ZigBee/IEEE 802.15.4 Technologies in Ambient Assisted Living Applications

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Abstract

Ambient assisted living environments are full of human attention demanding applications. The introduction of wireless solutions in the assisted living area brings convincing advantages in terms of staff burden reduction, observation reliability and treating measures response time. The paper identifies some typical application requirements. Applicability analysis of existing solutions is made. ZigBee with TCP/IP fusion initiative is considered as enabling point for ZigBee/IEEE 802.15.4 integration into ambient assisted living environments.

1. Introduction

In developed countries, elderly people represent the fastest growing segment of the population, growing twice as fast as the population as a whole. By the year 2035 over one-third of the population will be more than 65 years old with over one-ninth of elderly living beyond 85 years of age in some of EU countries [9]. Elderly people do not have as high dexterity, memory, and sensory capability as in younger years and thus often need help with medication, mobility assistance, and during emergencies such as falling (the leading cause of morbidity or serious injury). As more people over sixty join assisted living residences, the facilities themselves face shortages of resources and of competent carers. One method for solving such problems is to introduce technology and process automation in order to reduce burden on the carer staff, as well as reduce error and improve response time. Thus we introduce with idea of using ZigBee/IEEE 802.15.4 solutions for Ambient Assisted Living (AAL) serving as an enabling technology for numerous potential services and seeking to help elderly people spending a humane and comfortable life in their own homes.

In this paper we analyze the AAL's application requirements, make proposals within available CEESAR competences and finally express our vision on the future developing trends. The presented systems are deployed within the iHomeLab facility at the Lucerne University of Applied Sciences & Arts.

The remainder of this paper is organized as follows: Section 2 discusses the requirements derived from AAL inhabitants' needs, Section 3 provides details on system solutions developed within CEESAR activities, Section 4 demonstrates a visualization example; and finally Section 5 provides a summary of work accompanied by future development trends.

2. Requirements for Ambient Assisted Living Environments

To effectively support e.g. an elderly person in their daily life, it is valuable to know more about their current condition and behaviours in general. The assisted home should be aware of its inhabitant. Depending on the context, it should provide the services they need, should learn from their actions, detect any abnormal situation and act accordingly. In order to do this, the following application fields have been identified:

- Informational Assistance

  An intelligent house should provide the information and services a person currently needs. For instance a medication instruction in the morning in front of the bathroom mirror; a key finder application; an all-in-one remote control that is easy to use and shows only actions of devices in the room where the person actually is in.

- Intelligent Environment Behavior

  The AAL environment should learn from human actions and offer the right action at the right time. Even automation of often repeated actions is possible. High potential scenarios often involve similar action sequences such as getting up in the morning (light on, blinds up, radio, bathroom).

- Emergency Case Prediction

  Based on physiological and behavioral changes it is possible to predict future possibly dangerous situations with an appropriate preventive measures like alerting family members or/and medical staff. For instance, dangerous situations include falling or forgetting the oven on; in this case someone (including the inhabitant) can be alerted, or the oven disabled. For example, upon the change of blood pressure or body temperature a monitoring system can report a risk of undesired case development.

- Emergency Case Recognition

  Intelligent environments should detect any abnormal situation and act accordingly. The system could sense that the person did not get up as usual in the morning and initiate a message to alert her family for instance. Fall detection is another well known AAL application.

- Security

  Elderly people require and desire an increased security level because of possible partial physical or/and mental disability. For example, a system should recognize an unlocked door and take an action varying from giving an alert to locking the door automatically. The communication channels of sensors and actuators have to involve reliable authorization and authentication mechanisms.

- Privacy

  Beyond security, privacy questions always remain on the top of considered topics. The Georgia Tech Aware Home study on privacy concerns among elderly people [2] has analyzed people's attitude to different types of images generated by video camera, point-light, and blob tracking. The study has shown that a person's physical and mental level of functioning is a primary prerequisite in judging the level of privacy concern and potential benefits.

