data streaming from network-connected devices to be delivered and transformed into other types of information to be included in virtual simulations.

Research efforts to integrate IoT and BIM for creating platforms to facilitate various processes in the architecture, engineering, construction and facilities management (AEC/FM) industry have already started. Dave et al. (2018) [10] developed Otaniemi3D platform, which integrates the BIM model of a campus and its corresponding environment data with IoT sensors. The system was used to monitor energy usage, occupancy and user comfort. Pasini et al. (2016) [11] presented a framework for connecting BIM with IoT for operating cognitive buildings. IoT sensors and BIM virtual models were integrated to track the behavior of occupants and provided an opportunity to predict building performance. Previous studies on the integration of BIM and IoT are mainly focused on automating the transfer of sensor information to BIM models [8]. However, when integrating BIM and IoT, in addition to data transfer, special attention must be also paid to the visualization of sensor data. Generating appropriate and targeted visualizations helps stakeholders better comprehend sensor outputs and eventually make better decisions.

In a board sense, BIM refers to a digital transformation of information throughout the building lifecycle [12]. The integration of IoT systems with BIM models remains a great challenge, though, it offers potential benefits for operation and facility management [13]. Integrating BIM and sensor data facilitates measuring environment parameters, such as comfort conditions. Although such integration has been investigated in recent research projects, storing real-time sensor readings and visualizing calculated comfort-related parameters have not been explored sufficiently. To respond to the aforementioned research gaps, this research presents a novel method for live sensor data visualization. In particular, an AR-based visualization technology has been used for indoor comfort condition monitoring. This paper presents a framework for integrating BIM information and IoT sensor data to support visualization of live data streams.

A number of Arduino-based sensing devices have been used to capture real-time values of comfort parameters including, air temperature, humidity, and light intensity. The sensor data are then transferred from Arduino units to BIM and then stored in the BIM file using visual programming. The developed virtual charts are provided with a real-time display of sensor readings in a dedicated AR application. Autodesk Revit, Unreal Engine, and a number of plugins for scripting in those environments were used in our developed prototype system.

2 Proposed Methodology

The proposed architecture for AR live sensor data visualization is an integrated framework for storing IoT sensor data in BIM models, as well as visualizing sensor information in an AR environment for monitoring indoor conditions and assessing indoor thermal comfort. The proposed system provides a real-time measurement and representation of physical environmental variables influencing the experience of indoor environment. Moreover, it provides occupants and facility technicians an ability for identifying problematic issues with indoor conditions in a real-time manner while moving within the facility. The proposed system utilizes a marker-based localization scheme for AR registration. The AR system can visualize the measured values of environmental conditions by augmenting corresponding virtual charts each of which assigned to a predefined maker. The detection of markers triggers the display of the charts on a real-world scene. The system works on the basis of a seamless connectivity between various sources of real-time sensing data, an existing BIM model, and an immersive AR environment. The realization of the proposed framework consists of five steps (as shown in Figure 1). The first step is to install IoT sensors to collect real-time data about environmental variables (e.g., indoor air temperature, humidity, and light intensity). Localization markers are also installed at this step. The second step is to create a BIM model of the facility and to identify the locations of the markers in the BIM model. The locations of the markers and sensors in the model correspond to their real-world placements. In this step, the BIM model together with the location information of markers and sensors are transferred to a game environment. In the third step, sensor readings are transferred by an IoT controller (Arduino in our prototype system) to the BIM server and are stored in the BIM database. In the fourth step, an effective connection is established for allowing a seamless flow of sensor data to the game engine environment. For this purpose, this study takes advantages of visual scripting features of selected game engine. For our experiment, four types of virtual charts have been created for displaying comfort-related parameters in the game environment. These charts are assigned to represent data about indoor air-temperature, humidity, light intensity, and thermal comfort chart which shows acceptable range of air temperature and humidity values according to the Predicted Mean Vote (PMV) method [14]. The virtual charts are registered with respect to the markers' locations. The predefined markers allow accurate registration of the virtual charts for the AR experience. In the last step, the live sensor data and the result of the indoor thermal comfort assessment are visualized in an AR application in a handheld device.

