Laboratory # 2

ECE:4880, Principles of ECE Design, Fall 2019

Introduction

This lab involves an important problem that frequently arises in capstone projects: dealing with noisy sensor data. A naïvely designed system that is built and tested assuming perfect signal inputs cannot be trusted to work reliably in practice. In this lab, we will look at an example of such an application where we need to design a system that observes a physical variable predictably and reliably even when the signal of interest is mixed in with various disturbances.

Problem Statement

We will design and build an "electric eye" light beam-interrupter safety system. The system consists of a transmitter that projects a beam of light onto a receiver (see Figure 1). When an object physically obstructs the beam, a small buzzer sounds (or a warning light is powered on). When the obstructing object is removed, the buzzer stops.

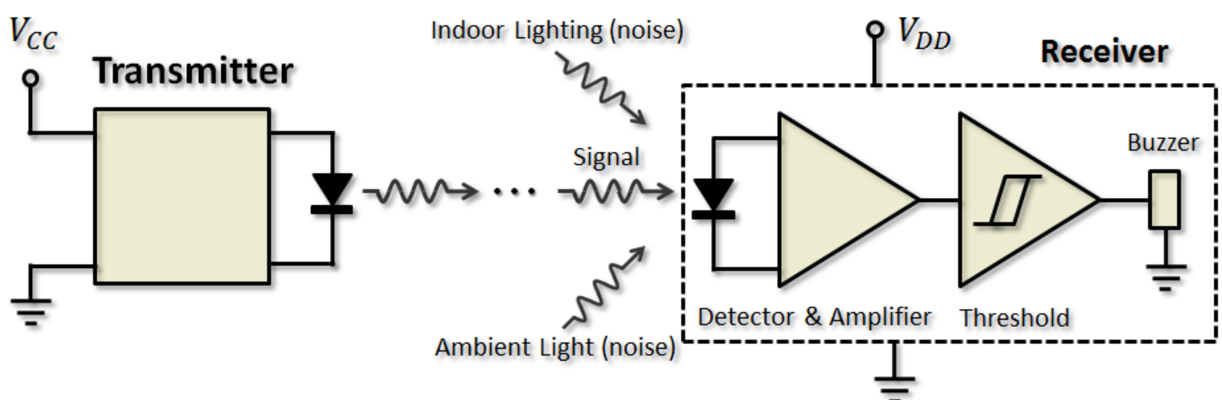

Figure 1 An "electric eye" light beam interrupter safety system.

Figures 2 (a) and 2 (b) show example applications of electric eye safety systems. When the garage door is closing, and the beam is interrupted by an object, the garage door stops, and then opens. Beam interruption is also widely used in industry, often in the form of so-called *light curtains*. The light curtain can be a sheet of light or several beams that surround dangerous parts of a machine as shown in Figure 2(b).

Figure 2 (a) “Electric eye” for a garage door opener. (b) A light curtain in an industrial setting.

Design of such a safety system requires careful consideration of several factors. For example, in a garage-door application, an IR beam, invisible to humans, is preferable. However, in a factory environment, it may be preferable to have a visible light curtain.

Possible Design Approaches

In all applications of an electric eye safety system, the receiver must work reliably over a range of ambient light levels. Often, it is necessary to ensure that the system functions in the presence of artificial room lighting, or nearby light sources such as desk labs and computer screens.

In the garage door application, the distance between transmitter and receiver, combined with misalignment often result in quite low signal levels at the receiver. One cannot solve the problem by simply increasing the intensity of the transmitter light beam, perhaps using a laser diode, since this may become a vision hazard. Simply amplifying the signal at the receiver is not an option either: the photodetector at the receiver sees the beam, but also sees fluctuations in ambient light and other light sources. If we think of the beam as the signal and the other light sources as noise, we can say that the signal-to-noise ratio (SNR) at the receiver is poor. Increasing the amplifier gain increases both the desired signal and the noise, with no improvement in the SNR; in fact, any practical amplifier will have a noise figure greater than unity, which means that the SNR is actually degraded by the process of amplification.

