Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 87 (2016) 24 – 28

Physics Procedia

44th Annual Symposium of the Ultrasonic Industry Association, UIA 44th Symposium, 20-22 April 2015, Washington, DC, USA and of the 45th Annual Symposium of the Ultrasonic Industry Association, UIA 45th Symposium, 4-6 April 2016, Seattle, WA, USA

Directional receiver for biomimetic sonar system

Francesco Guarato[a,]*, Heather Andrews[a], James F. Windmill[a], Joseph Jackson[a], Anthony Gachagan[a]

[a]*Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow G1 1XW, UK*

Abstract

An ultrasonic localization method for a sonar system equipped with an emitter and two directional receivers and inspired by bat echolocation uses knowledge of the beam pattern of the receivers to estimate target orientation. *Rousettus leschenaultii*'s left ear constitutes the model for the design of the optimal receiver for this sonar system and 3D printing was used to fabricate receiver structures comprising of two truncated cones with an elliptical external perimeter and a parabolic flare rate in the upper part. Measurements show one receiver has a predominant lobe in the same region and with similar attenuation values as the bat ear model. The final sonar system is to be mounted on vehicular and aerial robots which require remote control for motion and sensors for estimation of each robot's location.

Peer-review under responsibility of the Ultrasonic Industry Association.

Keywords: receiver design; beam pattern; robot navigation; acoustic measurement.

1. Introduction

Vehicular and aerial robots can transport ultrasonic sensors for NDE, Friedrich et al. (2006). They are a cheap solution and useful when exploring dangerous or non-accessible areas. A sonar system to support them with autonomous navigation was developed by Guarato et al. (2012), Guarato et al. (2013). Such a sonar system is able to reproduce bat echolocation, and is equipped with an emitter and two receivers resembling the mutual displacement

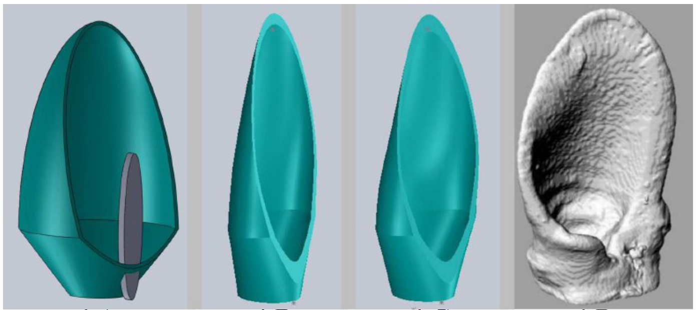
* Corresponding author. Tel.: +44 (0)141 444 7409.
E-mail address: francesco.guarato@strath.ac.uk

Peer-review under responsibility of the Ultrasonic Industry Association.
doi:10.1016/j.phpro.2016.12.005

of mouth and ears, respectively, on a bat head. The localization method implemented on it uses the directional properties of the two receivers to estimate the orientation of a target. As the beam pattern of bats plays a crucial role in echolocation, Lawrence et al. (1982), thus the design of receiver shape in the sonar system is inspired in this paper by a bats' external ear. In particular, in this paper the external ear of a *Rousettus leschenaultii* is considered and some receiver shapes are derived from it. In the receivers' design, parameters such as perimeter, tragus and outward bending of edges are considered and evaluated as important factors in the beam pattern corresponding to the final receiver. Inspiration from bat sonar has led to other sonar systems such as those presented by Reijniers et al. (2007) and Kuc (2012).

2. Bat-inspired receivers

The beam pattern of several receiver structures inspired by *R. leschenaultii*'s left ear was measured. The design of these receivers is modelled on the basic receiver shape by varying the following parameters: perimeter (circular or elliptical), presence or absence of tragus (flat structure in front of the upper opening) and outward bending of upper edges of the receiver. These parameters contribute to approximate the basic receiver shape to that of the *R. leschenaultii*'s left ear. These parameters were considered and their effect on the beam pattern was measured. Fig. 1.A shows the basic receiver. Fig. 1.B Template 1 was obtained from the basic receiver by using an elliptical perimeter and removing the tragus, while Fig. 1.C shows Template 2 where upper edges, in addition to the features of Template 1, were bent outward. These modifications to the basic receiver led to a receiver structure more similar to the *R. leschenaultii*'s left ear, depicted in Fig. 1.D.



1.A **1.B** **1.C** **1.D**

Fig. 1 (A) Basic receiver, (B) Template #1, (C) Template #2 and (D) *R. leschenaultii*'s ear.

3. Beam pattern evaluation

3.1. Measurements

Receiver structures such as those in Fig. 1.A-D were designed in SolidWorks and 3D printed. The beam patterns associated with these receivers were measured using the reciprocity principle, see Shaw (1988) and Fahy (2003). Namely, a 1ms long chirp from 20kHz to 32kHz (which the bat specie uses to echolocate) from an electrostatic transducer (Ultrasound Advice Loudspeaker http://www.ultrasoundadvice.co.uk/index.php/ultrasound/usls last viewed August 3, 2015) was conveyed to the base of each structure through a funnel as depicted in Fig. 2.A. The signal through the structure was recorded with a Brüel & Kjær 4138 microphone at several positions on the surface of a quarter of a sphere. Exact positioning of the tip of the microphone was automatically performed by a KUKA robot (KUKA robotics http://www.kuka-robotics.com/usa/en/ last viewed August 3, 2015), see Fig. 2.B. The sound emission from the transducer was triggered by the robot moving to the next position, monitored and controlled through a program written in LabVIEW. An average of 5 replications of the chirp returned a signal for each position on which a Fourier transform was calculated. For each orientation (θ,φ) and frequency f, the Fourier transform $M(\theta,\varphi,f)$ of measurement signals on the quarter of sphere were compared to a reference signal $R(f)$ (the chirp recorded in front of the transducer with no filtering of any structure to get rid of non-linearity effects due to the transducer itself). Thus the filtering D due to only the beam pattern associated with the structure was returned: