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Measured Beam Patterns of Biomimetic Receivers Improve Localisation Performance of an Ultrasonic Sonar

Biomimetic Receivers Improve Ultrasonic Sonar Localisation

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***Abstract*—The Beam Based Method (BBM) is a novel sonar system inspired by bat echolocation for a sonar system with one emitter and two receivers. Knowledge of the beam pattern of the receivers makes it possible to estimate the orientation of a reflecting target. In this paper, the beam pattern of four biomimetic receivers is included in the sonar system model to test which one makes the BBM localization method most accurate. Simulations are designed in MatLab and, along with the sonar system, they also model ultrasonic emission, reflection by a target and filtering through the receivers' beam pattern. All receivers are associated with similar error values in estimating target orientation. This sonar system will be built and mounted on robots for non-destructive evaluations.**

Keywords—beam pattern; biomimetic receiver; ultrasonic sonar; ultrasonic localisation

I. Introduction

Ultrasonic localization can be achieved using not only time of flight information from the echoes but also using spectral cues. Inspiration from bat echolocation is in this case crucial as it provides suggestions on how to process echoes from a target to estimate its position with respect to an ultrasonic sonar system. Work performed by Kuc [1] and Reijniers [2] is focused on biomimetic sonar so that acoustic features from bats are the inspiration for ultrasonic sonars in particular to determine the orientation of a target.

A novel localization method, called Beam Based Method (BBM), for a sonar system equipped with one emitter and two receivers was designed [3, 4]. In this method, target orientation is estimated from knowledge of the received signal and of the beam pattern associated with the receivers.

In this paper, the system in Fig. 1 with one emitter and two receivers implements the localization method described in [3, 4]. The system as well as the BBM are modelled in MatLab in order to test in simulations the accuracy of the BBM when some receivers are used.

II. Methodology

A. Localization

The Beam Based Method [3, 4] was developed by the author as a biomimetic sonar making use of bat inspired receivers to estimate target orientation. The sonar system where to implement the BBM is equipped with one omnidirectional emitter and two directional receivers whose mutual displacement resembles that on a bat head of mouth and ears, see Fig. 1. In the BBM a broadband ultrasonic chirp is emitted by an omnidirectional transmitter and the echo from a target is filtered through the sonar system's directional receivers. While time of flight is used to calculated the distance of the target, the orientation is estimated from knowledge of the received signal and of the beam pattern of the receivers.

In the BBM, the received echo from a target is processed in order to extract the attenuation at each frequency and, by comparison with the beam pattern of the receivers, an orientation is estimated as that of the reflecting target [3]. It is important to note that the BBM is strongly dependent on the beam pattern shape across frequencies and how directional and asymmetric it is [4]. These features indeed make it possible to perform a more efficient discrimination between orientations the echo could come from.

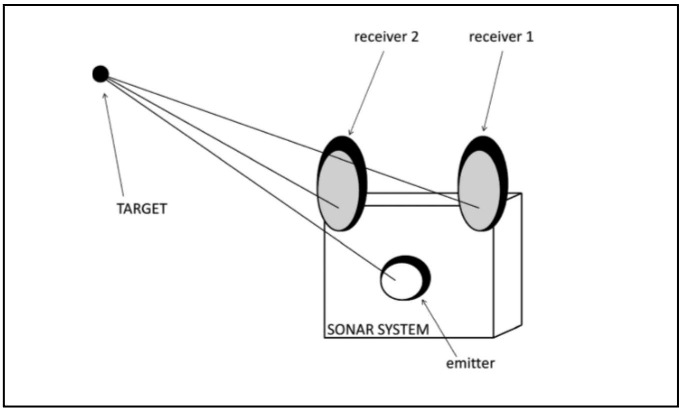

Fig. 1. Sonar system with one emitter and two directional receivers for the Beam-Based Method.

B. Beam pattern evaluation

The aim of this paper is to evaluate the accuracy of the Beam Based localization method using different beam patterns as those of the receivers of the sonar system. The measured beam patterns associated with geometrically regular receivers inspired by the ear of *Phyllostomus discolor* [5] were used. The *P. discolor* bat specie shows a directional beam pattern associated with its external ear structure [6]. This feature is particularly important in the BBM in order to discriminate effectively between orientations. For this reason, a set of beam patterns associated with receivers designed after the *P. discolor* ear were considered.

The BBM was implemented in Matlab software along with a code to model sound emission and absorption through air. The filtering of the sound through the receiver beam patterns was also implemented in Matlab to simulate the effect of receivers on the echoes from a target. The effect of the receivers is a spatial filter as beam patterns modulate the amplitude of sound depending on the direction of sound arrival; they also depend on frequency.

