

Applications of the iLoc indoor localisation system in the area of assistance systems

Stefan Knauth ^{a,1}, Jan S. Hussmann ^b, Christian Jost ^b and Alexander Klapproth ^b

^a *HFT Stuttgart, Schellingstr. 24, D-70174 Stuttgart, Germany*

^b *iHomeLab - Lucerne University of Applied Sciences, CH-6048 Horw, Switzerland*

Abstract. iLoc is an ultrasound ranging based indoor localisation system which is deployed at the iHomeLab laboratory. Currently the system is used for person tracking: Persons to be tracked get an electronic name badge comprising an ultrasound transmitter. This badge can be localized with an average accuracy of less than 10 cm deviation in its spatial position, by means of reference nodes distributed in the lab rooms. Depending on the position update rate, a small battery may suffice for several month of tag operation. Also the badges are equipped with a low power information display. Other advantages when compared to existing ultrasound ranging systems (like CRICKET, CALMARI, BAT) are for example the simple deployment with its 2 wire "IPoK" bus system.

Keywords. Indoor localization, path tracking, ultrasound localization

Introduction

Ultrasound time-of-flight measurement is proven technology for indoor ranging and has already been successfully applied to indoor localisation systems in the past. Prominent ultrasound based localisation projects are for example the "CRICKET", "CALAMARI" and "BAT" systems ([5,7,6]). They provide high and reliable accuracy, achieved with moderate effort, when compared to newer approaches like ultrawideband systems. The known ultrasound systems are now some years old and the capabilities of embedded systems have evolved considerably since that time. The newly developed iLoc system takes advantage of developments among others in hardware size, cost, deployment effort and accuracy.

The iLoc ultrasound ranging based indoor localisation system (Fig. 1) comprises badges (name tags), detector nodes and a position server, as well as network infrastructure. The tags (Figs. 5, 6) are equipped with a micro-controller, a radio transceiver and an ultrasound transmitter. They emit ultrasound pulses at a rate of about 1 Hz, with a duration of 1 ms. These pulses are received by some of the detectors.

The detector nodes, also called reference nodes, are located at known fixed positions. They comprise a micro-controller and an ultrasound receiver as well as a 2-wire network

¹Corresponding Author: Stefan Knauth, HFT Stuttgart, Schellingstr. 24, D-70174 Stuttgart, Germany; E-mail: stefan.knauth@hft-stuttgart.de

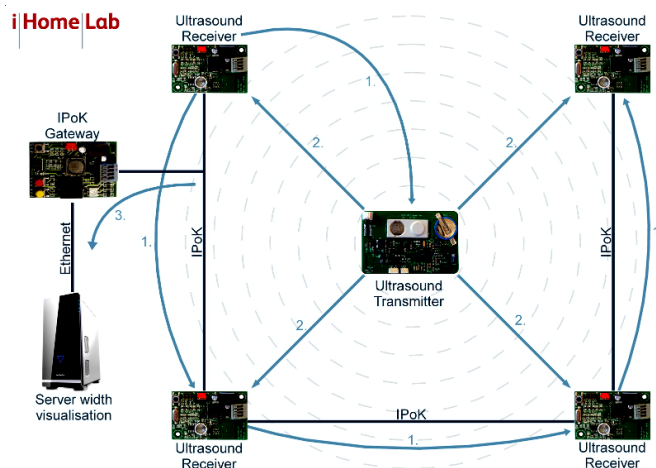


Figure 1. Setup overview: Four reference nodes are shown. The upper left receiver sends out a synchronization signal (arrows labelled "1") by wire ("IPoK") to the other reference nodes and by radio to the mobile node (center). The mobile node emits an ultrasound pulse (arrows "2") and the reference nodes record the reception time.

connection. to exchange data and time synchronization information. The nodes record the reception times of ultrasound bursts transmitted by the badges and transmit this information to an IP gateway via the 2 wire bus ("IPoK", [3]). A server calculates position estimates from the received data by multilateration. In the iHomeLab, the position data is used among others for visualisation of visitor positions (see Fig. 3).

A more detailed system layout is sketched in fig. 2: The detector nodes are combined in groups of 10..15 devices (4 each drawn in the figure) to form one IPoK segment, linked with a "foxboard" embedded linux system to an ethernet infrastructure. Position calculation takes place at the iLoc server, from where the data is accessed by applications, for example the visualisation. Synchronization and communication with the interactive badges is decoupled from the iLoc server and performed by a dedicated communication server, to increase reliability of the system.

