Directional Receiver for Biomimetic Sonar System

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Outline

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- Introduction: NDE of hazardous environments using robots
- Sonar system supporting autonomous navigation
- Biomimetic receiver for sonar system inspired by bat ear
- Measurement of beam pattern of bat ear and biomimetic receiver

Inspection Problem

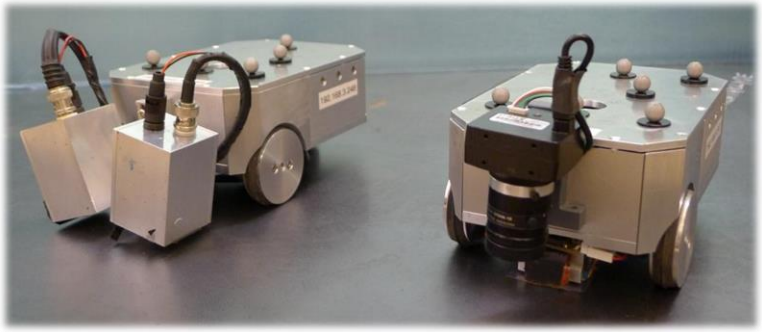
- Ageing infrastructure require periodic inspection, often in situ, to ensure continued safe and economic operation
- Oil, nuclear, gas, aerospace and power generation industries present difficult inspection scenarios



One solution is to use inspection robots

- Safety
- Cost
- Minimal disruption of inspection site
- Large area coverage

Inspection robots



Remote Sensing Agent

- 175×124×85 mm
- Onboard power
- Wireless communication
- Visual/ultrasonic/electromagnetic sensors for NDE

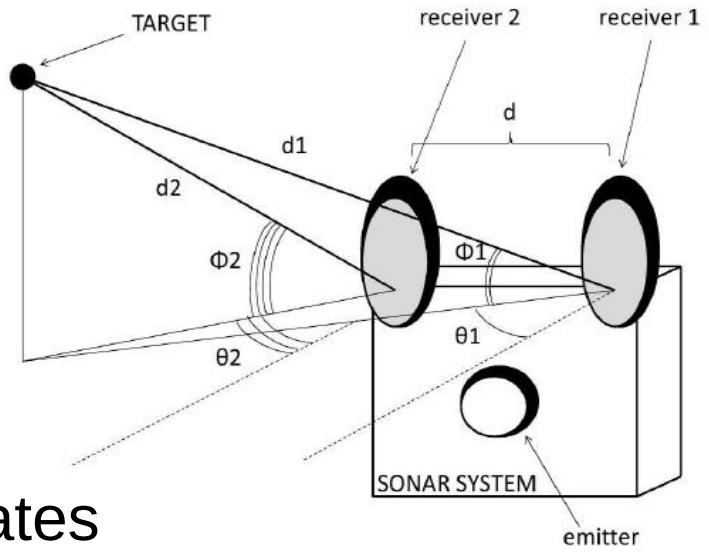
ASCTEC Farefly (UAV hexacopter)

- 605 x 665 x 165 mm
- Intel® Core™ i7 Processor
- Max. take off weight 1,6 kg
- Wireless communication and autopilot

Ultrasonic localization

Sonar system

- 1 emitter, 2 receivers
- Broadband signal generation
- Directional receivers



Target position in spherical coordinates

$$(\rho, \vartheta, \varphi)$$

- Distance from time of flight
- Orientation estimated from sound attenuation of reflected echoes that is compared to beam pattern of the receivers
- **Directional receivers** ensure a more accurate estimation

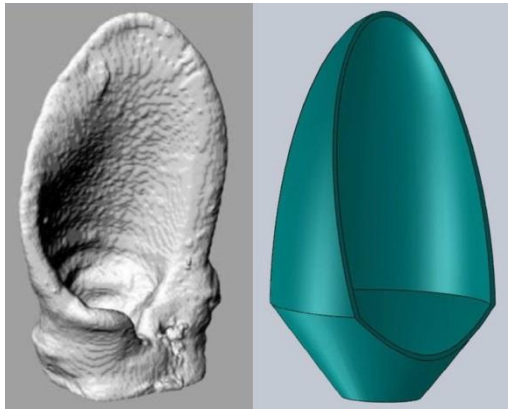
Sonar system components

- **Emitter** is an air-coupled electrostatic transducer
- **Receiver** is B&K microphone mounted onto with external structure