In this paper, a set of receivers was tested in order to provide the BBM with the best accuracy in estimating target orientation. Namely, the measured beam patterns of different receivers were alternatively used in the Matab model along with the BBM.

III. Receivers and Associated Beam Patterns

Four pairs of receivers were designed using a basic template whose dimensions and features were inspired by the bat ears of the real bat *P. discolor* specie. These receivers are designed as the combination of geometrically regular shapes: a cone in the lower part and a parabolic flare both having an ellipsoidal perimeter. In such a way, the basic structure of the bat ear is rendered. Fig. 2 and Fig. 3 show the receivers along with the left ear of the *P. discolor* bat.

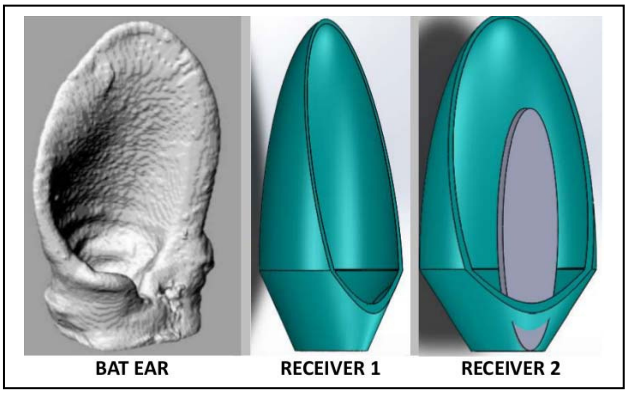

Fig. 2. Receivers 1 and 2 along with the left ear of the *P. discolor* bat.

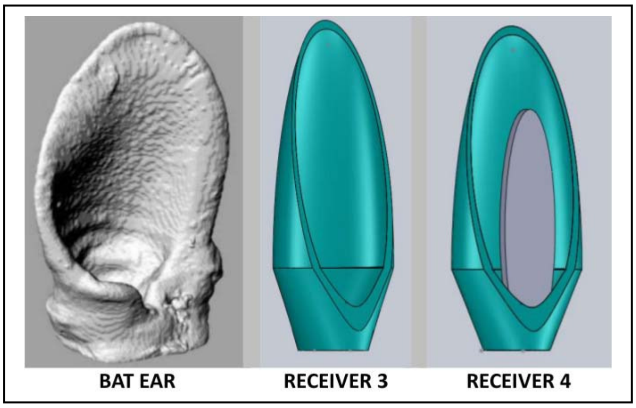

Fig. 3. Receivers 3 and 4 along with the left ear of the *P. discolor* bat.

In both Fig. 2 and Fig. 3 an additional structure is added as the tragus: the tragus is present in receivers 2 and 4. This feature is considered as it potentially diffracts the sound hence it has a significant impact on the beam pattern of the receiver [7].

The beam pattern of each designed receiver was known from previous measurements [5]. These are depicted in Fig. 4 and Fig. 5 and compared to the beam profile associated with the bat ear for three frequencies: 25kHz, 40kHz and 55kHz.

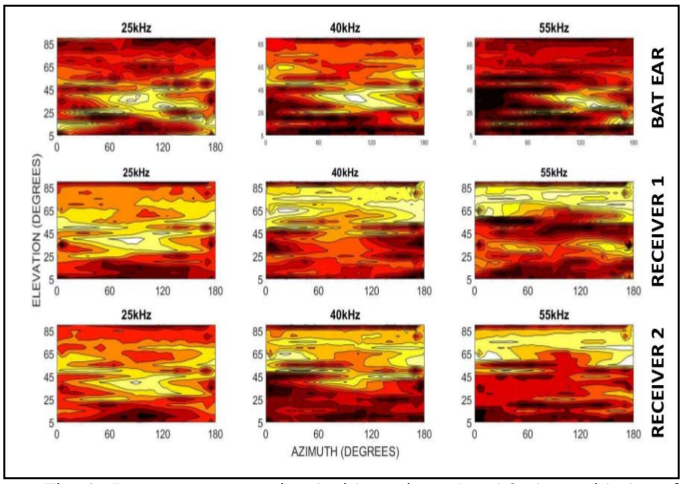

Fig. 4. Beam pattern associated with receivers 1 and 2 along with that of the *P. discolor*'s left ear.

