Commercial Hybrid IR/RF Local Positioning System

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Abstract: Location-aware applications for supporting the mobile user require reliable information about their position and the environment. Based on a critical review of solutions so far, a very cost effective solution of a local positioning system (LPS) is introduced for the need of positioning indoors as well as on a constrained outdoor campus with dynamic granularity. The simple and cost-effective hybrid IR/RF (Infrared / Radio Frequency) technology fits into a suite of distributed Smart IP devices within a scalable and flexible architecture. It enables applications like in-house navigation, user centric home & building automation, or dynamic access control systems.

Keywords: Location-Awareness, Local Positioning System, Infrared, RF, Mobility, Smart IP devices, Distributed Objects

1 Introduction

Location Awareness in general describes applications in computing and telecommunication, which alter their behaviour in dependance of the location of an entity. The latter might be the user of the application, a person the user of the application wants to communicate with, or an object capable of changing location.

With the recent thrive in Ubiquitous Computing, dozens of applications demand such location information. It has sufficiently been discussed, that localization indoors has different technological and topological requirements than outdoors. Even if we could derive a probable positioning of one meter, e.g. if we were able to receive GPS even indoors, this left us uncertain if we were at the one or the other side of the wall between two rooms. Thus, a different approach is required in local environments.

In the relation of localization and communication [12], we can distinguish two major categories.

The first category is *receptive* localization. The position information is distributed ubiquitously, and the mobile device can derive its own location from this information. Satellite distributed GPS is a typical example. The mobile device can either relate the derived location to a map independently and provide a local service (without revealing its own position to any third party), or purposely transmit this location in order to obtain a value-added service.

The second category is *transmissive* localization. The position is derived by a fixed station which either sees the mobile device or receives a beacon from it. The station can then either transmit the derived location information to the mobile device, or use it to generate the value-added service for the mobile user. Sub-cell GSM positioning is the example, where the beacon of the mobile communication channel is also used for positioning. At cell level, receptive location is possible in this example also, when the mobile device can identify the very cell it is in.

Reviewing existing technology, the Fraunhofer research institute FOKUS and its commercial spin-off company Ivistar AG were looking for a solution that would be commercially manufacturable and reliable in large scale, as well as affordable for customers who want to deploy the system in large office or representational buildings. It needs to be adjustable in precision from approximately a meter (e.g. in front of an exhibition object) to the coverage of rooms and whole company campuses, thereby working indoors as well as in a confined outdoor area.

The mobile devices need to be easily worn and accepted by all employees and visitors, as well as easy to mount onto movable objects.

Finally, the system should fit into the environment of Smart IP devices currently under development at the two authoring institutions (cf. section 4 for some details).

Within this paper, we briefly discuss in section 2 some existing technology with regards to the above goal in mind. The main section 3 introduces the solution of combining infrared (IR) and radio-frequency (RF) technology in a cost-effective way, followed by examples of deployment, conclusion and future work.

2 Related Work

The following collection of related localization technology is not meant to provide an exhaustive analysis, but merely a collection of examples in order to discuss the pros and cons of each approach.

Receptive radio localization, such as the Global Positioning System (GPS) [6], beside reception problems indoors, is not suitable for room-level positioning, as discussed in section 1. Sub-cell GSM positioning [13] – as an example for transmissive radio localization and as demanded in the "E-911 mandate" [14] and similar European requirements – is currently too immature, requires still relative expensive mobile devices, and cannot distinguish room boundaries. The diversity of network providers hinders the usage within a specific company.

RF localization in general could not provide the dynamic granularity of either to know on which side of the wall the object is (10 cm), or the proximity (e.g. 1 m) to a particular Point of Interest (PoI). Bahl [2] describes an approach based on existing WLAN infrastructure, analysing the signal strength already measured in any WLAN card (RSSI: Receiver Signal Strength Indication). Within the coverage of multiple base stations for triangulation, he achieves a resolution of 2...3 m, without requiring extra hardware beyond the WLAN.

Modulated Infrared (IR) light based technology provides advantages such as the restriction of signals within rooms (IR does not pass walls) and absence of electromagnetic interference. The signal power can easily be adjusted to cover small areas only.

Olivetti Research (ORL) and Cambridge University, UK, pioneered with the nowadays classical approach of the (transmissive) Active Badge [7][8] infrared sensor system, later supported by the weight-measuring Active Floor [9], and the (transmissive) ORL ultrasonic location system [10]. While the floor measures the movement of people and carried objects, analysed by Markov Chains, the latter employs hardware attached to objects, transmitting ultrasonic pulses in specific directions, detected by a matrix of receivers mounted on the ceiling. It obtains a resolution of 10...15 cm.

