Microprocessors and Microsystems 68 (2019) 74–83

Contents lists available at ScienceDirect

Microprocessors and Microsystems

journal homepage: www.elsevier.com/locate/micpro

An embedded framework enabling access of elderly and disabled persons to IP-based emergency communications

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article info

Article history:
Received 11 January 2019
Revised 5 May 2019
Accepted 13 May 2019
Available online 16 May 2019

abstract

Being able to perform promptly and accurate emergency calls is crucial for every human life. However, people with impairments feel precluded when there is need to have access to emergency centers. The main reason is the absence of IP-based emergency systems triggered by assistive devices and body area networks. To guarantee that anyone can benefit from emergency systems, it is essential to enable em- bedded devices to trigger calls to emergency centers and support IP-based real time communication. To achieve this, the present paper extends SEEK framework (Andriopoulou et al., 2018), an embedded frame- work consisting of environmental, body sensors and a haptic device. SEEK framework enables elderly and disabled people who live independent to perform emergency calls. Sensors embedded in SEEK, aggregate environmental data and vital signs that monitor user's current health status 7and automatically trigger emergency calls when an emergency occurs, providing continuous real-time sensor data. The haptic de- vice provides further modalities to the end user (disabled person or elderly) supporting audio, media and text communication with first responders and healthcare providers at emergency centers. A prototype im- plementation and initial results are presented as a proof of concept for deaf and speech impaired people enabling them to report emergency events and establish real time communication with first responders. The results depict that even lower capability hardware platforms may be used in order to minimize the cost and increase usability by minimizing power consumption of such an embedded framework.

1. Introduction

The expansion of interconnected smart devices forming the so called Internet of Things (IoT) and the evolution in communication technologies have enabled the continuous monitoring of humans as well as the things that carry the embedded sensors and their surroundings [1]. In the context of Ambient Assisted Living (AAL) advances in the area of embedded systems and sensor technology have provided solutions and valuable assistance to elderly and disabled persons, helping them to live independently with robust communication mechanisms to overcome emergency situations [2]. However, during an emergency incident, IoT devices have not been used to trigger emergency calls directly to healthcare providers mainly due to their constrained capabilities and lack of support of session-oriented communications [3]. Moreover, emergency services are currently offered by public safety stakeholders that do not support call triggering by IoT devices.

The evolution of assistive technologies (AT), Augmentative and Alternative Communication (AAC) technologies and IoT has enabled users with impairments to determine an alternate communication with the others expressing their needs or requesting daily assistance. Using the aforementioned technologies their quality of life can be enhanced so as to live autonomously. However, existing AT and embedded devices fail to report emergency incidents and high risk attention events such as fire incidents, acts of terrorism or floods which remain real challenges for the handicapped.

Despite being able to report emergency incidents, AT and embedded devices cannot be integrated to the existing emergency systems and PSAPs precluding citizens with impairments to have equal access to them. The main reason is that traditional emergency communication networks have been implemented with limited capacities, supporting only voice calls. Meaning that emergency systems and Public Safety Answering Points (PSAPs) fail to serve IP-based calls such as media and web-initiated calls. Moreover, assistive devices are dedicated to particular applica-tions and it is difficult to adapt them for other applications. These adaptability limitations lead to unaffordable costs since the user has to be supplied with new devices based on their changing needs.

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https://doi.org/10.1016/j.micpro.2019.05.006
0141-9331/

In terms of the recent advances in providing IP-based emergency services over modern communication infrastructures, while most operators have already migrated to broadband IP infrastructures, emergency systems still need to adapt their emergency communication platforms to fulfil regulatory and interoperability requirements. However, during the last few years several research projects have studied the integration of IP to emergency systems in Europe [4] and worldwide [5]. According to the definition of this architecture, emergency calls are delivered through the Emergency Services IP network (ESInet), which is designed as an IP-based internetwork, handling IP communications based on the Session Initiation Protocol (SIP) [6] and providing the required functional- ity to appropriately process and route sessions based on location information.

Following the challenges and technological advances mentioned above in this paper we propose an embedded framework, named SIP-based Emergency Embedded frameworK supports elderly and disabled to perform emergency calls (SEEK), that aims at mak-ing next generation emergency services available for people with health problems and/or disabilities. An implementation of SEEKhas first been presented in [7] based on a standalone embedded device for aggregating sensor data over plugged in wired health sensors. An extended implementation with distributed sensor dataaggregation over both wired sensors as well as non-intrusive sen- sors embedded on wirelessly connected health trackers is de- scribed in this work. SEEK is a low cost embedded framework,with focus on low resource usage that extends the IoTA frame- work [8] incorporating tactile feedback in order to support dis- abled people to perform emergency calls and get expressed. Hard- ware wise it is composed of two sub-systems, an in-house de- veloped haptic platform that enables user initiated SIP calls andan extended sensor platform that monitors user's vital-signs, body position and environmental information with capabilities of non- intrusive user state measurements, arranged and connected as a singular distributed computing system. SEEK performs emergency calls generated either manually by the haptic device or automati- cally by the sensor platform. The haptic device provides a Graphi- cal User Interface (GUI) based on a set of graphic symbols/pictures arranged as an array of buttons and a buzzer that can trigger vi- bration patters to notify the user according to the translation of received messages or attract his attention to one of the other communication interfaces via text messages, video and audio. Each picture/button corresponds to a predefined text word or phrase and can be used successively to compose messages that allow them to express their thoughts, feelings or needs and communicate with others. These symbols are translated and forwarded to the sensor platform as a preformatted text message. The sensor platform parses the received message, correlates it with vital signs or environmental information by sensors and may trigger when judged accordingly an emergency call. Whenever an emergency call is performed, sensor data and/or text are forwarded through a SIP client (i.e. SIP phone) that establishes an emergency call with the appropriate PSAP supplying information about the location of the event, sensor data, user's feelings or needs. Moreover, it supports mechanisms that establish a continuous channel of communication with the PSAP through continuous update of sensor data and/or text by haptic device.