Directional beam pattern

- Main lobe extending on both azimuth and elevation
- Main lobe allows a more accurate discrimination between the direction of the echoes

Rousettus leschenaultii



Bat-inspired receivers

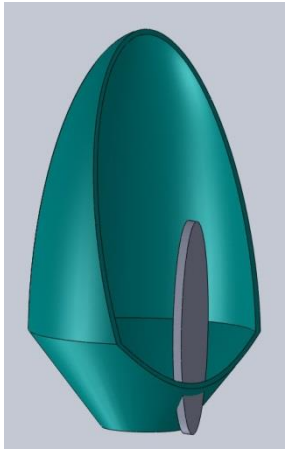
An ideal version of *Rousettus leschenaultii*'s left ear is designed as the **Basic Receiver** using:

- Lower cone with linear flare
- Upper cone with parabolic flare
- Tragus

Dimensions (extreme points)

	Bat Ear	Basic Template
height (mm)	20	22
width (mm)	19	15
depth (mm)	10	15

Bat ear



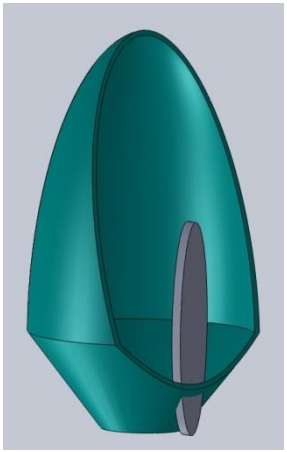
Basic receiver

Bat-inspired receivers

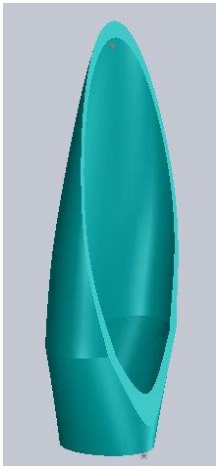
Receiver #1 and #2 are constructed by modifying the following parameters of the basic receiver

