Smart Device Prototype for Automated Emergency Calls
Using SIP and TTS to Reach Legacy Emergency Services

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Abstract: The Internet-of-Things (IoT) promises to transform our society into smart environments, incorporating smart objects that cooperate to fulfil specific goals. Amongst its many applications, emergencies can also benefit from IoT principles and use of automation for a better emergency response and reducing the number of fatalities. Smart devices can be used to detect emergency events (e.g., fire, presence of hazardous gases). In this paper, we present a prototype applying the IoT paradigm to the concept of automated calls. The prototype is capable to measure environmental parameters - such as smoke, temperature and gas - to determine the occurrence of a serious incident (e.g., fire in room) and automatically initiate an emergency call. To make our approach interoperable with most platforms and operational practices (including emergency services that mostly rely on voice calls), the system generates an audio call using preformatted messages and a text-to-speech engine. Our approach brings the benefits of automated calls without requiring significant investments to existing infrastructures (including those used by emergency services).

1 INTRODUCTION

The Internet-of-Things (IoT) promises to transform our society into smart environments, environmentally aware and well informed about its wellbeing, interests and security. IoT refers to the extension of the Internet paradigm to the world of objects and places, each able to communicate their own data and access aggregated information from other objects and places. Building blocks of the future IoT, smart objects cooperate to fulfil specific goals (Fortino et al., 2013) finding applications across many societal domains, including safety and security of citizens

Their presence is becoming ubiquitous and global: Gartner forecasted that 8.4 billion connected things will be in use worldwide by 2017 and will reach 20.4 billion by 2020 (Gartner, 2016).

The emergency services sector is not immune to the penetration of IoT concepts and applications.

Emergency Services (ES) deal with urgent life threatening situations that require a swift response. While they mainly rely on voice calls (via the 112 number for most of Europe), initiatives like eCall, part of the eSafety initiative of the European Commission (European Commission, 2014), represents a most notable and successful effort in bringing automated calls and data exchange with ES into reality.

The eCall is applied to the specific event of a car accident: if the car's sensors detect a crash, the car automatically calls the nearest emergency centre. Even if no passenger is able to speak, e.g. due to injuries, a 'Minimum Set of Data' is sent, which includes the exact location of the crash site, the time of incident, the accurate position of the crashed vehicle and the direction of travel (European Commission, 2014). The eCall concept was designed having in mind circuit switched emergency calls, specifically working in 2G and 3G networks using an in-band modem (3GPP, 2017). Despite, it is expected that eCall cuts emergency services response time by up to 50% in the countryside and 40% in urban areas. It is estimated that eCall can reduce the number of fatalities by at least 4% and the number of severe injuries by 6% (European Commission, 2017).

Further applications can be deployed to the benefit of citizens. As proposed in (Manso et al., 2017), these include eHealth, Smart Building

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applications and the next generation eCall that fully exploit IoT concepts, IP and packet switch networks.

Despite novel approaches for ES, such as those taken by the EU funded action NEXES (Next Generation Emergency Systems) (NEXES, 2015), which embrace IP technologies and data exchange, ES worldwide mainly rely on circuit switched voice calls.

This paper extends the work presented in (Buf et al., 2017) by describing the implementation and demonstration of a smart device conveying environmental data relevant to determine the occurrence of emergency incidents (related with fires or combustible gas leaks). In such a case, the system automatically initiates an emergency call and conveys a message in audio format, thus being able to operate with any ES deployed nowadays.

The remainder of the paper is structured as follows: it starts by presenting two cases where automated emergency calls can be used to improve safety of citizens and property; then the system concept and architecture is described, including the implementation of the smart device system; the "Workflow" section presents the sequencing between the relevant steps, followed by the structure of the emergency messages; in the "Demonstration" section we present two examples of the detection of emergency events that initiate an emergency call; the paper finalises with the conclusion section.

2 THE NEED FOR AUTOMATED EMERGENCY CALLS

As part of the NEXES Action, several use-cases were described involving the use of automated alerts to enable a prompt response to an emergency and save lives (Manso et al., 2017). In one scenario, a tank at a small chemical plant develops a breach and hazardous materials began leaking out. A security guard, responsible to monitor incidents, failing to follow the appropriate security precautions, is quickly taken ill upon inhalation of noxious fumes and loses consciousness. Since the chemical plant uses smart devices, the leak is detected and an automated alert is initiated. Because no human intervention is possible (the guard is unconscious), a call to emergency services is automatically established. The emergency call taker develops awareness of the emergency situation and dispatches relevant personnel and resources, including specialist containment and decontamination crews and personal protective equipment.