A prototype application has been implemented as a proof of concept in order to demonstrate the functionality of the proposed framework. The case study used for evaluation purposes is basedon a real-time scenario for supporting deaf and speech impaired people.

The rest of the paper is organized as follows: in Section 2 the related work is presented. The proposed SEEK framework architecture is presented in Section 3. In Sections 4 and 5, the implementation details and indicative results regarding system resource usage are presented and discussed respectively. Finally, Section 6 con- cludes the whole paper.

2. Related work

To our knowledge the most recent effort focusing on provid- ing access of citizens to emergency services' daily operations over commonplace Internet-enabled communication technologies have been the NEXES NEXt generation Emergency Services and EMYNOS - nExt generation eMergencY commuNicatiOnS EU funded projects [4,9]. NEXES aimed at supporting a total conversation service to citizens in general and persons experiencing impairments, includ- ing not being able to speak or hear (either temporarily or perma- nently) or non-native speakers such as tourists and immigrants. NEXES considered different modalities and data exchange flows in- cluding interactive chat, video calling, providing accurate GPS lo- cation from users' mobile devices, providing up to date emergency information, and being informed with relevant information. NEXES proposed the integration of the sensor devices using the MSD for-mat in order to establish automatically SIP-based emergency calls. NEXES run in parallel with EMYNOS an EU founded project; that proposes a next generation emergency management platform ca- pable of accommodating rich-media emergency calls that combine voice, text, and video. Finally, another complementary European initiative is the Infrastructure Harmonised eCall European Pilot I_HeERO project [10]. I_HeERO focuses on piloting the deployment of EU-wide eCall ("I" standing for "Infrastructure") and is aimed atthe preparation of the PSAP in Member States for the deploymentof eCall based on 112 as reference implementations addressing ex- plicitly the PSAP element of the eCall roll-out. While the above projects have only recently delivered the first prototypes for an in- frastructure that can efficiently support next generation IP based emergency communication services, interoperable end user plat- forms that can efficiently exploit this infrastructure are still open to research. The above projects have demonstrated that rich-mediaIP based emergency communications, with efficient location-basedservice routing and sensor information encapsulation in different formats are feasible and identified the requirement for enhanced client platforms that can present the enhanced functionality to the end users and especially elderly and disabled persons that have re- quirements beyond those of a typical smartphone or a connectedcar platform.

In the domain of AAL numerous embedded devices have been proposed and developed to support elderly and people with impairments such as motion and fall detectors, smoke alarms, bed detectors, speech recognition systems, assistive devices for blind and deaf [2]. The innovations in human-computer interaction and embedded devices with more capabilities have further benefited people with impairments to communicate and interact properly with others using computing entities. Numerous AAC and AT solutions have been developed for users suffering from multiple chronic diseases that have as a consequence the permanent or temporary loss of some of their physical abilities, as for example diseases like autism spectrum disorders, Down syndrome, dementia, Alzheimer, stroke or traumatic brain episode that lead to speech, hearing or motor malfunctions [11–13]. There is a considerable number of AT and IoT devices available on the market and research efforts for people with disabilities that provide away to communicate through symbols, speech synthesis, comput- ers and special software. Many persons that are not able to speak or write, they use graphic symbols to compose messages that al- low them to express their thoughts and communicate with oth- ers. There are several graphic symbol systems available that are used for AAC purposes worldwide, such as Widgit Symbols™ [14], Blissymbols™ [15] and Makaton™ [16].

Smartbox Assistive Technology company provides solutions such as Power Pad, Grid Pad Pro and Eye Gaze [17] that gives voice to people without speech to communicate through symbols using touch or switch access on a portable device. Central Alert CA-380 Combo 1 Notification System [18] provides alert notifica- tions for people with hearing impairments. It uses a loud ringerand bright flasher to alert you to incoming landline, cell phone, Skype and FaceTime calls and text (SMS) messages. Text Typewrit- ers telephone devices (TTYs or TDDs) [19] can be used by peo-ple with hearing or speech disabilities to send and receive text messages over telephone. Such devices include a keyboard, like a computer or typewriter, and allow communication over the traditional telephone and a text telephone using a relay system. Such systems provide an intermediate operator who transfers printed text to speech and vice versa in order to make a telephone conversation possible. Moreover, haptic feedback shoes [20] have been introduced in order to allow blind users to walk freely without canes or guide dogs. Haptic shoes enhance GPS technology to pro- vide directions and guide the visually impaired user. Haptic shoes contain sensors and actuators that give haptic feedback on user's movement as he/she walks vibrating to inform about obstacles and when to turn or stop. Moreover, head mouse [21] and eye tracker [22] systems have been implemented that allows the user to control the mouse cursor using head or eyes moves respectively.

Many researchers and practitioners in computer science, electronic engineering, and robotics are leveraging the sensing technology of Microsoft Kinect [23] platform to develop creative new ways to interact with machines and to perform other tasks, from helping rehabilitation process after a stroke or with motor disabilities [24]. Pan et al. [25] have proposed a portable sensory augmentation device (SAD) for rehabilitation of balance. SAD aims to provide postural sway information through additional skin stretch feedback. Lotte et al. [26] proposed a tongue computer interface to be used by disabled people for environmental control. AsTeRICS [27] is a free and Open-Source construction set for assistive technologies (AT). It allows the creation of flexible solutions for people with disabilities using a large set of sensors and actuators. AsTeRICS platform is a dedicated PC running Windows operating system, built on nanoETXexpress-SP board with Intel Atom processor. SafeAwake [19] is a fire/smoke alarm system that can be placed under the pillow of the bed supporting elderly and deaf people even during the night-time producing vibrations that shake. How- ever, the aforementioned systems are limited to reporting events, training, rehabilitation and monitoring purposes and fail to support emergency calls.

