Design and Development of Smart Home Sensing Supported by Blockchain Technology

Maode Ma, Zhaozheng He
School of EEE
Nanyang Technological University
Singapore

Quanqing Xu
Institute of High Performance Computing, A*STAR
Singapore

Xue Jun Li
Department of EEE
Auckland University of Technology
New Zealand

ABSTRACT

This paper presents the design and implementation of a smart home system in the context of Internet of Things (IoT) with Ethereum private Blockchain, Raspberry Pi, Blynk platform, DHT11 temperature and humidity sensors. By Raspberry Pi, it collects real-time room humidity and temperature information by DHT11. The data is then uploaded to the Blynk App, which is stored on the smart contract deployed with the Ethereum private Blockchain. When the real-time humidity or temperature value exceeds a predefined threshold value, warnings are given by turning on LEDs. The system functions as a proof-of-concept prototype, showing the feasibility of applying blockchain in smart homes with IoT functionalities.

CCS Concepts

Networks → Data center networks•Computer systems organization → Real-time system architecture•Computer systems organization→ Sensor networks

Keywords

Blockchain, Bitcoin, Internet of Things, Raspberry Pi, machine-to-machine communication

1 INTRODUCTION

In 1991, Stuart Haber and W. Scott Stornetta worked on a cryptographically secured chain of blocks to prevent change of timestamps of documents. This pioneer work led a new technology called Blockchain [1], which was first introduced to the public by Bitcoin in 2008 [2]. Since then, the potential possibilities of the Blockchain technology to improve the efficiency and reduce the cost of maintaining the existing software or networks have been shown to developers, entrepreneurs, and investors all over the world.

In Blockchain, a common database of records is maintained among all the participating nodes in a distributed network. Through a consensus protocol, transactions are used to change the states in the network. The Blockchain technology is a combination of several advanced technologies, such as distributed networking, cryptography, hashing, and distributed consensus [3]. Consequently, Blockchain technology has properties like privacy safeguarding, resiliency to attack, history immutability, distributed fault tolerance, and transaction automation.

The salient feature of blockchain is that no Trusted Third Party (TTP) is needed to maintain the network as all the participating nodes would take part in the maintenance of the system. Therefore, many companies and organizations have been attempting to apply Blockchain in in decentralized applications in cryptocurrency, assets management, financial services, resource sharing, and Internet of Things (IoT) [4].

Applying Blockchain to IoTs remains challenging due to many factors, such as trust management, adaptable and dynamic security framework, resilience against combined cyber attacks, energy-efficient data mining, vehicular cloud-based advertisement dissemination [5], social networks, blockchain-specific network infrastructure, and Skyline query processing [6].

With Blockchain, single point of failure can be eliminated as all the participating nodes will take part in the transaction recording and validating. The data transactions will be more secure with a more resilient-to-attack system for different kinds of device to run on. Additionally, the Blockchain together with the IoT infrastructure will provide automatic transactions with fully autonomous device corporations, reduced cost and settlement time [4].

As the Blockchain and IoT gaining popularity among the society during these years, companies and start-up teams are developing new systems or software by integrating them. Here we highlight some examples as follows. Slock.it is trying to make the rental and return process of Airbnb apartment fully automated with the smart contract to control the door lock remotely [7]. Oaken Innovations is cooperating with Toyota Research Institute to build a decentralized car leasing application which could provide secure and fast car rental transaction [8]. Filament aims to provide the hardware and software solution for the effective machine to machine communications which would enable the enterprises and industries to use data to create new efficiencies and cost savings at scale [9].

A smart home refers to a residence with information and communications technology (ICT) that anticipates and responds to the benefit of the occupants through appropriate decisions [10]. Alam et al. presented a review of smart homes in [11]. The technologies of Blockchain and IoTs are well fitted in the

ICIT 2019, December 20–23, 2019, Shanghai, China

ACM ISBN 978-1-4503-7663-1/19/12…$15.00
https://doi.org/10.1145/3377170.3377281

context of smart homes. Time synchronization in IoT devices in a smart home was discussed in [12], where Fan et al. proposed a blockchain-based scheme to assure the security. In [13], She et al. proposed homomorphic blockchain technique to preserve privacy of sensitive data in smart homes, through using a new block data structure and an encryption algorithm based on Paillier encryption.