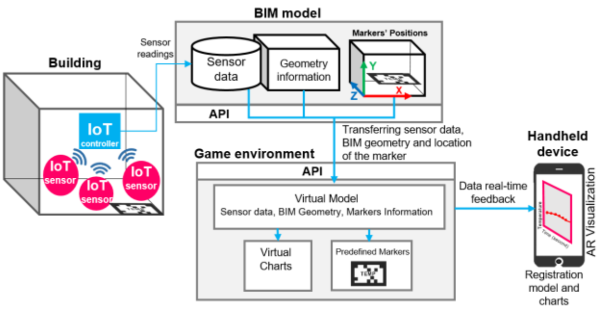


Figure 1. Overview of the proposed framework

3 Prototype system

Figure 2 shows the steps of using the developed prototype system. It follows the steps presented in the previous section. First, a BIM model is created using a BIM authoring application, and sensors devices are installed to collect environment data. Autodesk Revit (Version 2017) is used to create the BIM model of an existing building in our experiment. As mentioned previously, our prototype system uses a marker-based AR localization method. Hence, coordinates of the markers are defined in the BIM model. Environmental data (i.e., indoor air temperature, relative humidity, and light intensity level) is captured using sensors compatible with Arduino microcontrollers. The physical markers are then placed in the facility according to their assigned positions (Figure 2a). The sensor readings are then automatically stored in the BIM model. In order to store sensor readings in the model, a software application is developed using Dynamo, which is a visual programming environment for Revit (Figure 2b). The locations of markers are transferred to the game engine from the BIM model. The third step is to connect sensor readings to the game environment. Unreal Engine is used as the game authoring environment in our prototype system (Figure 2c). In this step, sensor readings are linked to the game environment using visual scripting feature of Unreal Engine. The live stream of sensors in the game engine is maintained using the developed tool. In the fourth step, virtual charts are created in Unreal Engine to represent the measured parameters of the physical environment (Figure 2d). In the fifth step, the sensor readings are visualized in the AR environment. The virtual charts are developed to display real-time data plot of sensor data in AR visualization agents (e.g., smartphone). To display virtual charts, the markers in each room need to become readily visible to the camera. The system then detects the location and the orientation of the smartphone relative to the marker and visualizes the appropriate virtual chart (Figure 2e). Users can quantitatively analyze the environmental condition and assess the indoor thermal comfort based on the PMV method by checking the charts in the AR environment (Figure 2f).

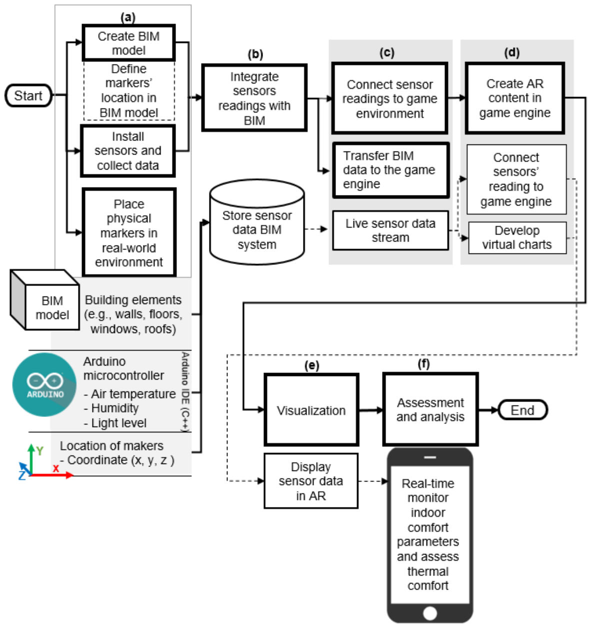


Figure 2. Process flow for integrating IoT sensors and BIM with AR

Figure 3 shows the user interface of our developed prototype system. The initial interface includes a scanning tool (Figure 3a). A marker is used to represent different environmental sensor outputs at once (Figure 3b). Once the smartphone camera recognizes the coordinates of the detected markers, the virtual charts augment the scene (Figure 3c).

