Development of an IoT system for fire-fighting in smart homes

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***Abstract**: This paper shows an example of an IoT system for fire-fighting in smart homes. As support to this system, web application for tracking of sensors detection and warnings is shown. The devices that register smoke and flame and inform fire departments are implemented. The web application should enable early detection of fire and extinguish early fire while informing the house owner of the situation via SMS or via GSM call. All data is followed in real time through web application which is used by fire department. Aim of this system is to detect and prevent fire disasters in real time.*

***Keywords:** Internet of things, smart homes, home security, fire protection, fire-fighting*

1. INTRODUCTION

The term Internet of Things (IoT) was reportedly coined by Kevin Ashton, more than 15 years ago. The new world of IoT is creating widespread connectivity which includes devices such as cameras, toasters, garage doors, environmental and security systems inside homes and business through remote control of different sensors such as temperature, light, motion and detection (The Internet of Things and the fire service, 2017). The IoT offers promising solutions to convert conventional systems into modern ones. The technology is based on wireless sensor network, actuators, GPS and mobile devices and units. IoT is a global network of devices which communicate among each other, have their identities, physical attributes, intelligent interface and are integrated into the information network (Vujovic, 2015).

Smart home technologies (SHTs) comprise sensors, monitors, interfaces, appliances and devices networked together to enable automation and remote control of the domestic environment (Cook, 2012). Controllable appliances and devices include heating and hot water systems (boilers, radiators), lighting, windows, curtains, garage doors, fridges, TVs, and washing machines (Robles and Kim, 2010). Control functionality of these devices is provided by software on computing devices (smartphones, tablets, PCs) or through dedicated hardware interfaces (e.g. wall-mounted controls). Global consumer research carried out in seven countries worldwide, including UK and Germany, suggests a high level of market support. Over half of consumers surveyed expressed a general interest in smart homes, and 50% believe SHTs will have an impact on their lives over the next few years (GFK, 2016). Market forecasts project over half a million households in Germany will have smart appliances or devices by 2019, driven by widespread adoption of smart phones. However actual levels of uptake of smart home technologies are still low, and smart product sales are dominated by internet-connected TVs (Harms, 2015). Market growth mostly depend on users who are perceiving potential benefits and acceptable levels of risks. Smart home technologies can greatly improve energy management, security, safety, enhanced leisure and entertainment services and personal independence through healthcare provision and assisted living. (Chan et al., 2009; Nyborg and Røpke 2011). The most significant barrier to adoption of SHTs is upfront cost, privacy, security of data, reliability and interoperability of different technologies. Also there could be a social impact such as increased laziness in domestic life.

The Internet of Things (IoT) has led much of the world becoming smarter and more connected. Fire protection is among the various areas that can realize the true benefits of Internet of Things. Fire prevention and fire safety equipment are undergoing a massive revolution thanks to the Internet of Things. Internet of Things devices are connected to low power wide area or cellular networks to enhance prevention, increase response time and keep the first firefighters on the scene safe. The National Fire Protection Agency reports that 1.170.000 fires took place only in the U.S. during 2017, which resulted in 2.430 civilian deaths and $11.8 billion in property damage. Despite improved safety equipment and training, the greatest danger that firefighters face are the unknown factors they must deal with on the scene. Many departments already employ smart technology, such as thermal cameras. IoT goes even one step further, it enables leaders on the ground to see what is happening on the scene while tracking every team member's location in real time. IoT can integrate with existing alarms, personal safety devices and fire suit technology with only minor adjustments. Tracking technology keeps firefighters safer by reporting each member's exact location directly to the shift commander, but these devices don't work using GPS technology because of its low reliability inside a concrete or steel structure. Lightweight RFID based trackers are used instead. By using the exact location and thermal cameras commander can map the area and offer guidance for other team members (Fire fighting with IoT, 2017).

The model of fire fighting system in smart homes is developed that should enable early prevention of loss caused by the fire and smoke. A web app should enable monitoring in real time, reducing the response time and automatically extinguishing small fires. With complete implementation of the system it should reduce costs, increase efficiency regarding the intervention, increase security inside home and improve living conditions overall.

