Towards embedding hearing instruments in intelligent environments- Einbettung einer Hörhilfe in eine intelligente Umgebung

Martin Biallas, Aliaksei Andrushevich, Clemens Nieke, Rolf Kistler, Alexander Klapproth
CEESAR-iHomeLab, Lucerne University of Applied Sciences, Technikumstrasse 21, CH-6048 Horw, Switzerland
{martin.biallas, aliaksei.andrushevich, clemens.nieke, rolf.kistler, alexander.klapproth}@hslu.ch

Kurzfassung

Es wird ist ein Vorgehen beschrieben um akustische assistive Geräte (AAD) in intelligente Umgebungen einzubinden. Durch die Verwendung eines Lokalisationssystems und ein AAD werden standortbezogene Dienste realisierbar. Dazu sollen ortsabhängige, nicht-störende Nachrichten, über multiple Audioverteilungsknoten, zum AAD geleitet werden. Diese Knoten werden untereinander durch ein drahtloses ad-hoc Netzwerk verbunden. Obwohl in TCP/IP basierten Netzwerken erhebliche Latenzzeiten erwartet werden können, sind diese nicht so kritisch wie in anderen Systemen, welche mit weiteren Modalitäten synchronisiert werden müssen (z.B. Lippensynchronizität bei Filmen). Im Folgenden wird über die Idee, die Systemarchitektur und erste Erfahrungen aus dem im Gange befindlichen Implementierungsprozess berichtet. Um die Benutzbarkeit des Funktionsmusters zu testen, besonders in Hinsicht auf die akzeptierten Latenzzeiten, wird eine Versuchsreihe im iHomeLab Living Lab vorgesehen.

Abstract

An approach to embed acoustical assistive devices (AAD) in intelligent environments (IE) is described in this paper. Location Based Services (LBS) become feasible by combining an indoor localization service and AAD. Location dependent, unobtrusive and short messages shall be streamed to the AAD via multiple audio distribution nodes. The last ones connect via a Wi-Fi mesh network. However, streaming audio data over wireless TCP/IP can be a subject of substantial delays, increased latency is not as critical as in other application because the streamed message does not have to be in direct synchronization with other modalities (e.g. lip synchronization in movie pictures). Information on the idea, system architecture and first experiences during the ongoing implementation is reported. To test the usability of the prototype, especially with regard to experienced and acceptable latencies, a trial is planned at the iHomeLab Living Lab.

1 Introduction

The number of patients with different cognitive impairments under general umbrella term of dementia has increased in Europe to about 7.3 million [1] in 2006 and it is expected that it will double within the next 25 years. Dementia can be categorized into 3 levels of severity: mild, moderate and severe [2]. People diagnosed with mild-to-moderate (Mi-Mod) dementia suffer from mild cognitive, functional and behavioral impairments. Besides the loss of memory, spatial and temporal disorientation belong to the earliest and most easily perceived symptoms [2]. For many years, there was an ongoing discussion whether dementia and partial hearing losses are significantly correlated. Recent advances indicate [3] [4] that this hypothesis is true

Based on these research results, we propose the idea to combine acoustic assistive devices (e.g. hearing aids) with domestic Location Based Services (LBS) to enhance the quality of life for people suffering under mild and possibly moderate dementia. Such a system could provide valuable location dependent reminders or information for forgetful users. For example when a person leaves the table in the dining room at lunchtime, a short unobtrusive reminder for medication could be send to the Acoustic Assistive Device (AAD) worn by users.

1.1 Related work

All LBS are enabled and based on indoor and outdoor localization systems. Although indoor localization topic forms its own field of Ambient Assisted Living (AAL) research [5] [6] [7] [8] [9], taking advantage of the combination between AADs and indoor localization services has not been well enough described in literature yet.

The potential of hearing instruments (HI) for AAL has been already recognized by several research groups before. In the project Hearing at Home [10], devices as personal computer (PC), HIFI-systems, TV, digital camera, telephone, fax, intercom, VoIP, pay TV and home automation are collected and presented to the hearing impaired user by a gateway, in form of a set-top box (or PC). Another example is the home information and communication platform, which takes audio inputs from VoIP, audio/movie, digital TV streams, functions as home media center computer, but additionally meets the requirements of hearing-impaired users by providing supportive audio signal processing and an artificial talking head [11].