- Perimeter
- Tragus
- Outward bending of the upper edges

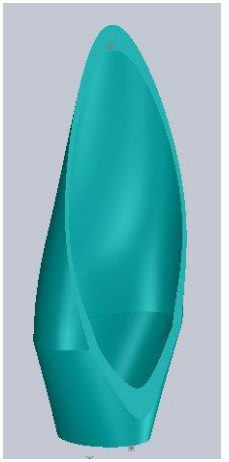
Bat ear



Basic receiver



Receiver #1



Receiver #2

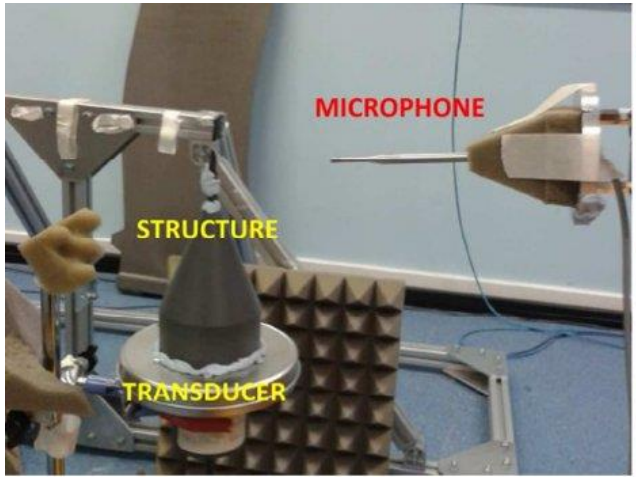
Measured beam pattern

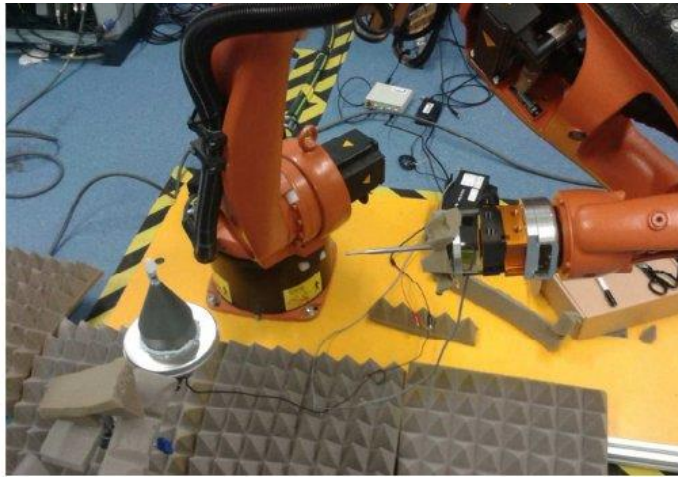
Experimental setting

- KUKA robot arm and B&K 4138 microphone
- LabVIEW program
- Reference signal recorded straight ahead of transducer
- Measurements at points where microphone is placed at with robot arm

Air-coupled transducer

- 5cm diameter
- 18 to 300kHz
- >80dB SPL @25cm





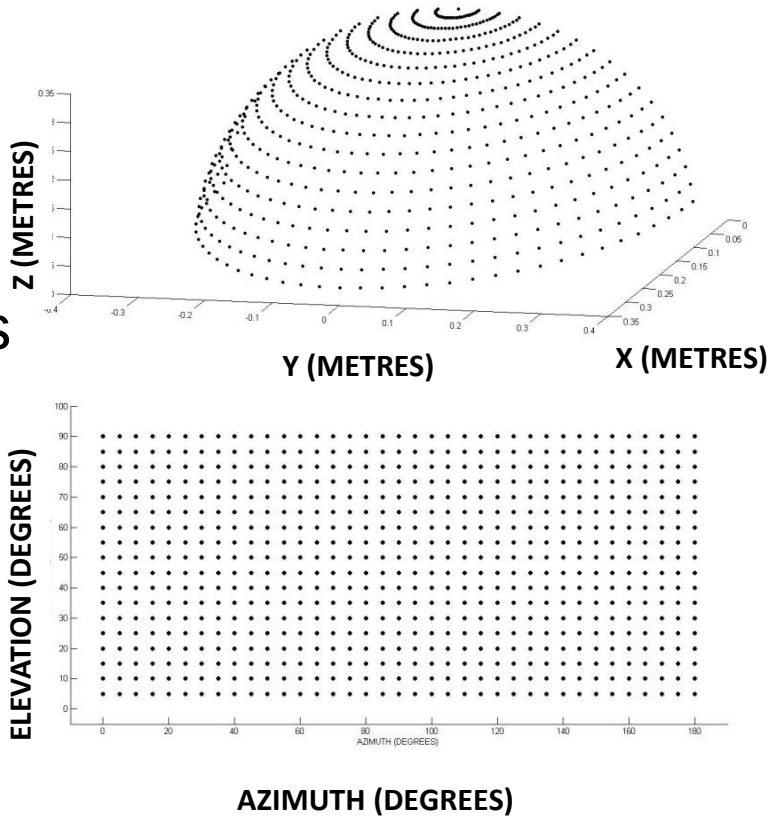
Measured beam pattern

Sound attenuation in frequency domain

- Reciprocity principle
- 3ms chirp, linear sweep rate
- Average over 5 chirps for each position
- Fourier transform of measurements and of reference signal