Emergency events and disasters can strike quickly and without any warning. Users with impairments ought to have equal access to the emergency systems. In the literature, limited work can be found related to emergency call provisioning to disabled people. REACH 112 project [28], was the first initiative that implemented an alternative to voice telephony in order to enable conversational access and person-to-person communication to emergency services supporting deaf, hard-of-hearing and deaf-blind people. However, relay services are inappropriate for reporting emergency events since they increase the response time between the initiation of the call and the emergency service provisioning. On the other hand, AAC technologies and haptic devices enable force or tactile feed- back to be synthesized to speech or real time text [29]. In this context, the inclusion of haptic and AAC devices in order to per- form emergency calls, seems to be the most prominent solution. This is due to the fact that in emergency situations even healthy people without any disability may not be able to speak or reactdue to an acute stress reaction, shock. Haptic and AAC devices im- prove the task performance and the sense of togetherness avoidingpreclusion of the disable people from emergency services.

To the best of our knowledge, there are neither solutions nor research efforts that integrate haptic and sensor devices in a wearable/portable form in order to initiate emergency calls. In this paper, we propose SEEK framework that meets all the aforementioned challenges by triggering and receiving emergency calls generated either manually by haptic device or automatically by the sensors. It is a low cost embedded framework that extends the IoTA framework [8] incorporating tactile feedback generated by a haptic platform as well as interfaces to third party wireless wear- able health trackers for non-intrusive health status monitoring and sensor data aggregation. SEEK framework is composed of two primary embedded sub-systems, a haptic and a sensor platform that monitors user's vital-signs and body position. The haptic device incorporates a set of graphic symbols/pictures to support disabled people to get expressed and vibrations to alert them in time when needed (e.g. when public warning systems are in operation orother incoming messages arrive). In the case of user initiated calls these symbols are translated to text and are forwarded to thesensor platform that also acts as a personal/body area network (PAN/BAN) communication gateway. The sensor platform parses the received message, associates it with vital signs or environmen- tal data aggregated by sensors directly attached to the sensor plat-form or received wirelessly over third party devices and triggers an emergency call through a SIP client (i.e. SIP phone). The SIP client establishes an emergency call with the appropriate PSAP or emergency center supplying information about the location of the event, sensor data, user's feelings or needs based on the EMYNOS communication architecture presented in [4]. Moreover, it supports mechanisms that establish a continuous channel of communication with the PSAP through continuous update of sensor data and/ text by haptic device.

3. Seek framework architecture

3.1. Overview

SEEK aims to facilitate handicapped people performing emergency calls based on their profile and special needs. In this con- text, SEEK consists of two lightweight portable independent subsystems; a haptic device and a wearable sensor platform as presented in Fig. 1.

The haptic platform exploits the sense of tactile feedback and incorporates a user-friendly human computer interface based on Widgit graphic symbols/pictures which is a standardized way of communications for people with monitor or speech impairments [14]. Widgit graphic symbols permits user to select a picture from a screen monitor associated with their current feelings (i.e. happy, sad, dizzy), situations, needs, or emergency events (i.e.fire, flood, medical help, ambulance, police). The haptic platform receives the tactile feedback forced by the pressure of the picture, processes and translates it to a text message. The output of the haptic plat-

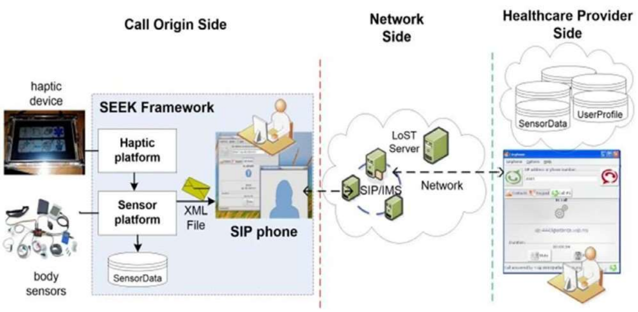


Fig. 1. The SEEK Framework architecture overview.

form is forwarded to the sensor platform/gateway and can trigger automatically an emergency call. The haptic device is used as a total conversation media that utilizes the sense of touch to enable the end user to physically interact and communicate with the oth- ers. Haptic platform incorporates methods that allow bi-directional communication between the user and the calltaker of the PSAP. In this context, a buzzer is used to notify the user according to the translation of received messages and provide a means of notifi- cation for incoming communications over the default client com- munication application and GUI. This extends the concept of total conversation – a requirement discussed in [9] - and provides an al- ternative enabling mechanism especially useful for emergency sit-uations to person with specific impairments and disabilities that hinder their communications via speech and audio.

As mentioned above, the sensor platform receives, parses and processes the messages from the haptic platform so as to initi- ate emergency calls. Moreover, it is responsible for monitoring and aggregating information from various distributed sensors. It con- sists of a set of medical and environmental sensors that moni- tor caller's bio-signals, environmental indoors conditions and posi- tion respectively. More specific, it consists of the following sensors: thermometer, pulsioximeter, Electrocardiogram/ECG, smoke detector, gas detectors, humidity sensor, accelerometer, and gyroscope. The aggregated sensor data are processed and evaluated in orderto detect abnormal events and identify their type of the emergency event; either it is a healthcare or catastrophic incident. All the re- ceived data are stored to an internal SensorDatabase permanently for a day (a parameter also depending on the storage capabilitiesof the device). Then, there is the option to be forwarded to a cloud infrastructure otherwise they are deleted. In case an emergency event is detected, or a message is received by the haptic platform,the sensor platform generates a wrapper alert message encapsu- lating the data in an XML-format and sends it to the SIP client
i.e. SIP-based VoIP application - SIP phone) over a socket-based interface establishing a communication session with the appropri-ate emergency center or PSAP. The sensor platform can also sup-port and integrate to its functionality several other sensors such as galvanic skin response/GSR, electromyography/EMG, airflow, blood pressure and spirometer.

The sensor data interface has been developed as a client server model in order to enable the communication between the sensor platform and the SIP client. The interface accepts the critical data in XML format. Sensor Model Language (SensorML) [32], which has been selected as the standard of choice to convey the sensor data into the SIP signaling. Then, it encapsulates them in the body of SIP messages and forwards them to the emergency center through normal SIP routing. SensorML is a standard of the Open Geospatial Consortium (OGC) that aims to provide interoperability, first at the syntactic level and later at the semantic level. This approach is in conformity with already standardized solutions, like PIDF-LO (RFC 513943), and thus can be efficiently adapted to existing solutions.

