Implementation of Fog Computing for Reliable E-Health Applications

Razvan Craciunescu, Albena Mihovska, Mihail Mihaylov, Sofoklis Kyriazakos, Ramjee Prasad
Center for TeleInfrastruktur, Aalborg University
{razvan;albena;mrm, sk, prasad}@es.aau.dk

Simona Halunga
Telecommunication Department, University Politehnica of Bucharest
shalunga@elcom.pub.ro

***Abstract*— This paper addresses the current technical challenge of an impedance mismatch between the requirements of smart connected object applications within the sensing environment and the characteristics of today's cloud infrastructure. We investigate the possibility to offload cloud tasks, such as storage and data signal processing to the edge of the network, thus decreasing the latency associated with performing those tasks within the cloud. The research scenario is an e-Health laboratory implementation where the real-time processing is performed by the home PC, while the extracted metadata is sent to the cloud for further processing.**

Keywords*—*fog computing, eHealth, Sensors, ZigBee, AAL

I. INTRODUCTION

With the adoption of smart wireless sensing into all spheres of daily life, the value, quality and cost of current and future e-Health services could be significantly improved by enabling the collection and analytics of health-related data and transforming it into useful medical knowledge and personalized services. The cloud has been recently adopted as a way of handling the big data [1]. The huge data consumption, however, will on one hand increase the costs related to maintaining the cloud infrastructure [2], and on the other hand, jeopardizes the timely and reliable context extraction and processing of the collected data to provide personalized services and applications. With an increase of the number of devices in a network, also the cloud computational effort increases and the network will introduce a larger latency because the cloud servers get overloaded [2]. Therefore, recent research efforts have focused in offloading some of the tasks (e.g. storage or processing tasks) usually done in the cloud, to the edge of the network. The term that is used is 'fog computing' [3].

This paper proposes an implementation of the concept of fog computing for an e-Health scenario. We propose real-time signal processing algorithms that are implemented in a fog node, closer to the sensing environment and are responsible for all the real-time processing of health-related collected data to enable a set of personalized services. The research scenario is shown in Fig. 1. In this scenario the fog computing part is used mainly for critical e-Health situations and the cloud system is used for storing the relevant metadata and send them to the relevant caregivers. The fog nodes are used in order to speed up the real-time processing for life-dependent actions and the cloud platform, in order to store the patient history and retrieve it whenever the need arises.

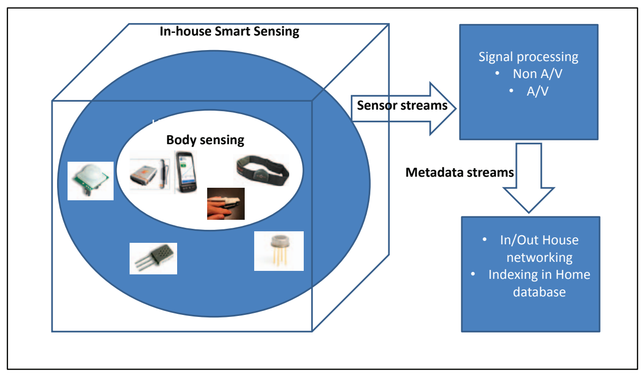

Fig. 1 Research scenario.

The in-house smart sensing collects data from a number of integrated devices (e.g., the Arduino solutions, ProMove3D device, MetaWear device, smartphones) about the user while he/she resides at home. The data is wirelessly transferred as a sensor stream to be offered for processing to the perceptual components through the device gateway.

This paper is organized as follows. Section II describes the fog system alongside with the fall detection algorithm and the gas detection algorithm; proposed model; Section III describes the fusion between different sensor data in order to enable a real-time fog system; Section IV concludes this paper.

II. THE IMPLEMENTED FOG SYSTEM

The implementation is within the frames of the European funded project eWALL, which is an EU-funded project under the ICT program [4], [5]. It encompasses a home environment based in the CTIF/AAU labs that is the eWALL home environment. The proposed architecture that consists of two stages:

- *First stage*: we have a home system that is used to process sensitive real-time data and to store all the data that came from the home environment, medical sensors and audio-video (A/V) modules. This is designated as the 'fog node'.
- *Second stage*: all the data, in metadata format, are sent to the eWALL cloud system in order to be available for the user or the user's caregivers or physicians.

The home environment sensing is done with several Arduino Uno boards that are equipped with a diversified family of environmental sensors [4]-[6]; a passive infrared movement detector that senses the individual's motion or presence inside the ambient space, and a set of analog gas sensors to detect the presence of smoke or other flammable gasses and provide a qualitative information regarding the concentration of such gasses in the breathed air. The board is shown in Fig. 2.

