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Embedded Wireless System for Pedestrian Localization in Indoor Environments

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Abstract: The paper presents an embedded telemetry system used in combination of localization algorithm for a precise indoor pedestrian localization. The system is based on the association of two wireless technologies: ultrasonic and 802.15.4. The novelty is the use of 802.15.4 RF signal to give the reference starting time of the ultrasonic emission. A ToA (Time of Arrival) measurement provides the distance between two mobiles or a mobile and a fixed beacon with a few centimeters accuracy. A material prototype implementing this method was performed and a first evaluation of energy consumption and packet error rate was conducted. *Copyright © 2012 IFSA.*

Keywords: Wireless sensors, Telemetry, Low power, Ultrasonic, Localization, 802.15.4.

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1. Introduction

Many localization techniques could be used to track people or devices in indoor or outdoor environment. In indoor, infrared, ultrasound, narrowband radio, WiFi, or UWB location systems are the most common [1-4]. In outdoor, we find essentially systems based on GPS location. The main problem is that these systems require heavy and cost infrastructure with a not easy deployment. In this context, this paper, which is part of a research project funded by the French National Research Agency (ANR), aims to define a new indoor localization system in continuation of outdoor localization system such as GPS [5]. The project is trying to address two specific problems:

- Helping people to locate themselves inside complex buildings.
- Helping to locate someone moving in a complex building.

Applications may be various: security, technical management, health… The system must enable the user to locate or to be located in the building with a good accuracy (few centimeters) [6]. We could also consider for mobile robot applications the improvement to one cm accuracy or less using data harvesting from other sensors. Although the project is intended to compute the location from different sensors and location prediction algorithm, this paper is focused on the distance evaluation to fixed points inside buildings.

Several localization algorithms are used to compute the exact location and to enhance the resolution [7-10]. The system presented here is a precise telemetry system composed of three devices: a first node, which is an energy efficient mobile device and worn by an instrumented person, a second node, which is fixed (called "Beacon"). These nodes help the mobile device to locate precisely. At last, a remote gateway saves localization information of all mobile devices.

In this paper, we first present the basic principles of the proposed system, then hardware and software development are described. Finally, electrical and radiofrequency characterization results are presented and a comparison with the Cricket localization system (MIT) [11] system is shown.

2. Operating Principles

The system has two main functionalities. The first one is to estimate the distance between a user, typically a pedestrian in a building, and a fixed reference, and the second one is to send distance data to a collecting point using WiFi local area network. Two possible operating modes are shown in Fig. 1:

- An "autonomous mode" where the system collects and stores data in a flash memory. Data is harvested through the serial link when desired.
- A "normal mode" where distance data isn't stored in the system but immediately sent to the collecting point using WiFi.

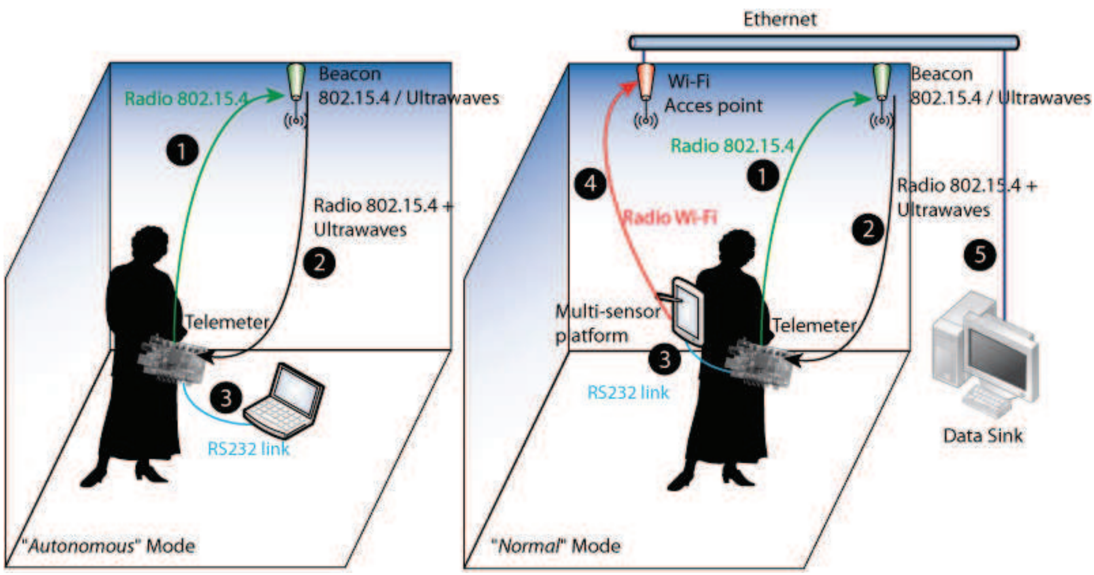


Fig. 1. System architecture with two possible modes.

Depending on the mode remote data collection involves several stages:

- Stage 1: the telemeter sends a request radio frame to the beacon using its 802.15.4 interface [12].

The frame will be presented in the next section.

- Stage 2: The beacon receives the request from the telemeter and replies to the telemeter by sending simultaneously an RF response and an ultrasonic pulse.

- Stage 3: When the telemeter receives the response frame from the beacon, the telemeter starts a timer, which is going to measure the flight time of the ultrasonic pulse (ToA method [13]). When the ultrasonic pulse reaches the telemeter an interrupt is generated and the distance is computed. In autonomous mode, data (distance, beacon address) are stored on the telemeter or are immediately sent to a collecting PC using a serial RS232 link. It is the end of operations in this mode. In normal mode, data are sent to a multi-sensor platform, which performs data aggregation from other sensors. In order to keep the free positioning of all the sensors on the person data are sent using Bluetooth protocol (not represented in Fig. 1).

- Stage 4: Data are received from the Bluetooth interface of the platform and are processed. Then, the platform checks all sensor parameters and transmits the status of the person using its WiFi interface.

- Stage 5: Data received by a WiFi access point is sent through the Ethernet network to the data sink.

3. Hardware Presentation

The telemeter system is constituted of two parts separated in two specific boards connected through dedicated Programmable Input/Output (PIO). The first board contains the processor and radio modem, while the second board is dedicated to the ultrasonic pulses emission/reception.