The SIP Client is the key component that implements next-generation IP-based emergency services. This means that SIP Client is responsible for transferring the output data from haptic and sensor platform to the IP-based communication methods and trigger emergency calls to PSAPs. The SIP Client supports location information and routing to the appropriate PSAP based on the EMYNOS communication stackand open source implementation [4]. It is enhanced in order to use Uniform Resource Names (URNs) identifiers for IP-based emergency calls and support SIP SUBSCRIBE/NOTIFY messages. A valuable service is provided by the SIP Client that allows URN-based classification and identification of emergency services to be triggered for each type of emergency event (i.e. ambulance, emergency room, etc.) obviating the need to manually search for the provider of that service. This implementation eliminates time delays due to manual search for the provider of the required

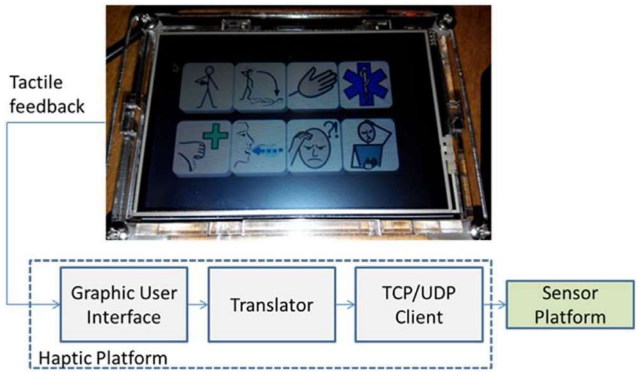


Fig. 2. The components of the haptic platform architecture.

emergency response serviceenablingautomated selection and accurate report to the appropriate provider [31]. In the SEEK Framework, the SIP client is enhanced to provide an additional interface to the sensor platform enabling real time communication through the haptic device and reporting in pre-defined or dynamically adjusted periodic update intervals via messages that encapsulate the data related to the caller's healthcare status. In this context, the SIP client supports the SIP SUBSCRIBE/NOTIFY message [30] providing a bi-directional communication between the citizens, the embedded devices and the responders of the PSAP. This bi-directional communication enables the call taker to be informed in an accurate way and request continuous real-time sensor data streaming in order to detect the emergency event, estimate its severity and respond swiftly and effectively, saving lives.

3.2. Haptic platform

The haptic platform is composed of a Graphical User Interface(GUI), a Translator and a TCP or UDP Client as shown in Fig. 2 (with both clients available as a setting selection). The GUI pro- vides the interface for receiving tactile feedback through the touch screen monitor incorporated in the haptic platform enabling per- sons with speech impairments and kinetic disabilities to easily communicate vie simply pressing large symbols that appear on the touch screen. The tactile feedback is associated to the pressure de- tection of a picture selected by the actuator. The tactile feedback is forwarded to the Translator for further evaluation and process. The Translator processes and correlates the images which appear in the GUI to text. The result of this process is forwarded to thesensor platform through the TCP or UDP Client component.

The TCP/UDP Client component creates a UDP datagram or a TCP packet with payload formatted as pure text (text string), XML or SIP message that contains the text received from the Transla-tor component and sends it to the corresponding server locatedat sensor platform. Currently for testing purposes, the Haptic Platform adds the message as a simple text string to a UDP datagram payload, however the Haptic's engine can also format the message as an XML or a SIP text message if such function is needed. Fig. 3 shows the detailed haptic platform software architecture

3.3. Sensor platform

Accordingly the sensor platform acts as the data aggregation and communication gateway in the form of a wearable embedded system. It implements the vital-signs, body position and environmental data aggregation from the wearable sensors, supports the decision making process for automatic call triggering and implements the communication server and clients as shown in Fig. 4.

The Data Acquisition Module is mainly responsible to provide interfaces aggregating data from various sensors. These data are

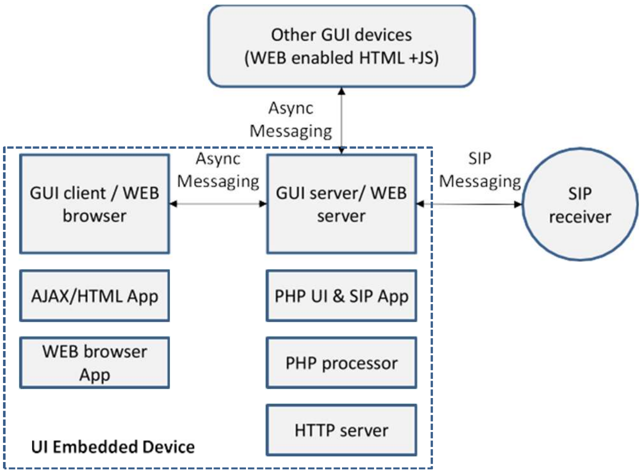


Fig. 3. Haptic platform software architecture.

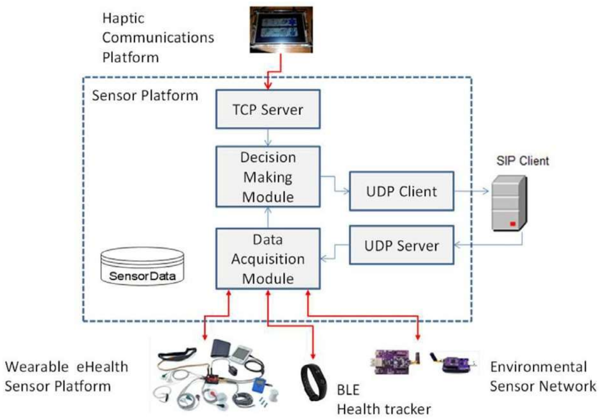


Fig. 4. The components of the sensor platform architecture.

stored temporarily in a local database (SensorData in Fig. 4). The interfaces we implemented facilitate sensor data aggregation via both directly attached wired sensors (since several of those as de- scribed in the previous section where made available at low costand with lightweight libraries for management and communica- tion) as well as via distributed sensors that are made availableon third party wearable devices like health trackers/smart watches etc. that usually can be interconnected wirelessly. Moreover, dur-ing the sensor update process, appropriate interfaces are providedfor retrieval purposes.

