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Semester Project at LCAV
Ecole Polytechnique Fédérale de Lausanne*

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Experimental Setup of Sound Emitting and Processing Robot for Acoustic-Based Slam Applications

Introduction

Motivation – Echolocation for Navigation



Fig. 1: Daniel Kish, founder of *World Access for the blind*

EchoSLAM: SIMULTANEOUS LOCALIZATION AND MAPPING WITH ACOUSTIC ECHOES

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ABSTRACT

We consider the problem of jointly localizing a robot in an unknown room, and estimating the room geometry from room impulse responses. Unlike earlier works using echoes, we assume a completely autonomous setup in which both the microphone and the source are mounted on the robot. First, we introduce a simple, easy to analyze estimator, and prove that the sequence of room and trajectory estimates converges to the true values. Second, we approach the problem from a Bayesian point of view, and propose a more general solution which does not require any assumptions on motion and measurement models of the robot. In addition to theoretical analysis, we validate both estimators numerically.

Index Terms— Room geometry estimation, echo sorting, sound source localization, simultaneous localization and mapping

1. INTRODUCTION

We address the problem of simultaneous localization and mapping (SLAM) based on acoustic echoes. We assume no preinstalled infrastructure in the room, and the bare minimum of sensing installed on the robot—a single omnidirectional source and a single omni-

ideas. An additional benefit of simplicity is that we can show that the algorithm converges to the correct solution when the robot is exploring the space randomly. Next, we formulate a Bayesian solution inspired by FastSLAM [12]. We empirically observe that this more sophisticated algorithm strictly (and by a large margin) outperforms the elementary solution.

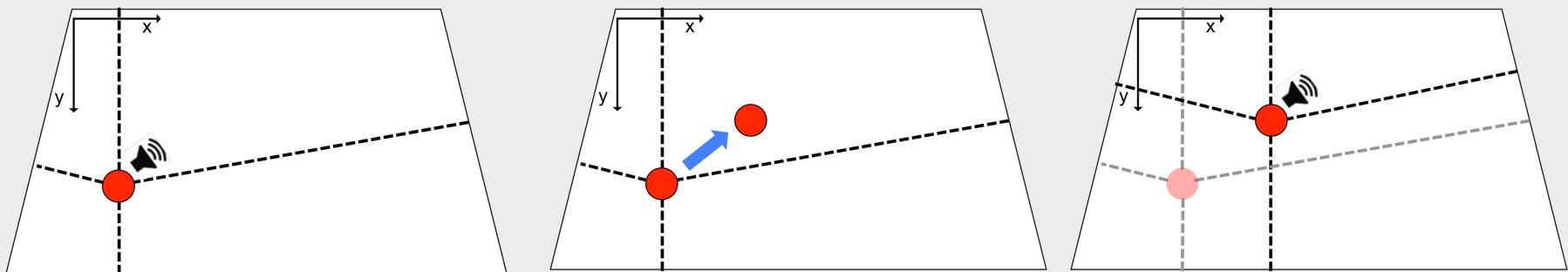
Section 2 introduces the notation, the problem setup, and the adopted image source model. In Section 3 we propose two methods for reconstructing the shape of a room from acoustic measurements. In Section 4 we numerically compare the performance of these two estimators, and we draw conclusions in Section 5.