3.1. Processor and Radio Board

The main component of the device is the 13213 from Freescale Semiconductors [14]. This component is a System In Package (SIP) including a processor and a 802.15.4 compliant transceiver. Our design is inspired from 13213-ICB reference design from Freescale, and all necessary interfaces have been integrated on the board to configure and to debug our telemeter. The block diagram of the system is presented in Fig. 2.

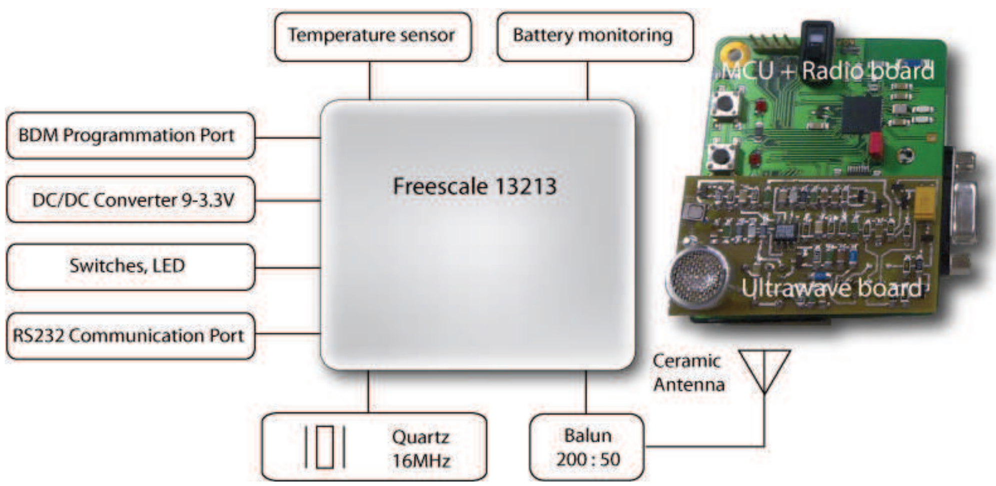


Fig. 2. System block diagram.

The 13213 processor is responsible for both functionalities: handling the transceiver and commanding the application. This characteristic limits the application code size (60kBytes) but enables to decrease the delay due to Physical layer (decoding demodulation). Indeed as soon as a frame is received a software interrupt is generated on the processor, which can start a timer on a beacon response (stage 2).

Moreover, the chip handles the serial RS232 link, which enables the system to send data to the multi-sensor platform (stage 3).

At last, several Input/Output and debug ports (BDM) have been placed on the MCU board in order to check the good communication between the boards.

The multi-sensor platform and the telemeter have been integrated by a company specialized in integration system. In Fig. 3 the analog part is located on the bottom face of the final system.

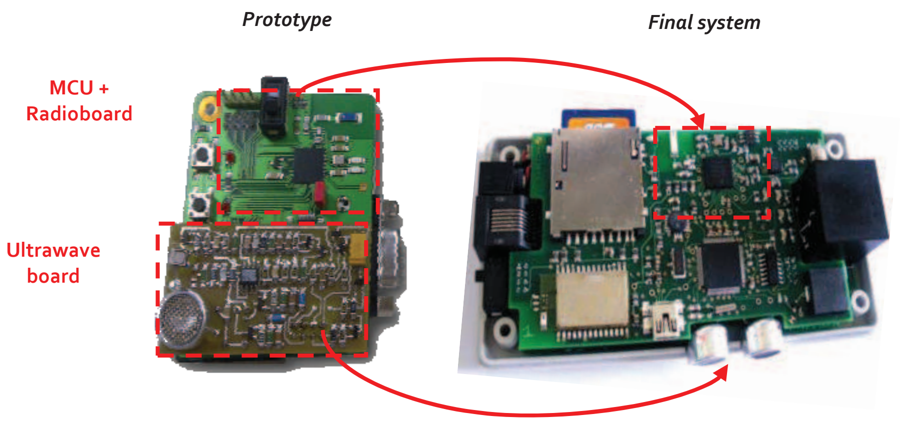


Fig. 3. Integration of the prototype.

3.2. RF and Ultrasonic Signals

The ultrasonic part aims at computing the flight time of an ultrasonic pulse in the 40 kHz frequency range. The system combines the use of one RF electromagnetic wave with one ultrasonic pulse. The propagation speed of the electromagnetic wave being higher than the sonic pulse speed, the flight time of the RF wave can be considered as instantaneous.

Thus, the RF beacon response to a localization request starts a timer of the processor, which timer is stopped when the ultrasonic pulse generated by the beacon node reaches the telemeter. Fig. 4 shows the temporal mode of the operation.

The ultrasonic pulse generation is managed by two programmable outputs of the beacon processor in push-pull mode (Em1 and Em2 signals), while on the telemeter the reception of an ultrasonic pulse in the 40 kHz frequency band generates an interrupt on an input configured in the input compare mode (Echo signal).

Two other outputs of the processor are used for managing the ultrasonic board: the “Block” signal, enabling to block the listening while an ultrasonic pulse is generated, and the “Sleep” signal enabling to put the ultrasonic part in low power mode.

The 15 ms guard time is due to the charging of the ultrasonic board input capacitor. The ultrasonic pulses have been limited to 2 ms in order not to fill the environment of parasitic echoes. If the telemeter doesn't receive the ultrasonic pulse in less than 60 ms, the telemeter puts the ultrasonic board in low power mode and goes to sleep mode until the next localization request.

The localization request can be either executed periodically from a timer, or requested from the serial link from the multi-sensor platform.