The Decision Making Module shown in Fig. 4 processes and evaluates the real time data received from the medical sensors and the haptic device. For each sensor, predefined threshold values are used in order to detect abnormal events. More details about the methods used to recognize emergency situations based on the flow of real-time data at appropriate time-scales can be found in [8]. Since this work is focusing on the embedded system design aspects of SEEK, we direct the interested reader to [8] for more information related to application level details. In case abnormal events are detected the system is expected to trigger emergency communication sessions so that even in the case that the person is unable to initiate the emergency service him/herself the system will execute that for him/her in an autonomous manner. As normal values we define values that their distance from the other time-series data is greater than the threshold margin. When an abnormal event is detected, a time-series outlier detection algorithm is performed in order to discern conditions between a faulty sensor reading and a user entering into an emergency state. Rule-based

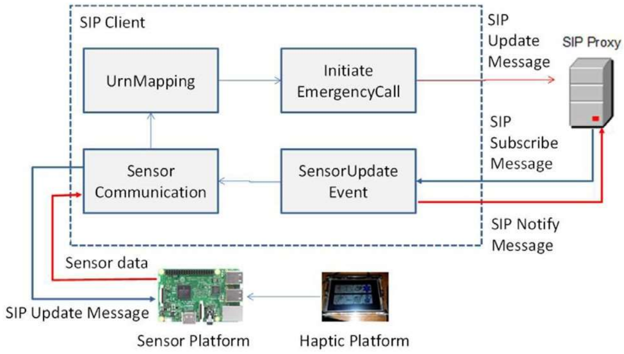


Fig. 5. The components of the SIP Client.

and J48 classification algorithms have been implemented in order to clarify the severity of the emergency and the appropriate emergency department in which the call will be forwarded through the UDP Client component. Additionally, emergency events can be triggered manually by the user through haptic device. In this context, the Decision Making Module provides mechanisms that parse the text provided by the haptic device and identify users' needs and feelings. In case of an emergency event reported directly by the user, the received text is correlated with data from sensors. Let's assume that a message "fire" is sent to the sensor platform. The Decision Making Module retrieves data from smoke and detector sensors as well as vital signs from pulsioximeter and respiration sensor in order to identify the user's current health state and the severity of the event. An alarm is created and is forwarded to the UDP Client component regarding the emergency event. This functionality enhances the content of the message sent to the emergency center. In case no message is generated by the haptic device, the Decision Making Module processes and evaluates the sensor data and detects abnormal events.

A TCP Server provides an interface for socket-based communications with the haptic platform and the sensor platform. It re- ceives TCP/IP messages from haptic devices and forwards them tothe Decision Making module for processing and evaluation.

Similarly the UDP Client encapsulates in an XML file the sensor and/or haptic data received from the Decision Making Module or Data Acquisition Module component and sends it over a UDP/IP protocol stack implementing an interface in a the same manner for socket-based communications with a SIP client.

Finally the UDP Server component provides similarly an inter- face to the SIP client that allows the PSAP responders to requestupdated real time data of the caller that initiated the emergencycall. The UDP Server receives SIP messages.

3.4. *SIP client*

The SIP client as mentioned above is responsible to adapt thesensor data to the IP-based emergency communication methods. It consists of the UrnMapping, SensorCommunication, InitiateEmer- gencyCall and SensorUpdateEvent components as shown in below(Fig. 5).

The UrnMapping component translates the PSAP Contact Telephone number (i.e. 112) to a corresponding URN service identifier (e.g., urn:service:sos) implementing the EMYNOS location based emergency service architecture [4].

The SensorCommunication component implements the communication interface to the sensor platform based on the SIP [30] communication protocol. It is based on the MESSAGE SIP method and exploits UDP as transport. It receives alerts whenever an abnormal medical event is detected by the sensor platform and triggers the InitiateEmergencyCall. After call set-up and during message exchange periodic updates of sensor values can be pro- vided; thus, this component is also able to submit queries to the sensor platform for data updates and forward the received data tothe SensorUpdateEvent component.

The InitiateEmergencyCall component initiates an enhanced emergency call via a SIP communication stack. In this case, the medical data and text provided by the haptic platform are included in the body of the INVITE message in SensorML format [32]. It also includes the provided URN identifier in the "To:" field of the IN- VITE message.

The SensorUpdateEvent component supports the update of the sensor values that can be collected as mentioned above during an emergency event at the client-side. For that purpose the SIP SUBSCRIBE-NOTIFY framework [30] is utilized, in order to allow the communicating parties to get near real-time updated values ofthe caller's sensor data (i.e. vital signs and environmental data). The SIP specific event notification framework allows the entities of the network (e.g., PSAP, first responders) to subscribe to the stateof other entities, which in return can send notifications when their state changes.

4. Implementation

4.1. System set up

A prototype application was developed as a proof of concept and experimentation and evaluation platform for the SEEK Frame- work. The application includes three main components: the haptic platform, the sensor platform with various directly attached and distributed sensors and sensing modules and the SIP Client.

The home environment of the caller is monitored by a network of environmental sensors (i.e., temperature, humidity, air pressure, etc.), which aggregate data in real-time to a home gateway. Specif- ically, the scenario involves the integration of three different dig-ital sensors: a temperature/humidity sensor (SHT21), an accelera- tion sensor (ADXL346) and a light sensor (MAX44009) interfaced to OpenMote-CC2538 [33]. This Internet of Things platform will be responsible for real-time monitoring and access to the provider's network. A decision making engine process these data and creates alerts as soon as, certain threshold values are exceeded. An emer- gency call is initiated automatically by the alarm system, which triggers the PSAP. Alternatively, haptic devices integrated over the user's terminal, alert the person with disabilities about an emer- gency situation in the vicinity and through the haptic interface the user setups a call to the nearest PSAP, or receives a call (audio, ortext, or visual stimuli) from the PSAP.

The haptic platform is developed upon a single-board comput- ing device (Raspberry Pi3) running a Debian based operating sys- tem (Raspbian Jessie) and using Ethernet or IEEE 802.11 wireless connection to the Internet, since the board provides built-in Gi- gabit Ethernet, Bluetooth 4.2 and Wi-Fi adapters. A low cost 3.5 Inch Led-backlit TFT-LCD with touch capabilities was chosen as the display of the haptic platform. The diagonal size of the LCD was selected to be 3.5 Inch, matching the size of the main board as closely as possible At this screen size, a resolution of 480×320 pixels was deemed high enough to produce a clean display with low user effort usability of the GUI in order to increase user's qual- ity of experience and support multiple type of impairments such as low and medium vision as well as low motor. The TFT-LCD screen monitor is used for tactile feedback. In order to achieve a hardware and OS-agnostic application design, the GUI of the haptic platform is developed in HTML and PHP. The software is initiated by the pressure of the image on the monitor. The touch sensitive GUI pro- vides the functionality to map pictures to text according to the graphical button selected by the user. Each icon when pressed im- mediately issues a text-formated asynchronous message to a PHP

Fig. 6. SEEK haptic interface made accessible concurrently via the on board touch screen and a networked tablet.

server (using AJAX). The text is encapsulated in a XML message and sending through TCP/IP protocol to the sensor platform. The system is designed following a black-box approach and only the GUI is made available to the user after system boot. Local area network auto- connect is enabled and a simple language indepen- dent, touch- enabled GUI using Widgit Symbols is coming up on the touch screen. From a developer's side easy access to the GUI con- figuration is provided on-line over the network (PHP/HTML files accessible). Easy access to system resources is supported throughan SSH terminal (OS settings accessible) and UI functionality con- figuration can be performed through the "settings.php" file and Message/Icons library configuration through a "translator.php" file. The design provides multi-device support with screen resolution detection (Fig. 6), thus even a group of web-enabled devices con- nected over the local network (CellPhones, tablets, Smart TVs, TV- Boxes, and smart watches) could access the GUI as well as alter-nate input devices like remote controls, air-mice etc. (Fig. 6).

While websockets technology was available in the initial system design, the different implementation of this technology in each dif- ferent web browser would have caused system compatibility prob- lems. Thus, the low-latency and event-driven capabilities of web- sockets were sacrificed in order to achieve better system stabil- ity in heterogeneous systems by using a mature and more sta-ble JS/AJAX-PHP scheme. This choice minimized the possibilities of system malfunctioning during an emergency.

The sensor platform was based on the e-Health Sensor Plat- form Complete Kit V2.0 for Raspberry Pi distributed by cooking- hacks [34], since the kit provided an adaptation board with ap- propriate ports and a number of wired sensors with the requiredlibraries and utilities for sensor communication, configuration andmanagement. The kit came without a package, so we developeda 3D printed custom packaging to use it as an actual wearable device, powered by a 5000mAh power bank for autonomous op- eration allowing the user to move around (which proved to last for over a day with average usage). A number of sensors include body thermometer, pulsioximeter, ECG, blood pressure, airflow and galvanic skin response sensors have been used to monitor user's health status. Moreover, a tri-axial accelerometer ADXL345 and a gyroscope ITG3200 were used in order to measure acceleration and angular velocity for detecting falls. The accelerometer/gyroscope is packed into a chest belt for optimum location retrieval. All the sen- sors are attached directly to the sensor platform, however the cur- rent implementation of these sensors is considered, in most cases, intrusive and impairs user functionality by limiting one's move- ments as a result of the wired connectivity. Even though recently a newer version of the platform has been released under a new brand called My-signals by Libelium [35] in a smaller form factor,also providing a number of wirelessly connected via Bluetooth Low Energy (BLE) sensors, the sensors themselves are still bulky and

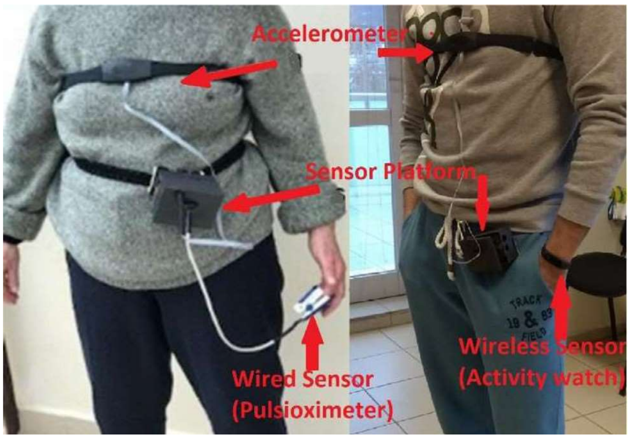


Fig. 7. Real time demonstration of sensor platform with wired or wireless sensors.

intrusive. Thus, even though wires can be easily eliminated sensor miniaturization and un-intrusive health monitoring is still an issue.

Towards this end several attempts have been made to integrate health sensors that can be also used for the detection of several emergency conditions, exploiting other smart devices already found in the position of users like smartphones, arm/wrist bands, smart/fitness/sport watches, health trackers etc. [36–38]. Thus, during the design of the platform it was decided to extend the system in order to support wireless (BLE) sensing based on widely available third party wearable devices. Keeping this requirement in mind an activity watch (Mi-Band 2) was selected as a proof of concept replacing the wired pulsioximeter as a heart-rate measurement device. This in turn fully released the hands of the user (Fig. 7) while maintaining constant, full-time measurement of heart-rate and adding the capability for secondary measurements like pace-counting or movement detection. The sensor platform is developed upon a single-board computing device (Raspberry Pi3) running Debian operating system, using Ethernet or IEEE 802.11 wireless connection to the Internet and Bluetooth 4.0 protocol in order to support any BLE PAN/BAN connectivity requirements.

The software of the sensor platform is developed in C++ multithreading programming model. The software that collects data from each sensor is implemented and runs as an independent thread enabling fast execution of the decision processes optimizing resource consumption, latency and responsiveness. In order to al-leviate any heterogeneity problems between the wearable devices and the rest of the system, a generic communications model was developed that implements a UDP based inter-process communica- tion method and a well-defined formatting of the data containingboth the description and the measurement information. After the implementation of this model as a discrete thread the main soft-ware platform remained unaltered on all occurrences while only a driver was developed for the wearable device running as a stan- dalone application which translates the BLE received data to the well-defined formatted data expected by the main software plat- form. The extensibility of such system is proven by the fact that for each different wearable device only a driver is required and may be developed to function as a middleware between the wireless sens-ing devices and the main system. The software that parses the text and identifies the occurrence of an emergency event runs as an- other independent thread for accurate detection. The sensor datais stored locally to a database located at Pi Storage Unit for tem- porary usage. Whenever an emergency issue is identified, data re- trieved from SensorDatabase is forwarded to the appropriate PSAP. The InfluxDB database [39] was used in both cases. An open source metric analytics and visualization tool, Grafana [40] was used in both user and healthcare provider's end in order to visualize time series data from sensors. Fig. 7 demonstrates users wearing some of the most significant sensors (pulsioximeter, tri-axial accelerometer ADXL345 and a gyroscope ITG3200 packed in the belt) on a daily basis.

The SIP Client is implemented based on the open-source Voice Over IP phone, Linphone [42]. SIP Client was extended in order to encapsulate information regarding the location, text received by haptic device and the sensor data and configure the update rate and flow of messages from the sensor platform for periodic sta-tus update and real-time health monitoring. SIP Client retrieves the user's location from location servers. The LoST (Location to Service Translation) protocol [41] which maps URNs and location information to one or more service URLs is used to retrieve the location of the appropriate healthcare provider. The SIP Client retrieves the location by the providers using a PIDF-LO XML payload and encapsulates it into the SIP INVITE message for initiating an emergency call. Moreover, similar to the location data, the SIP Client receives the aggregated bio-signals from sensors into an XML-format which is encapsulated to the SIP INVITE message body. The SIP Client used is developed in C, on the Ubuntu 14.04 operating system. Asa future extension a SIP client also available on Android could be used and then the SEEK framework could be completely ported on a powerful Android-based smart phone instead of the Raspberry board and this is something we are evaluating as future work.

4.2. System demonstration

In Fig. 8 we demonstrate a scenario emulating an emergency communication initiated by a person with speech disabilities utilizing the SEEK haptic interface. Fig. 8 shows the user screen and the resulting text messages as received and displayed on the re- ceiver's (PSAP side) client application as well as in-line packet transmission as captured by a packet sniffer application (wire- shark) during system operation.

In Fig. 9a screenshot is presented captured during the automatic emergency triggering process. The SEEK framework initiated an emergency call through haptic platform due to a medical issue detected by the sensor platform. A multimedia communication session is established with the first responder in the PSAP and the caller. The caller uses the haptic device to answer first responder's questions and the sensor platform provides information regarding caller's location, environmental and medical sensor data through a user-friendly GUI.

The system also provides a remote web-based monitoring and administration GUI (Fig. 10). The purpose of this application is to enable medical service provider personnel or any technical assistance personel or even the user him/herself - if technically com-

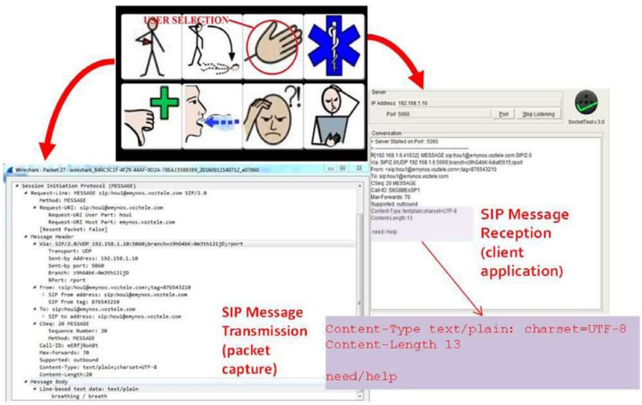


Fig. 8. Screenshots of SEEK framework triggering message transmission to the PSAP via the haptic interface.

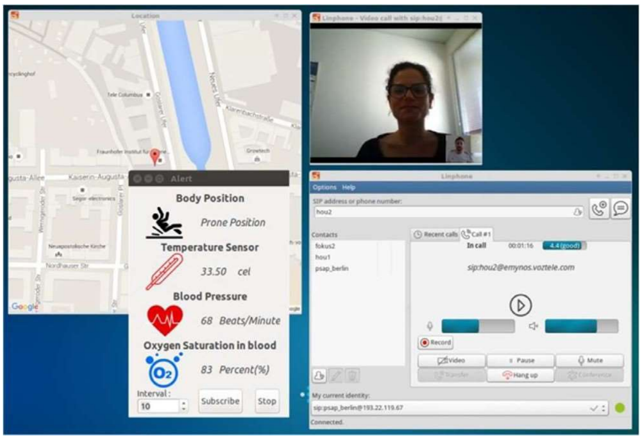


Fig. 9. Screenshot of SEEK framework triggering an emergency call to the PSAP.