To provide awareness for all these services, the system depends on real-time as well as historic data provided through various sources. Important data sources are smart sensors installed in the aware home. Wireless sensor networks have proven to be capable of delivering robust, easy-to-install and low-cost infrastructure for such tasks. The networks are self-healing, run independently for years, and don't require extensive cabling.

In the next chapter we will show how ZigBee/IEEE 802.15.4 solutions can be used for an AAL infrastructure setup.

3. Existing Solutions

With the goal of assisting to partially solve the issues listed above, the authors apply state-of-the-art ZigBee-enabled technology. By comparison to sensor networks a decade ago, modern systems are smaller and provide a complex of useful information, with sensors for motion, tilt, temperature, environment status; and user feedback devices such as buzzers and speakers; at a fraction of the power. Sensors such as accelerometers provide motion-detection and acceleration information that allows the detection of unusual body movement patterns which may preceed or indicate an accident or by an agility which differs from the normal behaviour of an inhabitant. In such cases a backend system may be programmed to alert family members or residence carer staff.

Indoor localisation offers an abundance of new services to be used within modern buildings. Amongst these, they provide more visibility, and can reduce routine tasks and human error, through information and server-side reactionary mechanisms. Herein we describe an RF- and ultrasound-based indoor localisation system useful within assisted living residences. The system-in-test uses an electronic name-tag that can be localised with an average accuracy of less than 10 cm deviation of its spatial position by reference nodes distributed through-out the environment. Extensible on-tag multi-use sensors provide additional input for scenarios such as fall detection. Preliminary prototype results for fall detection are exempli-fied through a demonstration software application frontend.

Another demanded application is currently in development: a small tag that will be attached to objects like a box for medicine. An inhabitant is then able to locate these belongings if he/she has forgotten the location where he/she has placed them. Since the position of such things will typically not vary much, a reduced duty cycle can be used, allowing battery lifetimes of many months or even years.

3.1. Miniaturised Awareness Wireless Sensor Node

WeBee 3G is a versatile lowcost IEEE 802.15.4/ZigBee [3, 12] sensor module optimized for awareness-oriented ambient assisted living applications. The module is equipped with high-resolution sensors for temperature, acceleration and pressure. It is extensible and provides the interfaces to attach further sensors to detect presence, light, etc. The design process produces a small module which operates several years on one battery. The actual size of the TI-CC2430 based device including antenna is 41 x 20 x 3 mm (batteries not included). Further, the module features a chip antenna with optimized strip band HF coupling for achieving high range, respectively low necessary transmission power. The module enables a variety of sensor network applications to be run for years on battery powered devices. A 1000mAh Li-Ion Battery is placed on the back side of the print. The self-discharging constant of the battery is specified to keep the required voltage for more than 15 years. In large quantities, the module may be produced at costs below EUR 15/module.

Applications with multiple AAL behavioral patterns can easily take advantage of the low-power low-size low-cost properties of the module. It has been used both in pure IEEE802.15.4 scenarios with a proprietary protocol where star networks were applied to create slim, very low power applications and extended mesh networks using a fully featured ZigBee Stack. The applications realised with the circuit so far range from very simple temperature measurements, to loss of balance detectors up to components of complex indoor localisation systems. The classical sensor application reads data from a local sensor and transmits it on a predefined interval to some gateway or "base" station.

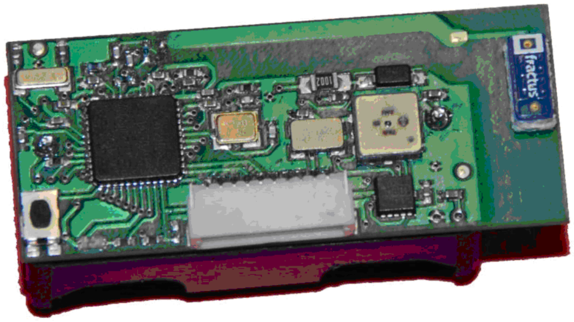

Figure 1. WeBee3G Sensor Node

Beside typical sensor applications like temperature monitoring, also applications which require bidirectional transfer, can be realised.