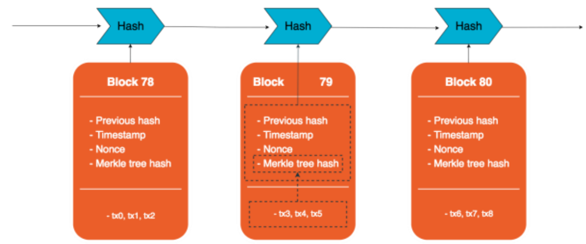
In this paper, a system was built to combine IoT and Blockchain for smart home application. We used two Raspberry Pis to collect the data from the humidity and temperature sensor DHT11 with an interval of 15 seconds. The captured data is then shown in the Blynk App, which is a mobile digital dashboard for IoT project, for the user to monitor and interact with the smart contract easily. Next, Ethereum was used to build the smart contract, which store the collected sensor data. In the Node.js runtime environment, the Raspberry Pi 3 would send and read the data to and from the Blockchain by running a JavaScript program. The user can also set the threshold value for both humidity and temperature stored on the smart contract. The JavaScript will compare the real-time humidity and temperature values with the corresponding threshold value whenever value changes were noticed. If the real-time humidity (or temperature) value exceeds its corresponding threshold value, warnings will be given by turning on the green (or red) LEDs. This system simulates a smart home automation application, which would turn on the air-conditioner or dehumidifier in two rooms. LEDs are used to emulate air-conditioner and dehumidifier due to the material and time limitation.

In this paper, we design and implement a prototype system for humidity and temperature sensing in smart home application with Blockchain and IoT. The rest of the paper is organised as follows. Section II revisits related work, and Section III presents the proposed design. Section IV presents the implementation and Section V discusses the results. Section VI concludes the paper with discussion on future work.

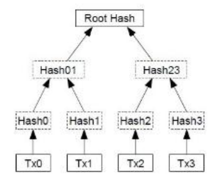
2 RELATED WORK

2.1 Blockchain

Blockchain is a decentralized database that records the chain of blocks. Each block in the chain is consists of the block header and the validated transactions of the within the period as shown in **Fig. 1**(a). The block header contains the hash value of the previous block, the timestamp of the block, the calculated nonce of that block and the Merkle tree root hash [1]. The hash value of the previous block is used as an indication linking the current block to the previous block. It is also used as a part of the information to create the hash of current block. The timestamp of the block is an indication of the approximate time at which the block is created. The nonce is the calculated result from the successful mining process which is defined in the consensus protocol. The Merkle tree root hash is produced by combining the hash value of each transaction included inside the block recursively in a binary manner until a single hash value occurs. The calculation process is shown in **Fig. 1**(b). The Merkle tree root hash can be used as verification if any transaction belongs to the block. If a transaction tampers exists, the final Merkle tree root hash will definitely different from the original one. It is easy to recognize this transaction is not valid on the block. The Merkle tree structure provides the integrity and tamper-free properties for the blockchain.



(a) Three Consecutive Block



(b) Merkle Tree Generation

Fig. 1. Key concepts in Blockchain

2.2 Internet of Things

The European Commission predicts that there will be 50 to 100 billion devices connected to the Internet by 2020 [14]. To manage these devices in a systematic and effective manner, the market potential is huge. For example, the market value for home automation will reach $ 44 billion by 2025. As such, one of the important aspects of IoT in the future will be smart home with appliances automation. It is necessary to design some efficient and optimal fundamental networking system. The networking system should connected devices to communicate with each other efficiently, and perform automation action depending on different conditions correctly. Nowadays, most of the IoT foundation systems are cloud-based. They face the problem with high centralization, potential vulnerability to attack. With the features like decentralization and high security, Blockchain can be used as a transaction platform. The smart contract can be implemented to set the rules for automation process. It is thus interesting to combine Blockchain technology and IoT in the context of smart home.