In Fig. 4 both receivers 1 and 2 show a beam pattern that at 25kHz is close to that associated with the *P. discolor* ear. At higher frequencies, 40kHz and 55kHz, most of the acoustic energy is directed upwards rather than being concentrated in a central lobe.

In Fig. 5 both receiver 3 and 4 show a beam pattern with a main lobe at 25kHz and 40kHz like in the case of the bat ear and for the same orientations. At higher frequencies, like 55kHz, the acoustic energy for receivers 3 and 4 is still concentrated in a main lobe though it tends to spread along a wider area than in the case of the bat ear.

The beam patterns associated with receivers 1, 2, 3 and 4 were included in the model implementing the localization method described in Section II. The accuracy of the localization method was tested using each of the receivers.

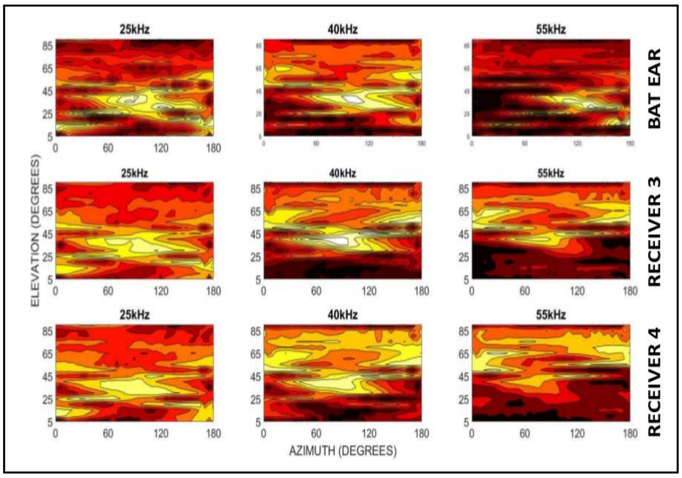

Fig. 5. Beam pattern associated with receivers 3 and 4 along with that of the *P. discolor*'s left ear.

IV. Simulations

A. *Simulation setup*

A model of the sonar system was implemented in MatLab and the measured beam patterns described in Section III were imported into it. The emitted signal is a 3ms long ultrasonic chirp spanning 20kHz to 70kHz; the signal reflection by a target and the reception are also implemented in MatLab. In particular, the filtering through the receivers' beam pattern is included in the MatLab model. The transmission of the acoustic signal took into account the attenuation due to distance as well as sound absorption due to humidity: these effects are due to the environment [8]. Further attenuation of sound is provoked by the receivers of the sonar system as they attenuate the sound differently depending on the direction of arrival. The modelling of the emission, transmission, reflection and reception of the ultrasonic chirp is depicted in Fig. 6.

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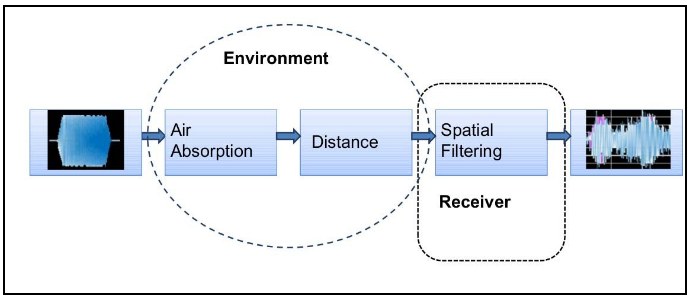

Fig. 6. Diagram showing the attenuation the emitted sound is subjected to. The chirp undergoes air absorption and distance; then spatial filtering is provided by the receivers of the sonar system.

16 orientations spanning [20°, 60°] in the azimuth range and [25°, 45°] in the elevation range and spaced 5° were chosen as being the orientation of the target. The orientation of the target was the real one. For each pair of receivers 1, 2, 3 and 4 chosen as those of the sonar system an estimate of target orientation was calculated.

B. *Results*

The angular error between the real and the estimated orientation of the target was chosen to describe the accuracy of the localization method. In particular, the dependence of the localization method on the beam pattern - and hence on the choice - of the receivers.

An average over the error values for all the 16 orientations was calculated for each beam pattern. These values are reported in Table 1. The comparison with the error values when the beam associated with *P. discolor*'s ear is chosen as that of the receivers is also shown. The performance of the BBM is evaluated for each pair of identical receivers 1, 2, 3 and 4 as the receivers in the sonar system. In Table 1 the error averaged values are calculated over all the 16 orientations so to give a general evaluation of the BBM when using one of the receiver pairs. In particular, the accuracy of the BBM using the beam pattern associated with the *P. discolor*'s ear is comparable with the accuracy using the beam pattern associated with receiver 4 while receivers 1, 2 and 3 give better estimates.