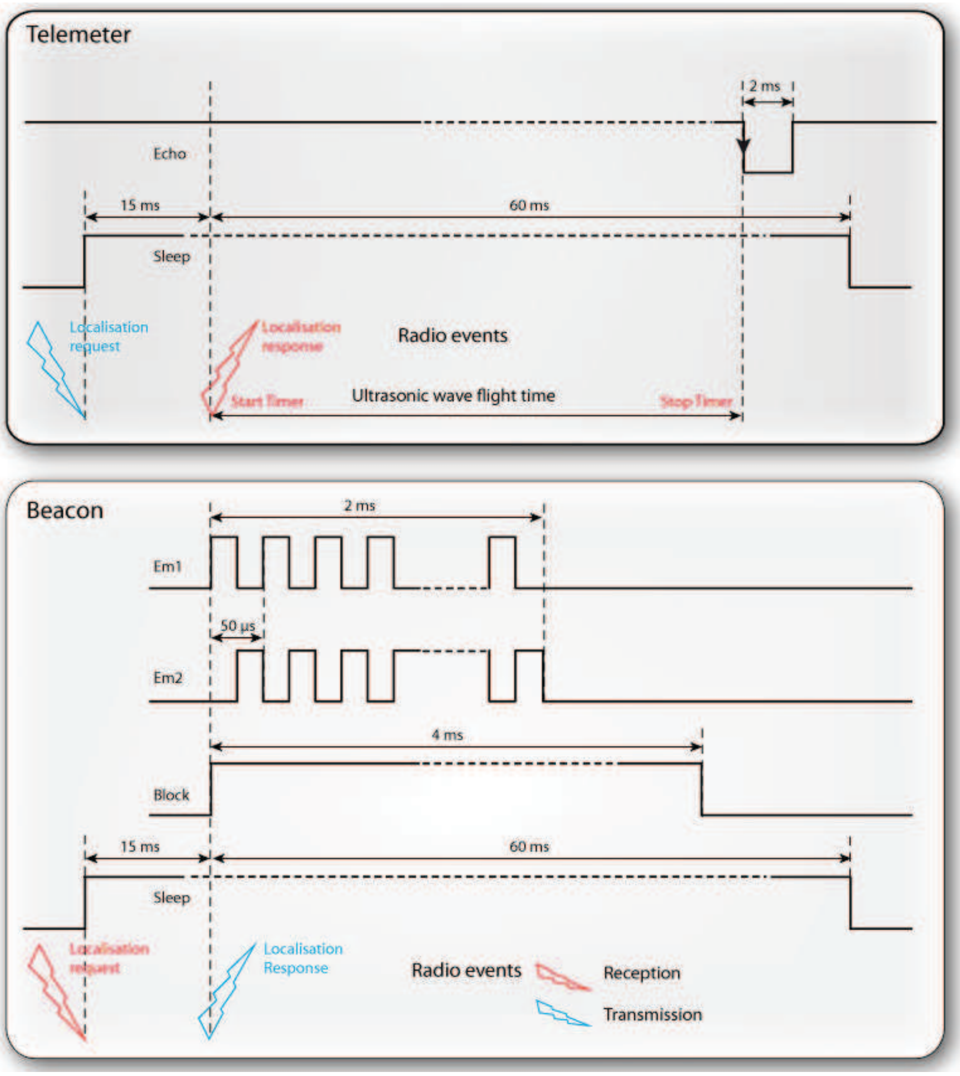


Fig. 4. Ultrasonic signals temporal management.

4. Software Presentation

In order to program easily the application Freescale offers several software solutions called Code Bases: a basic solution called SMAC, a more complex 802.15.4 compliant stack and a ZigBee compliant stack [16].

For our system we have chosen the basic SMAC (Simple Media Access Controller) for several reasons. The most important reason is that this code base is completely open source and gives access to very low level primitives enabling maximal energy savings. Moreover this code base is very small and easy to implement. The source code is in standard C language and the development environment is Code Warrior [15].

4.1. Application Software

The application code is integrated in a state machine running on the Beacon node and the Telemeter. Localization requests are done periodically (2 s) using a timer on the telemeter.

4.1.1. Telemeter System

The state machine is described in Fig. 5.

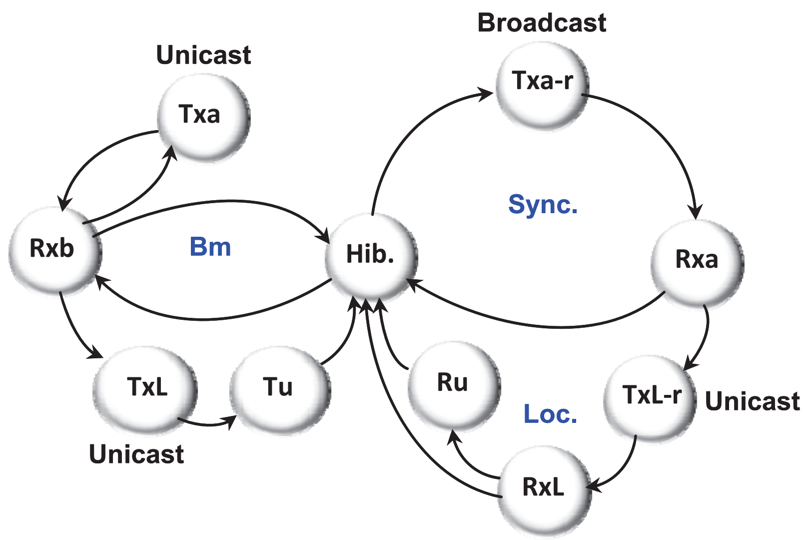


Fig. 5. Telemeter state machine.

In order to save energy the system spends the most of its time in a deep sleep mode called Hibernate mode. In the Hibernate mode both the transceiver and the processor are powered off. Only a crystal is powered allowing the processor to wake up and after to switch on the radio stage.

The system is wake up from Hibernate state (Hib) every 128 ms by the real time interrupt timer to manage pending commands (Idle). Each transition of the state machine goes through the Idle state. This state was not shown in Fig. 5. The state machine can be decomposed in three sequences:

- Synchronization sequence (Sync.)

In this sequence the telemeter tries to synchronize with another system (beacon or telemeter).

At the first wake up, the system broadcasts an acknowledgment request (Txa-r) to check if another system is in radio range. Then it waits an acknowledgment (Rxa). At this level, two cases are possible:

- Case 1: If acknowledgment is not received (no system in the radio range), then the watchdog expires after 2 ms and the system returns to the Hibernate. When the system wakes up again, it broadcasts an acknowledgment request. The telemeter broadcasts until ten acknowledgment requests, one every 128 ms. At the eleventh wake up, the system enters in the RxB state where he plays the role of a beacon.
- Case 2: If acknowledgment is received (another system is in the radio range) the telemeter

uses source address of the system which has responded for unicast a localization request (TxL-r).

- Localization sequence (Loc.)