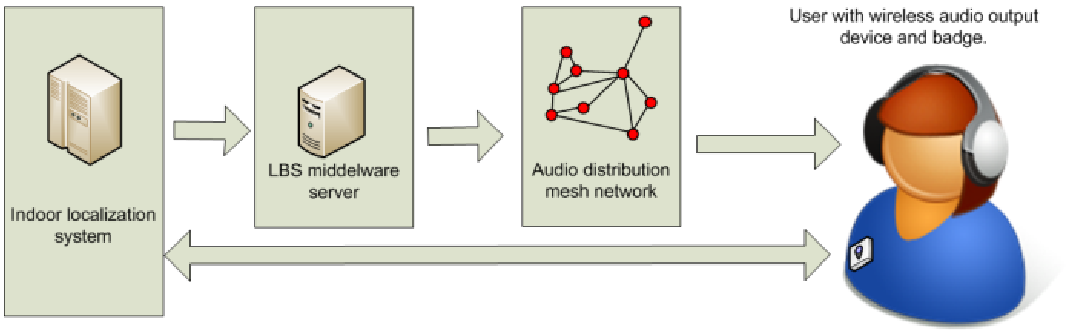

Figure 1 System architecture for the proof of concept consisting of indoor localization system, LBS middleware server and system configuration application running on a smart mobile device (e.g. tablet-pc).

This is a loss, since more and more manufacturers offer HI, which are able to receive audio wirelessly [12] [13] [14] [15] [16]. Missing standards between manufacturers impede the applications in research areas. Once this obstacle is overcome, HI will offer a new output modality for human building interaction.

In the following chapters we describe the idea for a system combining LBS and AAD. We also explain the implementation details and discuss identified open issues. We conclude with lessons learnt.

2 Architecture and key items of implementation

The system architecture consists of 4 major components: indoor localization system, LBS middleware server, audio sound distribution nodes, and acoustic output device (such as HI or wireless headphones). Figure 1 shows the system components.

Generic indoor localization system provides the position of the user to the LBS middleware server. This LBS server compares continuously the actual coordinates of the localized personal profiles with its stored boundaries of active regions. When such an active region is intruded, an event is triggered. In this set-up, the event causes a predefined acoustic message to be streamed wirelessly to the whole mesh network of audio distribution nodes. From there, the message is transmitted to the acoustical output device.

2.1 Localization system

The enablers of all LBS are the localization systems. To be able to distinguish whether the user inside a room is e.g. at the table, the shelf or the sideboard, indoor localization systems, which provide an accuracy better than 50 cm, are expected to be sufficient. Since available indoor localization system at our laboratory (iHomeLab[1]) meets this requirement, it will be employed to conduct the trails. It is an in-house developed active hybrid system, which is based on the IEEE 802.15.4 standard as well as ultrasonic propagation time of arrival measurements, and demands from the individual to wear a credit card sized badge. A single localization can be performed in 50 ms (i.e. when 10 persons/objects shall be tracked, the system provides position updates at 2 Hz) [17]. The achievable accuracy depends strongly on the domestic installation environment and can be as good as 10 cm. In the current installation the average accuracies is about 25 cm.

2.2 Audio sound nodes

With the existence of localization system, the main effort of our research is targeted to the audio distribution nodes. A single node consists of a data processing unit (DPU), and an audio transmitter (AT) (see Figure 2), which sends the audio to the AAD. In order to simplify the development and first validation phase in the future, a pair of wireless headphones is used as AAD. This allows both, healthy and hearing impaired test subjects to participate in both phases.

While there are best-case scenarios possible, which require only a single transmitting node to cover a whole apartment, it was opted for wireless mesh system architecture. These systems have proven their reliability in the home automation sector (IEEE802.15.4/ZigBee), and because they are wireless, no additional network-cables have to be installed in the domestic environment. Should the AAD be out of range, it can be extended by introducing further nodes. This scalability of the system grants users variety of possibilities to cover the complete domestic area, from a single room, an apartment and a multistory house. As a consequence, nodes must not only have the capability to transmit an audio stream to an AAD, but also to receive an audio stream from another node. The main responsibility of the DPU is to manage the audio content conveyed to the AT. Due to the mesh networking capability, sounds allotted to a certain location are not stored on the node itself in order to avoid the case when a specific node can only be useful in one specific location. Therefore a central home server is still required. This server is the gateway between the localization system providing coordinates of the test subject, and streams the sound file assigned to coordinates into the mesh network. Finally, the sound is transmitted by all distribution nodes.

For the proof of concept at the first stage, aesthetical design and energy efficiency considerations are not of high priority. Instead, rapid prototyping is preferred with the

[1] The iHomeLab is member of ENoLL [39].