This *futuristic* scenario highlights the potentially vital role of telematics in specific emergency scenarios. The use of telematics and automated calling means that in situations in which citizens are incapacitated, emergency services can still be timely contacted and properly informed about the incident, thus enhance the emergency response in terms of response time, the safety of the citizen and, in this situation, the safety of first responders as well.

Looking into incidents at homes, we see these are a major cause of injuries and deaths: according to the U.S. National Fire Protection Association (National Fire Protection Association, 2017), in 2015 there were more than 360k house fires causing more than 2500 deaths, 11k injuries and several billions $USD in damage. 3 out of 5 home deaths occurred in houses without smoke alarms. The utilisation of smart devices and alert systems could have a significant high positive impact in improving human safety and reducing financial losses.

3 SYSTEM CONCEPT AND DESCRIPTION

The concept described in this paper consists in deploying IoT systems to perform sensing and incident detection together with components capable to trigger specific actions - specifically initiate an emergency call - and convert digital messages into audio in a form that can be received and understood by any ES nowadays.

Smart devices are deployed in a cluster configuration connected to a Hub (within a LAN or via a router). The smart devices incorporate sensors capable to measure physical quantities of interest and detecting key events (e.g., gas concentration and smoke detection). The devices are considered to be resource constrained (i.e., limited processing capabilities, low power consumption) thus they perform limited functionalities. They are connected to a Gateway/Hub that collects all sensor data and perform computational intensive functions. In this regard, the Hub has the capability to perform data fusion and correlation to increase detection reliability (e.g., correlate fire and smoke sensor data to confirm a relevant event), generate event messages into audio (using its TTS engine) and, for our specific use-case, initiate emergency calls using the public network (other approaches could instead opt for calling the owner phone or a service operator).

An overview of the system is depicted in Figure 1 and is described next.

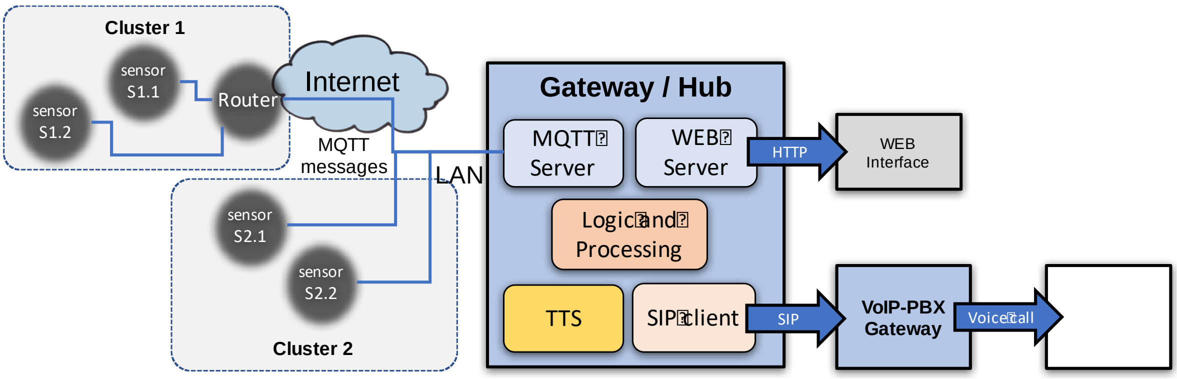

Figure 1: System Overview.

3.1 Hub System Implementation

The Hub main components are described next.

- **MQTT Server**

The MQTT Server manages publishers, subscribers and data exchange. It is responsible for message management, based on the publish/subscribe paradigm, disseminating messages to subscribers when these are published.

In our configuration, each sensor (i.e., publisher) has a specific topic to which it publishes messages (i.e., sensor data or alert). Via MQTT, the Hub allows authorised users to subscribe to sensor messages to e.g., monitor the area and be notified in case of emergencies. Internally, the "Logic and Processing", described later, also subscribes to sensor messages.

- **SIP Client**

The Hub includes a SIP client in order to be able to initiate SIP calls in case emergencies are detected. The SIP Client performs all required steps for setup (e.g., registration) and manage calls (e.g., initiation, establishment and termination).

- **TTS**

The TTS engine allows to convert text messages to audio. It requires significant processing and storage capabilities (typically above 1GHz processor and several Mbytes of storage for audio voice files) typically not present in sensor devices.