2. LITERATURE OVERVIEW

The fire service and other emergency first responders are currently benefiting from enhanced-existing but also from newly-developed technologies. Firefighters are operating in the sensor rich environment that is creating great amount of potentially useful data. The "smart" firefighter is going to be able to fully exploit selected data and to perform work tasks in a highly effective and efficient manner (Sundmaeker, Guillemin, Friess, 2010).

Firefighting safety field has made remarkable progress in recent years in the building of information network, and has many results in application, and part of application patterns have taken shape in terms of IoT. The overall society has great expectation and demand pressure to the improvement of Fire IoT management level, and provided a great market potential for its application.
The modern fire fighting system is based on wireless sensor network in combination with Internet of Things. Due to modern and advanced technology the system minimizes the losses caused by fire. There is significant variety of information accessible by fire brigades and great potential lies within Internet of Things. The Fire Protection Research Foundation's executive director Casey Grant says "Real-time information will greatly assist emergency responder situational awareness, which is especially critical during an event when time is precious" (Xin, Quanyi, 2010) .

Fire automatic alarming systems are very popular nowadays. These systems are widely used in most civil and industrial buildings in China. With only one additional internet interface and one management software in a single building, fire detection can be realized. Distant monitoring systems (DMS) are the link for to the buildings with the alarming system. Distant monitoring systems are based on modern communication network and allow real-time monitoring of all information. This is just the beginning of such systems which can be technically improved further. This improvement has been achieved by the rapid development of "Golden Shield" firefighting teams in China, by taking advantage of public security private network and specialized communication network. Progress in automatic office work, sharing and using of firefighting information as well as rapid response of firefighting teams have been achieved (Vijayalakshimi, Murugananad, 2017).

Fire protection management consists of 4 main parts:

1. Regulations - all public and some civilian buildings must have fire safety regulations in case of emergency.
2. Supervision - supervision management contains archives of fire management, fire safety inspection, fire control inspection and so on.
3. Response capacity of fire emergency - it contains response plan establishment, full-time firemen and voluntary fire brigade formation and response plan drills. Comprehensive fire emergency response plan can not only do a lot of help to assist commanders while giving commands, making decisions and deployment but also to ensure the fire officers and soldiers get familiar with environment immediately and deploy rationally.
4. Publicity and education training - building should have fire safety bulletin boards in the striking place, which disseminate fire hazards and the measures to be taken when the fire breaks out. Regular fire safety training should be organized to ensure that all occupants know the emergency evacuation process. (Ying-conga, Jingb, 2013)

Only two companies today successfully sell and implement smart IoT solutions. ZigBee and Aeris solutions are the leaders in IoT fire prevention systems. Aeris offers comprehensive solution meant to enhance security in emergency situation, and mostly prevent firefighting staff from injures or even death. The most important capabilities of Aeris' products are team members tracking in real time using the most advanced technology that is fireproof, light to carry into the scene and extremely reliable. Robotic response is another capability. These robots may be able in some cases to arrive on the scene faster than humans. They are supplied with oxygen and sensors to help and identify victims inside the fire and are able to map and clear the rooms before the firefighters arrive on the scene. The main downsides of Aeris are price. These systems are too expensive and they still involve a lot of human interaction to function properly (Gao Y., 2016).
ZigBee technology made a revolution in fire prevention. They made five systems that can work independently or together as a single unit. It involves fire control room as an intermediary between the building and fire department. Since the fire breaks out, thermal monitoring system sends a fire signal into the fire control room of the building and activates ZigBee's hydrant extinguishing system to extinguish the early fire. When the control room confirms the disaster, a fire signal is sent to the fire department. Where ZigBee's IoT terminal is used to find the shortest route to the fire scene.
The five systems of ZigBee are as follows:

1. Thermal imaging fire monitoring system
2. ZigBee IoT alarm system
3. Wireless ZigBee fire hydrant monitoring and related technology
4. Mobile terminal information sharing system
5. ZigBee IoT terminals and radio frequency positioning rescue technology (Y.Z. Jang, J.H. Gao, 2010).