Sensors fitted onto WeBee3G include:

- Temperature Sensor

  Transmitting temperature measurements every 10 minutes with a precision of 0.2°C leads to a sensor operation lifetime of more than 10-15 years. Here, the full ZigBee stack is not employed, and IEEE802.15.4 MAC frames are transmitted directly interfacing the hardware.

- Acceleration Sensor

  A sensor with acceleration resolution of 0.004g (3.922 cm / s^2) has been tested for the detection of unusual rapid movements (e.g. loss of balance preceediong a fall). Based on the acceleration information, the back-end control system can be programmed to alert carer party/staff to inspect the patient.

- Pressure Sensor

  Since air pressure changes linearly with an altitude, it is possible to teach the system to distinguish between different body positions of the inhabitant. We have integrated pressure sensors with a resolution of 25 cm altitude difference (0.03 hPa) and demonstrated reliable recognition, especially after filtering, of standing or sitting positions. Furthermore, combining accelerometer and pressure data we achieve an improved ability to detect falls. The WeBee 3G sensor node presented above has the capability to sense basic physical phenomena. However, it is beneficial in Assisted Living environments to be able to locate an aesthetically contained sensor node, as the iLoc demonstrates next.

3.2. Indoor Localisation System

iLoc is a fully functional ultrasound & radio-based system that provides location and orientation, as well as sensory information [6]. By comparison to existing localization systems, this system employs a variety of new approaches such as amplitude analysis, the IPoK bus system, and a new data fusion algorithm for position estimation. Our system offers considerable advantages in hardware size, cost, deployment effort and accuracy. Careful hardware- and software-design has shown the system to install easily into an on-site facility for testing at a moderate cost and with minimal wiring. The system shows reliable operation in initial prototyping stages, providing through a selective data-fusion algorithm position detection accuracy under 10 cm. The iLoc localization system is composed of three parts: name tags that transmit an ultrasound pulse, reference nodes that receive the pulse, and a server that estimates the location received from them.

- Name Tag

  The mobile component of the system, the name tag, is a credit-card sized (8.5 x 5.5) badge with the name printed on the front and electronics discretely hidden underneath. Exposed is an ultrasound transmitter that emits an ultrasonic pulse at a rate of 1Hz for localisation. This pulse is emitted following synchronization and time-division access is provided by radio signal. The name-tags use a TI-CC2430 system-on-chip with 8051 based micro-controller and IEEE 802.15.4 software-programmed radio, rechargeable power cell, and ultrasound transceiver. Tags are energy efficient and enter a low-power mode when idle, allowing operation for several days without a recharge on a 25 mAh lithium cell. Each name-tag is equipped with a buzzer and with an accelerometer. The buzzer can inform the wearer of events, for example, as reminders to periodically take medicine or to visit reception desk staff or a computer console for messages or instructions. The accelerometer, besides delivering input for the power management software, can detect gestures and unusual rapid motion.

- Reference Nodes and Bus

  Receiving the ultrasonic pulse are reference nodes that are wall-mounted or -embedded. To the server is transmitted the timestamp when the ultrasonic pulse was received via the IPoK bus. The reference nodes are constructed of an ultrasound receiver, a Freescale HCS08 microcontroller, and an IEEE 802.15.4 radio transmitter used for sending synchronization messages. Nodes are inter-connected by a 2-wire "IP over Klingeldraht" bus, that serves as power supply (7-30V) and, by coupling UART signals to the power lines, also as serial multipoint connection (e.g. RS485). The wired bus is also used for inter-node synchronization and for depositing onto the server sensor data (ultrasonic reception timestamps and other information).

  One synchronisation master node uses an IEEE 802.15.4 transceiver to broadcast synchronisation packets. The name-tags do not need to receive each synchronisation packet; they may also run for some seconds before losing synchronisation. This can allow the role of the master to be rotated between the reference nodes and increase the radio coverage. The radio chip on the reference nodes is also used to synchronise different IPoK segments between each other.

