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Mobile Test Bed for Development and Validation of Networked Multimodal Gas Leakage Detection

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Summary:
This work presents a mobile leakage test bed for gases (indoor and outdoor). This consists of a compressed gas cylinder on a cart that uses a mass flow controller to generate controllable leakage rates measured by multiple sensors. Bidirectional MEMS Microphones and MOS gas sensors are used for this purpose. Target is the development of multimodal sensor nodes combining different sensor signals with effective machine learning methods implemented on the sensor nodes for robust leak detection.

Keywords: Test Beds, Multimodal Measurements, Leakage Detection, MOS Gas Sensors, Directional MEMS Microphones.

Introduction

Leakages can occur in many places in an industrial context. Examples are gas containers and lines, compressed air, or rather pneumatics. The occurrence of leakages significantly reduces energy efficiency through loss of energy sources and can also result in safety risks. If these leakages can be detected and quantified, problem areas can be identified and fixed. Saving resources like compressed air or hydrogen is a significant benefit of leakage detection methods.

Various options are available to detect leakages. In previous publications, acoustic leakage detection was simulated [1] and performed with different sensor types [2-5]. Those sensor types used are vibration sensors [2], acoustic cameras [3], acoustic emission sensors [4,5], or a single microphone [6]. A different approach is the use of gas sensors [7]. To assess the combination of different sensor modalities for networked sensor nodes, a test bed was developed to simulate gas leakages. A compressed gas cylinder is installed on an aluminum cart and various leakages can be created, with the leak rate set by a mass flow controller. A pressure sensor is implemented to additionally monitor leakages with different sizes. Leakages can be simulated for any gas available in gas bottles.

Concept

The test bed is designed horizontally so that the gas cylinder is stored stably. The cylinder can be loaded from the back or front and is attached to the support surfaces with tension straps. Both 10 l and 50 l gas bottles are compatible, as the CAD model in Fig. 1 shows. Fig. 1 also shows

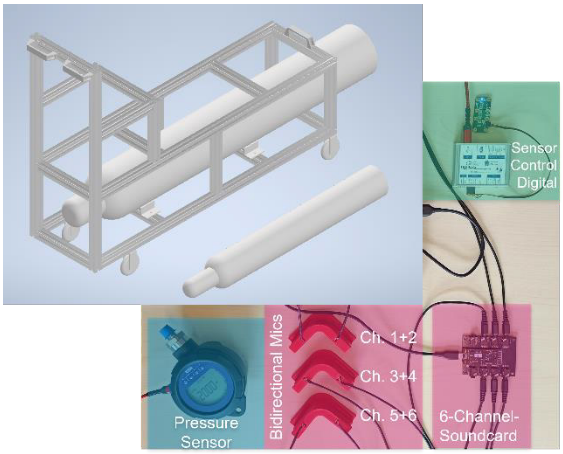

Fig. 1. CAD model of the test bed with gas cylinder and peripherals for flow control and data acquisition from microphones, gas sensors, and pressure sensor.

sensors and their data acquisition electronics implemented in the first iteration of the test bed.

To generate the targeted leak rates, a pressure reducer is attached to the gas bottle in front of a mass flow controller (MFC, MKS 1179A) allowing to set flow rates between 200 ml/min and 2000 ml/min (24 to 240 l/h). An outlet (in the first version a ¼ inch Swagelok pipe) is then used to allow the gas to flow into the environment. The pressure sensor is installed directly at the outlet in order to measure the relative pressure right in front of the restriction, which is shown in an example setup (Fig. 2).

The dynamic pressure depends on the outlet size and the flow rate. It is expected that the sound radiation increases significantly as the flow rate increases, but also depends on the outlet size and pressure. The sound characteristics will also depend on the outlet shape (initially round) and gas type. From an acoustic point of view, the goal is to determine the flow rate for different outlet sizes and shapes based on sound radiation in characteristic frequency ranges (cf. experiments on pneumatic cylinders, [8]).

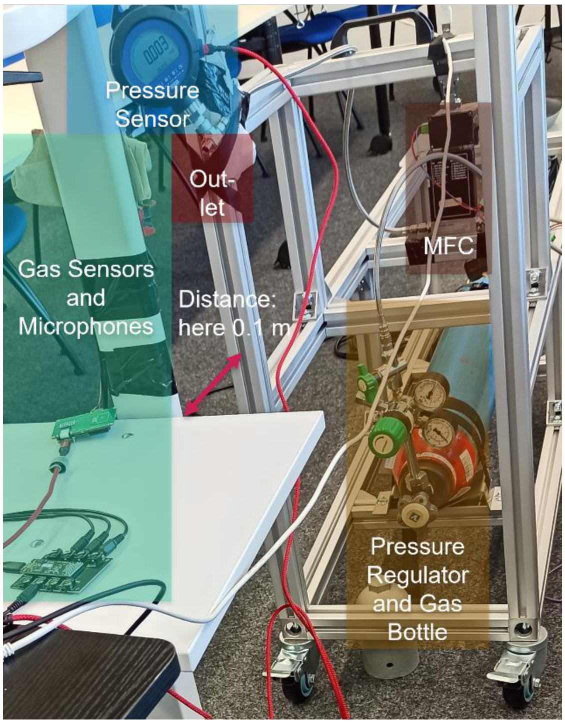

Fig. 2. Test bed setup for indoor experiments at different distances with four microphones (with/without housing, directed at the source/perpendicular to the source) and six gas sensors.

Regarding gas sensors, it is expected that complementary information can be gathered when gas is released due to the sensitivity of MOS sensors to a wide range of gases, e.g. hydrogen, methane, and VOC [9, 10] allowing more robust leak detection in industrial environments. Increased selectivity, i.e. based on multisensor arrays or dynamic operation, will provide further information on leak type and allow separation of various sources.

Design of Experiment

Experimental data, which will be presented in an upcoming journal, will include tests in indoor scenarios, i.e. with limited ambient influence, with sensors installed at different distances from the source. This experiment is intended to show how sensor signals change with distance. Further experiments will be conducted outdoors with different environmental conditions. This will allow optimization of the sensor set-up, i.e. directional information of microphones vs. undirected, optimal selection and operating mode of gas sensors for different sources as well as determination of the detection limit by combining microphones and gas sensors in different environments and at different distances. Further experiments will include acoustic and gas interferences as well as more complex sensor nodes, i.e. by implementing an anemometer for measuring wind speed and direction. This will also be tested under controlled conditions in indoor environments with fans to set defined wind directions and speeds.

The expected outcome are design recommendations for multimodal sensor nodes including the required signal processing for robust leak detection for various leak sources.

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