Downside of such a system is its price, even as a single system. It requires a lot of human involvement, it is not customizable enough, and it can only be implemented in the early phase of building construction, otherwise costs can be as triple as normal.

The requirements for the fire fighting system monitoring developed in this paper are as follows:

- Sensors for gathering information on the scene
- Database server for real-time tracking
- Automation of extinguishing process
- Fire department and firefighting personnel

3. MODEL OF IOT SYSTEM FOR FIRE-FIGHTING IN SMART HOMES

This paper presents a system that allows early detection of fire, alarming the fire department and activating the countermeasures. The system consists of a smoke detection sensor, a temperature sensor, a flame detection sensor, a relay, a solenoid valve, GSM module, Arduino microcontroller and a Raspberry Pi microcomputer. In the case of smoke detection, the fire department is alarmed through the web application and the location and smoke pollution information is sent to the screen of the brigade in charge. In addition to informing the fire department, using the GSM module, a mobile call is placed to the smart home owner. If the situation gets worse and early fire and smoke turn into real fire, the flame detector sends a signal to the control unit that activates the relay which activates a solenoid valve. Valve brings water to sprinklers in order to extinguish fire and prevent severe damage to the smart home.

When such events happen all information is sent to fire departments in order to improve the service and better prioritise emergency situations in the future. All necessary data is passed through a web application.

Using this kind of model it is very easy to determine levels of CO2 in the air or detect flame. This information is crucial to take next steps to protect the household and its residents. The use of this model allows complete automation of fire extinguishing. Additional information is provided by the temperature sensor and the humidity sensor. These sensors can be very useful in early detection of a fire.

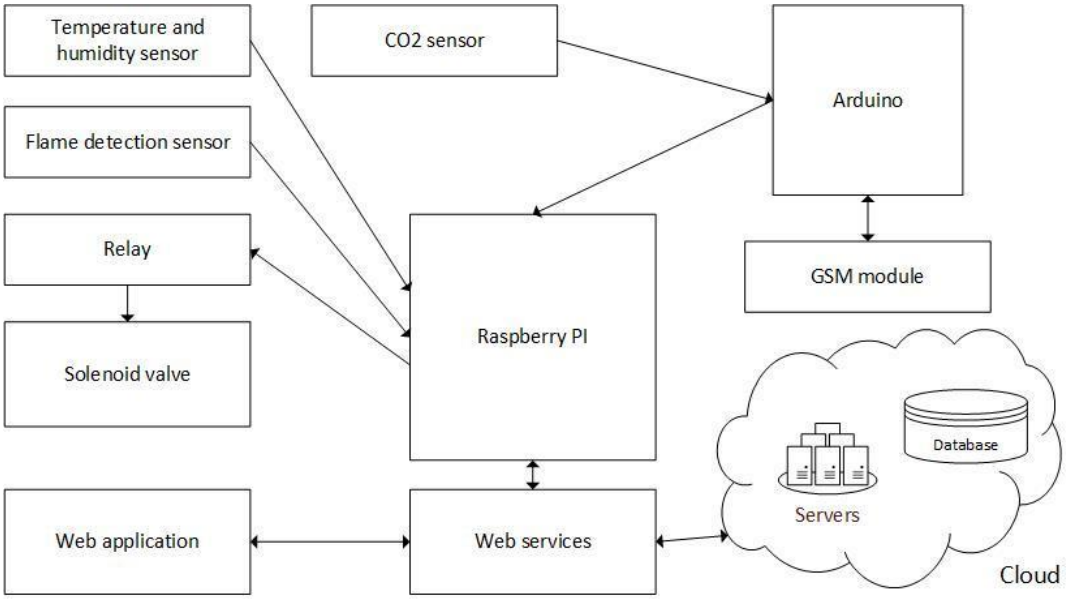

Figure 1: Model of fire fighting system in smart homes based on Internet of Things

Data is sent via web services to the server and it is stored in non-relational MongoDB database. MongoDB is an open-source database management system based on documents. It is classified as a NoSQL database that avoids the traditional structure of relational database-based databases. The basic structure consists of JSON documents with dynamic schema, or BSON format (binary JSON). Sensibility of the flame detection sensor is set to maximal, so it would detect any light in the room.