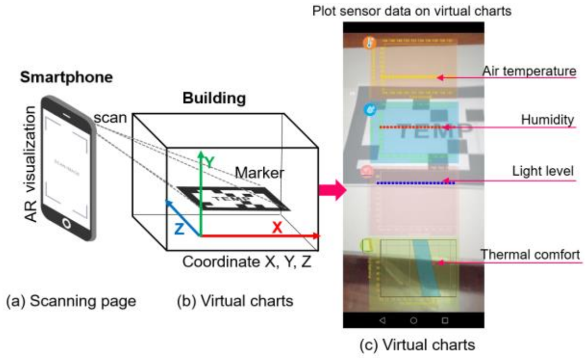


Figure 3. Screenshot of the prototype system

4 Case study

A case study for monitoring indoor comfort-related parameters was implemented using our developed application. To evaluate the capabilities of our prototype system, an apartment on the 7th floor of an existing residential building at Mahasarakham University was selected as an experimentation area. The apartment has two bedrooms with a living and kitchen areas, as shown in Figure 4. The environmental data was captured in the winter (December) from 9 a.m. to 6 p.m.

4.1 BIM modeling and installation of environmental sensors

Autodesk Revit version 2017 was used to create the BIM model of the case study. The markers were placed in the center of each room at a height of 1m from the floor (Figures 4a). For each room, specific visual charts to present related environmental parameters were associated to the corresponding marker. Three measurement points for capturing indoor air temperature, relative humidity, and light intensity were chosen at the level of 1m above from the floor (Figure 4b). Arduino Uno with its compatible sensor, (i.e., DHT11) were used to measure indoor air temperature and the percentage of relative humidity. Temperature range of the chosen sensor is from 0 to 50 °C, with ±2°C accuracy. Humidity range of the sensor is 20-90% RH, with ±5% RH accuracy. Light intensity of the case study was measured by Photoresistor sensors. The sensors were set to collect data with time intervals of 1 second.

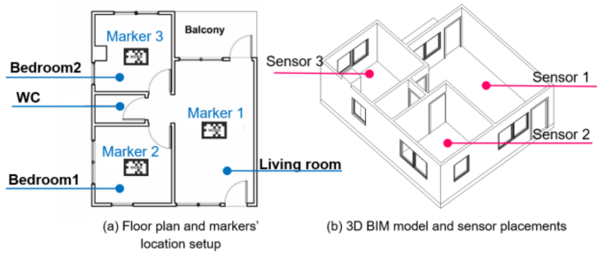


Figure 4. Experimentation room, makers' and sensors placements

DHT11 environmental sensor modules were connected to Arduino Uno microcontroller (Figure 5a). DHT 11 provides digital signal outputs of relative humidity and temperature. Arduino Integrated Development Environment (IDE) was used to build the code uploaded to the physical board. DHTLib library was installed to Arduino IDE to collect humidity and temperature readings. In this experiment, pin signal of the sensor was connected to a digital port of the Arduino board to read data output from the sensor. To measure the light intensity, photoresistor sensor modules are installed on Arduino boards. Analog pin A0 was used to read value of lighting level. Once the procedure to upload the developed code to Arduino boards is done, sensors start to capture readings. The code used to setup and run sensors for measuring the specified comfort parameters is shown in Figure 5b. Three variables are measured and displayed in the serial monitor (Figure 5c). The outputs of temperature, humidity, and light intensity level readings were represented in Celsius (C), percentage (%) and Lux (lx), respectively.