In this sequence, a Time of Flight measurement provides the distance between the telemeter and another system (position reference). First, the telemeter unicast a localization request (TxL-r). Then it waits the Radio localization response (RxL) during 160 ms maximum to allow the system that responds to awake its radio and ultrasonic parts. If there is no received request, after 160 ms the telemeter directly goes to Hibernate state. If the localization response is received, the telemeter waits the ultrasonic pulse (Ru). When the pulse is received or after 60 ms, the telemeter goes to Hibernate state where it waits the eleventh wakes up for enter in the Rxb state.

- Beacon sequence (Bm)

This sequence is used by the system data sink to increase beacon range and the robustness of the architecture. In this mode the telemeter plays the role of a beacon node for another telemeter.

First, it waits in the Rxb state for a 200 ms guard time. If there is no received request, after 200 ms the telemeter directly goes to Hibernate state. If an acknowledgement request is received, the telemeter unicast an acknowledgement (Txa) and goes to Rxb state again and waits localization request. When the localization request is received, the telemeter unicast the localization response (TxL) and ultrasonic pulses (Tu) are generated. A special attention has been given to the Rxb guard time (200 ms) since radio stage activation consumes more energy.

4.1.2. Beacon System

The state machine of beacon node is a special case of the telemeter state machine because the beacon node is always in reception state. As soon as the beacon node receives an acknowledgement request (Txa-r) or localization request (TxL-r) the beacon node generates the associated responses: first an acknowledgement response (Txa), then a localization response (TxL) and an ultrasonic pulse (Tu).

4.2. Frame fFrmat

4.2.1. Radio Frames

The radio frame format uses the 802.15.4 standard header and adds some fields. Frames are between 12 and 14 bytes long and are composed of three parts as described in Fig. 6.

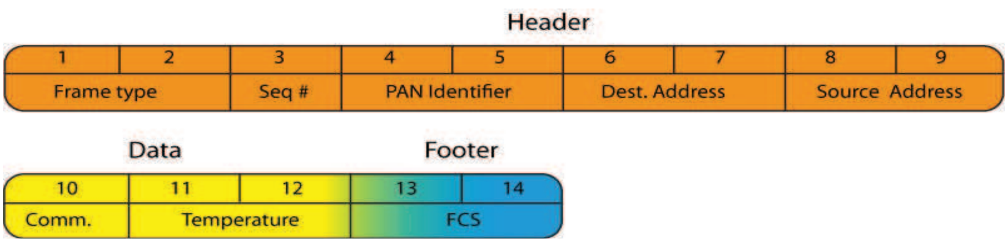


Fig. 6. Radio frame format.

Some fields are useless and could be optimized for energy savings (Frame type, Sequence number, PAN ID). Moreover the address field are oversized (2 Bytes) and could be limited to 1 Byte. However the 802.15.4 frame header enables to use most of network analyzers such as Daintree Network SNA [16] to monitor the radio communications.

The frame is composed of three parts:

- The header field.
  - Bytes 1 and 2 define the 802.15.4 frame type (Data, ACK, Beacon…).
  - Byte 3 is the sequence number incremented with each emission.
  - Bytes 4 and 5 define the network identifier and allow creating several networks.
  - Bytes 6 and 7 identify the destination address. 0xFF is used for broadcast (localization request).
  - Bytes 8 and 9 identify the source address. The first one identifies the node type (beacon or telemeter) and the second one gives them a number (short address).

- Data field: Byte 10 identifies the command type. Two commands are implemented: Localization Request and Localization Response. Bytes 11 and 12 enable to send the temperature from the beacon node to the telemeter in order to take into account for US wave propagation speed compensation. This field can be used as parameters for other non-implemented commands.

- The footer field: Bytes 13 and 14 are generated automatically by the data transmission primitive implemented in the SMAC code base. The FCS enables frame error detection.

4.2.2. Serial Frames

After the telemeter has received the localization response from a beacon node, the telemeter activates a 60 ms watchdog and a timer enabling the US wave flight time computation. When the US wave reaches the receiver (a MEMS microphone) or when the watchdog expires, a serial data frame is sent to the multi-sensor platform. The format of serial frames is given in Fig. 7.

1	2	3	4	5	6	7	8	9
Start	Flight time		Temperature		Battery level		RSSI	Stop

Fig. 7. Serial frame format.

Byte 1 is used as a start frame delimiter in order to limit erroneous frames.
Bytes 2 and 3 transmit the US wave flight time calculated with (1)

$$T_f = field \times 0{,}5\mu s. \quad (1)$$

Bytes 4 and 5 transmit the beacon temperature information to the multi-sensor platform.
Bytes 6 and 7 transmit the battery level from the integrated battery monitoring system.
Byte 8 gives the link quality indicator, which will enable us to compute the Receive Signal Strength Indicator (RSSI) with (2)

$$RSSI = -\frac{field}{2} dBm. \quad (2)$$

Byte 9 is used as a stop frame delimiter in order to limit erroneous frames.

5. System Characterization

Electrical and radiofrequency characterization have been performed. Comparison with a well-known system is also made.

5.1. Electrical Consumption

These measurements were performed with prototypes to evaluate the consumption generated by the telemetry part of the final system. In order to characterize electrically the telemeter, we have measured the current going through a serial 50 Ω resistor before the 9 V to 5 V DC/DC converter.

5.1.1. Localization Sequence (loc.)

Fig. 8 represents a localization sequence, which is done every 2 seconds. We have simplified the cycle by showing just localization sequence. Five different stages can be identified:

- The first stage is the wake up period. This stage is fixed by the LED in initialization and lasts 15 ms while current consumption sensed is 5 mA.
- The second stage is the acknowledgement period. This stage is composed by 2 parts: the broadcast of acknowledgement request and the reception of acknowledgement.
- The third stage represents both radio transmission and ultrasonic part powering. This stage lasts 20 ms and while the mobile device starts to transmit localization request (TxL-r) the ultrasonic part is enabled in order to compensate analog component delay. The current consumption is about 65 mA.
- The fourth stage is the received period. The device listening and the beacon response consume 35 mA. After the radio reception, the waiting for the ultrasonic (US) wave starts and the ultrasonic power is sensed by the analog circuit, the radio and the analog circuit is turned off.
- The last stage is the transition to *Hibernate* mode.

