Re-design of smart homes with digital twins

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Abstract. One of the key transformations in the epoch of the Internet of Things (IoT) and industry innovation is Digital twin. The top trending technologies like Machine learning, artificial intelligence, Cloud Computing platforms, Big data architectures, Software analytics and the Internet of things (IoT) are integrated and used by a digital twin concept in an immense way which changes the IT business productivity and reduces the cost of investment. Digital Twin is a flourishing tool which integrates the both physical and virtual scenarios/worlds. This paper presents the re-designing solution for Smart homes using the digital twin paradigm. The introduction and the concept of this technology are introduced first, and then presented a sophisticated smart home architecture with digital twin. At last we performed experiments on this digital twin architecture and compared with normal IoT implementations. In this Whitepaper, we reviewed the concepts of Digital twin technology, IoT and re-designing idea for building Smart Homes.

1. Introduction

With the mounting deployments of the Internet of Things (IoT) systems, the significance of the concept of a digital illustration of physical things has gathered trivial interest in the recent years [2]. Digital Twin is basically a living model of the physical skill or system, which will repeatedly adapt to changes in the milieu or operations and bring the best business outcome. It can also be rapidly, quickly and easily scaled for quick deployment for the other, similar applications. Building a smart building is often an essence for deploying all the sensors, software, network, and physical assets [5]. The data collected and analysis results are shared to the digital twin and can be monitored by an individual. The most outstanding example of this trend can be found in the Gartner's report titled "Top 10 Strategic Trends for 2017" published in October 2016, Digital Twins was Number 5 strategic trend for 2017 in this report [6][7]. These digital proxies are expected to be built from the domain knowledge of subject matter experts as well as the real-time data collected from the devices [1].

“Digital twin is the skill to craft a virtual depiction of the physical elements and the dynamics of how an Internet of Things device operates works and device act in response right through its lifecycle.” The source of the term “Digital Twin” was used by Dr. Michael Grieves at the University of Michigan, USA around 2001-2002. He initially defined this in the milieu Lifecycle Management of product. He initiates the idea of a “Digital Twin” as a virtual representation of manufactured object. He widen the design of comparing and contracting a Digital Twin to its engineering design to better realize what was produced versus what was designed. Likewise tightening the gap between design and execution [3][4]. Gartner predicts that by 2021, “55 % of huge industrial organizations will use digital twins, ensuing in those companies gaining 15 percent perfection in effectiveness.” So, while digital twin technology isn't
getting the same level of media consideration as 3D printers or voice assistants, there is little doubt that it
will be a game-changer and become an integral part of how all businesses of the future (not just
manufacturing) will optimize processes, products, and communication [3][11]. The Internet of Things (IoT) was motivating the design of digital twins so businesses could take action on data -- that crosses both the physical and digital worlds. Gartner foresee that above 20 billion components (most from the manufacturing industry) would be associated to the IoT by 2020 [4]. As a result, a large quantity of various data is breeded. Which would be in excess of 40 zettabytes (ZB) by 2020 [4], as well as structured data, semi-structured data and unstructured data [1].

Being able to see it, before we build it has been a long-time aspiration for the manufacturing industry. The technology called Digital Twins which makes it a reality. It allows you to understand how a product would perform before you have to build it [3]. Today’s proliferation of sensors, faster computing power and capturing data has grown exponentially [2]. The current acceleration in the usage of digital twins is mostly possible thanks to Internet of Things and the minor costs of technologies that boosted both IoT and digital twin [7]. This illustrates how a digital twin route sensor generated data from an instrumented advantage and Influences replication to forecast malfunction and make out in capabilities [5][8]. This makes possible an industry to take appropriate action to straight away to correct troubles and optimize the asset's recital. Digital Twin is also called as a replica of an object; it's more than a blueprint or a schematic, virtual twins, shadows, and device virtualization etc [2].

2. Related work

The conception of Digital Twin was initially proposed by Dr. Grieves. He defines it as by the following terms: Digital Twin Prototype, Digital Twin Instance, and Digital Twin Aggregate

2.1. Concept

The Connection of processed data and information between the physical and virtual world that cramp both the world products put together.

In the physical world, the real entities will have the data collected through sensors. In the virtual side, models maintain the information about the specific asset [8]. We have tools for collecting data on the physical side and tools for analyzing and processing data [3]. The establishment of a connection between the twins is a task [9]. But we need a tool for the unifying the virtual and real objects. We have a solution for creating a linkage between real and virtual world products that is Unified Repository (UR) which is a two-way connection between data collection tools and virtual development tools [10].

