Indoor Localisation – Technologies and Applications

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Abstract

Location awareness will be an important feature in next generation building automation and control systems. We give an overview on technologies and our current research and development on localisation techniques, at the CEESAR competence centre. Two projects are demonstrated more detailed, a high precision RF-Ultrasound position detection and a RF TDOA system for 2.4 GHz IEEE 802.15.4 based transceivers. Beyond detection of the position, our common software approach allows client applications to consume position information without being focused on a particular localisation technique.

Introduction

Indoor Localisation is the determination of the position of a device or a person in an indoor environment. While the localisation in outdoor environments can in most cases efficiently and accurately be performed by GPS, or some more accurate variants like D-GPS or kinematic GPS, this does usually not hold true indoors. Typically, the transit satellite signal is highly damped when traversing the Building and is not sufficient for a receiver to be detected. Satellite signals which are reflected by surrounding buildings may be detected through windows, but the path length for the satellites will be altered different each from another and the position determination will be inaccurate to some 10..1000 meters. Therefore the investigation of position detection technologies suitable for indoor environments is a current research and development topic.

Technology overview

For indoor localisation, two fundamental measures are commonly employed: distance between an object and a reference point, and the angle between an object and two reference points.
The distance between an object and a reference point may be obtained by the so-called TOF (time-of-flight) of some interaction between the object and the reference. Often it is not possible to directly determine the TOF, but it is possible to detect differences in arrival times (DTOA) from/at different reference points. The interaction may be propagation of sound or of radio waves or light. The distances may also be obtained by using some intensity measure, like radio signal strength (RSSI) or light intensity. Typically the intensity based methods are less accurate than the TOF methods. From the distance values, the unknown position can be calculated by trilateration i. e. by solving

$$\left|\vec{R}-\vec{R}_i\right|=c\,\Delta t_i\,,\; i=1..3$$

where c is the propagation velocity, t_i are the measured propagation times, the R_i-vectors are the reference positions and R is the unknown position. This equation gives the intersection

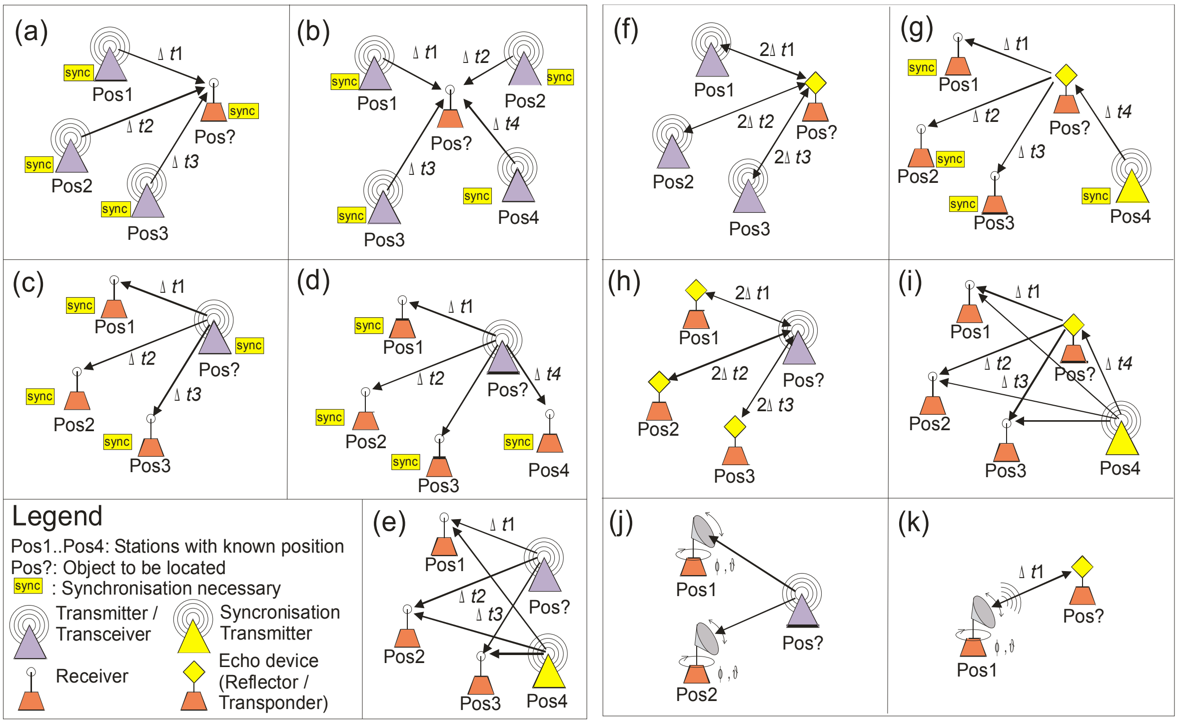

Fig. 1: A variety of distance- and angle based position determination schemes. (a) .. (e): TOF-based. (f) .. (i): Echo-TOF based. (j),(k): angle and angle-TOF based.