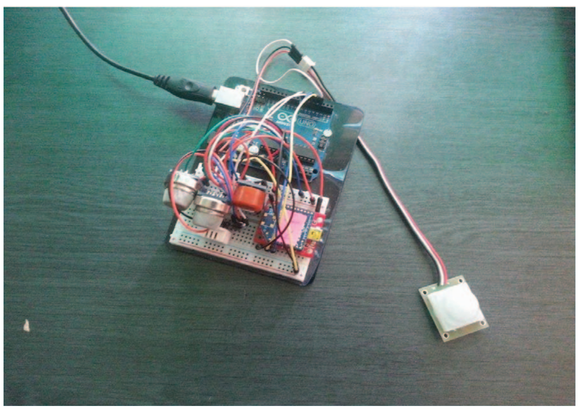

Fig. 2 Environmental module.

The chosen sensors exhibit high heterogeneity. Nevertheless, they operate simultaneously by using an algorithm that exploits the particular delays or interrupt functions to accommodate the characteristics of all hardware components. Also, additional hardware was added (resistors and capacitors) to prevent false triggers or even damaging the sensor.

The eWALL home system consists of four sensing modules: the environmental module, the wearable accelerometer module, the medical SPO2 module, the sleeping monitor module and the audio-visual processing modules. All the data from the modules are processed in the fog node and relevant metadata are extracted.

The algorithms, which are implemented in the fog node, are responsible for all the real-time processing and notification, namely:

- The quick notification to the user in the case of a gas leak;
- A quick notification that the patient's pulse or oxygen level is out of the normal range;
- A quick notification that the user has fallen down.

A. The fall detection algorithm

For the *fall detection* algorithm, we take the raw x(t), y(t), z(t) axis acceleration data from the wearable module that is shown in Fig. 3.

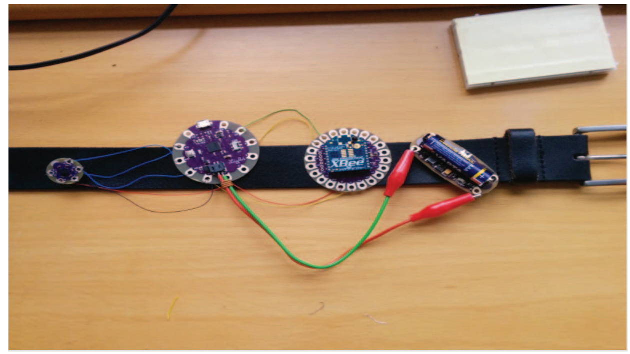

Fig. 3 Wearable module.

The axis acceleration data are sent every 50 ms. The data are combined in order to calculate the single magnitude component of the acceleration according to the formula:

$$SV(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2} \tag{1}$$

In (1), the *SV(t)* parameter peaks every time a fall occurs. Experimentally, we deduced that the peak value of *SV*(*t*) is larger than the peak value of a normal activity. First, we test if the difference between two consecutive points, one, which is the absolute minimum and the other, the absolute maximum, would be greater than 2G. If the answer is 'NO', then a fall has not been detected. If the answer is 'YES', then we evaluate, whether the maximum peak of the *SV*(*t*) and the base length of the triangle formed the 1G axis and the maximum peak value. Based on these assumptions, the ratio of the *Fall=SV(t)/(baseTimeofthetriangle)* [G/s] can be evaluated. The ratio, in the case of a fall detection is higher than 8 G/s, which becomes the selected threshold. In the simulated tests, the ratio is around 9-11 G/s. This is shown in Fig.5. All the processing is done in the fog node because we need a very fast decision in the case of a fall. If the fall is registered by the home system, a notification will be triggered to see the time, within which the user responds to the eWALL system. If the user responds to the system notifications in an interval of 5 to 10s after the fall has been detected, the system would register the fall, send the metadata to the cloud (timestamp and a fall flag=TRUE) and no further action will be undertaken. If the user does not respond to the notifications, the relevant caregivers (i.e., in the nearest proximity to the user) and the authorities would be contacted.

The algorithm has been tested and the algorithm detects a fall in more than 90% of the cases when a fall occurred. The local processing of the fall, i.e. the transmission of the signal from the wearable module and the algorithm running time, introduces a delay of maximum 1s. Processing the same data using the cloud introduces an extra 2 to 4 seconds to the processing time.

As the fall detection is a sensitive matter, the lower the processing time, the greater the chances are of providing an immediate assistance to someone.

The algorithm flow for the fall detection, implemented in the fog node, is presented in Fig. 4.