$$D(\vartheta, \varphi, f) = \frac{|M(\vartheta, \varphi, f)|}{|R(f)|}$$

Quarter sphere scanning arrangement and plane transformation

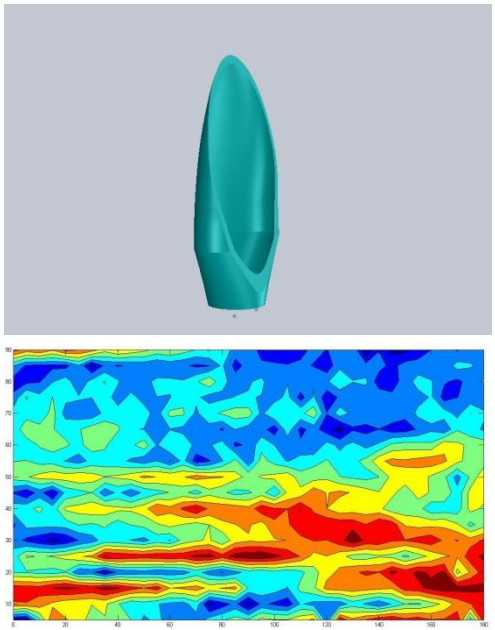


Measured beam pattern @ 20kHz

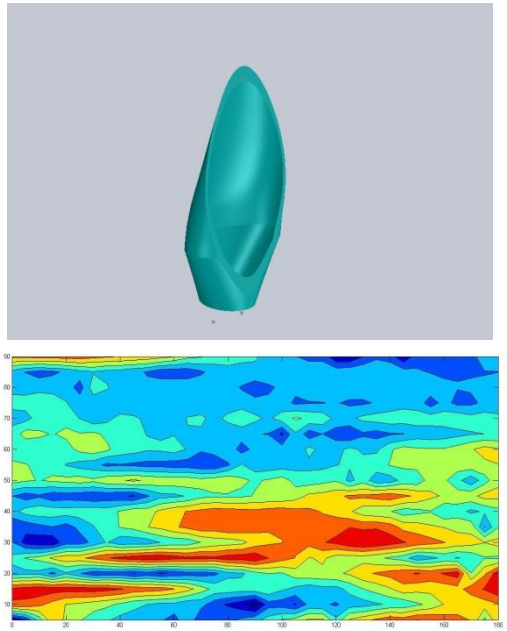
Beam pattern of two receiver structures compared to bat ear

- Main lobe domain for Template #2: azimuth 40° to 165°, elevation 20° to 50°
- Beam attenuation values from 0dB down to -8dB