By combining Blockchain and IoT, a smart district model was proposed to provide the power grid access for an individual [15]. This model is a prototype model for a user to interact with the power grid system. Anyone with a solar panel could participate in the network to buy or sell energy directly on the blockchain. The authors defined some important features for a home automation system. The system should have supervision and control over all the devices in the network. Different types of sensors and actuators should be implemented. The system should be resilient to malicious attack. To hide the sophisticated algorithm from the users, a user-friendly interface is necessary for the users to interact with this system. There should be enough memory space to store all the important data and parameters. The communication between devices should be effective. Scalability is also important. The way to connect the devices to the systems shall be designed carefully according to the requirements.

Next, a smart home system implemented with the Ethereum Blockchain was presented in [16]. The system uses the smart contract on the Ehtereum Blockchain to handle access control policy, data storage, and data flow management. With the smart contract, the utility meter could be tracked. The rules can be set to control air-conditioner and light bulbs to save energy. An Ethereum private blockchain is used to saves all the transactions of the smart home system. Owners in each home are provided with different levels of authority to control the accessibility of each owner to the system. However, it was not implemented in a real test bed environment.

3 PROPOSED DESIGN

Fig. 2 shows the overall design workflow of the system. Four major components are integrated to build this smart home system, namely DHT11 humidity and temperature sensor, Blynk App, Raspberry Pi and Ethereum private blockchain. The DHT111 sensor measures the room temperature and humidity and sends the sensor data to the Raspberry Pi in every 15 seconds. Blynk is a platform that provides iOS and Android app for the users and developers to control ESP8266, Arduino, Raspberry Pi, SparkFun and many other microcontrollers or single-board computer in the market. Developers are allowed to drag and drop the widgets

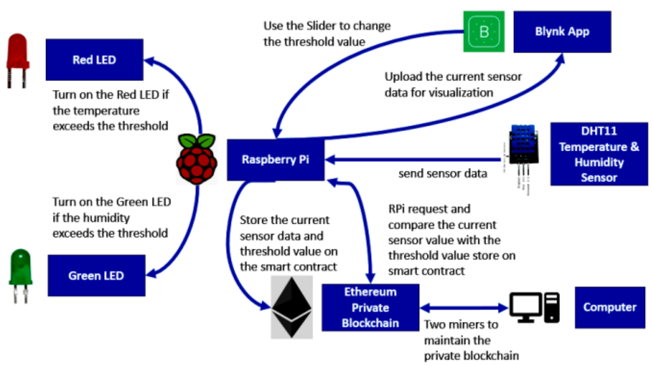


Fig. 2. Design Workflow of the Smart Home System onto the dashboard to build a user-friendly graphical interface for their projects. These widgets can be used to control the hardware remotely, visualize and display sensor data.

Raspberry Pi is a single-board computer which could simply do any task just as the normal computer. We chose Raspberry Pi 3 model B 2015. Two JavaScript files are used for RPi to interact with DHT11, Blynk App, and Ethereum private blockchain. RPi collects the sensor data from DHT11 and visualizes them in the Blynk App. Whenever new sensor data is received, RPi also uploads the sensor data to the smart contract. It would compare the current temperature and humidity value with the respective threshold value stored on the smart contract. If the current temperature value exceeds the temperature threshold, the red LED would be turned on. Similar procedures apply to the humidity value but instead, the green LED would be controlled. RPi will interact with the smart contract and change the corresponding threshold value if the users change it on the Blynk App by slider widget.

Ethereum is the platform used to build the private blockchain and the smart contract. The Ethereum private blockchain is maintained by the two miners from the same computer. The smart contract written for this work is to store the current sensor value and the threshold value submitted from the RPi..

