Stanford University

Designing a Sensor-Integrated Wearable to Prevent Unwanted Interactions with Service Dogs

Sensor Design Term Paper

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ME220: Introduction to Sensors

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Abstract

Service dog handlers often face interruptions from the public who want to interact with their working dogs. This can range from a minor inconvenience to a major safety concern if the service dog becomes too distracted to focus on their handler. Furthermore, people frequently approach and interact with the service dog without permission or acknowledgement of the handler, which can be difficult for the handler to prevent due to their disabilities. The current solution to this issue is signage. However, these signs can be difficult to see and read, especially for children, and are easily ignored or overlooked.

In response to this issue and capitalizing on the growing demand for instrumented pet wearables—a market projected to reach $4.9 billion by 2028 [1]—I propose a sensor-integrated dog harness attachment. This device incorporates proximity and sound level sensors to establish a boundary between the service dog and surrounding individuals, ensuring an undisturbed working environment for the dog. The proximity sensor, the core sensing component, detects the presence of people approaching the dog from the side opposite the handler. To enhance usability, the device includes a sound level sensor that dynamically adjusts a speaker's output volume based on surrounding noise levels. This speaker then plays a recorded message politely requesting individuals to maintain their distance and refrain from petting the service dog, thereby minimizing distractions and ensuring the dog's focus on its tasks.

Customer Potential and Product Specifications

This product is designed for individuals with impairments that may obstruct their ability to prevent unwanted interaction with their service dogs. It also caters to service dog training organizations and individuals preferring an automatic solution. There is currently no interactive solution to this problem such as the one being proposed.

For this application, some important specifications are:

- Proximity Sensor Detection Range: The sensor should detect at least 20 cm range to identify someone intending to physically interact with the dog without triggering false alarms.
- Material Detection: The sensor should detect human skin while rejecting most other objects. The circuitry will be covered by fabric for durability.
- Sound Level Sensor Sensitivity: The sensor needs to detect the absolute level of the current sound level to adjust the speaker volume.
- Power Consumption: Given the attachment will likely be powered by a lightweight, rechargeable battery, the power consumption of the sensors and other electronic components should be minimized.
- Durability and Comfort: The product should withstand physical activity and mild outdoor weather conditions. It should be comfortable, lightweight, flexible over large areas and not obstruct the dog's movements.
- Cost: The cost of the sensors and other components should be low enough to keep the overall cost of the harness affordable for customers, ideally less than $200 to be competitive in a very specialized market

Patented Related Inventions

While researching wearable technology for animals, it is evident that there is a gap in smart design for the service animal wearable market . The following table summarizes the most relevant patented inventions discovered during an extensive research on instrumented animal wearables, wearable proximity sensors, and sound level sensors paired with loudspeakers.

Patent Number	Description	Similarities/Relation	Distinctions
US10117802B2	A "Blind dog navigation system" that uses a distance sensor, microcontroller, tactile/audio stimulator, an accelerometer, a power source, a control panel, a body harness, and a head wrap to assist blind dogs in navigation.	This is a wearable instrumented device for dog assistance, using sensors to detect proximity of objects around the dog, with similar placement of sensors using body harness and head wrap as attachments.	The purpose of this invention is to guide blind dogs and detect obstacles, while the proposed design is meant to prevent people from petting the dog. It uses tactile stimulators to alert the dog of objects in its surroundings, while the proposed design uses audio stimulators to alert people around the dog.
CN106962222B	An "Intelligent pet necklace" that uses a GPS module, a Bluetooth module, a mobile network module, a loudspeaker, and a sound pickup fixed on a dog collar to control and track movement of the dog.	This is another wearable instrumented device for dog assistance, using a loudspeaker to convey audio messages remotely, and integrating a sound pickup device.	This invention is meant to help control and track the movement of the dog, allowing bi-directional communication between the loudspeaker and the dog when the location sensors indicate the dog is outside a user-set area. The proposed design uses a proximity sensor to detect nearby people, not position and Bluetooth modules to convey information to the owner.
US11647733B2	"Animal wearable devices, systems, and methods" is a device and method designed for training/controlling animals by integrating stimulating components and a computerized	This device also uses sensors and a stimulation device to convey a message remotely.	Like the “intelligent pet necklace”, this invention is mainly to help train and control a pet and is very general in its use. It is mainly a platform that incorporates wireless communication modules and allows the user to stimulate the pet using vibration motors on the wearable. The proposed