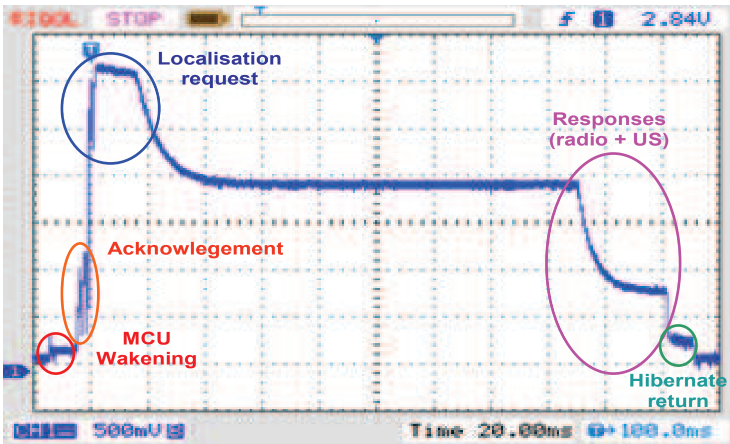


Fig. 8. Successful localization sequence.

5.1.2. Case of the Telemeter Alone

In this case there is no localization sequence (loc.). We observe on Fig. 9 ten current peaks (30 mA) that correspond to synchronization sequence (Sync.) unsuccessful. Then we observe the Rxb state during 200 ms guard time (35 mA). Then the cycle repeated.

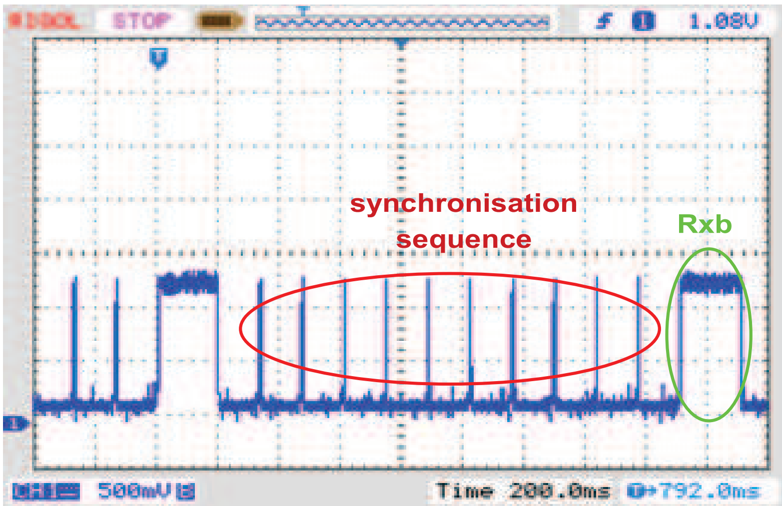


Fig. 9. Telemeter alone.

5.1.3. Case of the Telemeter which Communicates with another System

In case of the telemeter which communicates with a beacon, for each request (acknowledgement and localization) there's an immediate response from the beacon.

In case of the telemeter which communicate with another telemeter, for each acknowledgement request there is no an immediate response. On the waveform Fig. 10, we can see the synchronization sequence successful with two unsuccessful acknowledgement requests and the third acknowledgement request is successful. Then we see the localization sequence, the wait time of beacon mode and finally the beacon mode with associated transmissions Txa, TxL and Tu.

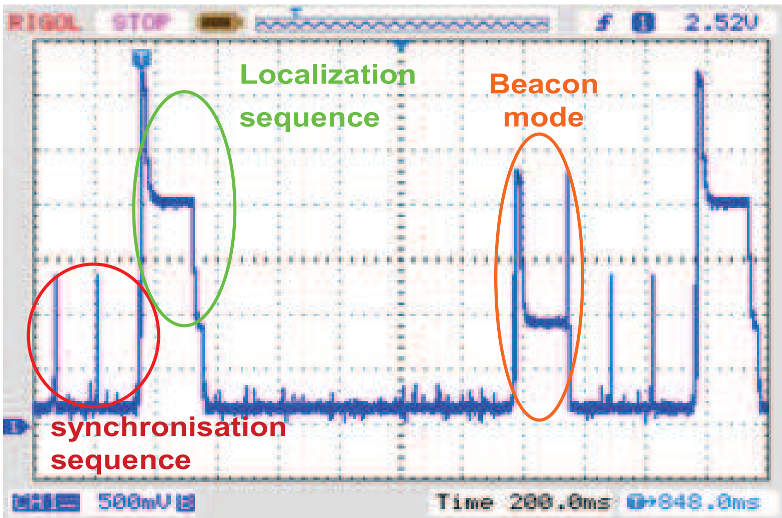


Fig. 10. Two telemeters communicating together.

5.1.4. Average Current Consumption

The average consumption is estimated during 20 s, about 20 full cycles. This series of measures, presented in Table 1, has been performed to choose the optimal combination between the Rxb guard time and the periodic wake up timer (RTI). The board below shows the average consumption of the telemeter 1.

Table 1. Average current consumption.

Average Consumption (mA)	Telemeter 1 alone	Telemeter 1 with a beacon	Telemeter 1 with a telemeter
Rxb = 50 ms, RTI = 32 ms	16.48	10.32	15.96
Rxb = 100 ms, RTI = 64 ms	12.22	10.52	14.02
Rxb = 200 ms, RTI = 128 ms	8.6	10.64	10.78
Rxb = 400 ms, RTI = 256 ms	13.3	15.52	14.58
Rxb = 800 ms, RTI = 512 ms	19.54	21.8	17.06

When the Rxb guard time is long, the consumption is important. When the number of acknowledgement sequences is high (low time RTI), the consumption also increases. In addition for each wake up RTI, the transition to Idle state also consumes a low current. This explains why consumption doesn't decrease when we decrease the Rxb guard time in the case of the telemeter with one beacon. The best combination is a guard time of 200 ms with a periodic wake-up RTI of 128 ms.

5.2. Packet Error Rate Measurement

When two or more devices communicates at the same time, there may be radio collisions, which cause errors in the data frames, including errors on the address's beacon (bad reference position). Laboratory tests have been conducted to measure the Packet Error Rate based on the number of tries (rebroadcasting). The tests on radio communication robustness have been performed continuously during six hours, about 10,000 acquisitions (1 acquisition every 2 s). The devices have been placed on a table and the distance between devices is 1m (good radio condition).