points of the distance-spheres surrounding the reference points. It forms a linear equation system which for reasonable t_i values and three reference points gives two solutions. The proper solution has to be determined by plausibility checks, or by including additional reference points. In fig. 1 some different distance and angle based schemes are outlined.

Fig 1 (a) is the basic TOF setup. Signals start at particular times t_i at the transmitters Pos1..Pos3 and are detected at the receiver (Pos?). The receiver knows the starting times, and by detecting the reception times, he can calculate the propagation times $\Delta\ t_i$. If for example light or RF signals are used, they propagate with the light velocity 3x10^8 m/s. In order to get an accuracy of 30 cm for the distance measurement, the time synchronization between transmitter and receiver must be better than 1 nanosecond. The synchronisation of the devices is typically an important design issue.

Also in (c), the to-be-localized object and reference points are synchronized. In setup (b) and (d) only the reference points are synchronized. Setup (b) is used for example in the GPS and GALILEO system, where the transmitters are kept synchronous by using atomic Cs clocks. In variant (e) the synchronisation is achieved by a synchronisation transmitter at a known position. In (f) the signal is reflected at the object respectively at the reference point for setup (h). Schemes (g) and (i) employ a dedicated signal generating transmitter. In (G), the transmitter is not visible from the reference points, while in (i) the transmitter synchronizes the reference points.

In angle-based setups, the positions are calculated by triangulation, i.e. given by intersections of cones. Fig 1 (j) outlines an angle based system, where bearing and azimuth of an object is determined at two positions allowing a non-ambigous position calculation. In (k) the angles and the TOF is determined. This is a typical RADAR (“Radio Detection and Ranging”) setup.

The most commonly deployed and investigated systems are probably the ones based on the strength of a radio signal, the RSSI systems [1,2,3,4]. These systems typically use WiFi/WLAN access points or IEEE802.15.4 transceivers as beacon infrastructure. The position of a mobile receiver, for example a WiFi (WLAN) equipped PDA, can typically be determined with an accuracy of about 2..3 meters, in indoor environments. The accuracy