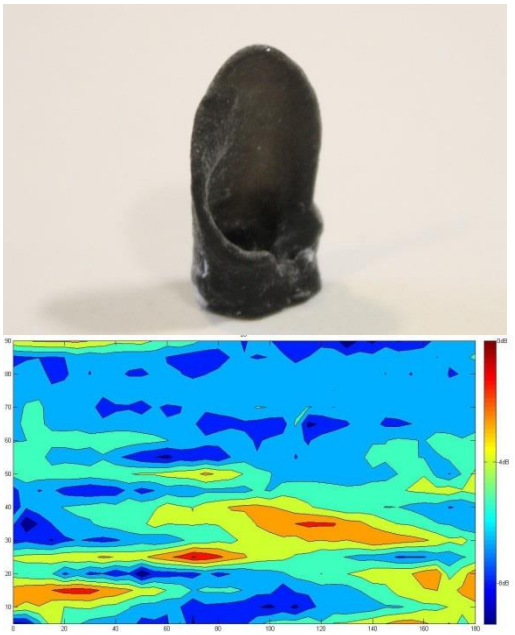
Template #1



Template #2



R. leschenaultii's ear



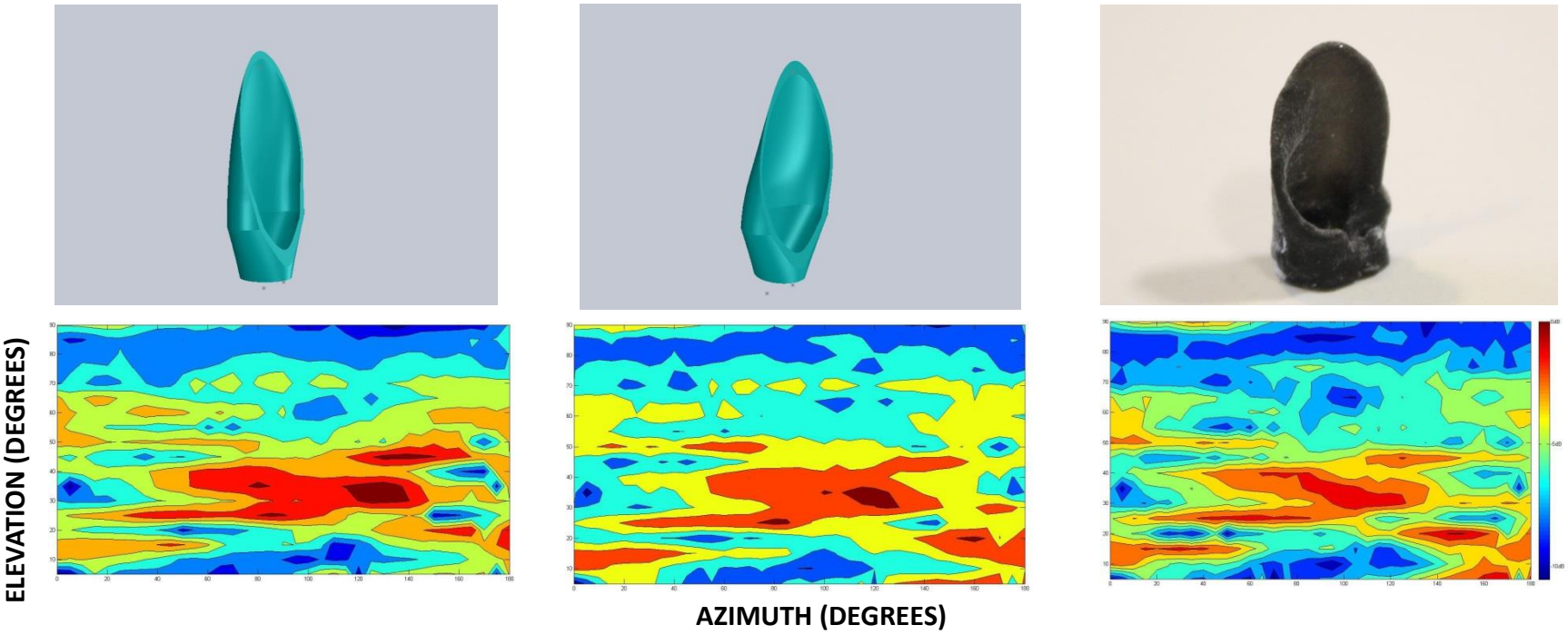
AZIMUTH (DEGREES)

Measured beam pattern @ 24kHz

Beam pattern of two receiver structures compared to bat ear

- Main lobe domain for Template #2: azimuth 40° to 160°, elevation 20° to 55°
- Beam attenuation values from 0dB down to -10dB

Template #1 | **Template #2** | ***R. leschenaultii*'s ear**

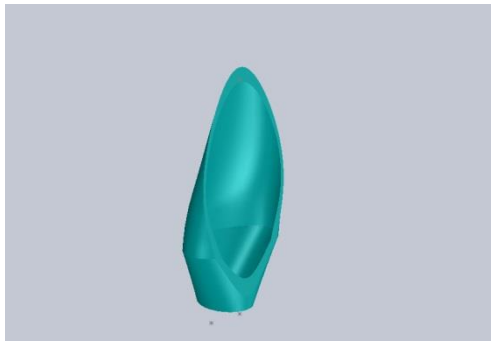


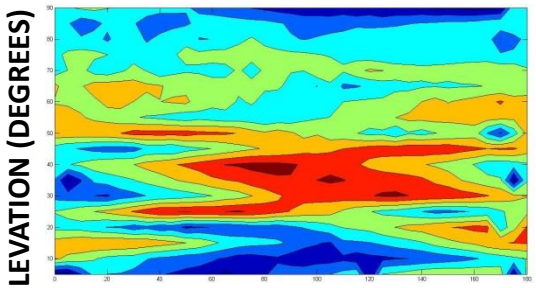
Measured beam pattern @ 28kHz

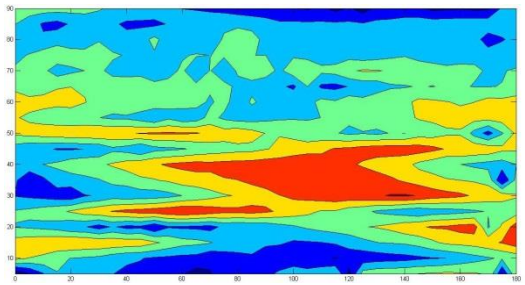
Beam pattern of two receiver structures compared to bat ear