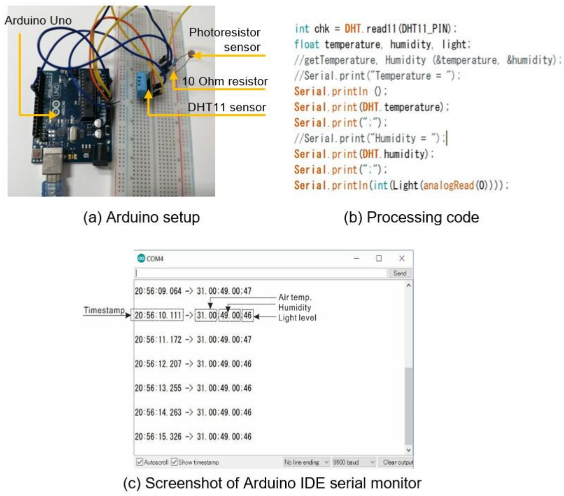


Figure 5. Circuit board setup, processing codeand sensor reading outputs

4.2 Sensor reading, BIM, and game engine integration

The procedure of connecting sensor readings with BIM is shown in Figure 6. First, DHT11 and photoresistor sensors were interfaced with Arduino board (Figure 6a). After uploading the developed code to the board, environmental parameters (i.e., air temperature, humidity, and light intensity level) were captured and the outputs of sensor data were displayed on the serial monitor console (Figure 6b). In order to transmit sensor readings from Arduino Uno to BIM, Firefly plugin provided in Dynamo (a BIM visual programming tool) was used (Figures 6c and 6d). To link Arduino sensor outputs with Unreal Engine, UE4Duino2 was used (Figure 6e). This plugin makes it possible for the Unreal Engine to retrieve data from Arduino in real-time. The user interface for representing sensor data in AR is created using Unreal Engine (version 4.20) (Figure 6f). Google ARCore, a plugin for Unreal Engine and an Android smartphone was utilized to build the AR application (Figure 6g).. Consequently, the AR live data visualization in smartphone can be performed. Consequently, the AR live data visualization in smartphone can be performed.

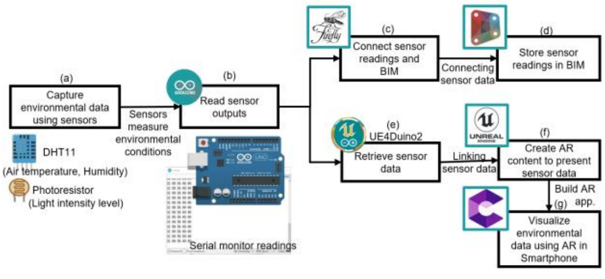


Figure 6. Sensor readings transfer to BIM and game engine

4.3 Connecting IoT sensor outputs with virtual chart in game engine

In order to visualize the measured values from IoT sensor readings, virtual chart widgets were created in Unreal Engine using Kantan Charts, a simple Unreal Motion Graphics (UMG) chart plugin. To monitor environment variables in real-time, Time Series Plot charts were used to represent the sensor outputs containing environmental information over the specified time intervals (Y-axis presents value of the measured values of environment parameters, X-axis presents time, in seconds). Cartesian Plot chart was used for real-time representation of indoor thermal comfort (Y-axis presents value of the measured relative humidity values, X-axis presents dry bulb temperature value).

4.4 Creating AR application using Unreal Engine

Our prototype application was run on an Android smartphone. In this experiment, the handheld device to support ARCore was a Huawei Y9 2019 (Android 8.1). To setup target markers in the AR application, the locations of the marker were obtained from the BIM model. The target images were imported to the Unreal Engine and added as a data asset using *GoogleARCoreAugmentedImageDatabase* and *GoogleARCoreSessionConfig*. To allow the AR content to be built and target image to be tracked by a smartphone, *Start ARCore Session* node was used. The created data asset was added in the configuration input.