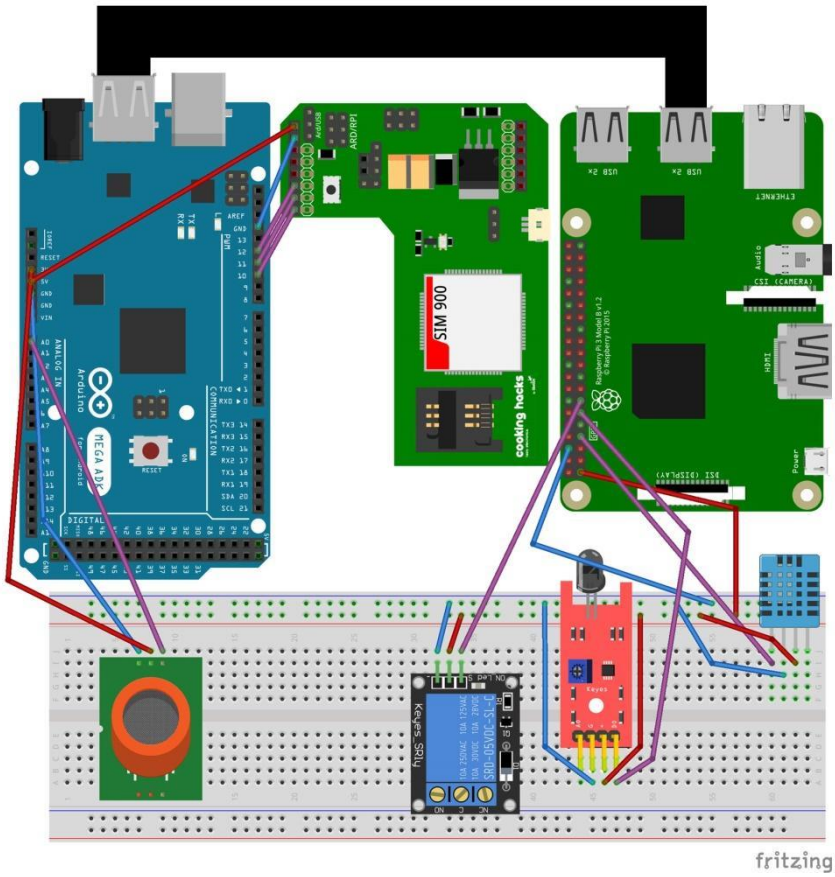

Figure 2: Physical connection of devices

On the figure 2 are shown Raspberry Pi microcomputer and Arduino microcontroller connected with sensors and actuators. Blue lines represent cables that are connected to the ground (negative pole) on Raspberry Pi. Red lines represent cables that are connected to power source of 3.3v or 5v on Raspberry Pi. Purple lines represent cables that transfer data between devices.

Raspberry Pi has a web server running. Arduino is connected to Raspberry Pi and sends data read from CO2 sensor. Temperature and humidity sensor, relay and flame detection sensor are connected to Raspberry Pi while GSM module is connected to Arduino. Because of big amount of data the non-relational database is used and it is located on the cloud.

4. DEVELOPMENT OF WEB APPLICATION FOR FIRE-FIGHTING SYSTEM

In order to implement such system in regular household few requirements have to be met. Whole house has to be covered with stable Wi-Fi connection, constant power and water supply. In addition to this requirements, the house owner should have mobile phone with GSM and SMS capabilities.

This paper presents a web application that allows firefighters in the control centre to monitor the state of carbon monoxide in smart homes. The web application is developed by using Bootstrap framework. Application logic on server side is developed in PHP programming language. Parts of the application logic which are executed on the client's side are developed using JavaScript. AJAX is used for data insight in real time. All communication with web server takes place through sending and receiving HTTP requests that carry data in JSON format.