2. PROBLEM SETUP

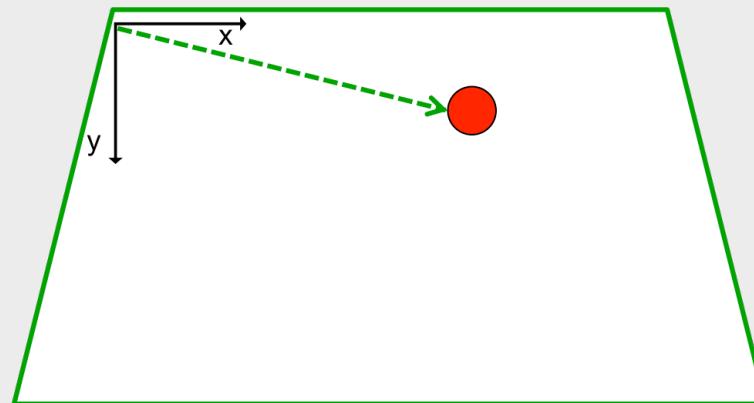
We assume to have an omnidirectional acoustic source and a collocated omnidirectional microphone mounted together on a robot, and placed inside a room. The robot moves autonomously. At every step, the source produces an impulse, and echoes are recorded by the microphone at the same point. We define a room as a 2D polygon, and derive all results in 2D. However, the derivations can easily be extended to 3D.

Introduction

Goal – Experimental Framework

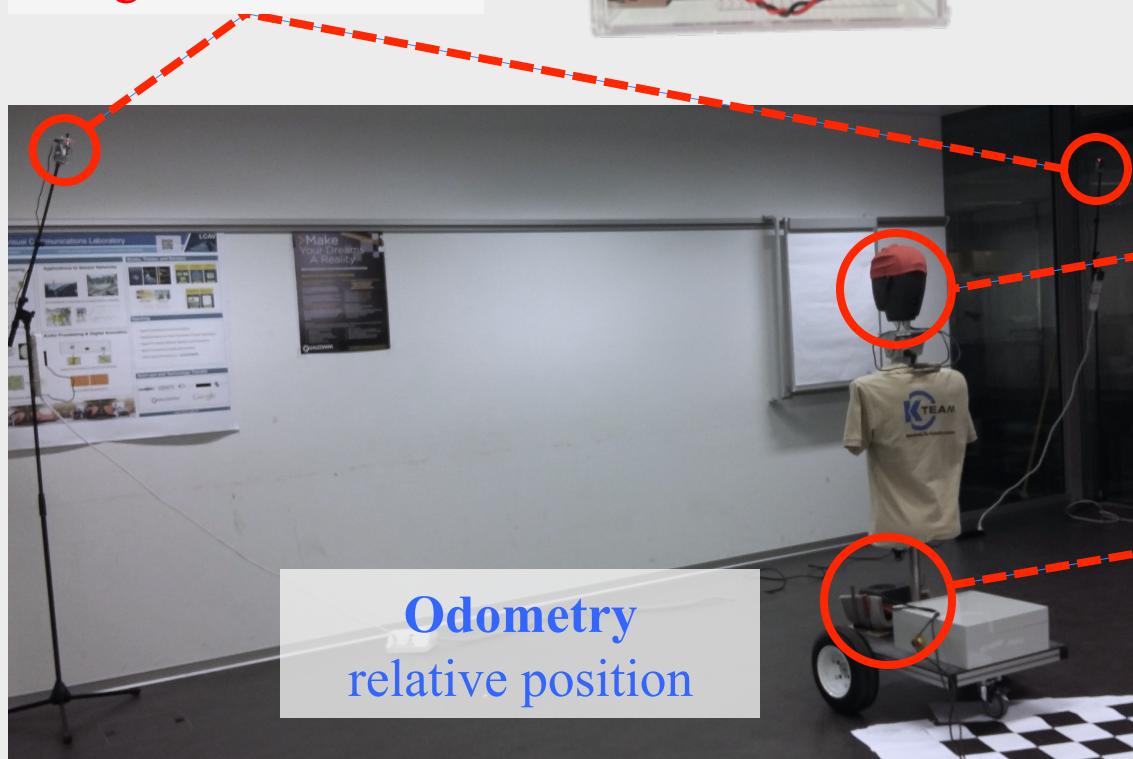


Visual localization
ground truth
Odometry
relative position
EchoSLAM
absolute position
and room geometry