1. Timing and Synchronization

The maximum detection range of the iLoc ultrasound signal is about 15 meters corresponding to a maximum ultrasound pulse "live time" of less than 50 msec. This live time is given by the transmitter ultrasound amplitude, the sound path loss, and the receiver sensitivity, and is a consequence of the specific iLoc device parameters and the used sound frequency of 40 kHz.

There exist several design approaches for ultrasound localisation systems with multiple mobile nodes. It is important to avoid ultrasound interference between the nodes (see for example [5]). One commonly used approach is to let the fixed infrastructure emit the pulses and send radio packets identifying the sending node. This has some advantages, for example privacy. The mobile node can detect its position without having the system to know that the mobile node exists. Also the number of mobile nodes is not limited in this case as they are passive. A disadvantage of this approach is that the mobile

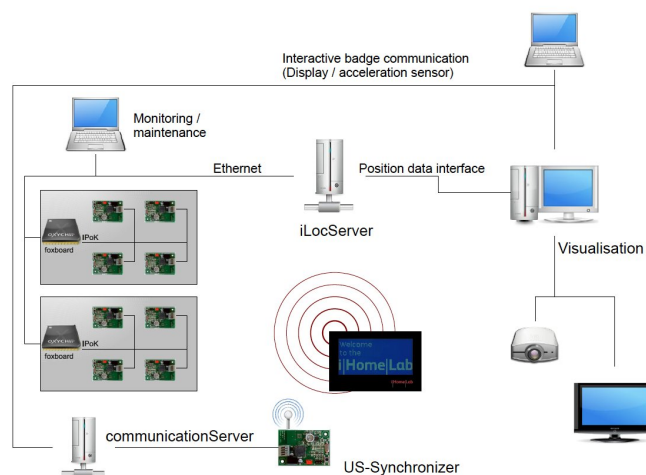


Figure 2. System architecture: a badge emits a synchronized ultrasound burst. Reference nodes measure reception times and send them via IPoK to ethernet gateways labelled “foxboard“. From there they are sent to the iLoc server. The server calculates the badge positions. The communication server broadcasts synchronization messages and handles the IEEE802.15.4 radio communication with the badges.

node has to listen for a certain time to radio and sound messages before being able to detect its position, thus increasing energy consumption.

A main design goal of the iLoc system is that the mobile nodes (for example name badges or other small tags) shall consume as little energy as possible. Therefore we chose the opposite approach, using active mobile nodes and a passive detection infrastructure. The mobile nodes themselves emit the ultrasound pulse. For each node a 50 ms timeslot is allocated, corresponding to the maximum lifetime of the propagating ultrasound pulse. The time needed for the position determination of n nodes is therefore $T = n \times 50\text{ms}$. A typical number of nodes in our lab is $n = 20$, so the position update rate for the nodes is 1 Hz.

To allow a slotted operation, the whole system is synchronized. The fixed nodes communicate via the “IPoK” bus, a two wire cabling which provides power to the devices and allows communication with 230 kBaud. The system comprises several “IPoK” segments, each connected via ethernet to the iLoc server. Within the segments, the nodes are synchronized by data packets via IPoK. Each segment comprises a dedicated node which receives radio synchronization messages from a central time information transmitter, driven by the communication server.

The central synchronisation radio signal is also used by the mobile nodes (name badges) for synchronization. To achieve a synchronization accuracy of about $50 \mu\text{s}$, the mobile nodes need to resynchronize every 2-5 seconds. Actually the operation is as follows: The synchronisation signal is sent with the slot rate, i.e. every 50 ms, containing also the number of the badge that shall send a pulse in the current slot. For $n = 20$, the nodes therefore wake up every second just prior to the moment when they expect their next synchronization signal. They listen for the synchronization packet, readjust their clock, emit their pulse and go to sleep again. The whole sequence takes about 5 ms, leading to a duty cycle of $1/200$. The electric current in active mode is about 20



Figure 3. 3D visualisation of visitor positions in the iHome Lab. The positions are given as “hovering” cubes indicating the name of the badge bearer, embedded in a 3D visualisation of the iHomeLab.