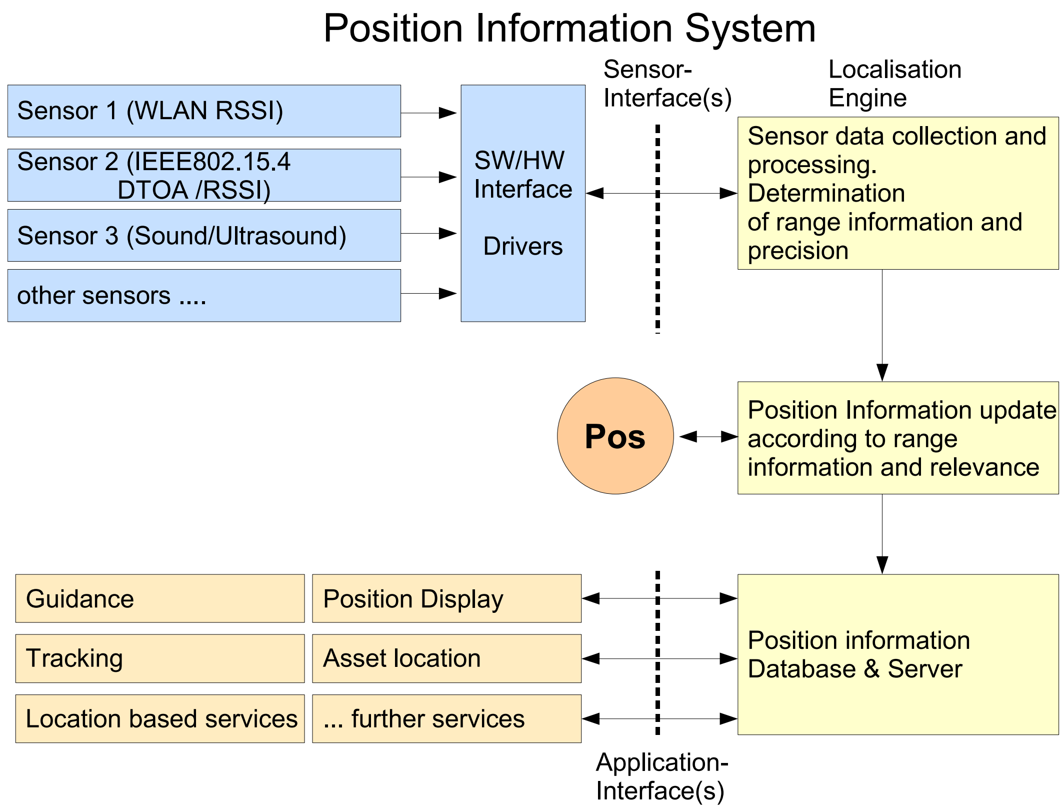

Fig. 2: High-Level Overview of a indoor position information system

rises if the algorithm is not only distance based but uses path loss maps, which have to be manually created for each deployment.
A higher accuracy is obtained by RF time-of-flight methods. There typically a setup as shown in fig. 1 (d) or 1 (e) is used. Methods using Ultrawideband pulses typically reach resolutions better than 30cm [5]. In the systems using more narrow frequency bands [6], multiple propagation path are more difficult do distinguish, on the other hand the carrier phase can be detected at the receiver side which principally enables sub-cm resolution.
Echo based RF methods [7], as shown in figs. 1 (f) and 1 (h) are also very promising. Here no synchronisation of the different receivers (subfig. f) is needed. The methods may use passive or active RFID tags, which give some echo signal with a timely synchronization to the desired accuracy (typ. 1 nsec / 15 cm).
Optical laser positioning methods are employed for example on automatic fork lifts in logistics, or other industrial machinery. The size and cost of the equipment normally prohibits use as tag for persons or small assets.
Infrared systems may use intensity respectively proximity [8] or angles recorded with a small IR chip camera [9].
Ultrasound positioning systems [10] offer a high accuracy, as long as line-of-sight between transmitter and receiver is provided. Typically, the propagation time of a sound pulse is measured and the transmitter and the receiver clocks are synchronized with an accompanying RF pulse.

Applications

The most common applications of indoor localisation systems in building technology are guidance, asset localisation, key personnel tracking and location based services. All this services are best integrated with a service oriented position information system as shown in fig. 2. Such a system is centred about an item position repository where the current position and, if needed, also past positions of all items are available, with accuracy and validity information. This repository is fed by the location engine, which calculates position estimates based on sensor readings, confinement information, mobility assumptions and history. The engine processes readings of a variety of sensors, with different accuracy and availability constraints, and calculates an optimum position estimate. The repository is connected to an application interface, where the different applications may register and get informations. Provided proper configuration has been performed, the interface does implement access control mechanisms to respect privacy and disclosure rules. The applications connect to the position information server, and request information. Services like tracking or asset location may request the position data from the server and display the results on the screen of an operator or, for example, to a nurse in the hospital seeking assistance from a doctor (or vice versa ...). Services like guidance reside typically on a mobile device, displaying a map and directions on where to go to the user. The mobile device is connected to the position information server via a WLAN link. This mobile device may also carry sensors. Via the sensor interface, these data are collected from or pushed to the location engine. The shown system is highly adoptable and expandable, while still allowing low resource embedded systems to be employed for the sensors and/or service applications.

Implementation example 1: RF-Ultrasound Roboter Guidance

We have implemented a ultrasound localisation system and employed it for position determination and control of a mobile vehicle (Fig. 3d).as well as for a mobile position display. The system comprises the following items: beacons which are low power and operate on batteries for months, and a beacon signal receiver which also calculates the position (Fig. 3e). Such systems have widely been deployed in mayor laboratories [10]. Our system distinguishes from the latter by using a two-point detection scheme which leads to higher accuracy in position detection, and due to its simplicity, offers the possibility to perform the position calculation on the mote itself. A beacon consist of a freescale HCS08 microcontroller, which randomly wakes up and sends, at the same time, an ultrasound pulse and an IEEE802.15.4 RF frame (Chipcon/TI CC2420) which contains the beacon ID and position. Collisions between different beacons are detected at the receiver side and the beacon does not bother. Of course, sleep intervals and variance must be carefully chosen. Best results were obtained with a repetition rate of (0.6 +- 0.1) sec. The ultrasound pulse is generated by a common 40 Khz transducer using a charge-pump and direct digital excitement by the microcontroller. The average current consumption of the beacon circuity is about 1 mA, allowing about two month of continuous operation with two AAA cells.