	controller to give signals to the animal.		design uses proximity sensors and speakers, of which there are none mentioned in this wearable design.
US20210120787A1	A "Smart animal collar system" that serves as a pet-monitoring system that can notify the user of substantial changes in the pet's health and its environment.	This wearable instrumented device for dog assistance describes the general method of using many types of sensors to monitor the state of a pet.	This patent describes a use case that most of the wearables in the market fit in which is health tracking. It uses temperature and heart rate sensors to track health information, which is not the purpose of the proposed design.
TWI619047B	A "Wearable device exhibiting capacitive sensing function and interactive robot pet" uses multiple touch electrodes integrated into a fabric.	This wearable instrumented device can detect human touch.	This invention responds to user touch gestures onto the instrumented fabric. The proposed design is designed to prevent contact, so there should be no touching involved.
US11569789B2	"Compensation for ambient sound signals to facilitate adjustment of an audio volume" discusses wearable computing devices that can characterize ambient sound to adjust the volume of an output speaker.	This method uses of some type of sound level sensor to automatically adjust the volume level of a speaker	My design only needs to recognize ambient noise level whereas this patent does characterization of the input sound signal. The device does pattern matching to an acoustic database to determine output behavior.

Beyond patented technologies, there are devices in research and commercial sectors that share similarities with the proposed design, albeit serving different purposes. For instance, the Sunu Band is one of many commercially available devices that employs ultrasonic sensors for proximity detection and communicates feedback via vibrations for visually impaired individuals. Magnetic field proximity sensors have also been used to detect interaction [8, 9] but necessitate large transmitter and receiver coils, making them less ideal for wearables as both parties must possess one. Furthermore, proximity sensors integrated into a service dog harness are being used in research [10], both ultrasonic and capacitive, but their purpose is for short range (<3 cm) detection of the service dog's own gestures.

Relevant Sensor Technologies

When integrating a proximity sensor into a wearable device, several types of technologies can be considered, each with their unique advantages and drawbacks. Inductive sensors, designed to detect metallic objects, and magnetic sensors, including Hall Effect sensors, are not suitable for detecting human presence, a key requirement for this application. Optical, infrared, ultrasonic, and radar sensors could be triggered by any object, resulting in a high number of false triggers in this application. There are other technologies, like those based on vision or LiDAR, that could excel in reducing false activations, but their complexity, specialization and current high cost make them less feasible for integration into this product.

Contrastingly, capacitive sensors emerge as the optimal choice due to their affordability and low power usage, coupled with their ability to be incorporated into a robust wearable interface. Their sensitivity to the human skin makes them particularly effective in detecting the presence of an approaching human hand. These sensors offer a reasonable sensing range that can be tailored to specific needs and can detect objects without physical contact. Consequently, capacitive proximity sensors are deemed the most suitable for this application.

Commercially available capacitive proximity sensors, however, are often unsuitable for wearables due to their metal housing, cylindrical shape, and highly directional nature. They also have a short sensing range, with an upper limit of 60 mm [11]. Yet, recent research in this field, driven by the COVID-19 pandemic and Human-Robot Interaction safety applications, has seen promising developments. For example, 'Graphene-Based Tattoo Sensor for Proximity Sensing' offers high sensitivity, flexibility, and a detection range of up to 20 cm but slow response and recovery time [12]. Other technologies combine inductive and capacitive technologies into elastic substrates to create conformable proximity sensors that can detect a wide array of materials and adhere well to curved surfaces [13, 14]. Some materials such as CNT-reinforced TPU as well as printed electrode arrays on plastic foil offer great flexibility and wearable integration, but require bigger footprints for comparable detection range [15, 16]. Inkjet printing is also widely studied as a way to create open-capacitor layouts in flexible materials, with the benefit of being relatively inexpensive as well as easy to iterate, scale, and manufacture [17, 18].