It should be clear from this discussion that that we need is a way of *separating* the signal of interest from the various noise signals. We can think of several possible ways of doing this.

- **Optical filtering.** If we choose an infrared LED at the transmitter, we can make the receiver robust to changes in ambient lighting, by using photodetector that is insensitive to the shorter wavelengths of light in the visible spectrum.
- **Electronic filtering.** We may process the raw received signal from the photodetector to suppress the effects of noise. For example, we may follow the photodetector output with a unity-gain buffer with a capacitive load. Such a circuit functions as an *integrator* that smooths out the received signal so that the system responds only to changes in the *average* lighting level, thereby suppressing rapidly fluctuating noise signals.

- **Software filtering.** Another alternative is to perform the integration operation described above in software rather than hardware by digitizing the photodetector output and processing the samples in a microcontroller.
- **Modulation.** A more sophisticated variant of the smoothing filter is a *matched filter* that allows us to selectively look for signals that fluctuate in a specific way. The idea is to gently modulate the LED at the transmitter, e.g., by using a timer to toggle the LED on and off e.g. every 2 milliseconds, and then tune the receiver to look for periodic variations in light intensity. In the above example, such a matched filter can be approximated by a *bandpass filter* tuned to 500 Hz (or a small multiple of 500 Hz). Again, such a filter can be built in hardware (a high-Q LC resonator tuned to 500 Hz), or in software.

The above methods all have advantages and disadvantages. In practice, the best approach may be to use some combination of these techniques in some combination of hardware and software.

Lab Requirements

You are provided a prototype of an electric eye safety system. In this system, the transmitter uses a 555 timer and a LED driver circuit to generate a modulated transmit beam. You are also provided a prototype receiver that uses a microcontroller to detect changes in the output of a photodiode.

The prototype receiver provided to you works reliably under low levels of room lighting. Notably it fails when the receiver is exposed to a powerful incandescent lightbulb. Your task in this lab is to design and build a receiver that will work reliably under as many different lighting conditions as possible. In addition, we want to add a remote SMS alert feature to the device. Specific requirements are as follows.

- Your receiver must work at least as well as the prototype receiver. Specifically, under low-light conditions, it should not have a measurably worse rate of false positives or false negatives compared to the prototype.
- Your receiver should work reliably in the presence of a 100 W incandescent light bulb and/or direct sunlight. As noted earlier, the prototype receiver fails under this condition. A slight performance degradation (e.g., a slightly increased latency) compared to low-light conditions is acceptable. However, the latency should not be so large as to make it unsuitable for use as a safety device.
- Every time the transmitted beam is interrupted, an SMS alert should be sent to a cell phone. The SMS message should include a time-stamp in the format “Critical safety event at HH:MM”, where HH is in the range 00 to 23, and MM in the range 00 to 59. The phone number for receiving these alerts should be hard-coded into the system. For demonstration purposes, you can choose any convenient phone number for your device.
- You will demonstrate your receiver using the existing prototype transmitter in the lab. You are not allowed to modify this transmitter in any way.
- The components used in the prototype transmitter and receiver will be provided to you (including the source code for the microcontroller), so you can construct replicas of the system for yourself. You will also have access to the prototype transmitter in the lab. You are expected to design and conduct experiments to characterize the behavior of the transmitter as needed to build a

compatible receiver. The design of such experiments and your observations from them are an important part of this Lab and should be carefully documented in your lab report.

- It is ok for your receiver to be based on the design of the prototype receiver i.e., you can choose the design of the existing prototype as a starting point and make modifications to it to improve performance. It is also fine to redesign the receiver from scratch.
- Your receiver should not have an abnormally large size or weight or other physical characteristics that may prevent it from being a reasonable replacement for the prototype receiver. In particular, you should be able to conveniently place it on the lab bench for your demo.
- It is acceptable for your receiver to be connected to a PC e.g. for the purpose of generating the SMS alerts. However, keep in mind the space and size limitations noted above. For instance, you need to protect against the possibility of cables attached to the receiver causing physical movements that affect the alignment of the photodiode.