In Table 1, the beam pattern associated with receiver 1 provides the BBM with the most accurate estimates.

TABLE I. Average Error Values

Bat Ear	Receiver 1	Receiver 2	Receiver 3	Receiver 4
11°	6°	9°	9°	13°

In Table 2 the error values for some target orientations are shown. The orientations in Table 2 were chosen as they are associated with a variety of error values hence to illustrate error distribution. Target orientation is defined with respect to the right receiver of the sonar system: both the real and the estimated orientations are hence expressed with respect to the right receiver of the sonar system.

TABLE II. ERROR VALUES ASSOCIATED WITH RECEIVER 1

Real Target Orientation (azimuth, elevation)	**Estimated Target Orientation (azimuth, elevation)**	**Error**
(20°, 25°)	(20.5°, 25°)	0.5°
(30°, 25°)	(15.3°, 23°)	15°
(40°, 35°)	(40°, 35°)	0°
(50°, 35°)	(46.7°, 35°)	3.3°
(60°, 35°)	(58°, 35°)	2°
(35°, 35°)	(39°, 25°)	10.7°
(35°, 40°)	(39°, 40°)	1°

C. Discussion

Table 1 shows that the BBM estimates target orientation with similar error values when using each of the four receivers. In particular, they are all associated with error values very close to those associated with the bat ear. This can be explained as all the receiver shapes in Fig. 1 and in Fig. 2 are inspired by that very bat ear hence leading to similar results.

For this reason, the inspiration from bats' acoustical features leads to a novel localization method as well as it shows that bat-like beam patterns do guarantee accurate target orientation estimates. These results show that a biomimetic sonar system implementing the BBM is not only interesting but can actually work and be applied to real world scenarios.

V. CONCLUSIONS

The Beam Based Method is a biomimetic ultrasonic localization technique which depends on the beam pattern of two receivers. This paper simulated the BBM in estimating the orientation or a target when using different beam patterns that were measured in previous works. It is found that one of the receivers that is inspired by the *P. discolor* bat ear has the most accurate estimates of target orientation and will therefore be used in the next development of the sonar system.

The results in this paper show that the design of a biomimetic receiver has a strong impact on the accuracy of a beam based localization method. In addition, the receiver shape among a set of bat-inspired receivers, is tested in simulations to ensure the best estimates of target orientation.

Further developments will consist of testing the BBM in a real environment such as a laboratory and then in an outdoor scenario. The targets for these tests will have different shapes and materials. The sonar system will be assembled using broadband microphones on which 3D printed versions of receiver 1 will be mounted.

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REFERENCES

[1] Kuc, R., 2012. Echolocation with bat buzz emissions: Model and biomimetic sonar for elevation estimation. *The Journal of the Acoustical Society of America*, *131*(1), pp.561-568.

[2] Reijniers, J. and Peremans, H., 2007. Biomimetic sonar system performing spectrum-based localization. *IEEE Transactions on Robotics*, *23*(6), pp.1151-1159.

[3] Guarato, F., Windmill, J. and Gachagan, A., 2013. "A beam based method for target localization: inspiration from bats' directivity and binaural reception for ultrasonic sonar". *The Journal of the Acoustical Society of America*, *133*(6), pp.4077-4086.

[4] Guarato, F., Windmill, J., Gachagan, A. and Harvey, G., 2013. An investigation of acoustic beam patterns for the sonar localization problem using a beam based method. *The Journal of the Acoustical Society of America*, *133*(6), pp.4044-4053.

[5] Guarato, F., Andrews, H., Windmill, J.F., Jackson, J., Pierce, G. and Gachagan, A., 2015. "Features in geometric receiver shapes modelling bat-like directivity patterns", *Bioinspiration & biomimetics*, *10*(5), p.056007.

[6] Firzlaff, U. and Schuller, G., 2003. Spectral directionality of the external ear of the lesser spear-nosed bat, Phyllostomus discolor. *Hearing research*, *181*(1), pp.27-39.

[7] Müller, R., 2004. A numerical study of the role of the tragus in the big brown bat. *The Journal of the Acoustical Society of America*, *116*(6), pp.3701-3712.

[8] Bass, H.E., Sutherland, L.C., Zuckerwar, A.J., Blackstock, D.T. and Hester, D.M., 1995. Atmospheric absorption of sound: Further developments. *The Journal of the Acoustical Society of America*, *97*(1), pp.680-683.