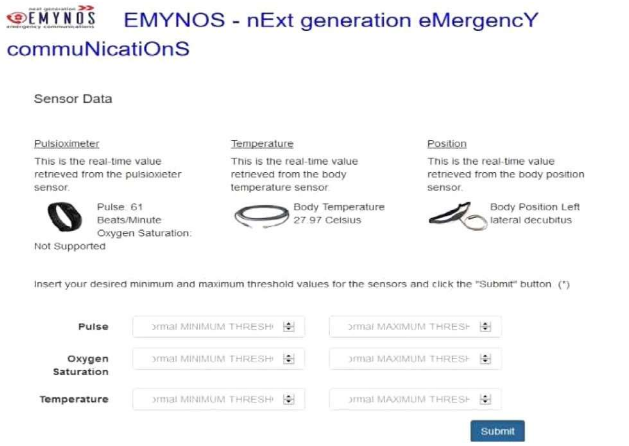


Fig. 10. Screenshot of user dashboard application allowing data management and configuration of attached and distributed sensors.

petent and given access to the administration dashboard - to both survey the user state, verify the system functionality and define the basic parameters of emergency calls.Thus, the platform could also serve as a generic health management system in the context of connected health applications [43], in addition to enabling emergency communication services.

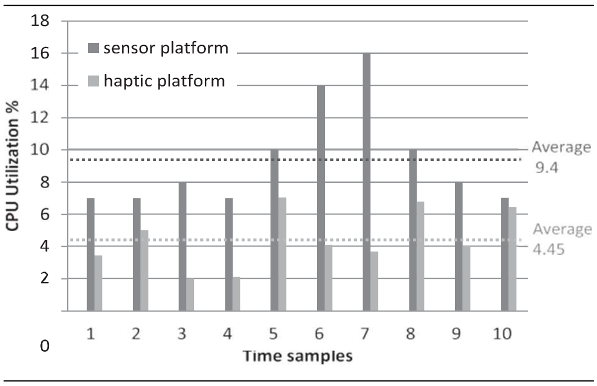
5. Evaluation

The SEEK framework has been implemented and demonstrated in the context of the European project EMYNOS [4]. The complete list of functionalities described above has been implemented and has been tested by real users, including people with disabilities having been invited at three pilot sites in different EU countries. However, since the EMYNOS project focus was on developing and demonstrating the communication infrastructure, long term testing in different user environments (including users with different profiles and monitored incidents) in the context of AAL was not possible. As future extensions of this work we intend to deploy the SEEK framework in the facilities of the Ambient Assisted Living House, developed by the collaborating Embedded System Design & Application laboratory of the Western Greece University Of Applied Sciences ([44,45]) and further investigate the human factor in the performance of the high-level application functionality. In the remainder of this section we present evaluation results related to the embedded system performance, which is the focus of this paper.

In order to verify the low-level system functionality, CPU load measurements were taken during system operation (message process, sending and GUI usage) with the use of HTOP application utility. Over the 10 measurement samples taken, the haptic device consisting of a quad core ARM v8 (Raspberry Pi 3) and a non-DMA SPI connected LCD screen while servicing OS background opera- tions, networking functions and SEEK services peaked at a single core load of 14.9% and an overall (all-cores average load) of 7.025% indicating the excessive CPU capabilities of the selected platform.

The average 4-core loads are shown in Table 1 for both hardware sub-systems used. Obviously the sensor platform due to the demanding operations that need to be performed requires more system resources, which however can be provided at any time without compromising the overall user experience and quality of service.

Table 1
CPU Load on SEEK Framework.



6. Conclusion

In this paper, we proposed the enhancement of the SEEK embedded framework. SEEK is a low cost, low resources usage embedded framework that performs emergency calls generated either manually by haptic devices or automatically by a set of medical and environment network connected sensors. an embedded framework consisting of environmental, body sensors and a haptic device. The aforementioned embedded sensors in SEEK, monitor and aggregate, process and evaluate data regarding the environmental indoors conditions as well as the user's current health status and automatically trigger emergency calls when an emergency oc- curs. Whenever an emergency call is performed, the SEEK frame- work provides continuous real-time data update in order to enablefirst responders to be informed about the urgency of the event. This means that sensor data and /or text are forwarded througha SIP client (i.e. SIP phone) platform. SIP client is responsible for emergency call establishment with the appropriate PSAP supply- ing information about the location of the event, sensor data, user's feelings or needs. Moreover, it supports mechanisms that estab- lish two-way communication with the PSAP through continuous update of sensor data and text by haptic device based on SIP SUBSCRIBE/NOTIFY messages.

The incorporation of the haptic device in SEEK framework, provides further modalities to the end user (disabled person or elderly) by supporting audio, media and text communication. A user friendly touch sensitive GUI has been implemented in order to enable user to select a picture that points to the current emergency event. The developed application provides the functionality to map the selected picture to text. The text is encapsulated in a XML message and sending through TCP/IP protocol to the sensor platform so as to trigger the PSAP and inform the emergency agent and the first responders.

A prototype application was implemented as a proof of concept in order to demonstrate the basic features and the effectiveness of the proposed system supporting deaf and speech impaired people. The evaluation results illustrate that SEEK can be considered as a promising solution for detecting and reporting emergency events. It should be mentioned that the proposed solution can be easily extended for other impairments.

The selected hardware proved to be more than capable to offer the designed functionality. Based on the CPU load, the measurements showed that even lower capability hardware platforms may be used in order to minimize the cost and increase usability by minimizing power consumption, however such systems, currently, do not provide the high level services needed in order to implement the desired functionality in a cost and time effective manner.

A model for supporting other sensing technologies, based on wearable sensing systems, was developed and merged to the device that improved the system's daily-basis usability.

Other than the replacement of the wired sensors it is deemed prudent to further study as a future work the capabilities of therich information provided by wearable devices in order to improve the user-context model and provide better emergency calls management or initiation.

Finally, in the case of sensor data collection rate, there is the possibility to construct a dynamic model of logging and transmitting rate based on the state of the user (e.g. when an abnormal health state has been detected). This may be implemented in the future with the assistance of medical science in order to accurately define the signaling and data rate requirements so the resulted data can be better suited for medical modeling thus capable of as- sisting in medically diagnosing a user remotely.

Acknowledgment

The present work was undertaken in the context of the "Multiser- vice cApable iNtelligent TransportatIon Systems (MANTIS) project" co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneur- ship and Innovation, under the call RESEARCH – CREATE - INNO- VATE (project code:T1EDK-04612).

Conflict of interest

None.

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