- Operation Principle

  The principle of operation from the hardware perspective is shown in Fig 2. One dedicated reference node broadcasts a synchronization data packet over the 2-wire bus periodically at a rate of 20Hz. Other nodes receive their signal, and their local clocks synchronize to within 1-2s. Simultaneously by radio, the synchronisation signal is also sent to the name-tags; the signal contains a sequence number indicating which tag should transmit an ultrasound pulse upon reception. The ultrasound pulse is received by ultrasound receiver sensor on surrounding reference node(s). Reference nodes record the reception timestamp and other information and immediately transfer them via the 2-wire bus to a gateway that in turn, forwards the data to a PC. The PC collects the reception times and calculates from the time-of-flight data the 3D spatial position of the name tag, which can be retrieved by the user application thereafter.

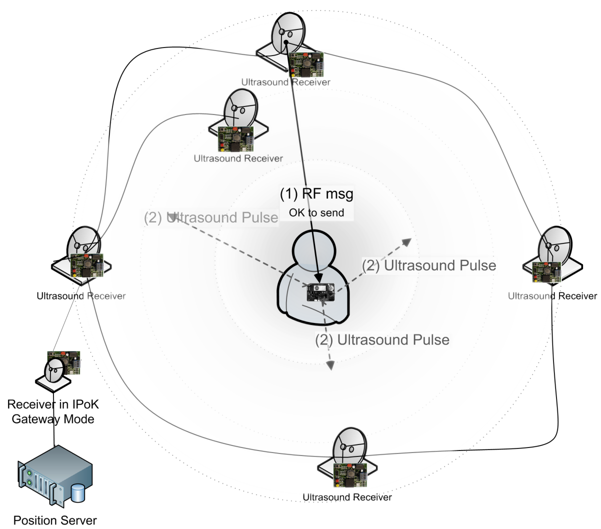

Figure 2. Five ultrasonic reference nodes receive an ultrasonic pulse after the specific name tag has been sent an RF signal to transmit the pulse. Time of reception is recorded by the ultrasonic receiver nodes, and forwarded to the IPoK gateway, to be forwarded to the position server via ethernet.

- On-site Deployment

  The maximum range of the ultrasound signal, for 32 nodes at 1 Hz, is about 16 meters. Principally, three range measurements at different positions allow the determination of the tag position. In practice, the density of reference nodes should be as high such as the distance to the farthest node does not exceed five meters, and that each point is covered by more than 3 nodes. This is due to the fact that the ultrasound signal needs line-of-sight for propagation, and can be shaded for example by the body of the wearer of the tag or other objects in the same room. In the iHomeLab, twenty nodes were initially placed in the two rooms and the entrance. Recently, the density has been increased to about 50 nodes to further increase the accuracy and coverage of the system. These 50 nodes are arranged in 6 IPoK bus lines, which are connected by Ethernet to the positioning server. For deployment reasons and easy firmware updates, all of the ultrasound transducers were mounted separate from the node electronics and wired with normal shielded audio cables.

  The positions of the reference nodes have to be determined at least with the desired positioning accuracy of the system. This turned out to be a quite time consuming task, and therefore the positions were not directly determined by meter measurements. Instead, an ultrasound transmitter was placed at positions of a well defined grid marked on the floor. The reference node positions were determined by the system itself, by recording the measured distance values and then calculating the node positions from the measurement results.

- Software Services and Visualisation

  An overview of the positioning software system is given in Fig 3. The obtained positions can be queried from the position server. One main application is the visualisation of the position of persons carrying the name-tag. Detection of falls has already been performed using the position information and the accelerometer included in the name-tag. If a name-tag (and presumably also the bearer) is detected to lie on the floor for a certain time, an alert is generated and emergency personnel may be alarmed.

  Note that the visualisation component is attached via the software-interface (currently .NET) to the position server and is therefore decoupled from the hardware system.