The receiver is also based on a Freescale HCS08 controller. The analog signal detection circuit consist of a sensitive preamplifier with a fixed amplification rate, and a further amplifier for each polarity to allow full signal rectifying for better accuracy. The rectified and low-pass filtered signal (see fig 3 b) is then routed to two comparators operating at different threshold levels, each one generating an interrupt. This allows to determine the gradient at the beginning of the ultrasound slope, which can be used to gain a more accurate starting point of the ultrasound burst. Accuracies of better than 1 cm have been obtained, at distances of up to 10 meters using standard 40 kHz ultrasound transducers with an aperture angle of about 90 degrees. For these accuracies, of course, a uniform temperature distribution in the room is needed, air turbulences have to be avoided and a reference measurement of the sound velocity has to be performed, in our setup this has been done between two beacons. On the other hand, the scheme is highly dynamic concerning input signal levels, and for distances between 20 cm and 15m, no automatic or manual gain adjustment is necessary.

In fig. 3 (a) the power consumption of a beacon has been recorded. Since the HCS08 microcontroller has a limited selection of wakeup-timer delays, specific delays have to be performed by subsequent wakeup cycles to successively approach the desired sleep time. These wakeup cycles are at the frequent small peaks of the pulse. In the middle of the oscilloscope dump, the send cycle is visible. The high peak marks the ultrasound pulse transmission, the lower saddle indicates activity of the RF-Transmitter.

