In-Room Noise Cancellation with Wall-Transmission Detection

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I. INTRODUCTION

Ambient noises are omnipresent and have the potential to be distracting. Within a room, sources of noise come from construction machinery, weather, and people. This project will use an active noise control device to measure sounds traveling through walls from outside and attenuate the sound to create a quieter environment. This conceptual design will evaluate all the necessary components and systems ranging from inputs, processing, and outputs. This document will be precise enough to allow the project to be duplicated by others while allowing enough flexibility to choose different hardware and software to achieve this design.

The team expects this device to work in a classroom, so several subsystems will be designed and discussed that make up the active noise control device catered towards this specific constraint. Sources that play a major role in the specifications and constraints of the device are professional engineering ethics, safety standards, and derived requirements. Verification methods will be centered on a "build a little, test a little" approach to effectively allow dynamic construction and flexible changes to design as unknowns are resolved.

A) Fully Formulated Problem

The device is expected to capture the sound or vibration coming from outside through a wall and output the negative of the captured signal to produce a perceived quieter environment. The functional expectations and constraints (listed in alphabetical order) include:

A System shall not play audio above 80 dB for more than 8 hours.*
- This standard comes from the OSHA safety regulations. These standards set a limit on prolonged noise exposure to sounds above 80 dB. If an individual is exposed to these loud noises for an extended period of time, it could cause permanent damage to one's eardrum. Therefore, in the case of a critical failure, the system will not emit potentially harmful noises for extended periods of time.

B System shall have a primary input sensor that measures acoustic vibrations through a physical medium.
- This constraint is derived from the need of the system to acquire vibrational acoustic data through a physical medium as an input.

B.1 Primary input sensor shall output an appropriate type of signal that is compatible with connected subsystems.
- This constraint is derived since the sensor must be able to communicate with the processing block. The processing block can only operate on certain data types and signals. The output of this sensor must therefore be an appropriate signal and data type, such as a continuous-time analog voltage signal, in order to be used properly.

B.2 Primary input sensor shall output a signal with minimal external interference generated by its power supply.
- This standard originates from the potential of the power source to emit a frequency that adversely affects the input of the system. Measures will be put into place to ensure the power supply emits a clean frequency with minimal interference.

C System shall have an error sensor that measures acoustic residual noise based on the primary input sensor.
- This constraint originates from the need to measure the accuracy of the emitted output from the system. If the emitted noise is inaccurate in comparison to the reference input, the error sensor will pick this up and send the data back to the processor for correction.

C.1 Error sensor shall output an appropriate type of signal that is compatible with connected subsystems.
- This is a derived constraint since the sensor must be able to communicate with the processing block. The processing block can only operate on certain data types and signals. The output of this sensor must therefore be an appropriate signal and data type, such as a continuous-time analog voltage signal, in order to be used properly.

D System shall have a primary output speaker that generates acoustic sounds based on its input from the system.
- This is an explicit device requirement since the device needs to output a signal to reduce noise from the wall.

E System shall have a primary processing subsystem that is able to receive input, process the input, and output the appropriate response.

- This constraint is an explicit requirement since the output must be processed from the input.

E.1 Primary processing subsystem shall convert two analog input signals to two digital signals with minimal clipping.

- Clipping of the inputs will lead to inaccurate or distorted results. The above constraint is therefore derived. Soft clipping of the signal will be utilized in order to alleviate any negative effects of hard clipping.
- Constraint **B.1** extends to the processing subsystem. Since the processing will be done digitally, the input must be converted to an appropriate digital representation.

E.2 Primary processing subsystem shall convert a digital input signal to analog signal with minimal clipping.

- Constraint **E.1** extends to output. The constraint is derived since speakers are driven by continuous-time analog voltage signals. The processing system must therefore be able to convert from its digital output to an appropriate analog output, whether through pulse width modulation, or other means.
- Constraint **E.1** extends to output clipping. Clipping of the outputs will lead to inaccurate or distorted results. The above constraint is therefore derived. Soft clipping is used in order to alleviate any negative effects of hard clipping.

E.3 Primary processing subsystem shall control the flow of data within the system.

- Multiple types of data will be applied to the data bus. The derived constraint is applied to prevent inaccurate or nondeterministic results.

E.4 System shall store three arrays consisting of: noise input, error input, and a control signal.

- In order to use the sampled inputs, outputs, and filter, temporary memory in the system must be allocated so processing can be applied to it.

E.5 System shall process data to implement adaptive filter algorithms.

- The desire to create an adaptable noise-canceling system is a desired constraint. In order to maximize the success to meet constraint **L**, the system shall use common adaptive filter algorithms.