- **Web-server**

The Web-server allows the remote configuration and management of the Hub (and the system). It allows the user or administrator perform functions like system configuration (e.g., security, setup users, setup sensors), generate reports, configure recipients of alerts, "live" monitor the system, etc. It also allows to setup emergency events (e.g., fire), workflows and associated messages (see Sections 4 and 5).

- **Logic and Processing**

The "Logic and Processing" is a central element of the Hub. It receives sensor data (via MQTT) and processes it to determine the occurrence of an emergency event and, if so, triggers related actions such the automatic initiation of an emergency call.

The implemented interfaces and protocols are listed below.

- **All-over-IP**

The Internet Protocol (IP) is chosen as common protocol between all devices and components within the system. IP has become a dominant technology worldwide successfully linking billions of devices over the Internet and within private networks. IP is used to interconnect smart devices, the Hub, web-clients and initiation of calls (using SIP).

- **Sensor Data Exchange Middleware: MQTT**

The Message Queue Telemetry Transport (MQTT) is a message broker middleware based on the publish-subscribe paradigm standardised as ISO/IEC PRF 20922 (International Organization for Standardization, 2016). It has become very popular in the IoT community given its lightweight Client Server publish-subscribe messaging transport protocol, making it fit for resource-constrained devices.

Smart devices share information using MQTT, by publishing information to specific topics. The Hub receives data from sensors by subscribing to those topics.

- **Management Interface: HTTP**

The HUB system management is performed over the Hypertext Transfer Protocol (HTTP) supported by most web browsers.

- **Emergency Calls: SIP, TTS and PBX Gateway**

Our concept involves the automated establishment of an emergency call to emergency services (specifically, a Public Answering Safety Point (PSAP)) in case of an emergency. For this purpose, the Hub supports the SIP protocol, which is widely used for IP telephony all over the world. Additionally, to "reach" the legacy public switched telephone network (PSTN), a VoIP-PBX gateway is added to convert SIP signalling and VoIP to a form supported by PSTN. To generate audio, the Hub uses a TTS engine.

3.2 Smart Device Implementation

The implemented smart device is depicted in Figure 2. The left picture shows the device casing and sensors used. The picture at the right shows the connections between the several components. The components that constitute the smart device are the following:

- **Flame Sensor** (Keyes KY-026 model) used to detect the presence of fire;
- **Temperature and Humidity Sensor** (DHT-11 model) used to measure room temperature and humidity (which may provide indication of increased temperature and likelihood of a fire);
- **Gas Sensor** (MQ-2 model) used to detect the presence of combustible gas, such as Liquefied Petroleum Gas (LPG), Propane and Hydrogen.
- **Arduino UNO Microcontroller Board** used to manage, control and read data from sensors. It also runs a lightweight MQTT client. A Wi-Fi shield was added to allow wireless connectivity with the Hub (described in 3.1).
- **Power Supply** unit (9v).

The smart device handles only "lightweight" tasks, such reading sensors data and periodically publishing them as MQTT messages to the MQTT server hosted in the Hub. The system workflow is described next.

4 WORKFLOW

The workflow related with our implementation of automated calls based on smart devices is depicted in Figure 3. The process can be split into two parts: the first one related with the smart device and a second one related with the Hub.

The workflow starts with the **initialisation** procedure where the system setup and configuration is performed, including establishment of MQTT topics (to where sensors publish messages), SIP client registration, and the fulfilment of required authentication steps.

After initialisation, the system enters a continuous loop. In it, each smart device **measures** their parameters of interest (for example, temperature, gas concentration or smoke detection) and publish the **value** using **MQTT** according to the defined criteria (e.g., raw measurement, measurement when above a certain threshold value or event) and to the appropriate topic.

The Hub reads the sensors' values, by receiving MQTT messages published in topics it subscribed.

The Hub then processes received messages to determine if there is an emergency situation (when out of "value safe side"), which can be based on direct sensor data (e.g., a smoke sensor produces a