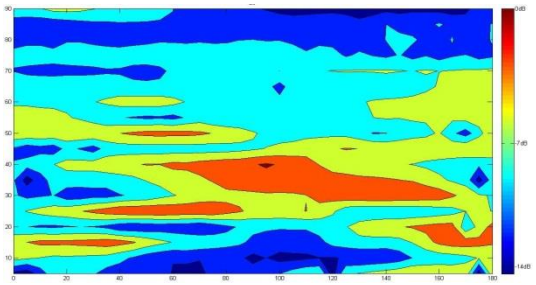
- Main lobe domain for Template #2: azimuth 40° to 150°, elevation 20° to 50°
- Beam attenuation values from 0dB down to -14dB

Template #1 | **Template #2** | ***R. leschenaultii*'s ear**









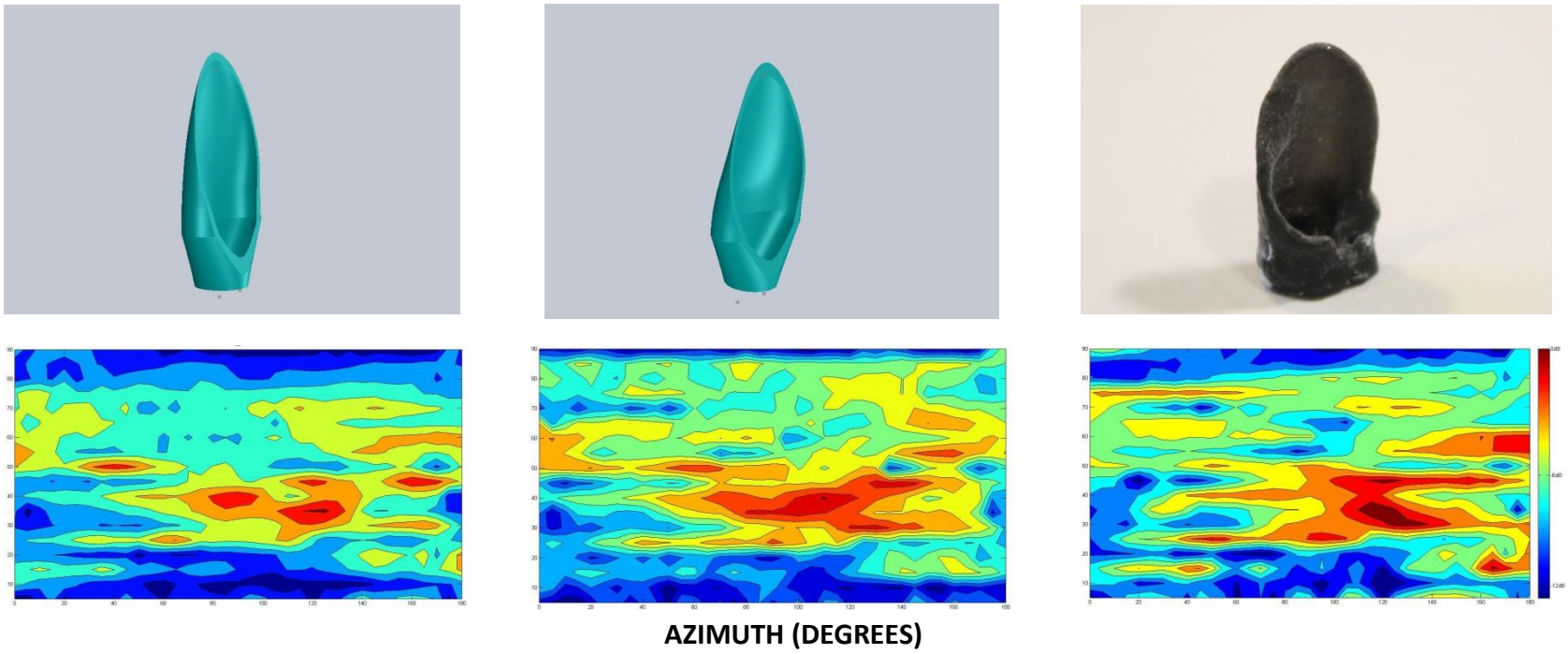
AZIMUTH (DEGREES)