The Active Badge system, designed, prototyped and trademarked by Olivetti Research between 1989 and 1992, provides a small device worn by personnel, transmitting a unique IR signal every 10 seconds. Each office or PoI within a building is equipped with one or more networked IR sensors. Localization at a terminal was achieved, in parallel to the IR system, with an experimental low-powered radio field.

Battery power is the scarce resource in the badge, allowing limited power of the IR emission only. Sensitivity of the wall-mounted receiver is crucial – but expensive.

While the commercial exploitation by Olivetti industries was less successful than the academic research, the idea has been used by other manufacturers at the cutting edge of infrared technology. Based on the same principles as described above, the EIRIS Infrared Localization System from ELPAS Electro-optic Systems Ltd., Raanana, Israel [4], provides more reliable sightings due to advanced use of diffuse infrared transmissions. The sensitivity of the IR receiver has been pushed to the limit by carefully shielding the diode and amplifier with meshed copper and complex signal regeneration – thereby increasing the price, significantly.

The ORL devices used to determine the intervals of transmission on the surrounding light (dark in the desk drawer, bright in the office); the ELPAS version introduced a motion sensor, checking whether the badge is worn or being laid on the desk.

A major problem of these transmissive IR devices is the requirement of an expensive sensor, expensively networked to each room or PoI. Further, a badge concealed from visibility (in a pocket, or just out of proper reception of the sensor) disappears from the system completely. While this might be considered as a privacy advantage, it is not acceptable for security applications.

C. Randell [3] compares the timing of four ultrasonic signals received from four transmitters within a room, while the timing of the signals has been transmitted via RF, and calculates the relative position. This approach is two-way receptive, in the ultrasonic band as well as in the RF. The localization is very precise (10...25 cm). However, the cost of setting up the ultrasonic transmitters, which must be networked for synchronisation, allows the deployment in selected rooms only.

The Cricket Compass [1] also receives ultrasonic signals accompanied with RF location IDs. Five receivers in the mobile device form a dedicatedly shaped layout. It then can triangulate from ceiling beacons and derive location as well as orientation ("compass") information.

Visual localization and tracking based on advanced stereoscopic image processing will be a very promising approach [17]. However, currently it is too expensive for recognizing a large population of users. Further, trade unions would currently strongly object the complete coverage of working areas with cameras, for privacy issues.

Beyond the approaches discussed above, a lot of technology is available for registering the probable location of an identified person or object, often by passing a specific gate, such as a door. Examples are readers for magnetic cards or chip cards, often used for access control and time registration, contactless inductive transponder systems, on-the-fly bar-code registration, low-power microwave transmitters [5], or at least the derivation from registration and log-in processes. To cover large areas with passive RFID transponder systems – very cost effective on the side of the mobile objects – would require costly set-ups of antenna loops.

Concluding this section, none of the developments discussed above would fulfil the requirements discussed in the introduction. To provide an affordable solution for a situation where the number of localization areas (office/meeting rooms, multiple PoIs in exhibitions) has the same magnitude than the number of persons or objects to be localized, the system discussed in the following section has been developed.

3 Combining Infrared, Radio Wave, and IP networks

3.1 Component architecture

Compared with the traditional badge/sensor pairs, the advantages described later are achieved by introducing a third major component type (Figure 1), now counting as:

1. Stationary, stand-alone infrared ID beacons,
2. Mobile, IR receiving and RF transmitting badges,
3. Stationary RF receivers with LAN (or WLAN) interface.

IR ID beacon. The beacon devices are used as *not-networked* tags in large numbers at lots of places. They periodically emit location information (the location ID telegram) in programmable time cycles.

A PIC reads a “silicon serial number” and generates the ID bursts. The signal strength of up to 15 mW radiant power can easily be modified by adjusting the current of the IR LEDs (2...100 mA), thereby adjusting the maximum transmission distance