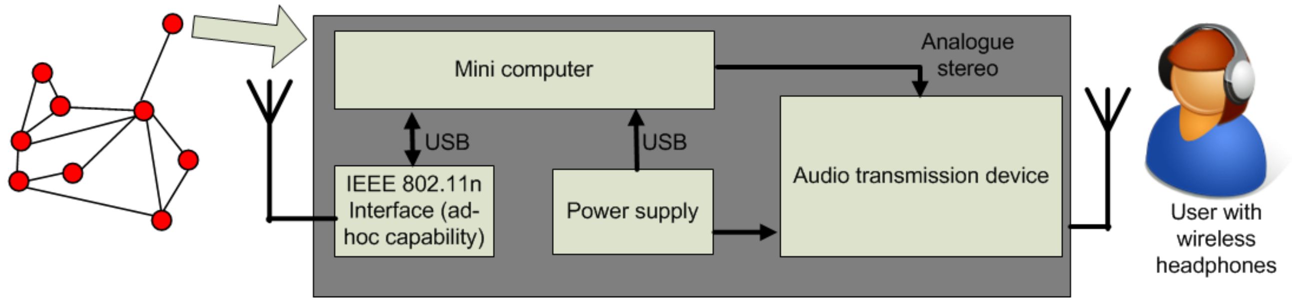

Figure 2 Schematic system architecture of an sound distribution node.

goal to base the implementation on already existing solutions and standards.

Since mesh networking and sound streaming are available as implemented applications for personal computers with TCP/IP networking capability, our node design is currently based on a mini computer with IEEE 802.11 (Wi Fi) interface. The performance to cost ratio and available online support by an active community were crucial reasons for utilizing a credit card sized board, with a ARM1176JZF-S 700 MHz processor, 512 MB RAM, 2 USB ports and a power dissipation of about 3.5 W. This board was successfully employed by other research groups [18] [19] [20] and is known as the Raspberry Pi® [21] [22]. For the purposes of the sound nodes, these boards are working under the GNU/Linux operating system (OS). Wireless capability is achieved by connecting ad-hoc capable Wi Fi USB dongles based on chipsets supported by the OS. The mesh network feature is implemented by reverting to the optimized link state routing (OLSR) protocol [23] [24] [25] [26] [27] [28]. All nodes are configured manually, to a static IPv4 address during the OS installation process.

In this application, a pair of common wireless headphones is employed as AAD, which features an analogue audio line-in input and a transmission channel selector switch. Since the minicomputer has an analogue sound output available, connecting the DPU with the AT is trivial. The set-up of the AT is completed, when correct channel number is chosen.

The key element of our system architecture is an audio distribution within Wi Fi based mesh network. Low latency audio distribution in a TCP/IP network can be challenging [29], especially wireless streaming is a part of the system requirements e.g. in situations where sound of a video must be quasi synchronously, or interacting with a computer requires acoustical feedback [30]. In the frame of the application intended here, latency in the order of a second is acceptable. Several approaches are currently under evaluation and testing: sound distribution by the web radio application "Icecast" (a GPL streaming media server) [31], by a network sound server system named "PulseAudio" under the license LGPL 2.1+ [32] [33], the open source multimedia framework "GStreamer" [34] [35] and a simple approach based on universal plug and play (UPnP) and a small program written on a script language.

2.3 Location based services middleware server

The Location Based Services middleware server has multiple tasks. One of these tasks is to provide a gateway. To prove the concept, the server must connect at least to the localization server and be able to stream to all audio distribution nodes. For further functionality, like access to home automation sensors and devices, remote access capability and internet access (e.g. for NTP service) another gateway must be provided. In addition to the before mentioned requirements, the server must also be able to store the boundaries of the active regions and sound files containing the acoustical messages. Such a sound file is streamed to the nodes in case the comparison between algorithm comparing the coordinates of the actual user position with the stored boundaries results in an intrusion, and certain criteria are met (e.g. duration and angle of intrusion, ID of intruder, time of day, etc.).

Except for IP-address configuration of the acoustical sound distribution nodes, all other configurations, especially during the installation phase, are done via the LBS middleware server. Therefore this server should also provide a friendly intuitive user interface.

3 Discussion

The introduced system is subject of limitations. Foremost, the localization system installed in the test laboratory is not a consumer product yet. There is still lack of standardized solution for indoor positioning regarding accuracy and data representation. A potential customer must deal with a trade-off between accuracy and cost. It is already possible to achieve millimetres of accuracy in the indoor localization but there are still not many applications ready to pay the high price for such a system. Rather widely adopted systems are based on Wi Fi setups [36] and have an estimated accuracy of up to ± 2 m. Optimizing Wi Fi layout increases accuracy until around ± 1 m under constant conditions. However, moving people, furniture, equipment reflect and absorb the radiation and disturb the measurements of the wireless signals leading to additional errors. This makes clear, that Wi Fi based localization systems must still be optimized a lot when intended for indoor LBS use.