E.6 System shall switch between pre-built filter models.*

- The desire to create an adaptable noise-canceling system is a desired constraint. In order to maximize the success to meet constraint **L**, the system shall be able to switch quickly between pre-trained models of filters. This constraint is derived from the inherent nature of common adaptive filter algorithms, which slowly tweak the control filter. The use of filter models that can be easily switched allows the system to deal with sudden changes that are not easily solved through constraint **E.5**.

F System shall manage excess heat that would damage system.

- Excessive heat, either external or generated internally must be controlled since the heat could damage components, especially over time.

G System shall be powered by standard wall outlets.

- This constraint is derived from the desire for the system to be implemented long-term. By connecting the system to a standard wall outlet, it eliminates the need for temporary battery power and the system can run for a longer period of time.

H System shall have accessible power toggle.

- This constraint originates from the safety standards in place for the system and the stakeholder requests for accessibility. If the system encounters a critical failure or needs to be shut down for any other reason, there will be an easily accessible power toggle that can shut down the system.

I System shall follow OSHA standards.

- This constraint originates from the need of the system to follow a proper set of safety regulations. OSHA contains many critical regulations that involve emitted sounds which is imperative in this project, therefore the OSHA standards will be followed in both design and in implementation.

J System shall not impede movement to and from desks.

- This constraint involves accessibility concerns that are strictly accommodated to in public schools. The American Disabilities Act ensures all environments across campus are made accessible to all students. Many classrooms have limited space and little room for adjustment, so leaving a device in a critical pathway of a classroom would cause many problems for individuals with limited mobility.
- The desire for a discrete system that does not limit mobility was also requested in the survey given to stakeholders. It was specifically requested that the device not be bulky or cause problems for students moving throughout the classroom.

K System shall minimize its visual distraction.

- This constraint originates from the survey given to stakeholders. Along with not impeding mobility, the device will not be a visual distraction to students and teachers. It will be implemented as discretely as possible, outside of the the direct line of sight of students.

L System shall attenuate targeted noises by at least 20 dB.

- This constraint originates from the critical measure of success for the system. While an ideal noise-cancellation system will be able to fully cancel out noises, the main goal of this project is to attenuate unwanted signals by 20 decibels.

M System shall follow the American National Standards Institute (ANSI) for safe use of lasers.
  - This constraint comes from the ANSI regarding the use of lasers for general use and in classrooms. OSHA uses their guidelines as a part of their own standards, so care should be taken to follow relevant standards ANSI set.

N System shall have a mount or multiple mounts so that it can be easily installed within the classroom in an unfrequented area.
  - This constraint was derived from the need for accessibility of the device and the room in which it occupies. With a mount, the device will not have to rest on the floor or furniture and will not be an obvious distraction. This creates more options for implementation and helps to fulfill constraints **J** and **K**.

O System shall not store the audio data for longer than needed to process.
  - This constraint comes from ethical considerations involving privacy within a classroom. Storing audio long-term is not a requirement for the device to function properly, so it should not be included to minimize unnecessary ethical questions.
  - Depending on the country or state, two-party consent laws may be a factor when limiting the device's audio storage capacity.

P Shall be easy to remove and setup in a different room.
  - This constraint was derived from consideration of broader impacts: Given the adaptability of the device, it is expected to be moved around to different positions in a room and to different rooms.

II. Background

III. Ethical, Professional, and Standards Considerations

With any device implemented that could have an affect on students and staff, there are broader considerations that must be taken into account. As the device is meant to be used by individuals with no technical experience, constraints are put in place to ensure the safety and intended effects for everyone to come into contact with the device.

A) Ethical

Along with the use of microphones and recording devices, there comes the ethical consideration of individual privacy. To account for this, the privacy and safety that is expected while conversing in the classroom will not be breached and accessed at a later date.

There are also ethical implications associated with the implementation of the device impeding movement within the classroom. The device should be implemented in such a way that nobody will be negatively affected by its placement and position, which could potentially lead to distraction or reduced performance for individuals within the classroom.

As engineers, the safety of the device is a very important matter to consider. The system should not function in such a way that could cause harm to an individual or individuals. If the system is capable of causing harm, that will be considered a critical failure.

B) Standards

If a laser is utilized in any portion of the device, whether it be in the input or output, the design will follow the safety regulations outlined by the American National Standard for safe use of lasers. These standards constrain the types of lasers that will be used, the area in which they are implemented, and ensure safe use of light emitting devices.

Due to the use of acoustic recording and sound emission devices and the methods that will be used to power them, the standards outlined by the International Electrotechnical Commission will be followed. These standards help to ensure safety when using audio, video, and other powered devices.

C) Broader Impacts

Ideally, the system will have high adaptability and be transferable between different areas. If the system is successful, then it can be used in multiple settings, drastically expanding its impact on the school and the potential noises that can be reduced.