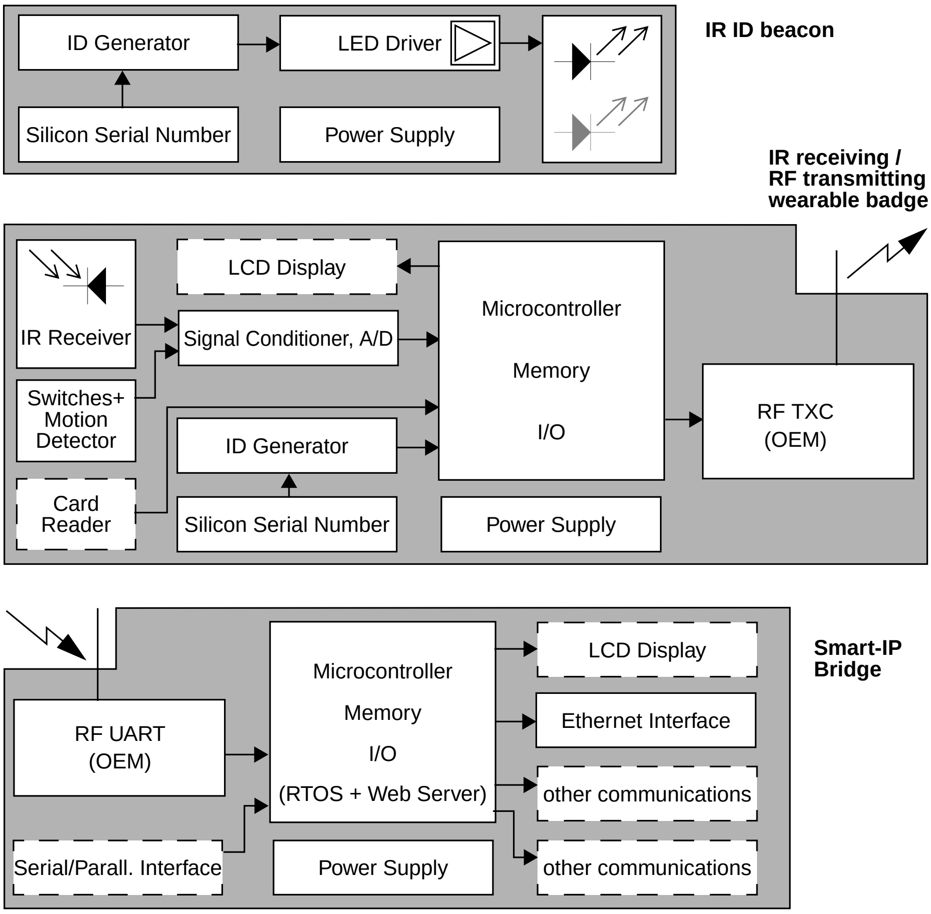

Fig. 1. Component Architecture.

from 0,5...8 m. Wide-angle (80^{o}) diodes are used for large coverage, while narrow-cone types can be chosen for near-range applications. In contrast to the scarce battery power in a wearable IR transmitter, power consumption is not an issue because of the fixed location. Standard remote control components (employing an IR wavelength of 885 nm and a carrier frequency of 455 kHz with Sharp-ASK modulation) can be used and result in a very inexpensive bill of materials (in particular for this component required in the largest quantity for an installation).

IR receiving and RF transmitting Badges. The form-factor of the badge is determined to be easily and visibly worn as a corporate ID card, providing sufficient space for the photograph and name of the wearer.

The badge, just slightly thicker than a credit card, listens to IR location IDs in varying time cycles, depending on the motion of the badge (short cycles while moving, longer cycles while the badge is stopped, immediate scanning when a button is pressed).

Because the IR ID beacon transmits with a relatively high power, the sensitivity of the IR receiver is not critical, and the receiver can be implemented with inexpensive (consumer) remote control components, as well. In particular, the receiver is approx. 10 times cheaper than the highly sensitive, stationary EIRIS [4] receiver. The low bit rate also allows indirect transmissions (reflections) out of sight of the beacon with a distance of up to 8 m, i.e. covering a typical office room. A CRC check-sum is used to recognize transmission errors.

When a new IR ID has been received, the badge transmits a telegram to a base station via RF. Besides various control and check-sum information, the telegram consists of a unique badge ID and the location ID that has been received last.

A low cost 868/915 MHz FM transmission module with 10 mW output power allows an in-house transmission distance of up to 30 m, up to 100 m outdoors. The transmission is uni-directional, therefore the lack of a handshake is compensated with three redundant repetitions. Please note that an immediate RF transmission is only necessary when a location change has been recognized, in contrast to the Olivetti/ELPAS