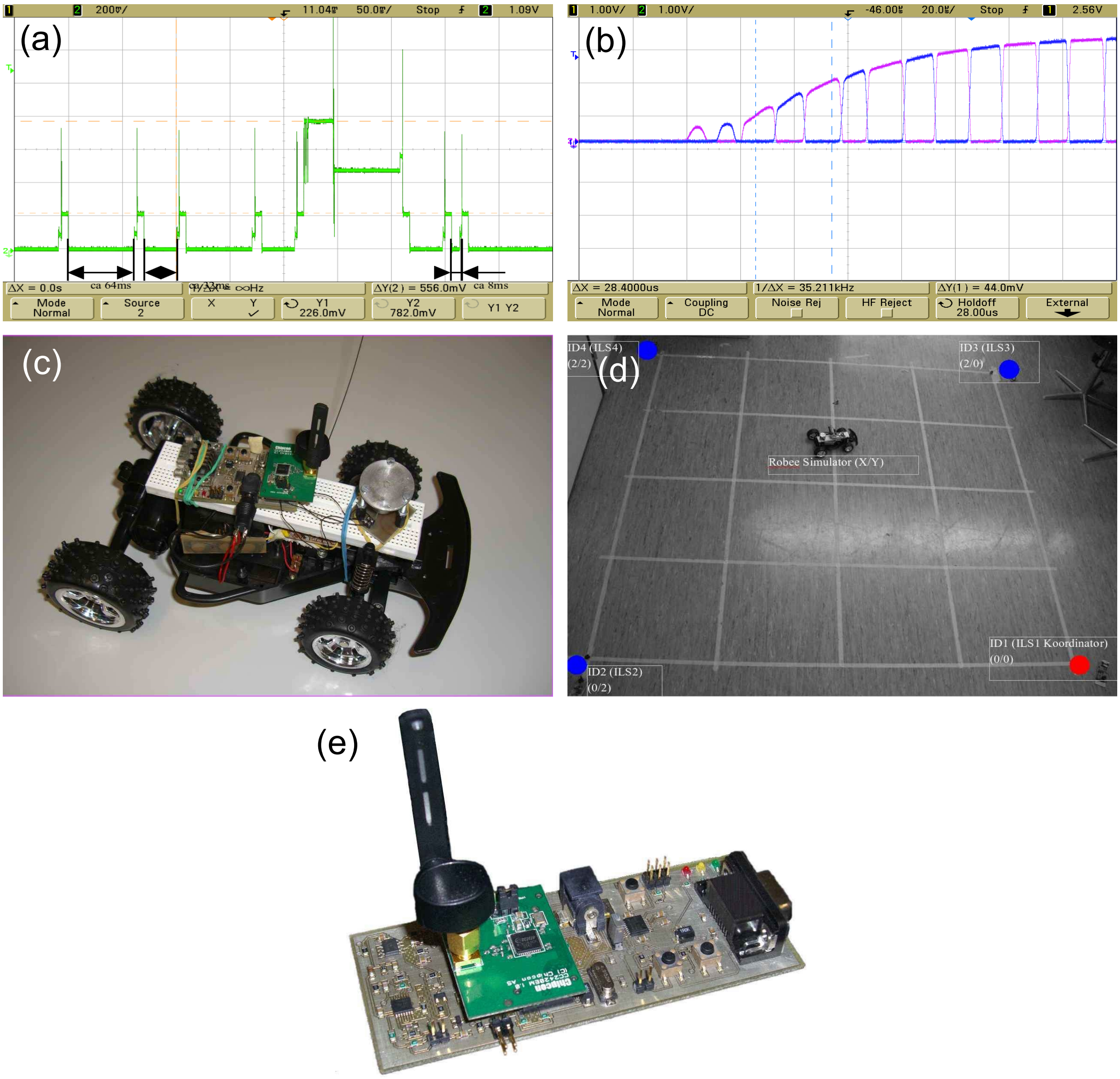

Fig. 3: (a): Power consumption of the beacon transmitter. (b): output signal of the two-channel ultrasound amplifier. (c): Stripped mobile roboter (Toy RC-Car) with ILS receiver. (d): Accuracy measuring yard. (e): ILS print with plugged RF-Device.

Implementation example 2: DTOF localisation of IEEE802.15.4 tags

We investigate the requirements and obtainable accuracy of a localisation scheme which uses differences in Time-of-Flight to localise devices (Fig. 4b.) which transmit standard IEEE802.15.4 data frames. The setup is as shown in fig. 1d. A more detailed view of the 4 channel receiver is shown in fig. 4a. The RF Signal is received and amplified at four antennas with different positions. The signal is then mixed with a common local oscillator and band-pass filtered. For IEEE802.15.4 with a bandwidth of about 2 Mhz x 2, an intermediate frequency of about 20 Mhz is chosen, and the signal is sampled with typically 100 Mhz. IQ demodulation and calculation of the phase derivative is performed in a PC (see also fig. 4c). Since the PC can not process 4 IF channels at a rate of 100 Mhz, the frames are buffered in a FIFO and read asynchronously by the PC. After reception of a frame, further frame recording is blocked until the PC has finished processing the frame.
Currently (early 2007), this work is in progress, With a simplified setup, consisting of only two channels and a sample rate of 4 Mhz, signals have already been recorded and processed,