In addition, to measure ambient noise levels and dynamically adjust speaker volume, common low-cost microphone modules use electret condenser microphones and MEMS microphones. Electret condenser microphones are larger and more fragile, making them less suitable for this wearable application. On the other hand, MEMS microphones are extremely compact and robust, with significantly lower power consumption and vibration sensitivity which is very important for this application. The size as well as the physical robustness of MEMS microphones make them ideal for this wearable application over the electret condenser microphone.

Preferred Design

The preferred design for the wearable device to prevent unwanted petting of service dogs will incorporate two main sensors: a proximity sensor and a sound level sensor.

For proximity sensing, the preferred design will incorporate the Skin-Type Dual Proximity Sensor, a combined inductive-capacitive sensor as detailed in the paper "Skin-Type Proximity Sensor by Using the Change of Electromagnetic Field" [14]. This sensor is chosen for its flexibility and lightweight nature, making it suitable for integration into a wearable device. It demonstrates sufficient sensitivity on moderately curved surfaces and provides effective shielding from the rear side, with a substantial detection distance range of up to 30 cm. The sensor operates on a combined sensing principle of inductive-capacitive proximity sensing, enabling it to detect both conductive and non-conductive objects. However, the ratio of capacitive to inductive electrodes can be adjusted to enhance sensitivity towards human skin. The STPS can be fabricated in various dimensions and shapes, with smaller sensors offering higher sensitivity but a smaller sensing range. A 40-mm sensor, which fits ideally into the size constraints considering the expected size of a service dog harness and head size, could detect an object at 200 mm with high sensitivity of around 0.5 to 1.2 change in impedance (Ohms) per millimeter, a measurable change.

The sensor's performance has been experimentally validated and analyzed under different mounting configurations that are similar in curvature to my application. An isolator layer and a conductive fabric layer are used to shield the backside of the sensor with a 98% effectiveness, while maintaining an overall thickness below 3 mm. Given its flexibility and lack of moving parts, this sensor offers great durability that most other proximity sensor technologies lack. The cost of the STPS is not explicitly stated in the paper as the sensor is not in production, but the material cost should be comparable to similar multilayer sensors, with a generous estimate of $50 per unit once in medium/high volume production.

For the sound level sensor, I will use the SPH0645LM4H microphone, a low power MEMS microphone with I^2S digital output. The relevant specifications for my application include a high Signal-To-Noise Ratio of 65 dB as well as a low typical current of 600 μA. This microphone has a mostly linear frequency response in the range of 50 Hz to 12 kHz, where a majority of the expected ambient noise's frequency range is. The acoustic overload point of the microphone is around 120 dB SPL, which is above the expected typical ambient noise of 20-90 dB for this application. As an omnidirectional microphone, placement near a central location in the wearable should give us the best reading of ambient noise level. The operational temperature range covers any expected temperature range a service dog is exposed to and reliability testing including vibrations with peak accelerations of 20G in all axes shows that this microphone is robust enough for the product expected use [19].

The SPH0645LM4H operates as an I^2S slave, and has a bigger bandwidth when operated with a higher clock frequency (range of 1 to 4 MHz). The microphone requires use of decoupling and RF filter capacitors for optimal operation as well as pull down resistors for connection to an I^2S master. However, the microphone is sold as part of Adafruit I2S MEMS Microphone Breakout board for around $6 per piece with the capacitors already included. This appears to be the most cost-effective method of obtaining this sensor, and the convenience of the breakout board connections facilitate prototype development.