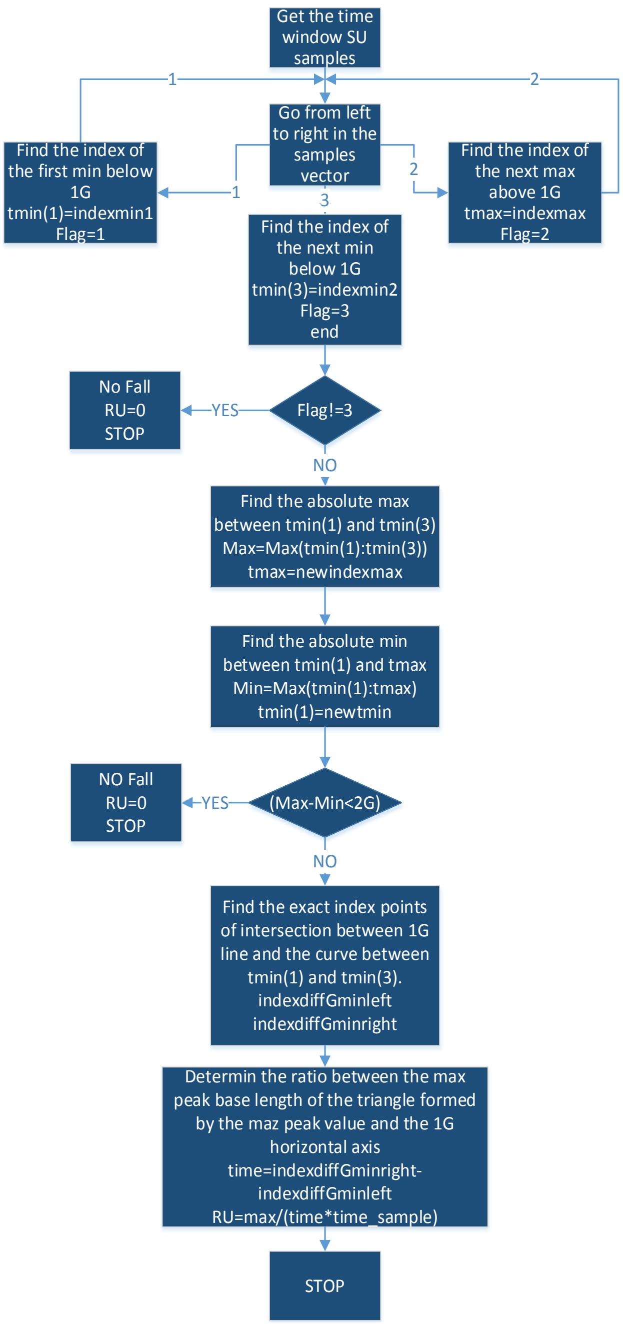

Fig. 4 The fall detection algorithm.

B. *The gas leak detection algorithm*

The concentration of gasses indoors is an indicative measure of the quality of the air and is directly related to the health and comfort of the residents. There are many gasses that are odourless and colourless and cannot be detected by humans. Therefore, there is a need for a constant monitoring of their concentration in order to ensure a healthy environment. Almost all of the toxic gasses interfere with the normal oxygen, thus lowering its concentration [7].

In order to determine a gas leak we used three types of gas sensors, LPG, CO and natural gas (see, Fig. 2). The gas concentration is measured in the international system unit of ppm. For each indoor gas, the medical literature, as well as the the Occupational Health and Safety (OHS) regulations specify the following thresholds that were taken into account while adopting this scale [7]:

- **LPG**
  - Sensor's Detection Range: 200 - 10000 ppm;
  - 8-hour time weighted average : 1000 ppm;
  - Short-term exposure limit: 1250 ppm.
- **NG**
  - Sensor's Detection Range: 300 - 50000 ppm;
  - 8-hour time weighted average : 1000 ppm;
  - Short-term exposure limit: 1500 ppm.
- **CO**

  Sensor's Detection Range: 20 - 2000 ppm.

It was also considered that, for a final user, a ppm concentration may not express a useful information regarding the potential poisonous atmosphere that surrounds him; therefore, a 0 to 10 scale was adopted, where 0 has the significance of a hypothetical scenario, of a non-polluted air, while 10, an extremely hazardous scenario [7]. From mathematical considerations, a logarithmic scale was adopted, according to the detection range of each sensor. The final scores, implemented in the fog node prototype, will correspond to the concentrations [7] from Table 1.