4 IMPLEMENTATION

Table I and **Table II** summarize the specifications of Raspberry Pi 3 (as shown in **Fig. 3**) and DHT11 (see **Fig. 4**), respectively. DHT11 is a temperature and humidity sensor complex with a calibrated digital signal reading. There is only one wire for the data signal which makes it very easy to set up. DHT11 is popular for use in remote weather stations, soil monitors, and home automation systems. The DHT11 is composite of a surface mounted NTC thermistor and a resistive-type humidity measurement component. A high-performance 8-bit microcontroller on the back of the module converts the resistance measurements from the thermistor and humidity measurement component into digital temperature (in ℃) and relative humidity measurements. It provides advanced properties like excellent quality, fast response, anti-interference ability and cost-effectiveness.

Table I. Raspberry Pi 3 Model B Specification [28]

Component	Specification
CPU	Quad Core 1.2GHz Broadcom BCM2837 64bit
RAM	1GB
WLAN	BCM43438 on board
Bluetooth	Bluetooth Low Energy (BLE) on board
GPIO	40-pin extended
USB	4 USB 2 ports
AV	4 Pole stereo output and composite video port
HDMI	Full-size HDMI
Camera	CSI camera port for a Raspberry Pi camera
Touch Screen	DSI display port for touchscreen display
Memory	Micro SD port for data

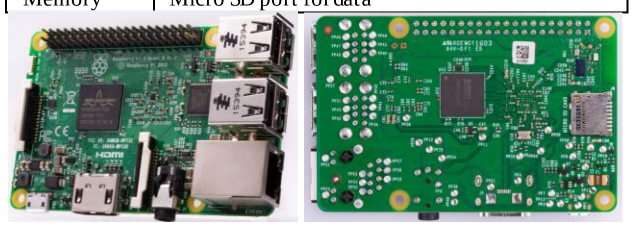


Fig. 3. Raspberry Pi 3 Model B

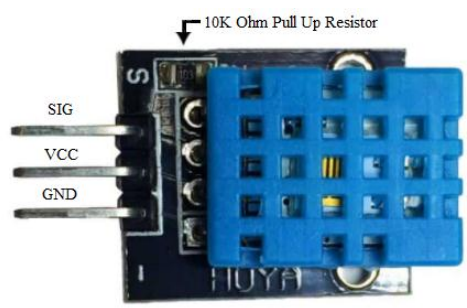


Fig. 4. Three-pin DHT11

Table II. Specifications of 3-pin DHT11 [29]

Specification	Value
Range of Humidity	20-90% RH
Accuracy of Humidity	±5% RH
Range of Temperature	0-50 ℃
Accuracy of Temperature	±2% ℃
Operating Voltage	3V to 5.5V

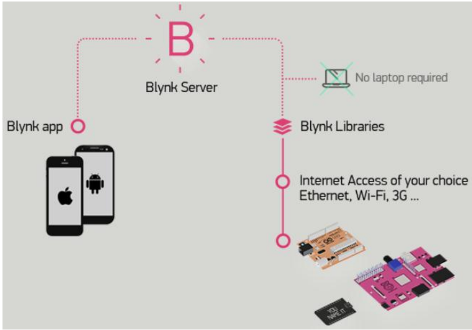


Fig. 5. Communication among the Three Major Components in Blynk

Notice that there are two types of DHT11 on the market, which are four-pin version and three-pin version. The three-pin version was chosen because there is a surface mounted 10K Ohm pull up resistor for the signal line on it. Users can mount the DHT11 on the PCB board easily.

Blynk is a platform that provides iOS and Android app for the users and developers to control ESP8266, Arduino, Raspberry Pi, SparkFun and many other microcontrollers in the market. Developers are allowed to drag and drop the widgets onto the dashboard to build a graphical interface for their projects. These widgets can be used to control the hardware remotely, visualize and display sensor data. It is an end-to-end solution for the IoT. It reduces the time and resource needed to build the applications for connected products and services. The Blynk platform (see **Fig. 5**) enables organizations to move smoothly from prototype to production in short iterations. It also allows a developer to collect feedback refine the product at every development stage. Blynk has the properties of secure, scalable, lightweight and fasts with the capabilities of managing billions of requests to and from the edge device. .