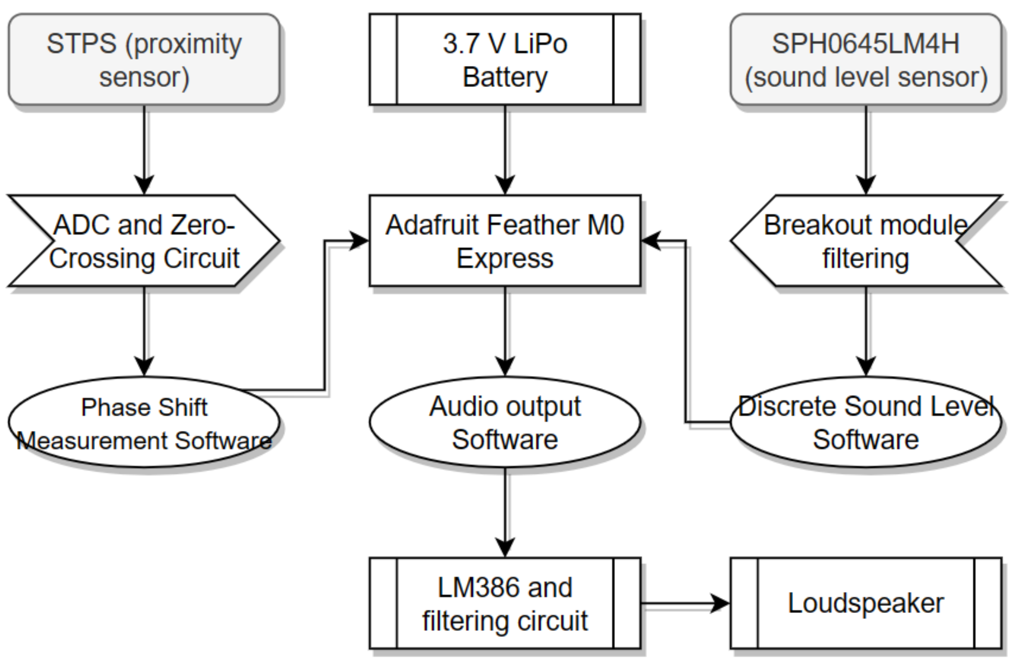
Given the need for an I^2S master, an excellent choice of a microcontroller to tie this product together is Adafruit's Feather M0 Express. This board is small, can be powered and distribute power from a single cell 3.7V battery, can do I^2S communication as well as read analog inputs from the proximity sensor and manage the volume control of the speaker by intermittently reading the ambient noise level and outputting a 16-bit, 44.1 kHz WAV audio file stored in its Flash storage to a speaker module. This board can also manage the charging of its attached battery. The cost is around $20, and its debugging accessibility would be of great use during sensor tuning and product development.

Outline of system electronics

The main components of the system electronics are:

- Skin-Type Dual Proximity Sensor: Estimated at $50 per unit, is the main sensor for detecting proximity. It connects to the microcontroller for data processing, with measurements made via the microcontroller's ADC and a zero-crossing detector circuit for phase shift measurements
- SPH0645LM4H MEMs Microphone: Costing $6 per module, measures ambient noise levels and connects to the microcontroller through a breakout board.
- Adafruit Feather M0 Express Microcontroller: Priced at $20 per module, serves as the system's central processing unit. It processes data from the proximity sensor and microphone and controls the speaker system.
- Speaker System: Emits a message asking people to maintain distance from the service dog. The message is stored in the microcontroller and transmitted via the DAC0 output pin to a low-power audio amplifier, such as the LM386, and then to a speaker, which would need to be tested in real-world situations. The price of a simple speaker and LM386 is less than $10.
- Power Supply: A single cell 3.7V lithium polymer battery will be used to power the system. Approximate cost of $10.

The following diagram illustrates the interfacing of the main modules and software:



System Packaging

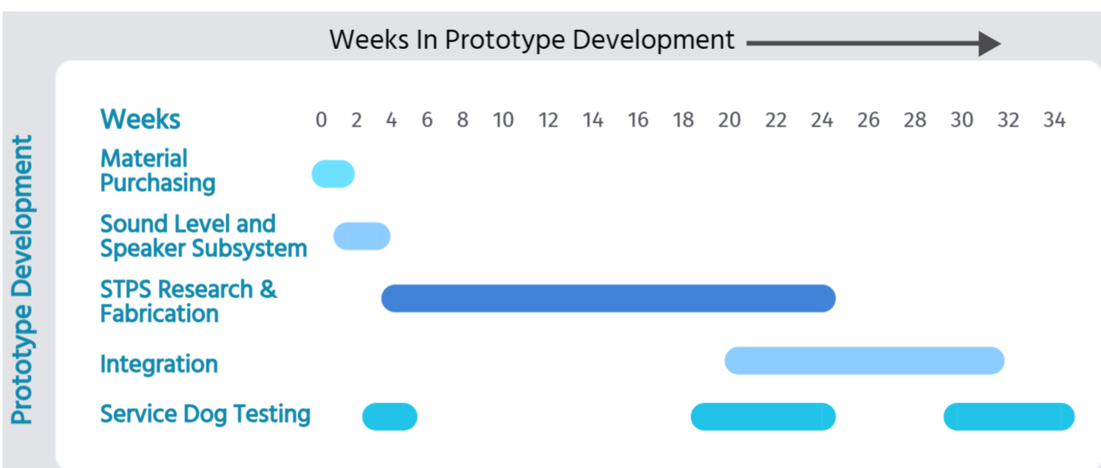
The packaging for this device needs to be robust, lightweight, and comfortable for the service dog. It should not interfere with service dog attire but rather complement it. In order to do so, all the electronics will be enclosed in a light and non-conductive waterproof fabric pouch that is attached to a dog harness of equipment through velcro mounting. This setup ensures the safety of the electronics and allows the sensors to effectively monitor their surroundings. This attachment will be divided into two sections to hang on opposite sides of the service animal, with the proximity sensor on the side opposite to where the dog's handler holds the leash since this is where people will often approach the dog from. The rest of the electronics will be placed on the opposite side. The device is symmetric so that it can be rotated for service dogs that walk on the right or left side of their handler.