TABLE I

GAS DETECTION SCORES FOR THE DETECTION ALGORITHM

Score	LPG [ppm]	NG [ppm]	CO [ppm]
0	<296	<500	<32
1	296 – 437	500 – 835	32 – 50
2	437 – 647	835 – 1392	50 – 80
3	647 – 956	1392 – 2322	80 – 126
4	956 – 1414	2322 – 3873	126 – 200
5	1414 – 2091	3873 – 6460	200 – 317
6	2091 – 3092	6460 – 10775	317 – 502
7	3092 – 4573	10775 – 17972	502 – 796
8	4576 – 6762	17972 – 29977	796 – 1262
9	6762-10000	29977 – 50000	1262 – 2000
10	>10000	>50000	>2000

Based on the scores described in Table 1, the system administrator can set the proper threshold, based on the user's condition (i.e. if the user is more sensitive to a specific gas, the threshold, for alerting the caregivers, should be lower than in the case of a normal user).

III. ENABLING UBIQUITOUS REAL-TIME E-HEALTH SERVICES

The proposed implementation is part of a highly virtualized platform, which provides local (i.e., fog) computing, data storage and networking services between end user devices and cloud infrastructure.

In terms of e-Health applications, the improved location awareness, low data processing latency and independency from the Internet connection failure, enable an undisrupted operation of vital for the users services for real-time interaction. The proposed implementation achieves an optimal balance between the fog and cloud level operations in order to benefit from both.

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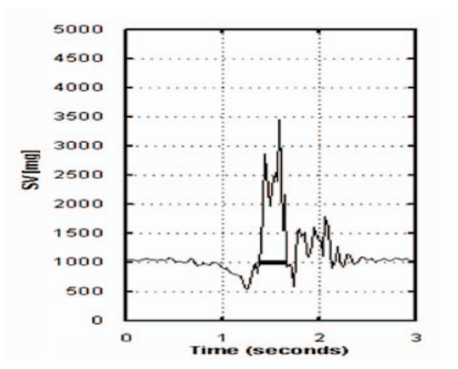

Fig. 5 The SV parameter curve for a fall [7].

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The system handles data and metadata from diverse sources, aiming to understand the context of its users in order to offer them personalized e-Care services. Context understanding is not easily done with a single source of data/metadata. Thus, the fog node, has in its attributions the processing and fusion of sensor data [8]. After this fusion process the metadata (e.g., '*timestamp* and t*heUserLeftTheRoomX/EnteredRoomX'*) are combined with other metadata streams (e.g., "the user has fallen") in order to send to the caregivers the exact information about the user condition and placement. Thus, in order to determine the position of the user we will fusion data from the PIR sensor and the magnetic contact sensor [9]. When the door closes, two scenarios must be taken into account: either the subject has left the room and closed the door, therefore the room was left unoccupied, or the subject closed the door for no particular purpose of leaving, so the room is still occupied. In order to distinguish these two scenarios, the PIR sensor will be used: if the PIR alarm goes high, as motion was detected, this scenario corresponds to the subject still inside the room, so it will be marked as occupied. Otherwise, if there is no motion, the room is marked as 'unoccupied'. This fusion of data (i.e. PIR + magnetic door switch) is one of the cores of the fog system and enables accurate real-time data about the user of the system.

Some of the metadata fusions can be done in the cloud, using the data retrieved from the fog node. For example, to evaluate the level of social activity of a user, the system should know about received visits, remote communication (phone calls, messaging services and social media) and outdoor activity of the user. The visits themselves are understood from the presence of multiple people, gauged by the presence sensors, the detection of faces in video and the detection of speech in audio [8], [10].

It can be said, that the eWALL platform may be referred to as a pioneer in the deployment of fog level operating applications and services for reliable and distributed ambient assisted living (AAL) support.

V. CONCLUSIONS

We proposed and implemented a fog computing system for e-Health applications. The system has been implemented in a laboratory setting at the Center for TeleInfrastruktur (CTIF) at Aalborg University.

The fog system is used for real-time detection of unwanted events (e.g. falls, gas leaking, etc.) that should be detected and reported in a very short time. The system is implemented in the home of the user so that the processing time is as small as possible. Thus, we presented an algorithm for the fall detection, which has a 90% accuracy and a gas leaking algorithm, which can be customized based on the user's condition.

Another, very important feature of the system is the capability to fusion data from multiple sources. The fusion of data can enable real time delivery of information, about the user, to the caregivers. Also, the use of multiple data sources is preventing the system of giving a false alarm and enables a correct assessment of the user's condition at a given time.

Future work will include adding more sensors and adding off-the-shelf devices, that are currently mainstream, and to fusion data from this devices with the custom devices developed, in the project, and described in the above sections.

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