Table III. System Evaluation Results

ID	T1	T2	H1	H2	TT	HT	RLED1	GLED1	RLED2	GLED2	Block Time
1	25	26	45	44	25	44	off	on	on	off	11
2	25	26	45	44	25	44	off	on	on	off	12
3	26	26	44	44	25	44	on	off	on	off	30
4	26	26	46	44	25	44	on	on	on	off	20
5	26	26	46	45	25	44	on	on	on	on	255
6	26	26	46	45	28	60	off	off	off	off	15
7	28	26	46	45	28	60	off	off	off	off	16
8	28	27	46	45	35	30	off	on	off	on	18
9	28	27	46	46	35	30	off	on	off	on	22
10	24	28	44	46	35	20	off	on	off	on	23
11	24	29	45	46	39	20	off	on	off	on	30
12	24	30	45	46	40	15	off	on	off	on	31
13	26	30	45	48	40	15	off	on	off	on	18
14	26	31	45	48	40	60	off	off	off	off	19
15	26	31	45	48	40	60	off	off	off	off	20
16	29	31	45	48	20	70	on	off	on	off	10
17	30	32	45	47	20	70	on	off	on	off	19
18	31	33	45	47	20	23	on	on	on	on	8
19	32	34	45	47	15	23	on	on	on	on	6
20	33	35	45	47	15	23	on	on	on	on	18

Construct and test the smart contract on Remix and make sure it can work properly. **Fig. 6** shows the variables and functions defined in the smart contract. The basic logic workflow is shown by the arrows. There are 6 functions in this contract:

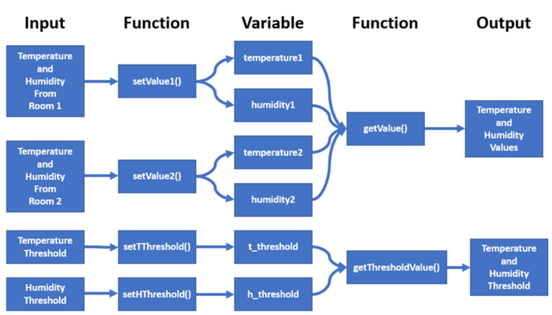


Fig. 6. Structure of the Smart Contract

All the JavaScript files that use the Blynk App must include the blynk-library and define the authentication token corresponding to the Blynk project. The node-dht-sensor library is used to read the sensor data. Definition of the type of sensor and the GPIO pin connected to the data pin of DHT11 in needed. The sensor data is uploaded to the Blynk App every 15 seconds since the average block time for Ethereum private blockchain is 15 seconds. The onoff JavaScript library is used to control the LEDs. Definition of GPIO pins connected to the LEDs are needed in the initialization. The new sensor data is compared to threshold value and actions are taken according to the result. When the temperature exceeds the threshold, the red LED is turned on. When the humidity exceeds the threshold, the green LED is turned on. The flowchart of the coding implementation is shown in **Fig. 7**.

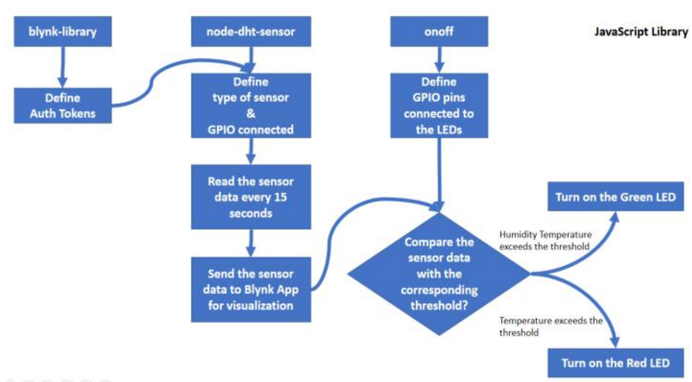


Fig. 7. Flowchart for Connecting the Blynk with RPi and DHT11

- setValue1(): update the temperature and humidity value of room 1
- setValue2(): update the temperature and humidity value of room 2
- setTThresold(): set the temperature threshold
- setHThresold(): set the humidity threshold
- getValue(): retrieve the sensor data store on the smart contract
- getThresoldValue(): retrieve the threshold value set by the user.