Experimental Setup Overview

Visual localization
ground truth



EchoSLAM
absolute position
and room geometry



Experimental Setup

Visual Localization Procedure

- ◆ Governing equation

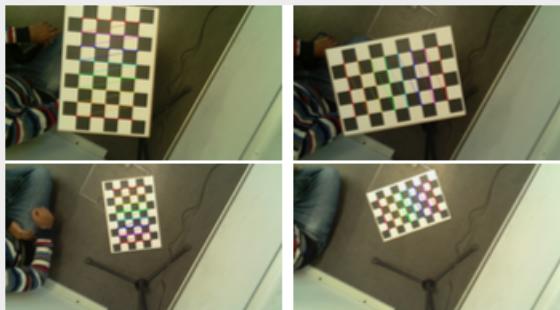
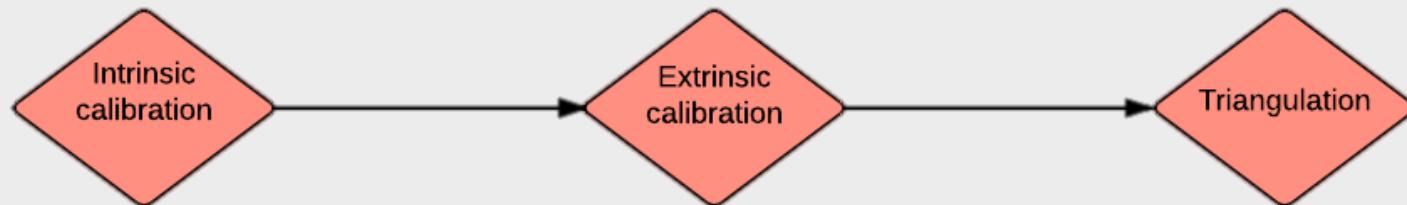
$$s_i \begin{bmatrix} u_i \\ v_i \\ 1 \end{bmatrix} = C[R \quad | \quad t] \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix}, \quad \text{for } i = 1 \dots N_{\text{pts}}$$

- ◆ C and distortion coefficients obtained by **intrinsic calibration**
- ◆ Two different cases are treated:
 - Positioning of cameras (R, t) based on image-object space correspondances
 - Localization of point given its image in 4 cameras.
- ◆ Minimization of **reprojection error**

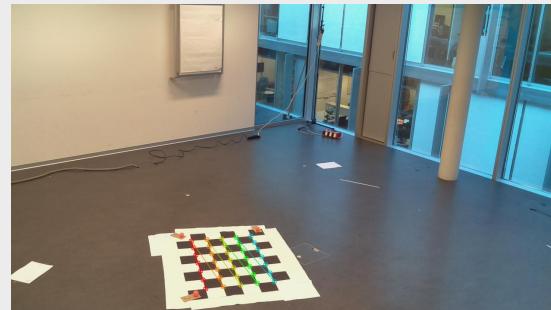
Experimental Setup

Visual Localization Procedure

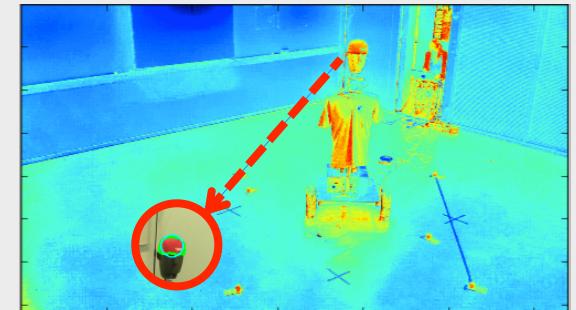
$$s_i \begin{bmatrix} u_i \\ v_i \\ 1 \end{bmatrix} = C [R \quad | \quad t] \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix}, \quad \text{for } i = 1 \dots N_{pts},$$