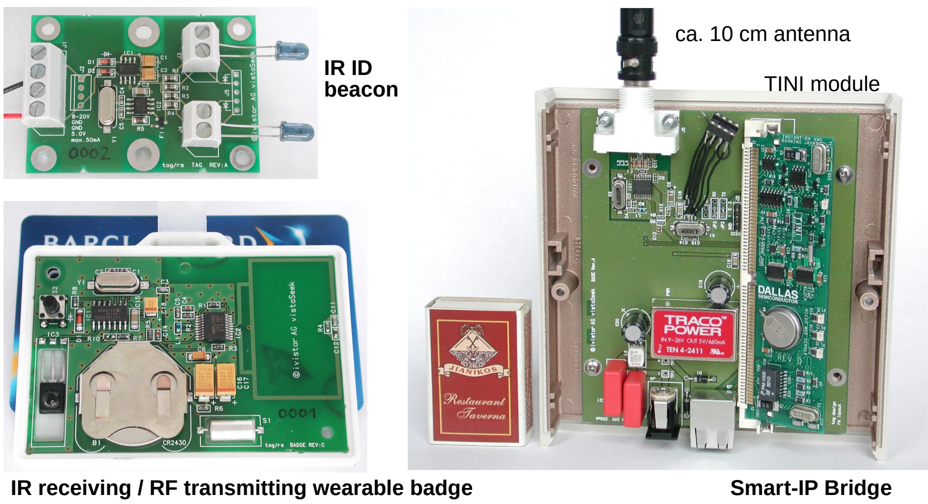

Fig. 2. Hardware Setup.

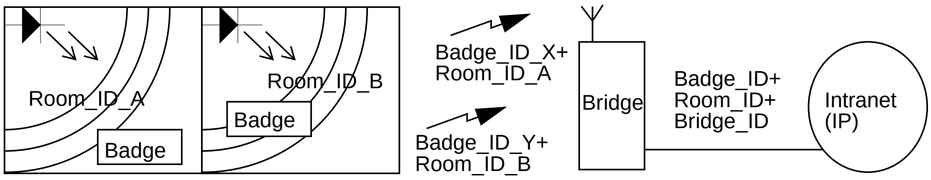

Fig. 3. System Architecture and Signal Transmission.

principle of IR transmissions every few seconds. The badge has a typical battery lifetime calculated as 2 years.

The architecture allows further features, such as an interface for an additional chip card (more security) or a small LCD display for more interaction with the user (paging, simple navigation, etc.).

Smart IP bridge. The RF base station has been designed as simple as possible.

It incorporates a low cost micro controller module (Dallas Semiconductor TINI) that offers a Real Time Operating System (RTOS) and a built-in Java Virtual Machine (JVM). Via the Ethernet interface, the software of the base station allows to query the location information in three different ways:

- Directly via socket communications,
- Directly via a built-in Web-Server,
- Indirectly via an external location server for large installations with more than one base station (cells).

The power for the base station is supplied through the twisted pair cabling using Power over Ethernet [15].

For future applications, the bridge already includes an RF transceiver, although only the receiver path is currently used. The controller module provides interfaces to additional networks and an optional LCD display.

Further communication interfaces can be used for a low-profile system-specific bus (OneWire, CAN, etc.). Providing a way of cascading a couple of bridges with such a bus (instead of twisted pair in star topology), can help to reduce cabling cost through more topological flexibility.

Figure 2 illustrates the hardware setup. Compared to the Olivetti Active Badge and the ELPAS system, installation costs could be drastically reduced for the use cases already discussed. Instead of needing one expensive, networked IR sensor per room or PoI, only the cheap, not-networked beacon devices are required. The networked bridges, which are a little more expensive than the other two components, are shared by a group of 5...15 rooms.

3.2 LPS Architecture

Figure 3 illustrates the system architecture and the signal transmission. The Room_ID beaconed by the cheap IR transmitter is received by the badge. The latter adds its own Badge_ID and transmits the information via RF to the bridge.

The bridge either stores the location information for direct access, or pushes it towards a centralized server somewhere in the IP based intranet of the company, after adding its own Bridge_ID to the message.

Cascading bridges with a low-cost bus would not require complex gateway functionality towards the IP network. Instead, the low-cost bus can be considered as an extended device-internal master-slave communication, and the group of near-range distributed devices can be seen as a single "multi-cell bridge", providing multiple bridge IDs while having one IP number only. The advantage is the reduction of cabling cost in specific building constellations, but keeping the system transparent for the user.

Distributing bridges within a building and over a corporate campus leads to a cellular topology, where the size of a cell is approx. 30 m indoors and 100 m outdoors.

Using the built-in bi-directional RF connection between bridges in overlapping cells is currently under investigation as a further method of cascading bridges, especially for areas which are difficult to wire. A further way to connect such areas is to use WLAN at the IP interface.

A specific advantage of the system approach is the possibility to place multiple beacons in one room. Due to the burstiness of the IR signals collisions are rare; and the IR power can be adjusted. No additional conflict resolution is necessary for up to 15 or more (power-adjusted) beacons in one and the same room.