The fabric pouch may slightly dampen the microphone's sound signal and reduce the proximity sensor's range, but these effects are mitigated by gain calibration and the sensor's extensive range, respectively. To further reduce false triggers, an insulating layer is added beneath the electronics, on the Velcro side in contact with the dog's harness. The device includes an opening for the Feather board's USB charging port and an external push button for activation.

While this design focuses on a harness add-on packaging, the same technology could be incorporated into head, neck, or torso wearables. However, further product development research would be required to optimize placement, size, and component selection.

Estimate of cost and time to build working prototype.

The estimated cost for the prototype includes the electronics, approximately $102, and the fabrication of the pouch, which requires fabrics costing around $10 per yard [20], and an insulation layer material, bringing the total to approximately $150. However, the chosen proximity sensing technology is not currently in manufacturing, which could make the fabrication process costly in terms of time spent researching the materials and iterating over tuning and fabrication. This could add up to hundreds of dollars, assuming testing and manufacturing equipment is available. Therefore, I estimate that prototyping expenses could reach around $1000 in materials and fabrication alone due to the unfinished state of the main sensor. Below is a prototype development chart that estimates around 7 months of development for a functioning prototype.



Once the fabrication of the proximity sensor is resolved, the product could be made significantly less expensive by further integrating the chosen components into a standalone flexible PCB configuration. Instead of using separate breakout boards with the MEMS microphone, the Adafruit microcontroller board, the sound amplifier, and all other parts of the circuit, a PCB design containing only the necessary components could be built. Given that the Feather M0 is an open-source design, the required components can be extracted and the circuit simplified to a single board, which would significantly reduce the price and size of the electronics. With this change, the price of the assembled product could be brought down to roughly $100 altogether, making the device competitive with existing pet wearables, especially within the specialized market of smart service dog wearables.

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Appendix A: Motivation

The motivation behind this project stems from a project I got to work on last quarter in ENGR210: Perspectives in Assistive Technology. My group and I worked with Abby, a student, artist, designer and clinical social worker with multiple disabilities, including a mobility challenge and a visual impairment. The issue that my proposed product tries to address is one that Abby encounters often when people try to interact with her service dog, Nathan, as she is busy checking out at the grocery store or doing her schoolwork in the park. Due to time and experience limitations, our project did not integrate any sensors but rather consisted of a bulky and heavy remote controller that used a raspberry pi storing pre-recorded messages that could be played over bluetooth on an external speaker when Abby pressed a button, as pictured below.

Although Abby was very happy with the product, we knew that there were many issues with the design that we could not address: the need for the user to be aware of when to press the button as well as unreliable bluetooth connection, fixed output volume, and short battery life significantly decreased the usability of the device. Nonetheless, Abby has shared the product in multiple disability conferences since, and it is now a finalist student project at the 2023 RESNA (Rehabilitation Engineering and Assistive Technology Society of North America) Annual Conference. When presenting the device to the service dog organization that trained Nathan and has trained thousands of service dogs across the country, they wanted to know when the device would be available for purchase! This is evidence that a product like the one proposed in this paper would help solve a big issue in the service dog and handler community.