Measured beam pattern @ 32kHz

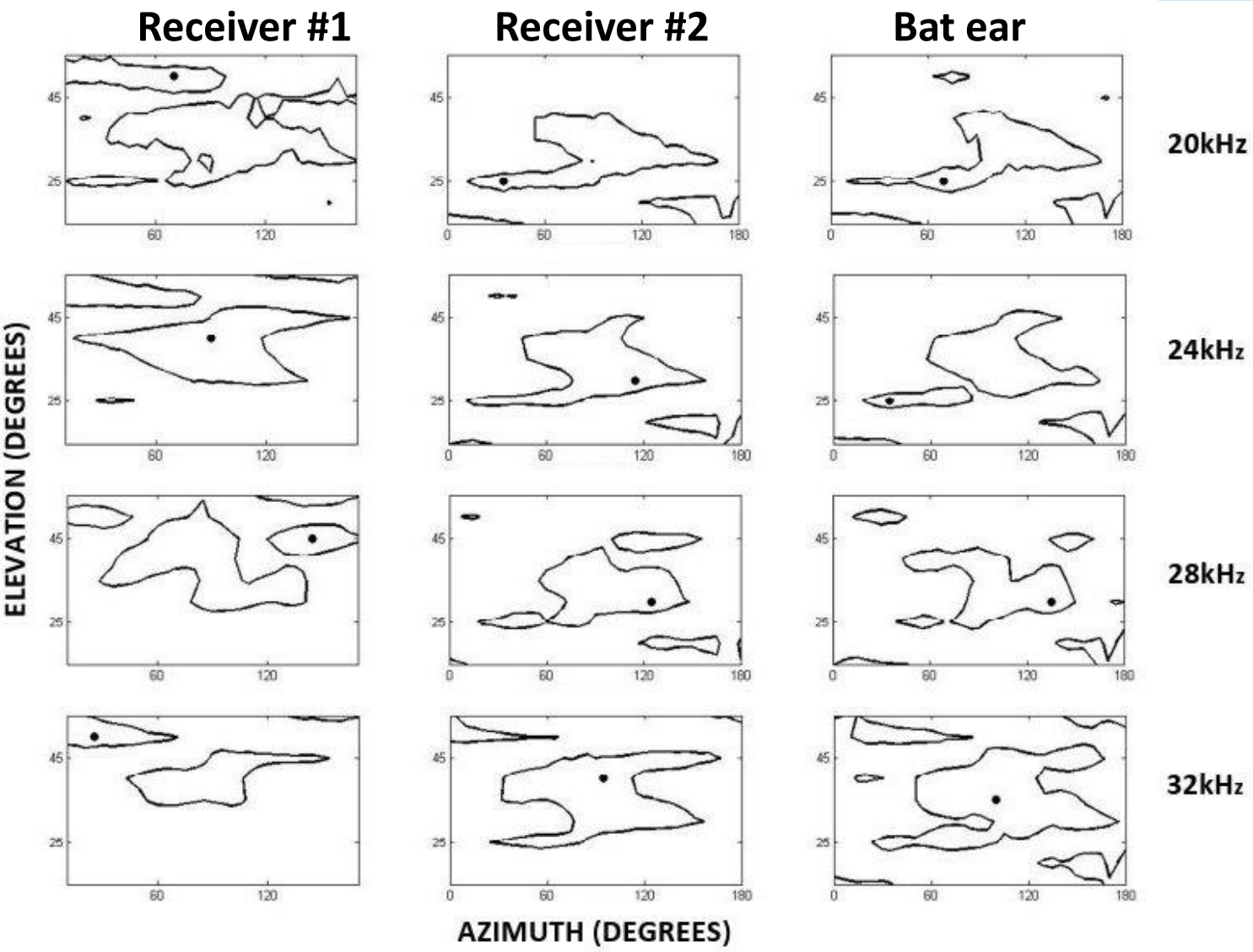
Beam pattern of two receiver structures compared to bat ear

- Main lobe domain for Template #2: azimuth 50° to 160°, elevation 20° to 50°
- Beam attenuation values from 0dB down to -12dB