Along with carbon monoxide information, in case of emergency, application shows CO2 level, address and option to send fire fighting vehicles to the location. Location is visualised, using Google maps as it is shown on Figure 3. Based on location, system calculates ETA by checking the location of the nearest emergency vehicle.

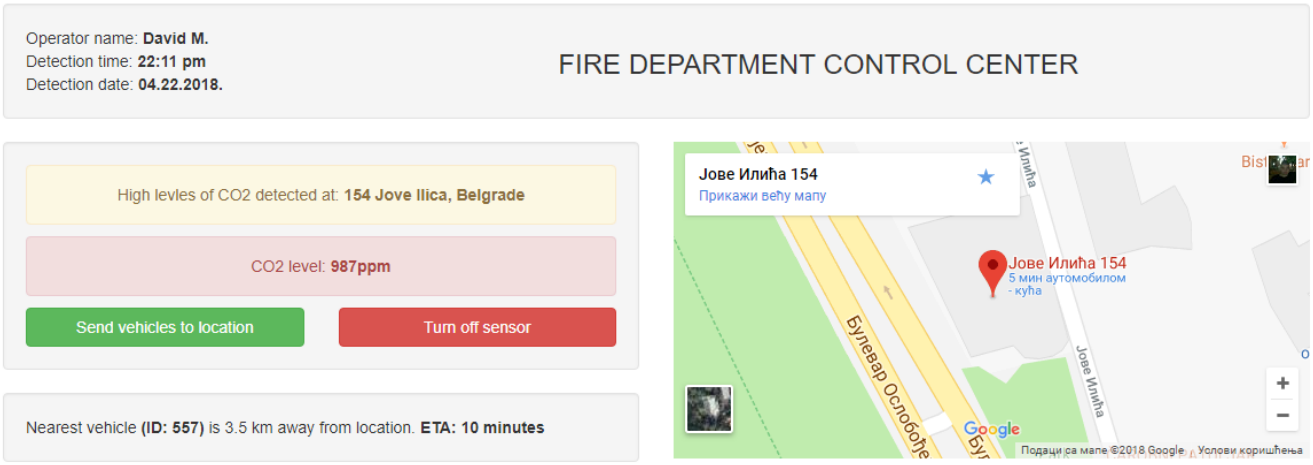

Figure 3: Fire department web application

At the same time while sending the information to the fire department, the system, uses GSM module which is connected to the Arduino and calls home owner to inform the about potential fire disaster.
As an alternative to web application it is possible to develop mobile application. Within mobile application user would have an insight to the data from the sensors inside the smart home, with some additional functions like push notifications.

Figure 4: Call initiated via GSM module

5. CONCLUSION

In this paper, development of an IoT system for fire-fighting in smart homes is shown. System was developed on Department of e-business at Faculty of Organizational Sciences, University of Belgrade. Architecture of the proposed model is defined. Furthermore, implementation for fire fighting system in smart homes was presented.

Main advantages of this solution are simplicity, low cost of equipment and possibility of implementation in other smart environments like smart buildings, offices and storages. Important advantage of this solution compared to other solutions is versatility. This system can easily be implemented into civilian homes without a need for major construction works. Model can be improved with additional sensors. Expanding the sensor network will increase data collection which will lead to improvement of system precision and it will allow better recognition of early fire.

One of disadvantages of this system is that it requires advanced technical knowledge needed for implementation. In order for system to work with optimal performance participation of the city administration is needed to enable communication between smart homes and emergency services.

While other solutions mostly relays on human involvement and low automation, system shown in this paper overcomes these difficulties by using solenoid valve which is connected to water source. Solenoid valve is able to send water to sprinklers and quickly extinguish early fire, which makes it completely automated system.

Real-time data is shown inside the fire department which includes temperature, gas level, and data gathered from flame detector. This way quick intervention of fire brigade is always provided to those who need it.

This system can be improved by analysing all the collected data from sensors. Analysing large amounts of data in real time and using machine learning can allow the fire department to detect the fire before it actually starts.

This new approach gives a reliable solution that can permit to detect fires risks, in order to avoid severe damage of this disaster, when it happens. Application of IoT in fire monitoring is an excellent solution that leads to smart city development.

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