Indoor localization data, as used by indoor localization systems, are traditionally represented as (x, y)-coordinates of a floor plan, where (0, 0) is the upper left corner of the plan. Different floors are represented by different maps. And indoor data are usually given in pixels from a floor map. Therefore, the approach for the proof of concept will be to enhance interoperability with localization platforms by processing only continuously spatial information in form of (x, y)-coordinates. All other localization specific control processes are performed in a dedicated localization server.

The fact, that the localization system essentially determines badges positions, instead of individuals, is ambivalent. In a realistic environment outside the laboratory, forgetting to attach a badge to the own cloths happens easily. Avoiding additional body worn sensors is desirable, as end users communicate often in AAL related end user requirements sessions. On the other side, being able to locate small objects, such as badges, can also be the foundation of new solutions. Badges could be attached to the sound distribution nodes to circumvent the initial configuration phase needed otherwise, to map the positions of the nodes to a map manually.

Preliminary tests in regard to the sound distribution have shown that latency from the sound source to a node is not critical, in contrast to the synchronization between the nodes. The demands on latency for the proposed LBS are not critical, because the individuals do interact indirectly with the system and do not expect an immediate feedback. In simple terms: when an individual comes to the closet with the medication, it does not matter whether the audio reminder reaches the AAD with one second delay. However, problems associated with synchronization between nodes can occur in when the receiver in the AAD cannot lock on the significantly more powerful signal. A bad-case scenario would be an individual in-between 3 nodes, which generate the same field strength at the receiver of the AAD. As a consequence, the receiver could begin to randomly jump between the signals of these nodes. If the sound content of all the nodes is not synchronous, the audible output of the AAD will be rendered incomprehensibly. At first glance, one possible solution would be to stream the audio content always to the one node closest to the individual wearing the AAD. However, then the challenge lies in the seamless hand-over between nodes.

While the whole system of localization, nodes and AAD can be managed without much effort by the laboratory staff, installation and configuration procedures are still far away from being user friendly – even if an indoor localization system would be already be in place. Therefore, simplifications to improve the usability during the installation process are needed. Configuration application being executed on a mobile device (smartphone or tablet-PC) should be employed to set-up the link to the localization server, and after that, to create the map of the domestic environment. For convenience, all nodes could be equipped with NFC tags, enabling the automatic configuration of the node mesh network.

OLSR was employed because it is simple to install and to configure. Since in this application, there are no mobile nodes of the mesh, which would require highly dynamic network reactions, the selected ad-hoc wireless mesh routing daemon “olsrd” should be sufficient. Though it can be expected that in the near future, employing the IEEE 802.11s standard will be widely spread and future proof approach [37], for it is more efficient due to its implementation on the MAC layer and it will be part of the common operating systems.

Significant part of the future research will be targeted to basic usability of the system. The plan is to compare the minimum latencies between the four software defined ways to distribute audio in a TCP/IP network. Equally important is the question, how much latency is tolerated by the user but still creating the sensation with the user, that the messages are well timed. Further questions will comprise topics, such as “what duration of a message will be accepted best by users?” and are speech messages perceived as being as unobtrusive as earcons [38]? Do users prefer a mixture of speech and earcons? Finally, it will be interrogated whether users would formulate the wish to be able to interact with the system (e.g. acknowledge certain messages, to prevent them from appearing again).

4 Conclusion

The goal is to offer location based services in a domestic environment to users, who wear a wireless, mobile acoustical output device (e.g. headphones, hearing aids, earplugs, etc.). To lay the foundation for future end user tests, a dedicated reference evaluation and test environment has to be further designed and extended in laboratory environment. Here, the authors have described the first version of implemented system architecture. Since an indoor localization system with sufficient accuracy is already available, the research and development focus is put on the distribution of sound via a Wi Fi mesh network based on mini computers. By utilizing mini computers the vast body of already available and well supported software solutions can be tapped. While audio distribution in wireless and TCP/IP based networks remains a demanding task, there are several alternative solutions, which are likely to meet the less critical demands on latency and synchronization. In the future, the proposed and partially implemented solutions will be deployed, compared and systematically evaluated. In parallel, lab tests will be started to advance the integration of wireless, mobile acoustical output devices in smart domestic environment and thereby enabling people with mild and potentially moderate cognitive impairments to improve their quality of life.

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