The parameter studied is the PER (Packet Error Rate) calculated with the formula (3).

$$PER = (Number\ of\ error\ packets\ /\ Number\ of\ transmissions) * 100 \quad (3)$$

The proposed study is limited to 4 devices that communicate together. Table 2 shows the Packet Error Rate in different scenarios based on number of attempts to acknowledgment.

Table 2. Packet Error rate measurement.

Scenarios	PER without ACK	PER with 1 ACK	PER with 3 ACK
1 telemeter and 1 beacon	0.11	0.01	0.00
1 telemeter and 2 beacons	2.92	0.57	0.09
1 telemeter and 3 beacons	5.09	2.88	0.44
2 telemeters	0.13	0.00	0.00
2 telemeters and 1 beacon	1.02	0.33	0.04
2 telemeters and 2 beacons	3.56	1.57	0.17
3 telemeters	0.24	0.03	0.00
3 telemeters and 1 beacon	1.98	0.67	0.11

The acknowledgment reduces Packet Error Rate by increasing the number of tries, but the energy consumption increases. In context of the location in a complex building the beacons are not nearby. The cases with several beacons can be eliminated. The worst case took in consideration is when three persons meet in a corridor equipped with a beacon. In this case and with three attempts to acknowledgment, the Packet Error Rate is 0,11 %. This solution is adequate for ongoing trials. If the project would come to be industrialized, a network dimensioning must be done. This study could lead to the implementation of a method access control.

5.3. Ultrasonic Characterization

5.3.1. Test Environment

The analog part characterization has been realized in an empty 9 m × 7 m lab room. Fig. 11 shows the room configuration and angular tests performed.

The room height is about 3 m and the ground and walls are mixed reflective surface (concrete, plaster, bricks…).

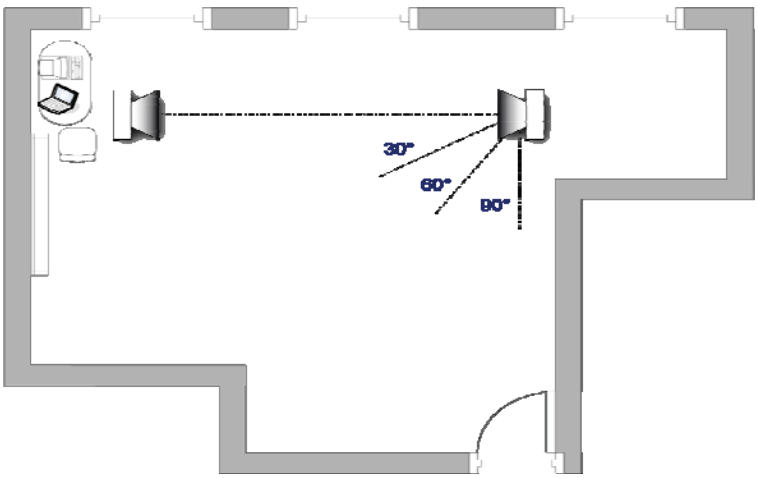


Fig. 11. Test room configuration.

5.3.2. Distance and Polarity Impact

This characterization is focused on the distance and polarity impact on measurements. The temperature during these tests is kept around 22 °C (± 2 °C).

The measures presented in Fig. 11 were realized at 1.1 meter from the ground and with constant temperature.

Due to piezoelectric transducer directivity we tried several test pointing positions to compute the directivity effects on measurements. Four test positions were performed: 30, 60 and 90° from the direct view position. The maximal range of the system is 9 m but it can be improved by increasing the US pulse power. However, this modification increases the measurement variance. The absolute error in all position stays under 8 cm and the maximal error is observed when the device is in the 90° from the beacon position (See Fig. 12).

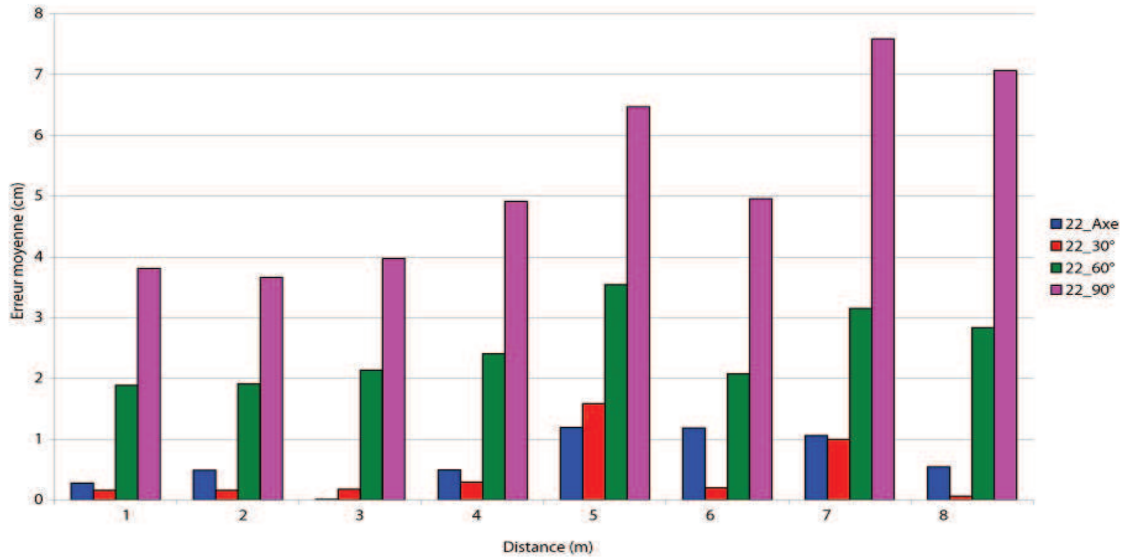


Fig. 12. Distance error function of time and position (22 °C).

Fig. 13 represents the polarization impact on measurements. For these measures we only made a quarter turn in the board plane to measure the XY directivity of the transducer but we haven't noticed any impact on the flight time measured.