Another greater impact that this system could impose is an effect on other noise cancellation devices: Whether or not the device outputs a signal that negatively affects other nearby devices should be considered. Testing will need to be done to ensure that individuals' devices are not negatively affected.

D) Constraints Derived From Broader Considerations

Constraint **O** is directly derived from the consideration of privacy ethics. This constraint emphasizes that the device will not store the audio that it records. Instead, it will analyze it and send it to the next block.

Constraint **P** is derived from the broader considerations of the future use of the design. By constraining the design to be relatively easy to remove and setup, the overall design and structure of the system is influenced.

Constraints **H** and **A** are derived from the consideration for the safety of the device in mind. In the case that the device experiences a critical failure and is outputting a potentially harmful signal, it is imperative that the system can be shut off or limit the time it emits such signals.

IV. Block Diagram

A) Input Sensor

The input sensor is going to be the primary source of data for the rest of the system. This is where the acoustic sound signals will be measured and prepared so that they can be sent to processing for further manipulation. This subsystem block

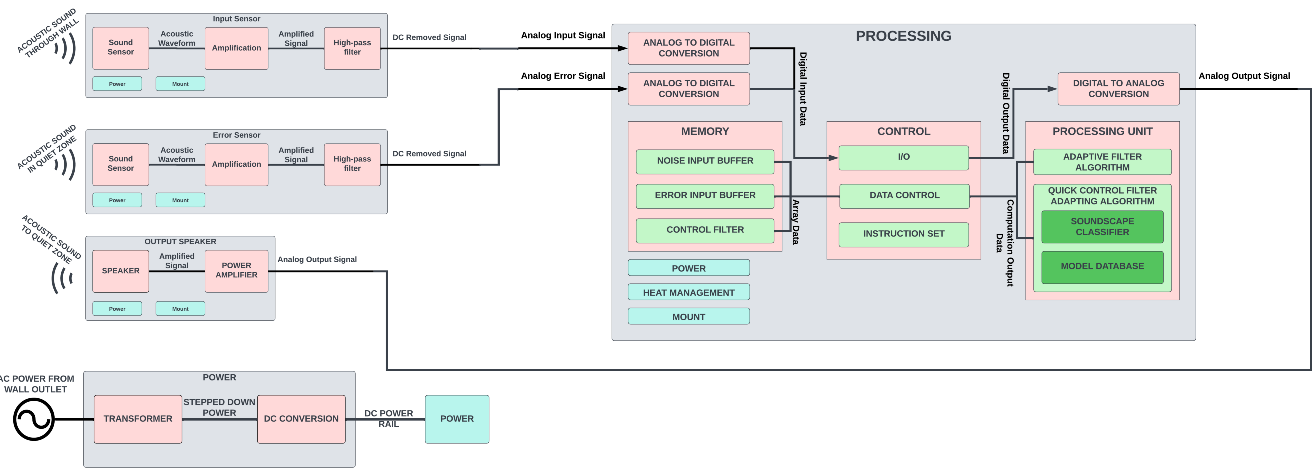

Fig. 1. Block Diagram

will consist of a sound sensor, a method of amplification, and a high-pass filter.

Input: Acoustic sound through wall

Output: DC removed signal

The input sensor will follow Constraints **B**, **B.1**, and **B.2** outlined in the in depth constraints section. These specify both the way in which the signal will be acquired and the state the signal should be in once it is transmitted. Proper functionality can be verified during design and testing by confirming that an acoustic signal is being received by the input sensor and the waveform has little to no interference.

1) Sound Sensor:

The sound sensor will be responsible for acquiring the raw acoustic data through the wall and turning it into a waveform that can then be filtered and amplified by the rest of the system.

Input: Acoustic sound from physical medium

Output: Acoustic waveform

This part of the system will follow the specifications outlined by constraint **B**. This part of the system can be verified by checking to see if it is able to acquire an acoustic vibration through the wall and output a general waveform resembling that vibration.

2) Amplification:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

3) High-pass filter:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

B) Processing

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

1) Analog to Digital Conversion:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

2) Memory:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

3) Control:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

4) Processing Unit:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

5) Digital to Analog Conversion:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

C) Output Speaker

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

1) Speaker:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

2) Power Amplifier:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

D) Error

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

1) Error Sensor Comparison:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

E) Power block

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

1) Transformer:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

2) DC conversion:

1)Explanation: - Conceptual functionality of block.
2)Input: What goes in
3)Output: What it sends out
4)Constraint Derived: What constraint does this connect to that we explained in the intro section

V. CONCLUSION

The conceptual design of the in-room noise cancelling with wall-transmission detection involves three major subsystems: noise detection, signal processor, and noise output. Each of these major subsystems are divided into individual components that fully make up the device. This conceptual design displays a transparent and specific overview of the device while allowing flexibility in hardware and software to recreate the device.

REFERENCES