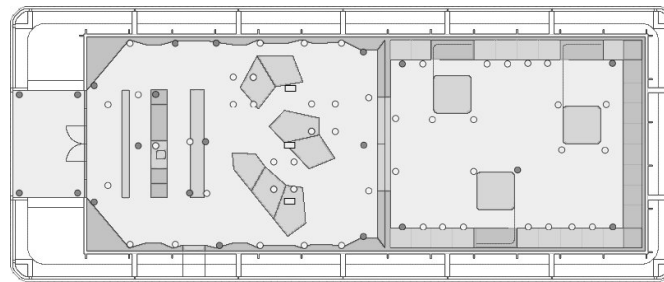


Figure 4. Positions of the 70+ ultrasound receivers in the iHomeLab. The inner grey rectangle indicates the covered area (about 300 m²). The iHomeLab is located at Lucerne University of Applied Sciences at Campus Horw.

mA, leading to an average current of about 100 μ A, at a voltage of 2.5 .. 3 V, enabling operation times of several weeks with a small lithium coin cell. The following table lists some operational times:

Battery type	Duty cycle	operational time
Lithium coin 25 mAh	1 sec	10 days
	10 sec	3 month
Lithium 500 mAh	1 sec	7 month
	10 sec	7 month
AA 2000 mAh	10 sec	> 2 Years

2. Deployment in the iHomeLab

The maximum range of the iLoc ultrasound signal is about 15 meters. Principally, 3 range measurements from 3 different reference positions allow the determination of the tag position. These conditions would be fulfilled when deploying the reference nodes in a lattice with a spacing of about 10 meters. Practically, depending on the desired accuracy, the density of reference nodes should be much higher such that the distance to



Figure 5. Name badge with IEEE802.15.4 radio transceiver, ultrasound transmitter and cholesteric LCD.



Figure 6. Small tags without display. Top: A device equipped with accelerometer and air pressure sensor [1]. Bottom: Simple transmitting device without sensors on board. Both tags are designed for long term operation.

the furthestmost node does not exceed approximately 5 meters. Then every point in the room is in the ultrasound range of more than 5 reference nodes, increasing the stability of the system against ultrasound interference for example by noise emitted from machinery or people. The ultrasound signal needs a line-of-sight for propagation, which can get lost by a shading caused by the body of the wearer of the tag or by other visitors in the same room. Also reflections have to be taken into account.

In the lab currently more than 70 nodes are arranged in 6 IPoK bus segments (fig. 4). Typically an emitted pulse is detected by about 5–15 receivers. Inconsistent range reports are rejected by the lateration algorithm with a simple but computing intensive procedure: From the reported ranges for all permutations of 3 readings a position value is calculated. By stepwise removing of calculated positions lying outside of the mean value, the most probable readings are selected for the final lateration [2].

The deployment effort is kept at a reasonable level by using a 2 wire bus system providing power supply and communication to the nodes. Such two wire systems are commonly used for building automation purposes, and are often referred to as “fieldbus”. There exist a variety of standards and vendors. As mentioned we did not opt for an existing fieldbus system but used our own implementation (“IPoK”) to keep the bus interface hardware on the nodes simple.

In order to achieve a high accuracy of the system, the positions of the ultrasound receivers need to be determined quite accurate as well. Actually only a fraction of the positions have been laser measured. The remaining positions have been entered to the database only to the accuracy given by the mounting drawings. Then they have been

adjusted by reference measurements: A mobile tag (name badge) was placed at a grid of known reference positions and time-of-flight results were recorded by the receivers. The position data of the reference receivers was then adjusted until the measured range values for a particular reference node matched best with the calculated distances. This process was performed by newtonian minimizing of the sum of the squared differences between measured range and calculated range for the set of reference positions.

Another possible automatic reference position determination solution is “leapfrogging” [4], especially feasible for temporary deployments: Here the position of the some reference nodes for example at a corner of the deployment area is determined manually. Then a subsequent node is localised by the system using the already localised nodes, and so on. This mode requires the ability to use a given ultrasound transducer of a node not only as receiver, but also as transmitter. This is currently not implemented in the node hardware but could be added with moderate effort.

3. Interactive badges

The interactive badge (Fig. 5) comprises the following hardware blocks: a CC2430 Texas Instruments micro-controller including IEEE 802.15.4 radio transceiver, antenna and HF matching network, a Bosch SMB380 triaxial acceleration sensor, a charge pump chip to generate a high voltage to drive the 40 kHz piezoelectric ultrasound transducer, the transducer itself, the cholesteric LCD unit, a rechargeable 25 mAh lithium battery as well as an inductive charging circuitry.

The LCD carries its own controller and is connected with a serial interface. Power of the display can be switched off by the micro-controller, while the content of the display remains visible. We observed that, depending on the environmental conditions (temperature, vibrations), the display content may actually decline. Therefore a display refresh should occur from time to time, for example once a day.

To ease the charging process of the badges, they are equipped with an inductive battery charging circuitry, comprising a coil (part of the PCB layout, not an own part), a rectifier and an overvoltage protection, as well as a charge controller. The badges are automatically charged when put into their storage box, without the need to establish any electromechanical connections, for example by plugs or contacts. The storage box comprises two charging coils operating at a frequency of 125 kHz.