4.5 Storing data in BIM and data visualization in AR

To store sensor data in BIM, readings were retrieved using Firefly visual programming plugin. Figure 7 shows sensor readings in Dynamo. Sensor readings along with their timestamp were saved as text file (Figure 8a), which can be used for tracking operation history for further indoor condition analytics. Figure 8b shows an example of the environmental data output visualization using the developed system.

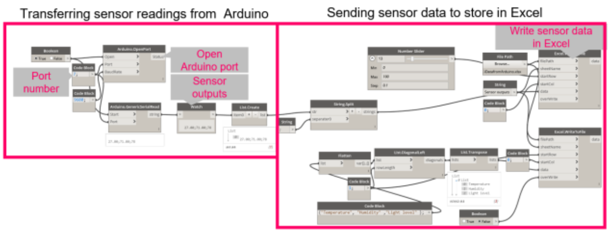
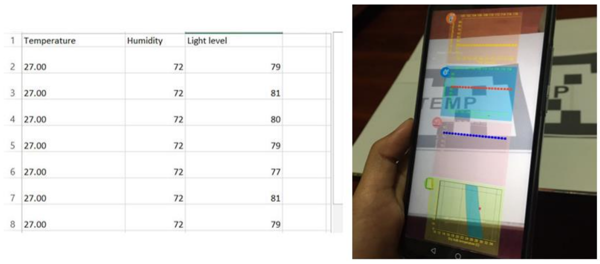


Figure 7. Screenshot of visual script for connecting sensor reading to BIM



1	Temperature	Humidity	Light level
2	27.00	72	79
3	27.00	72	81
4	27.00	72	80
5	27.00	72	79
6	27.00	72	77
7	27.00	72	81
8	27.00	72	79

(a) Transferring sensor data from BIM to store in Excel
(b) Data visualization on smartphone

Figure 8. Example of sensor outputs

5 Conclusions and future work

This paper presented a method for developing a live sensor data visualization of indoor comfort variables using AR technology. According to the real-world experiments reported in this study, integration of BIM, IoT-driven environmental sensing, and AR based visualization provides the opportunity for real-time monitoring of comfort-related parameters and indoor comfort condition tracking. The system also provides the possibility for the assessment of those indoor environmental variables that have significant effect on indoor comfort. The proposed system can assist users in the identification of problems in a real-time manner. The information collected about indoor environmental conditions can be stored within the BIM database to be further analyzed for knowledge discovery from historical data about the facility indoor conditions.

For the delivery of AR experiences, an AR application was designed and developed with the aid of marker-based localization method. The results demonstrated that the sensor data retrieved from Arduino Uno can be successfully transferred to the BIM model, and sensor outputs were also successfully integrated with the game environment. To build the AR application, Google ARCore plugin for Unreal Engine and ARCore for smartphone were used. In our prototype system, the developed AR application was able to successfully deliver the augmentation of the real-time sensor data in the form of virtual charts on a smartphone.

Some challenges need to be addressed in our future works, such as improving the system to assess thermal and visual comforts by integrating other sensors including, air-flow rate, infrared radiations, noise, and air quality. Additionally, calculating other variables necessary for comfort assessments (e.g. MRT) will be added. Regarding the visualization method, in order to provide a greater level of immersion for users, integrating the prototype system with other Mixed Reality (MR) solutions should be developed. The interaction between users and the virtual environment can also be improved by adding an ability to move the AR objects in the AR application. Further, investigating methods to use the developed system for other use cases in facility management, training, and design processes should be investigated. Further research should also focus on improving the system to automatically track the current environment conditions and push alerts to occupants' personal digital devices and warn them about the prospective causes of the detected undesirable comfort conditions. Finally, a method to use BIM as a central storage of sensor data which is connected to the AR system will be developed.

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