3.3. IP Integration Initiative

In April 2009 the ZigBee Alliance launched an incorporation initiative of Internet Engineering Task Force (IETF) standards into its specification activities. One result, TCP/IP support, will enable ZigBee products to serve as an infrastructure for Internet of Things. While ZigBee is already offering standards for extensible low-power low-cost wireless-sensor and -control networks, the addition of native IP support will also bring large-scale network addressability and security integration. These initiatives include:

- IP over ZigBee

  One straight-forward way to make IP functional over ZigBee is to build an IP stack on top of the ZigBee networking layer. In this scenarion all ZigBee nodes

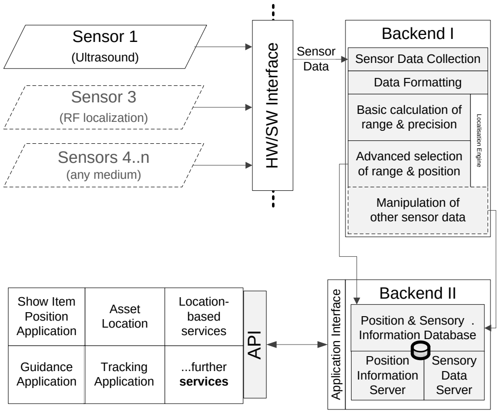

Figure 3. High-level overview of the indoor localisation system with emphasis on software perspective. Sensor data collected by the backend is processed and stored, to finally be made available to a user-level application.

would have IP addresses. Thus if a packet is going from an IP to a IEEE 802.15.4 network, it is first wrapped by a gateway at the ZigBee network layer and then forwarded to the ZigBee network. In the opposite direction the gateway unwraps the IP packet and transports it from the ZigBee to the IP network. The asynchonious nature of ZigBee/IEEE 802.15.4 puts constraints that only allow UDP protocol usage. Differences of packet sizes between TCP/IP and IEEE 802.15.4 cause fragmentation and routing problems. The solutions are discussed by 6LoWPAN standard.

- EtherBee 2

  EtherBee 2 is designed by CEESAR and endows a node with both IP and ZigBee functions. Our approach to integrate the sensors into an existing IT infrastructure is to use a IEEE802.15.4 - Ethernet gateway ("EtherBee 2", Fig 4.) which provides a sensor data interface on the TCP/IP side, allowing a standard PC to collect the data via a TCP or UDP connection. Using a star-topology, the simplest approach is to send a data packet without prior sensing the channel for activity (CSMA/CA), and without checking the transmission success by an acknowledgement. In this approach, no back channel is required and the receiver is actually not used for normal operation. As mentioned above, in this case the uptime of the transceiver is reduced to the sole transmission of the data packet, which makes the approach the most energy efficient. Here, the probability for a single data item to reach the backend application is not 100%; but in a typical sensor network application like sensing temperature in a warehouse, some percentage of measurement value loss is acceptable.

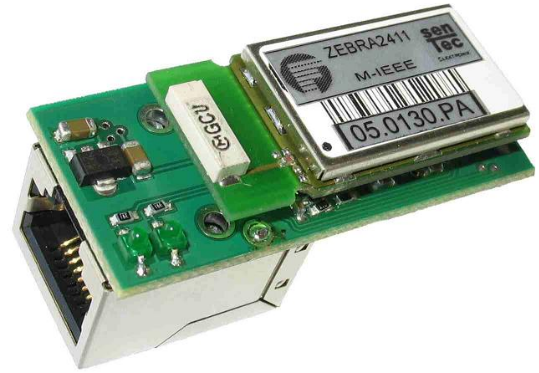

Figure 4. EtherBee 2 Gateway

- RIPlink

  RIPlink [7] is another known industry standard in the direction of IP connectivity and the accessability of resource-limited non-IP devices like ZigBee/IEEE 802.15.4, PLC, etc. RIPlink technology is composed of:

  1. RIPlink Gateway connected to IP network.
  2. RSP protocol: a simple RPC protocol transported over the non-IP network exposes the TCP/UDP portable socket API of Gateway. RSP is independent of the non-IP network used for a specific RIPlink implementation.
  3. RIPlink Devices, running an RSP Clients. In this approach every application of RIPlink Device is visible as running on a port of the RIPlink Gateway.
  4. The Gateway and Client Adapter are respectively parts of RIPlink Gateway and RIPlink Device, dependent of the non-IP network. They provide a reliable transport channel of the RSP protocol between RSP Client and RSP Gateway, adapted to the non-IP network standard.