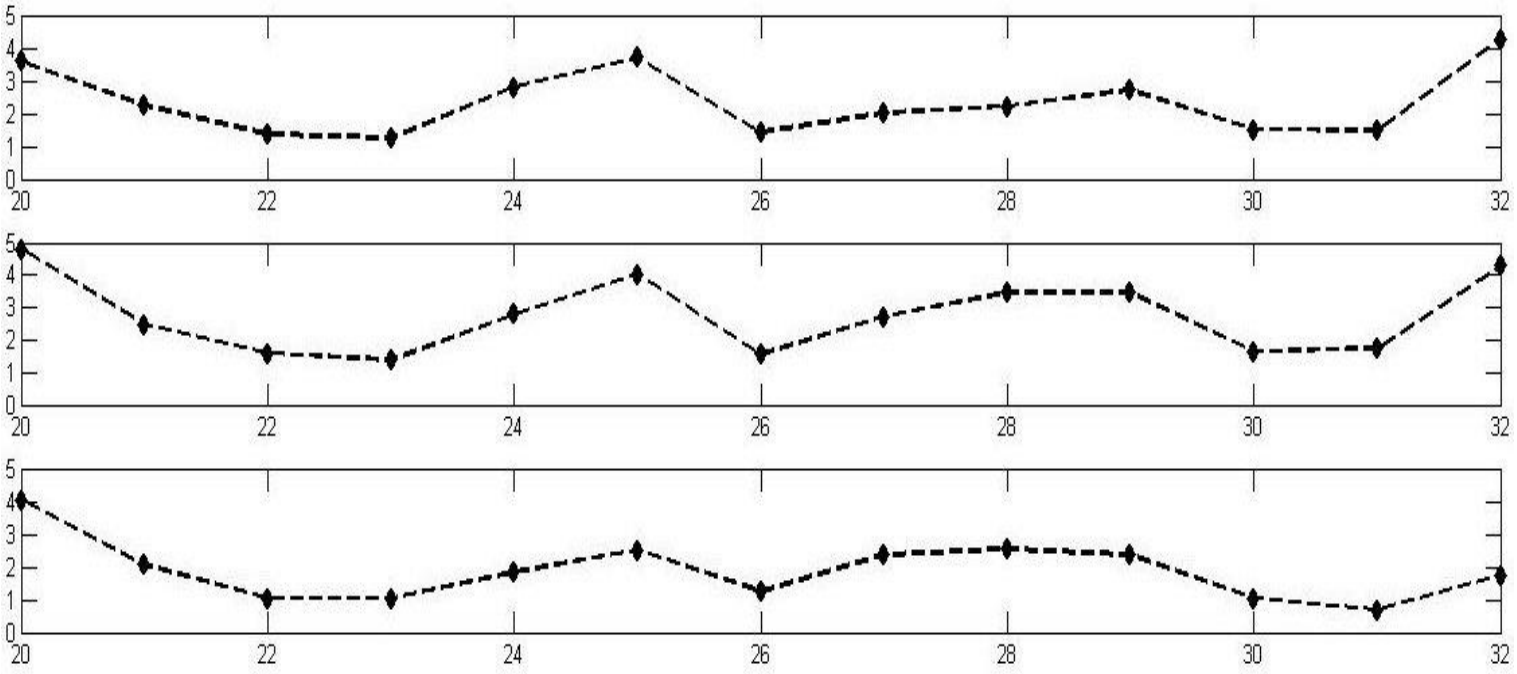
Template #1 | **Template #2** | ***R. leschenaultii*'s ear**



Main lobe extension



Maximum value of main lobe



Summary

- Sonar system to support autonomous robot inspection in NDE
- Biomimetic (bat-inspired) sonar system, in particular the receiver configuration
- Field measurements (beam pattern) achieved using high precision Kuka robot arm
- Receiver #2 has beam pattern comparable to that of *R. leschenaultii*'s left ear
- Presence of a main lobe makes it easier to discriminate between direction of echoes

Future work

- Two receivers like template #2 are paired together resembling bat ears' mutual displacement
- Sound source localization using paired receivers
- Target localization using paired receivers and one emitter
- Final assembly of the sonar system using 2 receivers and 1 emitter like a bat mouth-ears arrangement

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Thanks! Questions?

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