![Concept of a Digital Twin](image)

**Figure 1** Concept of a Digital Twin.

2.2. Applications

It has brought a wide range of applications such as smart buildings, smart cities, Smart Homes, oil and gas, aircraft engines, HVAC control systems, locomotives, wind turbines, off-shore platforms and in Health-care. For case in point, ‘Virtual Singapore’ is a part of the Singapore's government’s Smart Nation Singapore project. It’s the world's initial digital twin of an accessible city-state, pay for Singaporeans an valuable way for the digital literacy with respect to economy [11][12].
IBM, Amazon, Microsoft Azure IoT, GE Predix, and other industry vendors are already providing digital twin based solutions.

- **IBM**: In promoting the concept of digital twin, IBM is definitely a most prominent vendor. It would actually build a digital twin on IBM Watson IoT [12].
- **Amazon**: Amazon refers digital twin as device shadow. A device shadow is a JSON file that contains the information, meta-data, timestamp, unique client token and a version of a device connected to the device shadow service [6]. Amazon gives three basic REST APIs that can be used to interact with the device shadow: GET, UPDATE, and DELETE. You can also interact with the device shadows using MQTT messages [7][5].
- **Microsoft**: Microsoft Azure IoT does have the model of a ‘device twin’ that is part of their device management way out. A device twin is automatically created when a device is connected to the MS IoT hub. The device twin is a JSON file that stores the device state-information that can be used to synchronize device information with back-end processes [7][4].

2.3. Challenges

There are so many challenges to designing a smart home based on digital twin approach [3][7]. Basically, the following are the common challenges for developing a smart twin home.

2.3.1. **Data privacy.** The sharing of data about the home is a major privacy issue. Data administrators and cloud providers will sell the data to the industry vendors. Data privacy and security could limit the market up to 80 percent [2].

2.3.2. **Security.** Security provided to smart twin solutions are at major risk. Because the cost of the solution has to be increased, which leads to lower the value and demand to the market.

2.3.3. **Hardware.** Smart Homes requires lot more sensors, actuators and controllers for the maintenance of Smart Home. The cost and deployment of this type of hardware in providing the smart solutions will be high [6].

2.3.4. **Connectivity.** Connectivity refers to the infrastructure and protocols which connect devices to the cloud or network. Always the virtual product and the physical product are to getting connected with each other[ 8]. For the tracking of home, we could rely on the continuous data connectivity of sensors and the virtual model to the application.

2.4. **Internet of Things.**

IoT is a collection of physical entities by means of which the objects are associated in a network and communicate with one another. Internet of Things involves human to machine communication along with the machine-to-machine communication. Internet of things simplifies the life of every individual by making to feel like every object is really talking to us. Use of the IoT saves more human efforts and saves energy and time. IoT can be applied in every field like agriculture, Industries so that things get easier and much faster [7].

2.5. **Smart Home Applications**

Smart home applications are part of home automation. Smart Homes is not about turning devices on/ off, rather than it involves, a lot more energy savings. Using these applications brings a feeling that we are actually present with those objects and handling them. Some of the applications we consider are like Smart door lock, smart switching off lights and fans, and smart refrigerator. These smart home applications can be expanded according to future needs and convenience to make the easy and friendly environment around us.

Nothing is more important than knowing your family is safe and secure, automated door lock system gives you peace of mind, you are notified with status of door condition locked or unlocked so that you can lock the door and you can grant access permission to a person who wants to enter your house even from your workplace itself.

All the time checking the groceries at home and starving for the food which is already completed is a boring work for many people, so to overcome these problem smart refrigerators notifies you always with...
groceries needed if they are completed and places the order in the grocery store. With the smart switching system, the lights and fans get on and off according to movements of the humans in the area. We can even control them from anywhere according to the notification sent by the objects which makes life more comfortable, easier and flexible.

3. Proposed work
Before beginning the building of Smart Homes, just revisit the concepts of Smart Homes and IoT. Smart Homes involves automating the home using internet, sensors, actuators and network protocols. In designing of smart home, it make use of micro-controllers to supervise ovens, refrigerators, washing machines, lighting and VACH facilities (Ventilation/Air-Conditioning/ Heating) with respect to temperature or humidity and it is adjusted in accordance with house owner’s provisions[6]. As a result, it is manifest that home automation has some degree to take account for the indoor energy management and supervision with the guidelines of domiciliary owners. The computer which is user-friendly and seamless control unit in the household environments[6].Today's scenario of home automation, systems are written in dispense programming and monitoring control amid a devoted device in the home, like the control panel of the security system, and a user-friendly GUIs that can get into via an Internet-accessible PC, smartphone or notebook/tablet[6]. The system which bring about the connected thermostat and smoke alarm to generate a two-way association with the users where both benefit and communicate with each other. So it even sounds like an "acquainted home"[6].

The building of a smart home system design using the digital twin concepts, we design it by three steps.