- 6LoWPAN

  Low-power wireless personal area networks (LoWPANs) will be constructed of IEEE 802.15.4 devices characterized by short range, low rate, low power, low cost, and long sleeping periods with limited computational power, memory, and/or energy availability. The extended address space and autoconfiguration functionality of IPv6 make the stack attractive for the real Internet of Things, which is composed of large scale sensor network deployments. An IETF specification RFC 4944, 6LoWPAN [4] specifies the usage of IPv6/UDP over IEEE 802.15.4 networks. This specification brings both the interoperabiliy within domain of low-power wireless IEEE 802.15.4-enabled devices and standard routing communication methods within previously developed IP infrastructure. According to standard specification [4] it is possible to name the following **key** 6LoWPAN functional characteristics:

1. 6LoWPAN involves an adaptation layer above the IEEE 802.15.4 MAC. It makes IPv6 feasible for wireless sensor networks by compressing IPv6 headers allowing an effective data payload transmissions via IEEE 802.15.4.
2. The minimum defined size of IPv6 packet is 1280 bytes. From another side the maximum size of IEEE 802.15.4 frame size is limited by 127 bytes. IPv6 packet fragmentation into many IEEE 802.15.4 frames and reassembly functionality overcomes the difference between maximum IEEE 802.15.4 frame size and transmission unit of IPv6.
3. From one side routing enables border nodes in internetworking data packets between WSN-PAN and external IPv6 networks. From another side internal mesh routing is also handled by 6LoWPAN. But exact routing protocol specification is out of the scope of 6LoWPAN standard.
4. Discovery of neighbour devices and services will serve for informing the IP-enabled devices about the current state of ad-hoc network formation.
5. Broadcast/multicast support is generally defined within 6LoWPAN specification, leaving a choice of implementation to routing protocol designers. Such techniques as flooding, controlled flooding, unicasting to a PAN coordinator are most straightforward methods of broadcast/multicast implementation.

- ROLL

While provisions for routing and packet delivery in IEEE 802.15.4 meshes are part of 6LoWPAN protocol already, the the IETF has recently launched a Routing Over Low-power and Lossy networks(ROLL) [5] charter to specify the exact routing specifics. The working group is focused on requirements analysis and elaboration of routing algorithm for Low-power and Lossy Networks(LLNs). LLNs are mainly composed by variety of low processing power devices optimized for energy saving. The LLN links will be based on a variety of such technologies like Bluetooth, Low Power WiFi, IEEE 802.15.4, low power Powerline Communication, etc. The design of a specific routing protocol for LLNs is mainly caused by the necessity of an IP-based internetworking solution enabling the interoperability of technology diversified platforms. From the very beginning ROLL's protocol design is IPv6 oriented. High reliability, extensible connectivity, routing security and manageability are key considerations of ROLL development. The ROLL working group is aiming to define the metrics for routing path calculation, an architecture for path selection and routing security framework.

To give a summary of interoperability development we put ongoing standardization initiatives together in one comparison Figure 5.

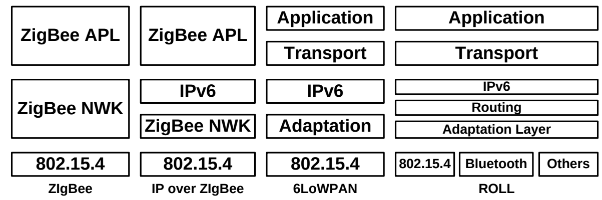

Figure 5. IPv6 Integration

4. Application Example

The authors have recently developed a demonstration application to show the real-time fall detection capability of available systems and technologies. The application tier takes advantage of WeBee 3G's hardware ability to detect altitude and acceleration changes of the node. The temperature measurement data are also shown.