Data communication between the badges and the communication server is carried out during respectively after the synchronization radio packet. The synchronization packet contains the information which badge shall send an ultrasound pulse on reception of the packet, in a badge ID field. The badge ID field can be followed by data for the addressed node. This currently comprises data to be displayed on the LCD display. Immediately after transmitting the synchronization packet, the synchronization transceiver listens to response packets. The addressed badge can now send back a message. This back channel is used for sensor information from the acceleration sensor, but can also be used to transmit other sensor data like battery status, temperature etc.



Figure 7. Fall detection application: The name badges transmit acceleration sensor data to the system. In case of a fall, an alert is generated, indicating the location of the incident.

4. Applications

Acceleration sensor data is used by the fall detection application: If the badge or measures unusual acceleration values, it reports these values to the system. The fall detection application acquires position data from the iLoc server, analyses the data and situation and decides whether a fall alert shall be generated. A sample of such an alert screen is shown in fig. 7. In a setup where the system is used in a hospital or a retirement home, context-relevant information may be indicated by the badges display such that a nurse nearby may immediately see relevant emergency medication or illnesses of the patient which may have to be considered in the emergency treatment. Of course, the system may also be used without display, allowing the employment of smaller tags (see for example fig. 6).

The system is generally suitable as a sensor for motion monitoring applications. The system provides absolute coordinates of a tag which may be attached to a person or a thing. It is suitable for example in monitoring scenarios, where unusual behavior of persons like changed wakeup time, slower motion speed, etc. may indicate a medical threat.

Of course such systems will work only if the user bears the tag. For research purposes, this could probably be achieved by reminding people to do so or by electronically detect whether the badge is worn or not, i. e. by temperature, position etc. Even more miniaturized devices might be “wearable”, integrated in the patients clothing.

Another application in the area of assistance systems is finding of assets. For example, the medicine box, telephone, or glasses may be equipped with an ultrasound tag. If the owner cannot remember where he had placed these things, he may by some modality be informed about the current position of his belongings.

5. Results

The iLoc indoor localisation systems currently tracks 20 mobile nodes with a position update rate of one measurement per second per node, with an accuracy below 10 cm, for single measurements with no temporal averaging applied. Fig. 8 shows data from a set of

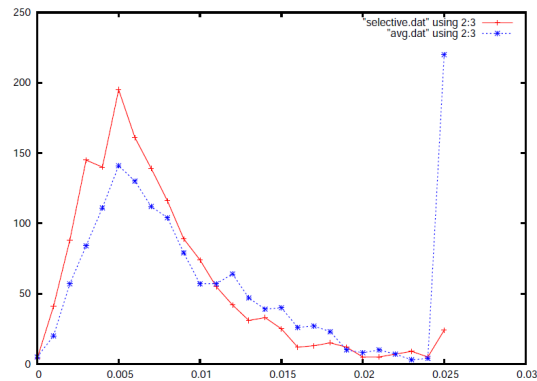


Figure 8. Observed position error: dashed line (blue, *) indicates positions which were obtained by multilateration. Solid line (red, +) indicates positions calculated with trilateration and a selection algorithm. X-Axis: meters, Y-Axis: number of results.

about 1500 subsequent measurement cycles, with at most 8 out of 9 reference nodes reporting timestamps. The rightmost values include all measurements lying outside of the graph's X-Axis. During the recording of the observations, the sound propagation was intentionally disturbed by noise, i.e. people walking around thereby shielding the ultrasound reflectors. The high overall accuracy of the reported position values (95% within $< \hat{\Delta} 2$ cm) has been achieved by careful determination of the sound velocity and position data of the reference nodes. Under less optimal adjusted conditions, the positioning error is still well below 10 cm.

The installation of the system is possible with moderate effort in typical indoor housing, warehouse or laboratory environments. The development includes not only the basic ranging electronics, but also system aspects and application software. Current applications of the system are visitor tracking and fall detection. The two way radio communication enables, among others, applications in the field of ambient assisted living. Long term battery operation is ensured by strict timing and operating in deterministic time slots. The iLoc system is installed at the iHomeLab (www.iHomeLab.ch) at Lucerne University of Applied Sciences.

6. Outlook

The system is under constant development but does already work quite satisfying. A focus of further applications in the iHomeLab is the sector of ambient assisted living. The locatable radio tag with cholesteric LCD and the whole system seems suitable for applications in hospitals or nursery homes. But also smaller tags are available respectively possible. The application "fall detection" has been implemented. Further outlined possible applications in the area of assistance systems include behavioral monitoring and asset location.

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