- DESIGN
- BUILD
- OPERATE

3.1. Design: How to create a Digital Twin
First, a Digital Twin is created using 3D software (E.g: ANSYS software). You can sit in front of your computer craft a Digital Twin. For example, create and design a Smart Home using 3D software as a replica of the physical system. Here using this software we can design the prototype of the home. Digital twins shaped using ANSYS simulation tools to optimize the operation of devices or systems, save money by sinking unplanned downtime and enabled engineers to test solutions virtually ahead of doing physical repairs[5]. Designing is a very vital phase. The house was outfitted with PIR sensors, controllers and actuators which were coupled to a data acquirement component that sample the data and offer analytical results in a smart way using the IoT platform. The design of the domicile is deployed into the recorded POV Holo-lens.

3.2. Build: Twin Home
The design of twin Home is to be visualized for that we have to first make a revisit that the designed physical system has collected data from sensors, storing in the database and performing analytical operations. The PTC ThingWorx proposal shaped an ecological unit to unite devices and sensors to the IoT, disclose the value of IoT data, develop enterprise-level IoT products, and authorize end-users all the way through augmented reality[5]. ThingWorx was used as the broker inbetween the sensors and the digital data, as well as the simulation model of the home[5]. A machine-learning layer in ThingWorx in a row on the EL20 scrutinize the sensors and other devices, involuntarily learning the usual state pattern of the home in operation, make out operational anomalies, and breed insights and predictions[5].

The ThingWorx policy was as well used to build web applications that display sensor and control data as well as analytics[5]. For example, the app exhibits the lights on/off condition, the status of the groceries stock etc. An augmented-reality front-end overlay sensor data and analytics as well as parts lists, repair directives and other personal-based information on an image of the home screen is seen through a user's PCs, Smartphone, tablet or hololens[5].
3.3. OPERATE: The Data processing task

To make obvious the worth of the digital twin, the home primarily was function usually. First, smart entities that use sensors to congregate data about real-time status, working condition, or position are incorporated with a physical assert. The apparatus are associated to a cloud-based system that obtain and processes all the data the sensors monitor. This input is evaluated aligned with business and other contextual data. Sensors detect the status of the environment and acts for that reason so that it reduces the energy consumption and power usage. The sensor readings showed that the energy consumption, resources usage etc. Red alerts were concerned, and the predictive analytics indicated that if any disaster takes place in the building. But the sensor readings and analytics did not clarify the effect of disaster occurs and does not afford solutions to the specific task. The Home encounters a problem of outflow of water in the home it informs to the owner and asks for obligatory action. It shares the data with the on hand plumber in the area.

The associated system model demonstrates the same HMI interpretation as the physical home, with abridged energy consumption level, the status of home and leakages of the water if any. A 3-D simulation model in the cloud associated to the physical home was set off by trigger a "3-D simulate" button on the system model HMI. The 3-D simulation gives you an idea about that the cause of a problem persists and elucidates the problem encounters. It may be constructive in the large industrial machines.

By detach the system model from the physical home, the system model's HMI could be used to strive various prospective fixes. The Internet of Things allows the simulation models to attach to in use products with a platform as ThingWorx. So there is a chance that industry can better understand and optimize product recital [5]. Companies can use these digital twins to spot and isolate faults, carry out diagnostics and troubleshooting. Also, it facilitates recommendation for corrective action, determine the ideal maintenance schedule depending on the essentials of the entity asset, optimize asset operation and turn out insights that can progress the product's next generation. The latent benefits of digital twins are noteworthy [5]. The bottleneck is in optimizing upholding and operational troubleshooting. But as customers begin to demand outcomes and not just products, the digital twin has the latent to be the key to unbolt this additional value for both corporate product manufacturers as well as their esteemed customers [5]. The following figure depicts the operational flow in the Smart building. Digital physical twin of the Smart Home next to the augmented virtual twin, recorded POV through the HoloLens or smart glasses. The bus or Wi-fi module of the house is connected via an MQTT gateway to IoT platform cloud-based service provider. This allows you to control and visualize the virtual twin in MS-HoloLens using gestures, and the physical twin is connected to the MQTT broker using ESP8266 OS to replicate lights for each room. The major and powerful advantage of the digital twin is its collaboration. An individual can monitor and operate the home by tracking the physical smart home through a replicated virtual model.
4. Experiments

In this section, we first give the Requirement Specifications in Section A, Procedure in Section B, Working of the prototype in Section C and results in Section D.