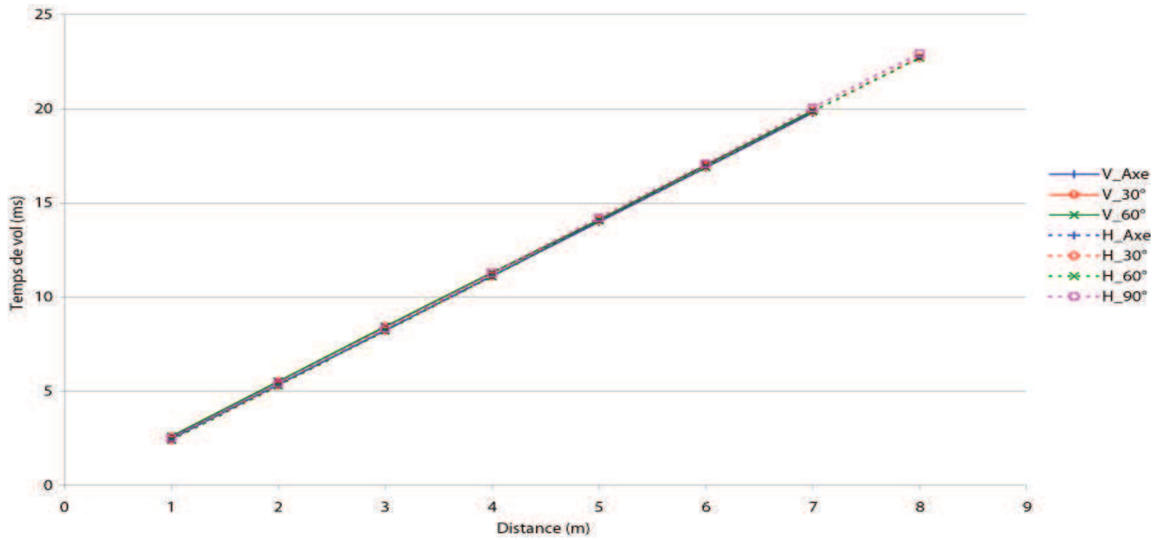


Fig. 13. Polarity impact on flight time measures.

5.3.3. Temperature Impact

For these tests we kept the same color convention for position. Fig. 14 describes the absolute error in function of distance for different positions at 12 °C (±2 °C). The error measured is computed without any temperature compensation. We notice that the behavior is the same as for 22 °C. The computed propagation speed is decreased from 344.8m/s to 336.9m/s. The maximal error is obtained for the 90° position. Although the absolute maximal error is increased to 30cm, the relative error stays below 5 %.

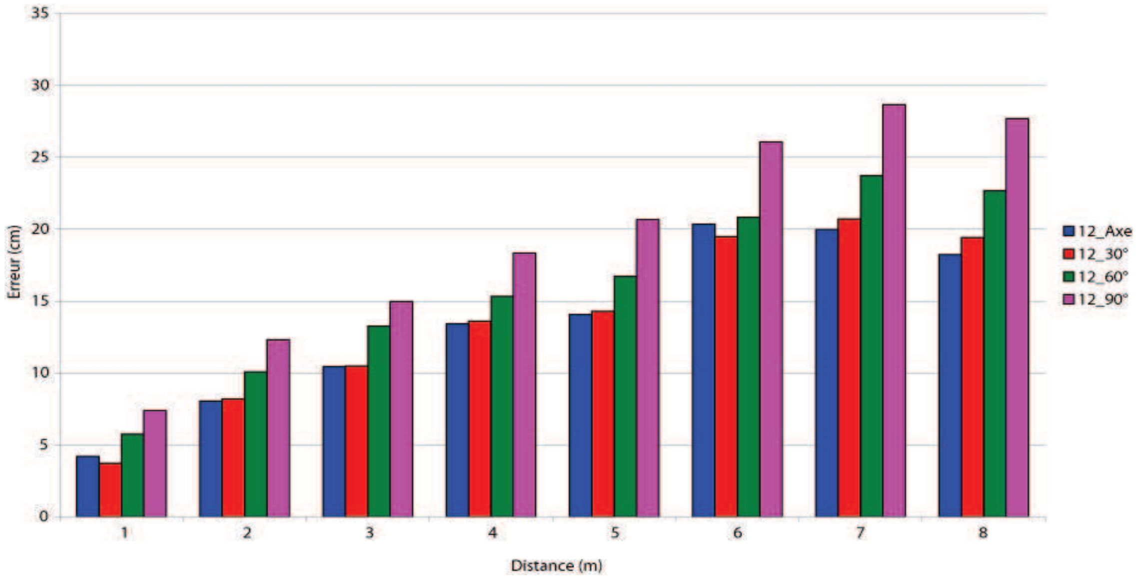


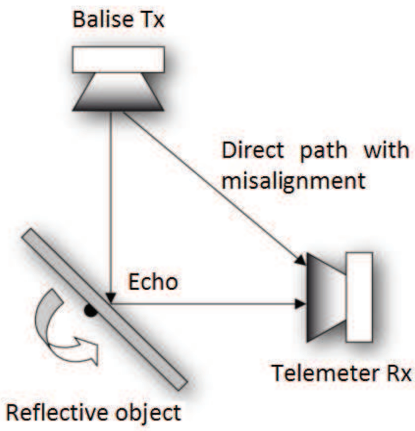
Fig. 14. Distance error function of time and position (12 °C).

5.3.4. Attenuation Impact

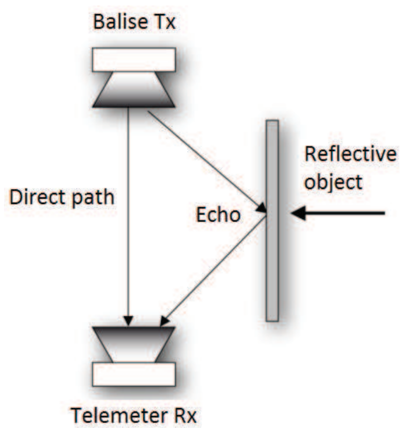
We covered the mobile device with a piece of cotton cloth and we have measured the absolute error in function of distance and position. The attenuation due to the cloth increases the absolute error and has an important impact on the error when the position is at 90° from the direct view. However, the results are clearly satisfying since the maximal absolute error without any compensation of temperature or attenuation stays below 35 cm and the relative error stays below 8 %.