given: pictures of
checkerboard
→ C and distortion
coefficients



given positions X, Y, Z of
 $N_{pts} = 5 \times 7$ points
→ R, t



given (u_j, v_j) for j cameras,
Z optional
→ X, Y, Z

Experimental Setup

Robot Movement Analysis

Fig. 1:
Commands file

0	f
2	s
0	f
2	s
0	f
2	s
0	f
2	s

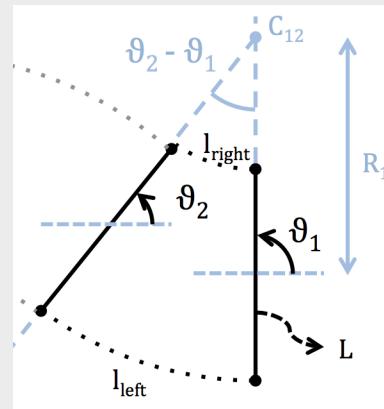


Fig. 2:
Odometry geometry
considerations

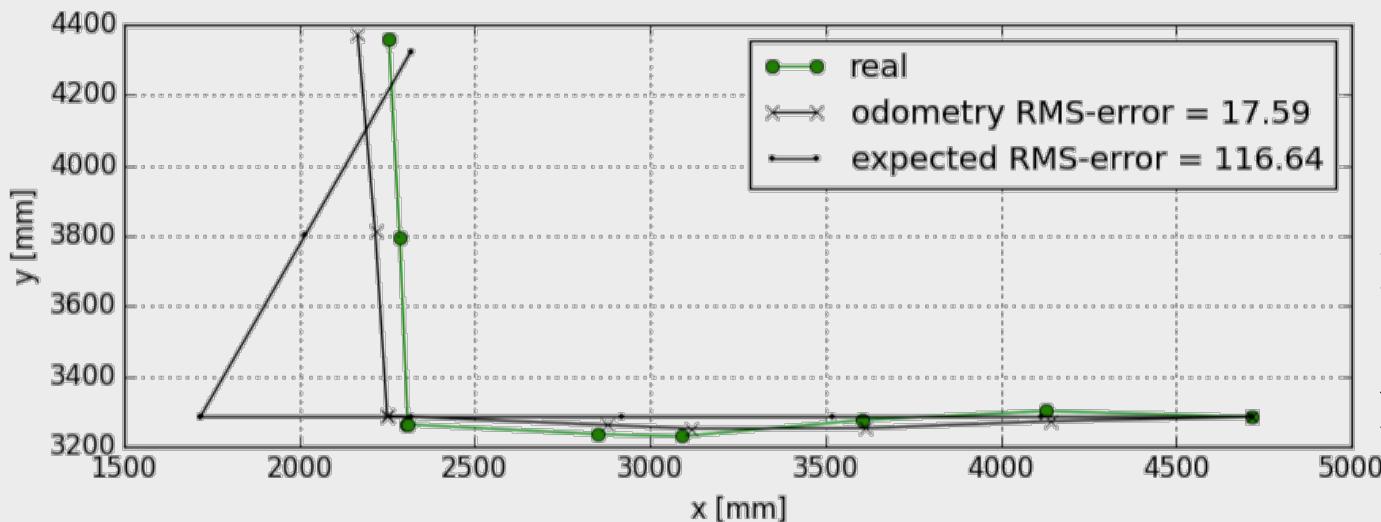


Fig. 3:
Resulting
positions

Experimental Results

Performance Measures

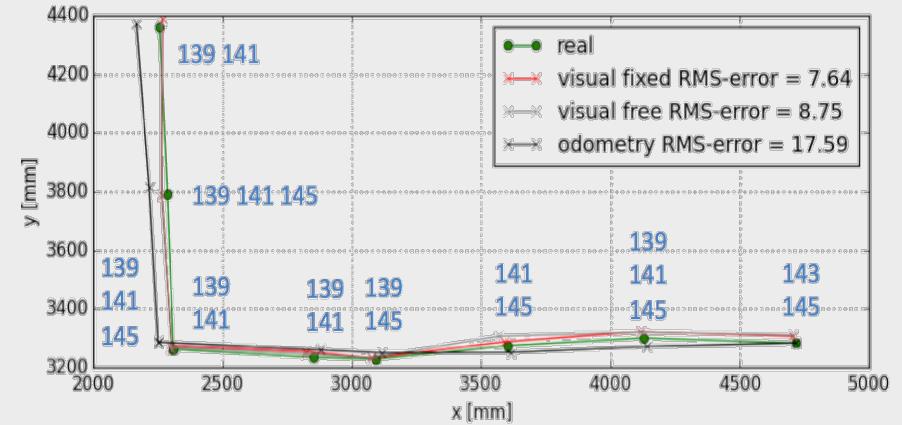
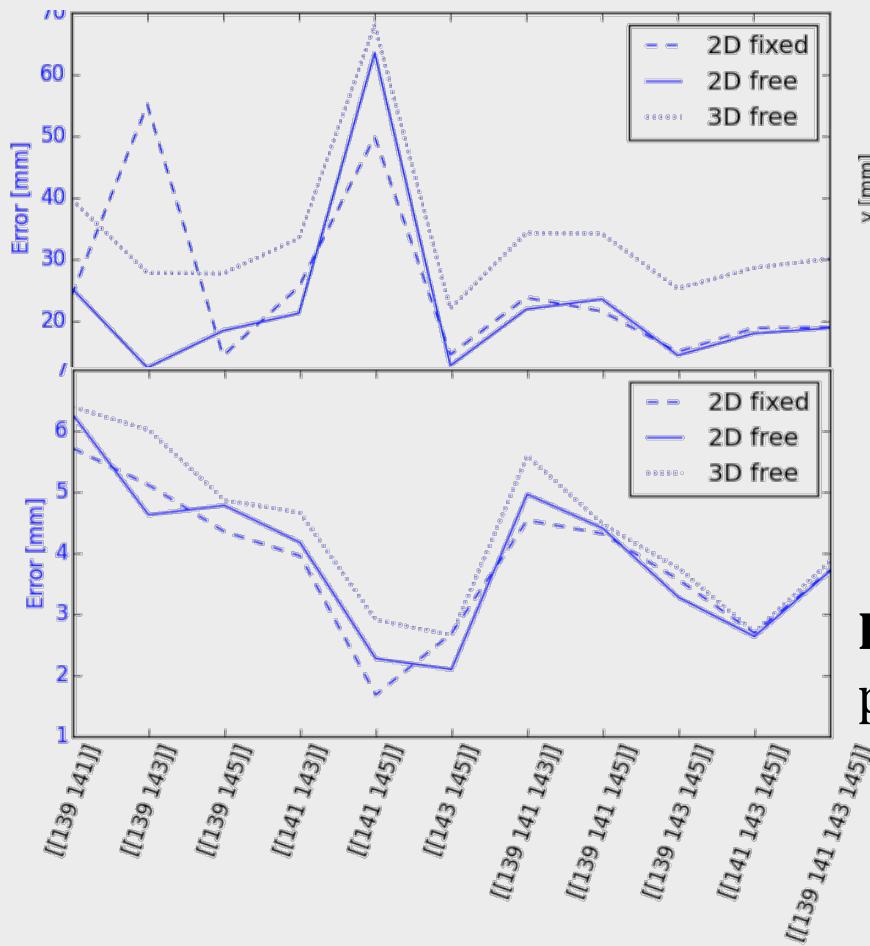