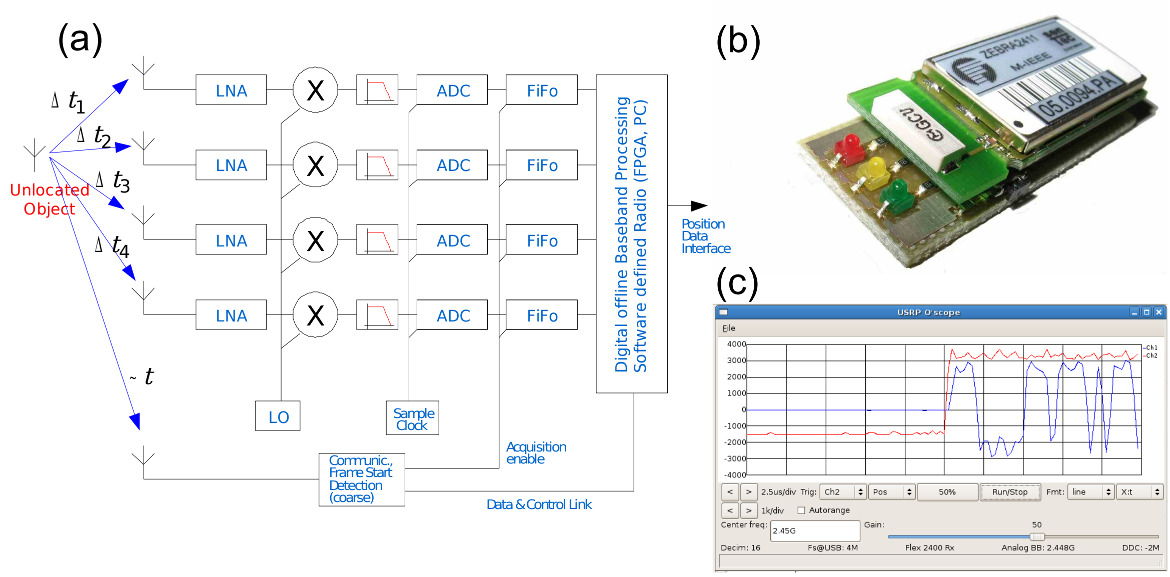

Fig. 4: (a): Setup for a DTOF detection HW. (b): IEEE802.15.5 transceiver board. (c): Online processing of an IEEE802.15.4 data frame, Amplitude and phase derivative shown

including despreading and demodulation of the frame data. The spatial length between two samples at 4 MHz is 75 meters. By cross-correlation and normalizing with the frame autocorrelation function of each channel, observed standard derivations of the frame displacement between the two channels have already been below 0.5 meters, for single frames. Since 50..100 frames can be processed in one second, the measurement noise is below 5 cm, for 1 second averaging time. Due to the low sampling frequency, different propagation path can not be easily resolved by the scheme. On the other hand, the carrier phase difference can also be detected by the system since the RF signal coherence of the different path is kept by using one common local oscillator. Once the correlation accuracy is better than about $\lambda/2$ ($\lambda_{2.45GHz} \approx 12$cm), the carrier phase information, which is measured with very high accuracy, can be included in the distance measurement.

Conclusion

Indoor Localisation enables valuable applications like guidance, tracking, or location based services, to name but a few of them. We gave an overview on a variety of technologies for localisation and their application areas and capabilities. We have investigated a technique-independent software framework for providing applications with position data. Our developed Ultrasound/RF localisation hardware setup delivers a high accuracy of better than 3 cm mean derivation from the actual position, at distances of up to 10 meters. This system allows position calculation on an 8 bit microcontroller, and the beacons operate battery powered, currently 2 month non stop. Since no wires are needed between the beacons and for power supply, the deployment effort of the system is quite low. We are currently working on a time-difference-of-arrival localisation system which detects the position of standard IEEE802.15.4 transceivers when they send normal data frames. First results show that the suggested scheme is feasible. Provided that frame correlation is not heavily disturbed by multipath propagation, very high ranging accuracy below 10cm seem realistic. The CEESAR competence centre (www.ceesar.ch) at Lucerne University of Applied Sciences, besides contributing to a high education standard, provides consulting and has a broad experience in industry research partnerships. If you are interested or have questions, don't hesitate to contact us.

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References

[1] WiFi based Microsoft-RADAR
http://research.microsoft.com/~padmanab/papers/infocom2000.pdf

[2] The Intel System uses several radio sources www.placelab.org

[3] Fraunhofer supports DECT, GSM/GPS, UMTS, WLAN, and HiperLan
http://www.iis.fraunhofer.de/ec/navigation/indoor/kompetenz/index_d.html

[4] TI-Chipcon offers a RSSI based solution based on their IEEE802.15.4 system on chip
www.chipcon.com

[5] Some RF propagation time based indoor localisation systems using short pulse respective UWB signals:
Sapphire DART, Multispectral Solutions Inc, Germantown, MD, USA
UBISENSE RTLS, Cambridge, UK
Parco RTLS, Parco Merged Media, Portland, Maine, USA

[6] Some RF propagation time based indoor localisation systems using “not-so-wide” bandwidth signals:
CAIROS Technologies AG, Karlsbad, Germany
Navysy POSCOMM, Navysy Corporation, Colorado Springs, CO, USA
Paric Measurement, Auckland, New Zealand
LPM System, ABATEC Electronic AG, Regau, Austria

[7] Symeo GmbH, Munich, Germany

[8] Active BAT Infrared: www.cl.cam.ac.uk/Research/DTG/attarchive/ab.html

[9] The IRIS IR Project: http://www.tk.informatik.tu-darmstadt.de/SpotlightProjekt/02_04/IRIS

[10] MIT cricket: http://nms.lcs.mit.edu/projects/cricket/
Berkeley Calamari: http://www.cs.berkeley.edu/~kamin/calamari/
Carnegy-Mellon Millibot::
http://www.contrib.andrew.cmu.edu/~rjg/millibots/millibot_localization.html
Cambridge Active Badge: http://www.cl.cam.ac.uk/Research/DTG/attarchive/bat/