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A surrounding world knowledge acquiring by using a low-cost ultrasound sensors

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Abstract

This article describes a bio-inspired method of identify the type of obstacles which could appear e.g. on the MAV's (Micro Air Vehicles) way. The method is based on measurements made by a low-cost ultrasonic sensor. This kind of sensors are widely used for a distance measurement. The bio-inspired method used by ultrasound sensors uses echo of ultrasound signal to collect the knowledge about the surrounding world. Bats, which use ultrasonic waves to navigate in the dark, were our source of inspiration. In our research we are focusing on the off-the-shelf sensors because of their wide availability. We have shown that we can determine not only the distance but also we can get the basic information about the surrounding space by using the measurement obtained from a simple ultrasonic sensor. Three types of obstacles (smooth surface, rugged or uneven surface, a multifaceted space) and distant space beyond the reach of measurement have been distinguished. All prepared obstacles have been identified properly in our experimental research. Additionally the proposed method can better determine the distance from the nonsmooth surface. A classic method for measuring such obstacles, for which a standard deviation is calculated may not be sufficiently credible due to too large error. In such situation, our analysis allows the use of distance measurement with much more confidence. Our method has been developed in order to support MAV navigation system based on distance measurements made by ultrasonic sensor.

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Keywords: ultrasound sensor, distance measurements, obstacle avoidance system, quadrotors, micro air vehicle, MAV

1. Ultrasound distance measurement

Ultrasound sensors are widely used for a distance measurement. The bio-inspired method used by ultrasound sensors uses echo of ultrasound signal to collect the knowledge about surrounding world. The unrivaled examples of animals which utilize echo location method are dolphins and bats. Dolphins use the underwater ultrasound waves for navigation and communications while bats use ultrasound waves propagating in the air for navigation and ranging during their flight through a completely dark caves. Especially bats are interesting in our research because our quadrotors [1,2] reach similar to bats flight speed - 1 to 6 m/s [3] and also we try to develop autonomous indoor navigation system.

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Although the ultrasound signals utilized by bats differ from our signals, the algorithm of collecting the knowledge about surrounding world is similar. Most bat species utilize the wide-band chirp signal[4,5,6]. The bat emits a broad directional beam of multi FM modulated signals. Next it analyses the echo signals received back through (using) its ears. There are many echoes signals with different time delay and different frequency structure of the received signal. Analysis of echo delivers the information about distance to obstacle but also the information about wide of this obstacle and about surface. Using two ears bat can also recognize the direction of the echo. In our algorithm we try to utilize many consecutive narrow-band ultrasound signals generated by a Commercial Off-The-Shelf (COTS) sensors. Such approach is usefully/functionally similar to multi FM modulated signal. the rest of the algorithm is similar - captured echo signals are analyzed to find the distance and some characteristics of the reflecting surface.

Popularity of ultrasound sensors comes from rather simple mathematical model behind the ultrasound waves nature. The wave propagates with the speed c from the ultrasound transducer toward a reflecting surface and return back to transducer. Therefore it is enough to measure ToF (Time of Flight) - t_{of} - and using simple formula $d = ct_{of}/2$ the distance from reflecting object can be found.

There exist many SOANR (SOund NAvigation and Ranging) methods utilizing different ultrasound waves. Among them pulse-echo techniques[7,8] are widely-known, because of their simplicity. More complex methods involving the modulation of either amplitude or frequency of ultrasound waves also exist[9,10]. Many of these sophisticated methods exist only in laboratories.

COTS robotic ultrasound sensors usually utilize piezoelectric transducers and embedded microprocessor, which usually convert ToF measurements to a PWM (Pulse Width Modulation) signal. Master processor orders the start of the measure, than embedded microprocessor generates short ultrasound burst signal at constant frequency about 40 kHz and in parallel it starts the a PWM pulse (i.e. changes the output pin to "one"). After detecting the echo signal embedded processor finishes the the PWM pulse (sets "zero" on the output pin). Besides the simplicity of this method there is a problem with decision which one echo should be picked up. Received echo can be very complex signal to analyze. In fact, it can contain many echoes with different amplitude, shifted in frequency and/or shifted in time. Moreover the way of determine of the ToF of the echo signal remains usually unpublished. Thus it is sometimes hard to discover the real source of the errors in distance measurements.

Also several acoustic conditions can affect the ToF measurement. First of all the speed of sound c in the air highly depends on temperature of the air. The $c(T)$ can approximated by the following equation[11]:

$$c(T) = 331.3 + 0.606 * T \tag{1}$$

where $c(T)$ is a sound speed in the air in m/s and T is temperature measured in °C. Second aspect is the variation of attenuation of sound as a function of both frequency and humidity. Albeit attenuation usually affects maximum target distance, but in some cases it can causes a refraction which changes the way through the waves propagate. Thus the third factor affecting ToF measurements is a multi-path propagation of the sound. In some cases indirect reflection can be treated as a direct echo signal thus sensor returns wrong range information. All of these problems have their reflectivity in accuracy and resolution of measurements.

Our researches are focused not only on the distance measurements but also on the knowledge acquiring. We are working on possibility of determining type of obstacle which is placed in front of the sensor. Some work has been done in this area but usual configuration utilizes many sensors placed around robot body[12,13,14]. In out research we try to pick up as many information as possible from only one ultrasound sensor.

2. Radiation pattern of an ultrasonic sensors

The radiation pattern or beam pattern is sensitivity of transducer as a function of spatial angle. The beam pattern depends on the size and shape of piezoelectric surface which vibrates with ultrasonic frequency. Low-cost sensors utilize circular radiation surface with the diameter equals 2Λ, where Λ is a wavelength of a 40 kHz wave. In this case the main beam angle equals approximately $BW = 30°$ what is relatively a wide beam. The beam pattern can be seen as a cone in the space in front of sensor, where the top of the cone is the sensor and the bottom of the cone is placed on the reflecting surface and forms the circle on it, with the diameter d depending on the distance l. For a given beam pattern and a given distance the diameter can be found by:

$$d = 2l \tan \alpha \tag{2}$$