Thus, large rooms can be covered easily, and positioning within the room is possible, e.g. by placing a reduced-power beacon at each Point of Information in an exhibition.

Outdoors, sunlight disables reliable IR transmission. In this case, the badge is localized on cell level. Further, the approximate distance from the bridge can be determined with RSSI (Receiver Signal Strength Indication).

The same cell level localization happens when the badge is concealed indoors (e.g. put into a pocket), or for privacy reasons certain locations (e.g. bathrooms) do not feature a beacon. The user or the secured object does not disappear, but transmits its own ID to the cell's bridge, indicating at least the part of the building to look for it.

3.3 Installations

The first lots of the system have successfully been deployed in real-life conditions; at Siemens AG (NYSE:SI) in the "C-Lab" to implement a follow-me mechanism for video-streams, the Deutsche Telekom AG (NYSE:DT) for building-wide recognition of visitors, standing in front of guidance and information systems, and for their smart home environment, as well as FhG FOKUS for various applications within the user-centric environments.

4 Experiences and Outlook

By combining the best of the worlds of RF, IR and wired IP in a new localization architecture, a completely new approach has been implemented. It overcomes the disadvantages of the systems described in the beginning, regarding functionality as well as cost. The modularity and flexibility of the interconnection allows to customize the topology to individual customer requirements. Patents are pending for the positioning principles for Ivistar AG.

Our approach seamlessly fits into a suite of Smart IP devices which have been and are being developed at the authoring institutions.

From the experience of integrating building-wide infrastructure networks, such as LON and EIB [18], into corporate intranets and the internet, the decision has been derived to focus current and future development on manifold sensors and actuators on *fully IP compliant* nodes, instead of providing expensive gateways to these proprietary networks.

Employing the TINI board discussed above as a core, a number of Smart IP devices has already been developed (as listed in the Appendix). All these devices receive their low voltage power through the TP cabling, i.e. using Power over Ethernet [15].

Together, they form a zero-gateway, homogeneous environment, enabling a large number of new service and application areas.

To program the LPS bridge as well as all these small “internet appliances” in Java, like any other PC or work-station platform, is a great advantage. Fine-tuning (e.g. a dampener software to avoid permanent change of the location information while border-crossing between two IR-ID zones), can be done on this level very comfortably.

Current work focuses on the implementation of a UPnP stack for the base station and “virtual” UPnP devices representing badges (users). This results in a fully transparent LPS with minimal management requirements, which can be altered while running (Plug-and-Play). Applications and services will recognize and communicate directly with virtual badge devices (featuring an automatically updated location property).

The mandatory networked coffee machine in the lab has already been upgraded to a fully automated espresso maker, freshly grinding and brewing the dark stuff on IP command, e.g. by pressing the badge button when approaching.

As the IR ID beacon transmitter is so simple to realise, the hardware is currently being added to all other Smart IP devices, which can then be equipped with IR LEDs wherever they are installed in the room.

Bluetooth is an alternative for the RF transmission, however, it provides a smaller area of coverage (12 m instead of 30 m indoors).

The TINI micro controller board of the current Smart IP devices has the size of a memory module. As a further hardware miniaturization, a single-chip controller solution with full IP stack is currently under development. A large office building which is presently being planned by Deutsche Telekom AG will serve as an installation base for a significant number of such miniaturized IP devices, thereby allowing to produce a sufficiently sized lot to be competitive in price compared to “traditional” building networks like LON and EIB.

Appendix

List of small Smart IP devices developed by FhG FOKUS and Ivistar AG, based on the TINI core module with Java virtual machine and full IP stack:

- LPS bridge, as described in section 3.1,
- Digital I/O card with 4 output channels, equipped with 230 V / 16 A power switches, and 4 sensor input channels, serving as the core for all controlling of light, heating, household appliances, etc.,
- Customizable D/A and A/D converters, where the micro controller can drive a large variety of converter chips for different precisions and sampling rates,
- Dimming device, which consists of a low-end D/A converter controlling a power regulator (triac),
- Online Door-Plate, using a 320 x 240 pixel b/w LCD display and a touch screen, interworking with an internet based room booking and accounting system,
- Graphical User Interface device, similar to the door-plate, using a 320 x 240 pixel b/w LCD display and a touch screen, with smart buttons for interaction with the home/office environment,
- MP3 audio streaming player, including a 1 W power amplifier,

- MP3 hardware encoder for audio capturing / streaming,
- FM radio, tunable and controllable via IP as an add-on for the MP3 encoder,
- active desktop image frame, using a 320 x 240 colour display,
- Specific gateway solutions, e.g. CAN (Controller Area Network) gateway for accessing this network in automotive environments.

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