Fig. 2: Results with best camera combinations

Fig. 1: Robot (top) and reference point (bottom) error

Experimental Results

Obtained Positions

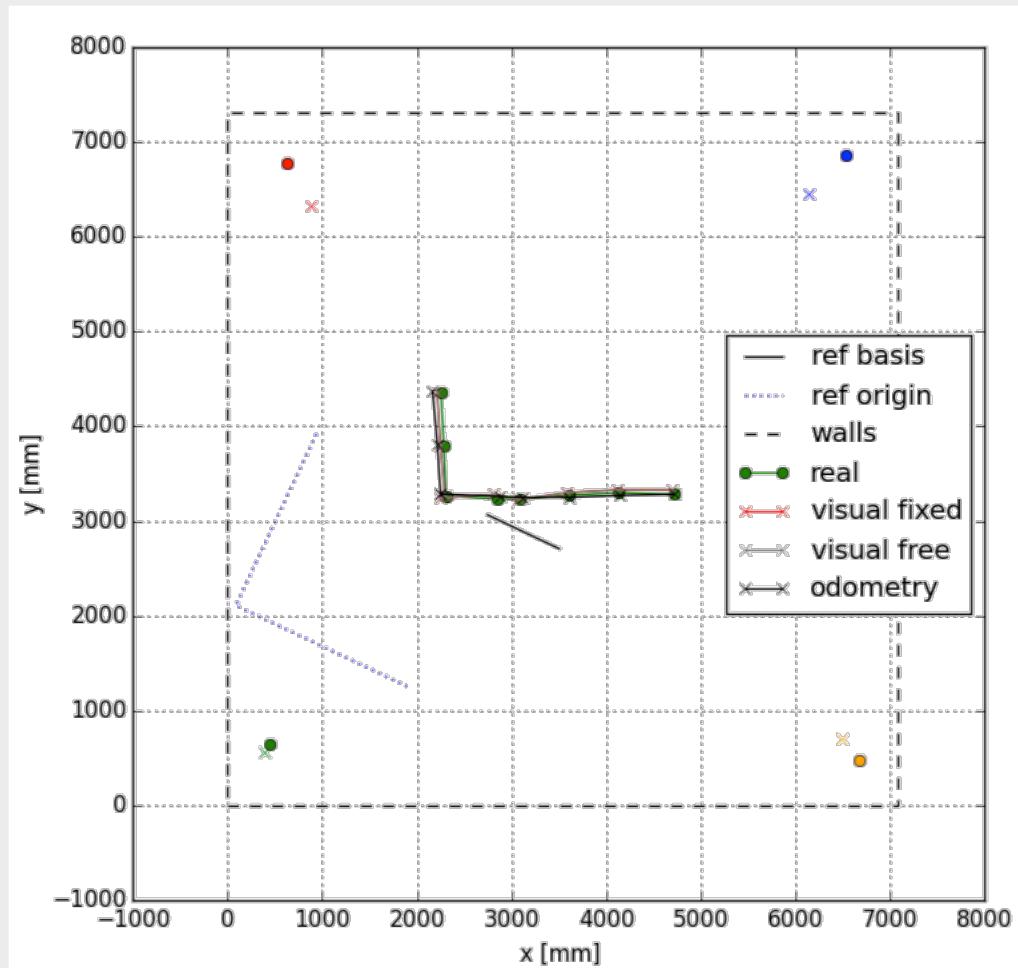
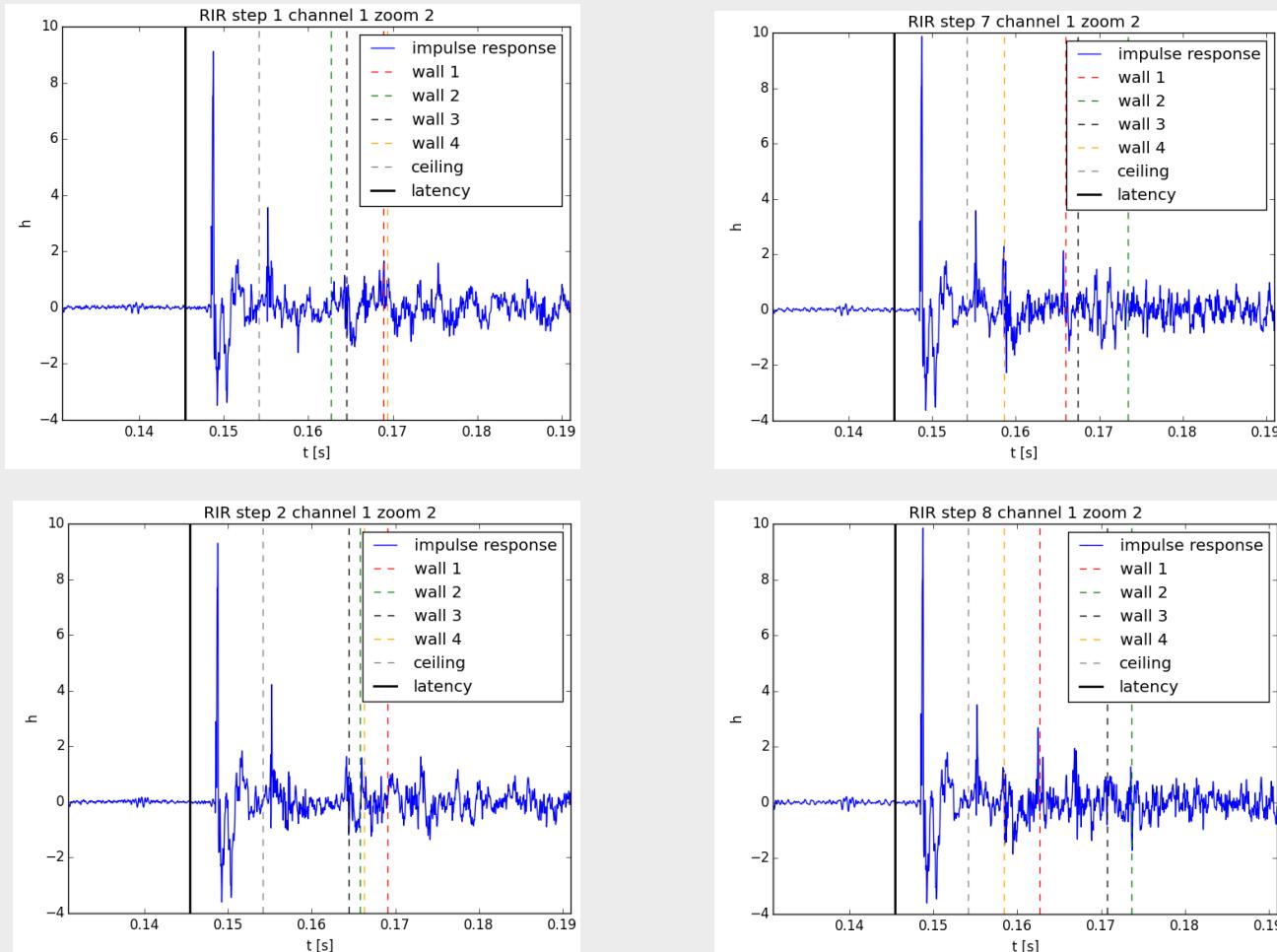


Fig. 1:
Results using all cameras

Experimental Results

Impulse Responses



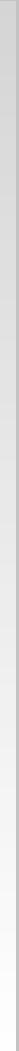
Conclusion Achievements

- ◆ Experimental framework (both **Hardware and Software**) tested and validated
 - Visual localization with precision up to 1 cm
 - Odometry analysis implemented
 - Room impulse response recording and deconvolution working
- ◆ Setup **instructions** and code **documentation** available online for later use

Conclusion

Suggested Improvements

- ◆ Smaller or more accurate **target point** for visual localization (checkerboard / *QR code*)
- ◆ Add **fisheye** lenses for wider views
- ◆ More robust robot **movement** and **audio control**
- ◆ Improve **signal processing** for reliable echolocation (e.g. averaging)



Thank you