



A range estimation system using coded ultrasound



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ARTICLE INFO

Article history:

Received 17 September 2015

Received in revised form 3 December 2015

Accepted 4 December 2015

Available online 11 December 2015

Keywords:

Ultrasound ranging

Coded ultrasound

Wireless range sensor

Correlation technique

ABSTRACT

Touchless human–computer interfaces, augmented reality, and mixed reality, need the location of user's limbs or direction of sight in real time, which can be provided by accurate Real Time Locating Systems (RTLS). RTLS can be realized using wireless accurate positioning sensors and multilateration techniques that compute the location of sensors from distance estimates between them and a set of reference points. The main practical difficulty relies in estimating, within the required accuracy, the distances between the reference points and the remote sensors. In addition, the majority of modern applications require miniaturized sensors with both severe size and power supply constraints, and thus limited computational power. In this work, a distance estimation technique using coded ultrasound and a miniaturized sensor is proposed. A prototype of the distance estimation system has been realized and characterized. It is composed of a beacon that emits a coded ultra-acoustic signal, a central processing unit (CPU), and a wireless distance sensor. The main advantages of the proposed system are the high miniaturization and low power of the remote sensor.

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1. Introduction

Emerging technologies such as augmented reality, mixed reality, touchless interfaces, and domotics, necessitate accurate Real Time Locating Systems (RTLS). Among touchless interfaces, gestural interfaces are the most natural way to interact with machines, thanks to the ability to recognize and interpret movements of the human body. In the future, these interfaces will become more ubiquitous, due to their enormous impact in fields such as social life, work, health and entertainment. Touch-screens, accelerometer-equipped game pads, and smartphones available today are only a taste of this future. A gestural interface can be conveniently built using an RTLS equipped with a number of low-cost 3D wireless location sensors or tags. In addition, augmented reality requires knowing the direction of sight and the position of the user's head in respect to the observed scene for an accurate superimposition of synthetic information onto the real world. Glasses equipped with miniaturized position sensors can provide the required position and orientation information.

An accurate locating system with the capability of absolute object location with sufficient space and time resolution is a technology that has the potential of enabling a number of

new applications in several fields of human life. Applications of man-machine gestural interfaces, interacting with virtual and augmented reality include domotics, controlling home appliances with human presence and movement; medical rehabilitation, monitoring body and limb location, posture and gesture; robotics, identifying objects and controlling flexible arms; security, controlling access, identifying persons, and monitoring assets. Further applications include safety, logistics, sport and military training, and gaming consoles.

Positioning techniques require carrying out distance measurements between reference points and a remote sensor. In the case of a simple 3D trilateration in a semi-space, at least three distance measurements are required to localize a remote sensor.

Current technologies on the market or in literature are not capable of providing ranging with sufficient time/space accuracy for implementing the described touchless interfaces or location-based applications at affordable cost.

Ultrasonic waves are commonly used to measure the distance between an emitter and a receiver. Ultrasonic distance measurement techniques include the time of flight (TOF) method, the single frequency continuous wave phase-shift analysis method, the combination of the TOF and phase-shift method, the multi-frequency continuous wave and phase-shift method, the multi-frequency amplitude-modulation (AM) method, the binary frequency shift-keyed (BFSK) method, several methods based on digital signal

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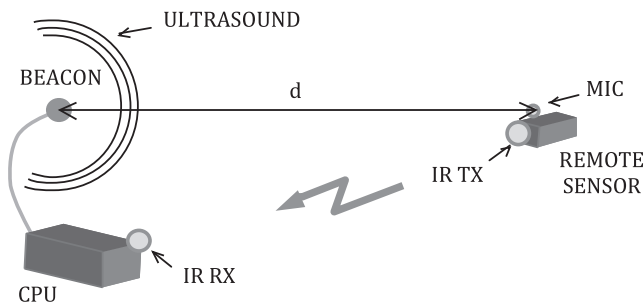


Fig. 1. System Architecture: the beacon emits ultrasound chirps and the impinged remote sensor sends back IR signals to the radio base CPU, where a cross-correlation based algorithm estimates the range d of the sensor.

processing, e.g., cross-correlation methods, and many others [1–18].

A major drawback of many ranging acoustic systems is their power hunger, and their wireless sensors have large batteries and weight as well as time-limited operating life. The above described innovative applications lead to severe constraints on sensor size and power supply that heavily limit the computational power available onboard, which, inversely, is required to apply the most accurate techniques such as the correlation-based ones.

In this work, a distance estimation technique based on coded ultrasound signals intended for implementing ranging systems with miniaturized sensors, is presented in detail in Section 3. Successively, a prototype of a system using the proposed distance estimation technique is described in Section 4. The experimental setup and some experimental results are presented in Section 5. The prototype is capable of estimating the range of a remote sensor with an accuracy of few millimeters within some meters, as required by most of the indoor applications.