Testing has been done on the system for typical 20 periods. It could be a good evaluation of this prototype system. The testing parameters and result for these 20 periods are stated in **Table III**. T1 and T2 mean the temperature value of room 1 and 2. H1 and H2 is the humidity value of room 1 and room2. TT is the temperature threshold value and HT is the humidity threshold value. GLED refer to the green LED status while RLED refers to the red LED status. The block time records the time for the block needed to be added to the blockchain.

The system was built successfully since the sensor data could be stored on the smart contract and displayed on the Blynk App. The LED would be turned on or off in the correct condition. The average time for block generation is 18.55 seconds for these 20 periods

5 RESULTS AND DISCUSSIONS

The implemented system simulates two rooms on the Blynk App with the sensor data collected from the sensor DHT11. The sensor data is uploaded to the Ethereum smart contract. The smart contract is deployed in the created private Blockchain with two miners from the computer and one normal node from each Raspberry Pi. If the real-time temperature and humidity value exceed the threshold set by the user, the red / green LEDs will be turned on as warnings. Raspberry Pi is used in this system to collect the sensor data, send the data to Blynk App and call the appropriate smart contract function at the corresponding situation.

The Etheruem block is mined in 15 seconds on average, which means that the sensor value is uploaded to the smart contract in every 15 seconds. Although 15 seconds seem to be too long for the real-time data stream, it is still acceptable in this scenario. It is not considered as an unacceptable delay if the warning is only shown 15 seconds on average after the real temperature and humidity of a room exceed the threshold.

There are some limitations in this system for business applications: (1) The price for Raspberry Pi and its accessories (mouse, keyboard, touchscreen, LEDs and DHT11) is relatively high, which costs about $150 per set. (2) When the temperature or humidity exceeds the threshold, only the corresponding LEDs will be turned on as a warning. In this situation, the air-conditioner or dehumidifier should be turned on in practice. Due to the time and budget limitation, we did not cover the infra-red controllers used to send the turn on command for air-conditioner or dehumidifier. (3) If a node in the private Blockchain wants to call a smart contract function in the Ethereum private Blockchain. It must have enough ether to pay for the gas to send the transaction to call the smart contract function. In this system, enough ether is manually sent to the nodes, which are the Raspberry Pi, before the system run.

6 CONCLUSION

In this paper, a system is built with the combination of Ethereum private Blockchain, Raspberry Pi 3 Model B, DHT11 temperature and relative humidity sensor and Blynk App. This prototype system is to simulate a smart home application, which will update the real-time temperature and humidity to the user and react automatically when a certain situation occurs. The sensor data is stored on the smart contract and the turning on or off the LEDs as warnings is the reactions for this system when the sensor data exceeds the threshold set by a user.

Here are some recommendations for the future work to improve this system: (1) Since the price of one set of Raspberry Pi and its accessories is too high, the other low-price microcontrollers can be used to replace the Raspberry Pi. Some of them are Arduino, ESP8266, SparkFun and many other small-size microcontrollers available in the market. (2) The reactions of this system when the sensor value exceeds the threshold are just turning on the corresponding LEDs. It is not useful in the real life smart home applications. Developers can try to implement infra-red controllers to turn on or off the air-conditioner or dehumidifier depending on the re-time value of temperature and humidity. (3) The gas fee needed to make the transactions is inconvenient for a smart home application. Because it requires manual transfer of ether to the Raspberry Pi nodes. There is a possible solution that adds some codes to the system which allows the miners to transfer a certain amount of ether to the Raspberry Pi nodes regularly. Or the other Blockchain platform can be tested. For example, IOTA is a scalable Blockchain which is aiming the be the backbone of IOT that does not require transaction fee. (4) Developers can also try to develop a consortium Blockchain among some companies which do not trust each other. This can provide the autonomous machine economy among these companies without trusting each other because the technology provides the credit endorsement.

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