4.1. Requirement Specification

For building a Smart Home, we require some hardware and software tools based on the digital twin approach. The hardware:

- Arduino UNO Microcontroller.
- ESP 8266 Wi-fi Module
- Sensors(PIR, HTU 21D-Humidity and temperature)
- USB to UART cable
- Male and female Jumper wires.
- Relay Driver Modules
- Breadboard and wires
- Buzzer
- LED bulbs
- Fan

The Software tools like:

- Arduino SDK
- PTC Thingworx IoT platform
- Microsoft Azure IoT hub
- ANSYS Software- Simulation Platform
- Windows 10
4.2. Procedure

Build up a prototype for a smart home in which sensors are connected to the lights, fan and at the door lockers. The Arduino Uno microcontroller is soldered with the ESP 8266, sensors and Relay drivers on a single PCB. The Arduino SDK is to be downloaded and installed into the Windows 10. Click on a sketch and upload all the configuration and header files onto a board. We are using C language for onboard programming. Using the serial monitor after enabling wifi, we visualize the numerical data in it. Using MQTT protocol under a TCP/IP connection, we transfer the data into the Azure cloud. For this, we need to have an account in Azure and Azure SDK installed on your system. Create a virtual 3D image for the smart Home Prototype using ANSYS software. It gives the perfect simulated image of the real home. The virtual image is to be connected to the Thingworx platform. For that, we need to have Thingworx account. Connect your Arduino Uno set up to Thingworx and upload all the values to a Thingworx “Thing”. First set up a ThingService, Thingshape, Thing, within your ThingShape and Application Key. Program your Arduino with Thingworx wi-fi library and Thingworx Ethernet library.

```cpp
#include <ESP8266WiFi.h>
#include<HTU.h>
#include<Adafruit_Sensor.h>
#include<Ethernet.h>

const char* ssid="MyNetwork";
const char* password="abcdef9678954";

// Application id key which gives login credentials
char app-key="287b9c77-983c-4abf-9f75-4fc237c7183a";

// create a thing and give the name to the things
char thingName[]="HTU21DThing";

// service Name offered by the service
char service-Name[]="setTempandHumid";
```

Edit the sketch file by giving values to the name and IP address of the Wi-Fi and upload onto the board. Install, configure and run your Thingworx Azure IoT hub connector and import all the objects present in the prototype that exist in Azure into Thingworx. Connect virtual image and simulated device to the Thingworx server. The MQTT protocol is a light-weight protocol that can be used for communication. The house is connected via an MQTT gateway to Azure IoT hub. This allows you to control and visualize the virtual twin in MS-Hololens. Get connect the real home devices and a virtual image of the smart home to the cloud using Wi-Fi.

4.3. Working of the Prototype.

The prototype works as follows: As a person enters into the house, it checks and opens the door for the person. If someone enters into the room, it automatically turns on the lights and off the lights when he left the room. The Virtual image reflects what’s happening in the house and in every room. As it is reflected a 3D virtual image so that the person feels the actual home and controls the home by the gestures. It’s easy to gain a controlled access on home application through 3D image than a 2D image in the Smart Phone. The cloud gives the time, temperature of every room, and energy saved throughout the day. The Thingworx platform creates a web GUI and gives the results on a dashboard on the smartphone using a mobile app. A 3D image is reflected the smart lens also enhances the same results and also gives a perfect view of his home and the problems that encounter in a home. For example, if the Fan encounters a problem from its actual working condition, it tells about where the problem occurs, and suggests solutions to the user.
4.4. Results.

After working of the prototype the results are sent from the cloud to the user which he can see a 3D image on which he can perform the necessary actions on the object and the cloud performs some analytical operations and displays the required notifications. For example, (If the door is left unlocked, notification is sent to the user and he can check anyone is there in the house and makes it locked automatically). Likewise, (If the refrigerator identifies some missing groceries it will be notified to the user to place the order in the grocery store and with his permission the order will be placed in the best grocery store automatically which will be selected according to the algorithms performed by the cloud and user here saves time in choosing which items are needed and in choosing the grocery store nearby). The analysis of energy consumption by the objects in the actual world and by using digital twin method is as shown below:

![Figure 3. General IoT vs Digital twin](image)

5. Conclusion

The Paper mainly focuses on the concept of digital twin and the implementation of this technology in smart Home applications. In starting of the paper we presented the basic concepts and challenges of smart homes. Next sessions include the digital twin concepts and its implementation. Furthermore, experiment setup is established. At last, it’s compared the results with digital twin IoT implementation and normal IoT implementations. Digital twin is a revolutionary development in IoT. Problems encountered during smart home automation are overcome through digital twins. IoT concepts are best simulated through digital twins. So efficiency and user friendliness is rapidly increased. Digital twins are the added advantage of smart homes. As the system design is needy on the user’s discretion and the judge aptitude of the circumstances. If a guest or intruder entering into the home, it may give by taking the photographs by the use of camera and connect to it microcontroller and send it to the owner and develop this application for the further more. So, digital twin is a boom to the IoT architecture.

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