Once per second air pressure and temperature values are updated internally by the WeBee 3G sensor node's hardware. Additionally, the node's hardware sets a flag if the last acceleration sensor value is higher then a predefined threshold. All this data is encapsulated and transmitted to a PC, where the GUI application is running.

By detecting the accelerometer event(that usually means a fall of the wearer) the SW-application reads the data from the pressure sensor right after the event. As stated in Chapter 3.1, the resolution of the pressure sensor is high enough to react on $\geq$25cm-change of altitude. After the first altitude reading we wait for some time (10 seconds) to give the fallen wearer a chance to stand up independently. After waiting for a defined time interval the software reads pressure/altitude data again. If the wearer successfully stood up the second reading would show the altitude of approximately 1m higher then by the first reading. Otherwise the software concludes that the inhabitant needs help and switches an alarm on. The responsible party receives a warning message about highly probable problematic fall.

Figure 6a shows the normal situation, Figure 6b demonstrates a tolerance time interval by fall detection, Figure 6c corresponds to the case of critical situation when the person could not stand up after the fall.

5. Conclusion

Understanding a growing role of assisting environments for elderly people we first identify and discuss some of typical requirements for ambient assisted living applications. We describe necessities from a general aspect in order to form a vision of future devices and systems. From these requirements, we form some clear assumptions of society's needs, which allow us to perform an applicability analysis of already existing wireless solutions. Three hardware solutions are thus studied. Drawing the ideas together, we

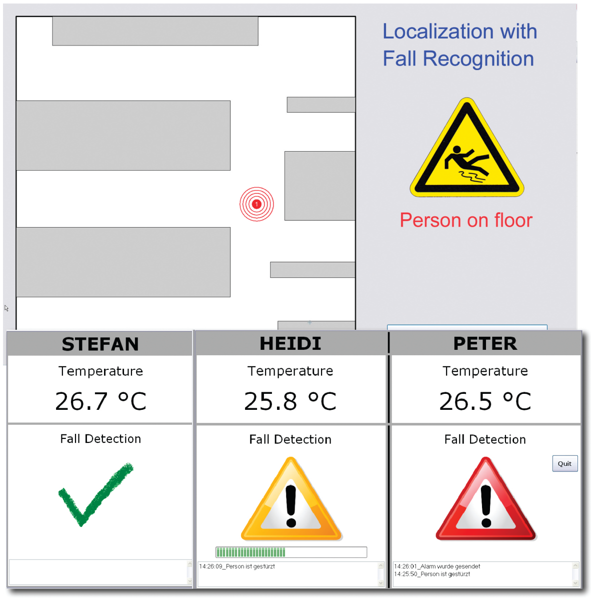

Figure 6. a) Normal Situation b) Fall Detection c) Alarm

observe that wireless sensor networks have shown to be promising solutions capable of satisfying at least some of the previously listed requirements. However we also observe that, for already existing infrastructures, issues of interoperability and maintenance of remain an open topic. Toward this, we look at existing solutions and postulate that the demanded interoperability solution will most likely go into the direction of incorporating native IPv6 support, as announced by the ZigBee Alliance.

The ZigBee-enabled technology demonstrated in this paper is in prototyped at the iHomeLab at the Lucerne University for Applied Sciences. The technology is directly integrated into the laboratory, and coexists along other advanced building technologies, with which it is tested. The research team contributes to a high education standard, consults with industry, and has broad experience in industry research partnerships with industry leaders. The iHomeLab itself is the Swiss think tank and test-center for intelligent living solutions that focuses on development and acceptance-tests of technological solutions on the topics of ambient assisted living, energy efficiency, security and comfort. Thus these technologies attempt to integrate all aspects into their design. If you are interested in particular technologies or have questions, please contact the corresponding author.

6. Acknowledgements

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