5.3.5. Multi-path Impact

Fig. 15 shows the two test scenarios performed to evaluate multipath effects. The first scenario in configuration (a) evaluates the case where the power of the echo is superior to the power of the direct path while the scenario presented in configuration (b) evaluates the impact of a reflective object in parallel at the direct path for different distance (Pdirect > Pecho).



(a)



(b)

Fig. 15. Test configurations for evaluating multipath effects.

For these scenarios several distances between the reflective elements and devices have been tested but none of them showed an impact on the computed distance. In the case (a) the direct path is always reported.

5.3.6. Obstacles and Acoustic Environment Impact

We tried to evaluate the impact of different objects being in the direct path. Several obstacles materials and sizes have been tested (cork, wood, carton, persons). The results have not allowed us to model precisely the behavior in function of the size or the material but we noticed that for a constant distance position and temperature when the obstacles size increases the flight time increases. The error is superior but the relative error due obstacles is negligible (<1 %).

The last tests evaluate the impact of a noisy environment on the measurements. In targeted applications (health) the main noise source is voice that's why we have focused our tests on FM radio noise source, white noise and pink noise (-3dB/octave). The tests have been processed in the same lab room with an ambient audio noise measured of 38dBSPL (Sound Pressure Level). The noise source was placed at 20 cm behind the transmitter (worst case) and the noise measures were taken at 20 cm perpendicularly to the direct path. The noise source was a speaker whose indicated bandwidth was 50-25000 Hz. Four noise levels have been tested 68, 78, 88 and 100dBSPL for the 3 noise sources. Until 88dBSPL, no change in measured flight time has been noticed. But for 100dBSPL the device started to indicate incoherent measurements.

6. System Performance Comparison

The Cricket system from the MIT laboratory [17] is a compact embedded system for indoor localization. It is constituted of ultrasonic piezoelectric transducers (40 kHz) and a 433 MHz Radio frequency transceiver. The distance computation is based on the round-trip flight time. An ultrasonic wave is generated by a transducer and is received by the other on the same board. Then, the distance is transmitted via the RF transceiver. This system has been chosen as the reference level for performance evaluation.

Another difference between the system developed in our work and the Cricket is that we use omnidirectional transducers whereas the Cricket only has a 40° opening. Even if the cricket datasheet announced a 40° opening all the position tested above 30° have been unreliable and the measurements only have been done in the direct path. Moreover the system has been designed for short range measurements (anti-collision robotic application). Due to the round trip of the ultrasonic wave, the attenuation is important and the maximum range measured is about 7 m. Fig. 16 indicates the relative error in function of distance for our telemeter localization system and the Cricket system.

The two extreme cases are presented: the best case is obtained at 22 °C in direct path (dashed) and the worst case at 12 °C plus attenuation without any compensation in 90° position. The Cricket system stays under 10 % of relative error from 30 cm to 3 m. In this range, the Cricket system is more precise than the worst case of our system however only the direct path was measurable for the Cricket system. Obviously, this comparison would need to be complemented and more compared for example in energy efficiency.

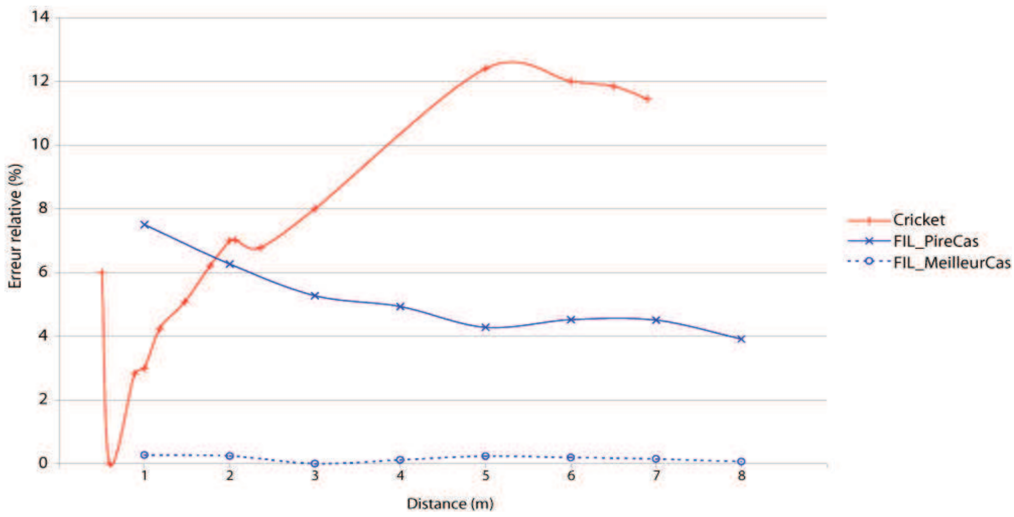


Fig. 16. Relative error of systems comparison.

7. Conclusion

This paper proposed an original telemeter system allowing localization for pedestrian in indoor environment. The system uses the 802.15.4 RF signal to start the time of an ultrasonic emission. The measure is computed from the flight time of the ultrasonic signal between the telemeter worn by the user and a beacon fixed in the environment. Characterization of ultrasonic performances shows good reliability, linearity and multipath immunity. This system have also been tested and compared with the MIT Cricket system and have demonstrated several advantages such as:

- Good accuracy (better from 5 % to 10 % in the worst case and over 3m).
- Good opening angle (90° from the direct path).
- Good maximal range (up to 10 m).
- Energy efficiency: The 802.15.4 low power modes enable up to two weeks with standard alkaline batteries (for a measurement every second).

Now, the system has been integrated and is currently being deployed in real buildings. The system is worn at the waist by persons moving into a complex indoor environment. Several recommendations emerged from these preliminary tests:

- Position errors can occur when more than two devices communicate together. A laboratory study was conducted to quantify the Packet Error Rate (PER) according to number devices. In future works, a synchronization protocol combined with an adapted medium access control algorithm could lower the PER when a high robustness is requested.
- The energy metrology has revealed the impact of Rx states: all receiving states wait an answer (ultrasonic or RF) for an undetermined time. Because the telemeter can be out of range of any other beacons or telemeter, a tradeoff must be made between the guard time and the periodic wake up time in order to maximize the autonomy of the system.

These recommendations will be introduce in the next system specification.

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