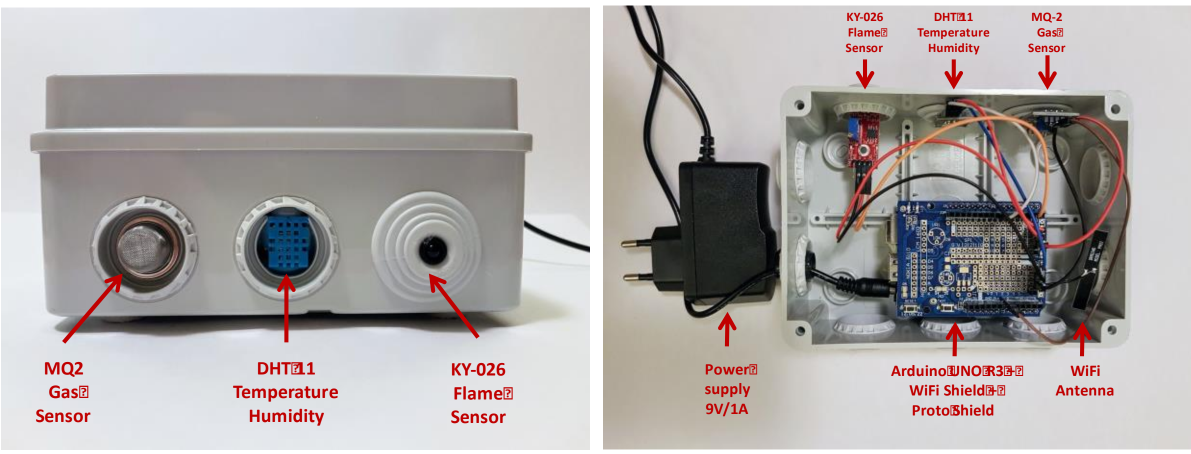

Figure 2: Smart Device Prototype Implementation.

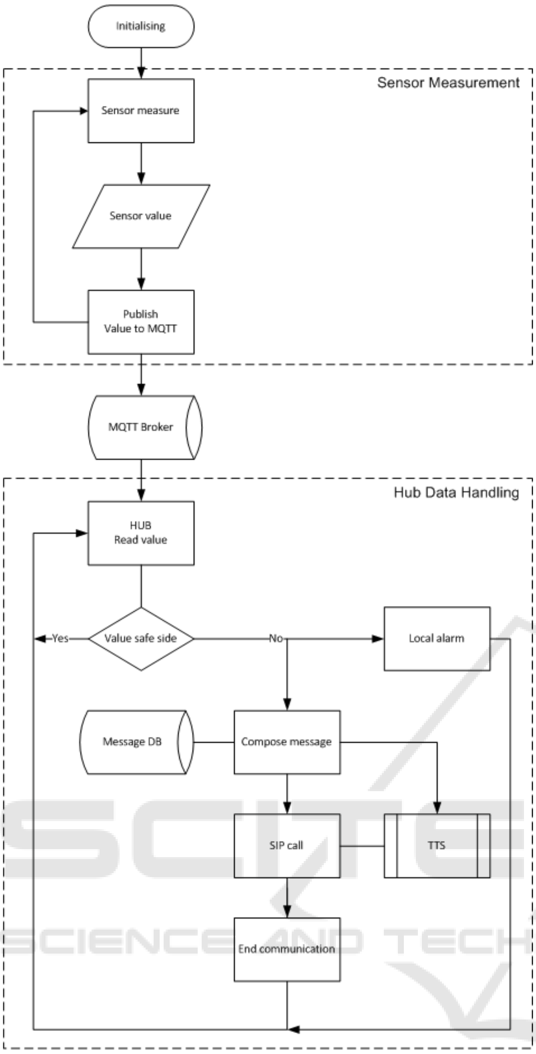

Figure 3: Automated Call Workflow.

message with value "true" for fire indication), a threshold value for sensor data (e.g., the sensor temperature is above 60ºC) or the result from correlating data between multiple sensors (e.g., temperature sensor report values above 60ºC and smoke sensor indicates presence of fire). It is critical that this step is highly reliable otherwise, in case of false positives, false emergencies are re-ported (resulting in unnecessary deployment of resources) or, in case of true negatives, emergencies are missed (resulting in loss of material and possibly lives).

In case an emergency is detected, an emergency call is automatically initiated (in addition or alternatively, a local alarm can be triggered to pre-defined recipients).

The following steps are taken when establishing an emergency call:

- Based on the emergency type and using a database of predefined messages (message DB), a text message is composed containing pertinent information about the emergency, which includes type of incident, date&time and sensor information (where relevant), but also caller information (name, address and location);
- Initiate a SIP outgoing call to the emergency services (which will use the VoIP/PBX Gateway to reach the PSTN and subsequently the PSAP);
- Once the call is initiated, activate the TTS engine to convert the text message to audio (and thus automatically report the emergency in a human understandable form). To ensure the message is received and understood by the PSAP (human) operator, it can be replayed a number of times (in our case, we set to 3 times);
- Terminate the call.