2. Motivation

The methods [1–18] require synchronizing transmitter and receiver with an accuracy of few microseconds, a task that is very difficult to achieve when considering a wireless connection. However, with the aim of realizing a low cost system with minimal computational and power requirements, it would be desirable to employ a basic technique based on simple digital filtering and envelope detection.

An example of such a low cost method is found in [19]. The system is composed of a central unit and several remote sensors.

The ranging is carried out emitting a short ultrasound pulse at a starting time and listening to the ultrasound pulse onboard the remote sensor. The incoming ultrasound signal is suitably transduced, conditioned, time sampled and digitally converted by the sensor circuitry. The sensor microprocessor continuously computes the incoming signal envelope. The maximum of the received pulse envelope at the microphone location is found and a proper timing signal is sent to the ranging system central unit in order to measure the time of flight. The expected ranging accuracy is roughly comparable to the pulse central wavelength.

Although on the market there are several microprocessors capable to carry out the computations required by the envelope-based technique within the given time constraints, they in turn require a power supply of several tens of milliwatts during operation, which is not compatible with a miniaturized battery. Massive processing and higher power levels are required by cross-correlation techniques. As a consequence, miniaturizing wireless range sensors results impossible even using the simplest techniques, and *a fortiori* employing more sophisticated techniques.

As a further obstacle, the envelope technique that could be potentially employed in conjunction with small ranging sensors, presents major issues on the range accuracy. In fact, ranging operations closely depend on the bandwidth and on the shape of the used ultrasound pulses. The wider is the bandwidth and the shorter is the ultrasound pulse, the better is the measurement accuracy. From this point of view, a desirable bandwidth should start from 20 to 25 kHz up to 200–300 kHz (e.g., $\lambda = 17.1$ –1.1 mm in the range 20–300 kHz with speed of sound in air 343 m/s). However, the strong air adsorption and the unavailability of cost effective transducers for airborne ultrasound beyond 60–70 kHz limit the maximum ultrasound frequency below 60 kHz.

As a further issue, the detection of the time-of-arrival of a simple ultrasound pulse becomes very difficult or even impossible in presence of strong environmental acoustical noise. Moreover, multipath distortion, i.e., reflections on obstacles and successive additive/destructive interferences between multiple delayed copies of the same travelling wave, could distort the shape of the received pulses. In this scenario, techniques based on simple threshold detection, or even identification of the signal envelope maximum, could dramatically fail, showing relevant ranging errors up to several wavelengths λ (e.g., $\lambda = 6.9$ mm at 50 kHz and speed of sound in air 343 m/s).

The wireless return channel also adds timing uncertainty. Assuming the speed of sound in air about 343 m/s, and aiming to a ranging uncertainty of few millimeters, the time uncertainty must be kept below a few microseconds. Commercial RF transmit-

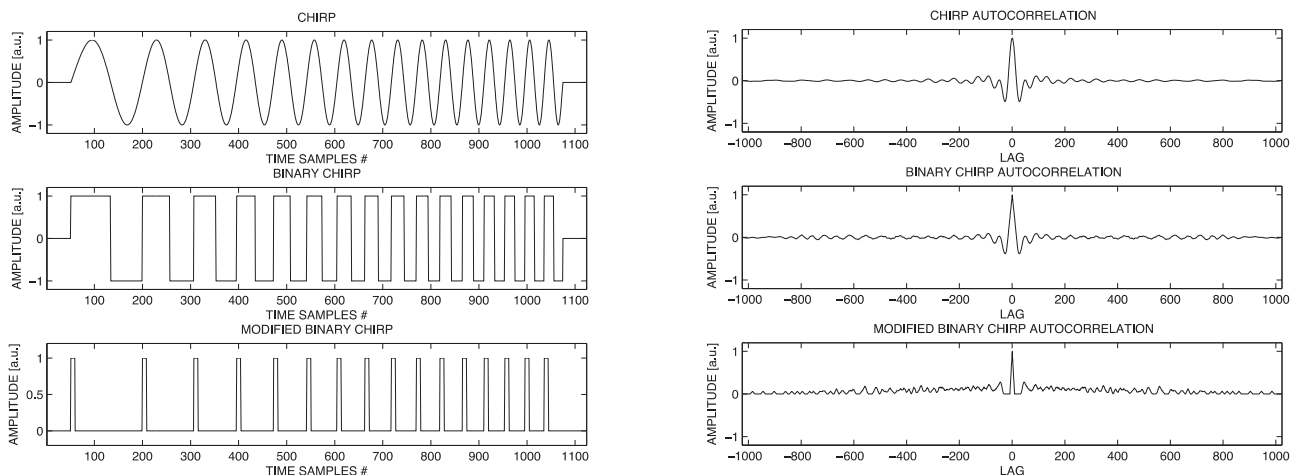


Fig. 2. Examples of short chirp, binary chirp, modified binary chirp (left), and their autocorrelations (right).

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