5 MESSAGES

During an emergency call, audio is generated from a text message that is built based on the type of event. Given the context of our application, the generated message needs to be simple, easy to understand and contain all relevant information for emergency services to react. As such, the text message should contain:

- The indication that it is an automatic message;
- Information about the type of emergency;
- Information about the subscriber/user (subscriber name);
- Location information (civic address);
- Optionally, associated sensor information when useful.

Example of pre-formatted messages, for situations of fire detection and abnormal temperature detection, are presented in Figure 4. Note that dynamic fields inside brackets are filled based on configuration values or sensor data.

Fire emergency predefined message:
`sipspeakfire: linphonecsh generic "speak default This is an automated emergency call from {{subscriber name}} home, address is {{civic address}}. Fire detected inside home. Please help."`
High abnormal temperature predefined message:
`sipspeakfire: linphonecsh generic "speak default Environment alarm at {{subscriber name}} home, address is {{civic address}}. The temperature is {{tdata}} degrees. The humidity is {{hdata}}%. Please help."`

Figure 4: Predefined Messages.

6 DEMONSTRATION

The prototype was installed in a fictional location, which was called John Doe's house. The smart device was located in the kitchen.

The Hub consisted of a **RaspberryPi** model 3 running the **Raspbian** operating system. Additional modules used were the **MQTT server** (based on mosquitto), **eSpeak TTS engine** and the **Linphone SIP client**. **Asterisk** (VoIP-PBX Gateway) was used to reach the public telephony and establish voice calls.

For purposes of managing the devices, logging, visualisation and triggers, the open-source home automation platform "**Home Assistant**" was used. See Figure 5 for an example of the provided output.

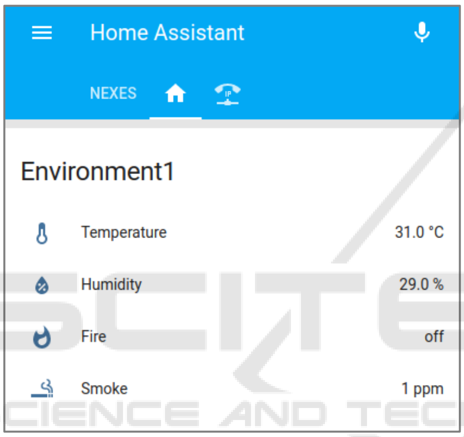

Figure 5: Device Data Visualisation via "Home Assistance".

The system was configured to raise an alarm if specific criteria are verified, which, in our case, was simplified to a sensor value being above a pre-defined value. Therefore, if the system detects a situation where a sensor data exceeds a given threshold, it automatically initiates an emergency call. Note that, for demonstration purposes and since emergency calls may only be placed in real cases, a personal phone number was used as a recipient for the generate automated alerts.

In our test scenario, we simulated two events:

- The first relates to the presence of smoke (i.e., fire indicator), by using a lighter. As it can be seen in Figure 6, the smoke sensor value had a significant increase close to 15h00.
- The second relates to the increase in temperature above a "safe" value (in our case, just above 35º C). We simulated a temperature increase using a heat generator (hair dryer) close to the temperature sensor. An increase in the measured temperature (above the 35 ℃ threshold) close to 17h00 is visible in Figure 6.

Both events triggered the automatic initiation of an emergency call. A message was composed following the format presented in Figure 4, which includes relevant details pertaining to the emergency including name of owner, address (i.e., location) and type of emergency. The system then establishes a SIP call and uses the TTS engine to convey the message in audio form to the specified recipient.

7 CONCLUSION

The IoT paradigm and increasing presence of smart devices across all sectors of society continues to find new applications including in emergencies. The eCall initiative brought the concept of automated calls in situations of serious car accidents, aiming to improve emergency response time and reduce the number of fatalities. It is reasonable to expect that other types of emergencies may benefit from this concept as well.

Figure 6: Sensor Data Visualisation Over Time.

In this paper, we extended our first work in (Buf et al., 2017) by describing the implementation and demonstration of a smart device capable to detect fire and abnormal temperature values that can be used to determine the occurrence of an emergency incident. In such a case, the system generates a preformatted message incorporating specific emergency-related information that is converted to audio format using a TTS-engine. In this way, our application considers the legacy nature of ES and PSAP specifically, which mainly operates with audio-based calls, bringing the advantage of IoT without requiring significant changes (and investments) to the ES infrastructure and systems.

However, considering the forecasted evolution for next generation ES to be implemented over the coming decades, as envisaged and explored in the NEXES Action, we will explore in future work the use of IP and data exchange to data-enabled PSAPs, following concepts such as the next generation eCall (Gellens and Tschofenig, 2016) and smart environments (Manso et al., 2017).

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