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A comprehensive analysis of different types of proximity sensors in wearable electronic devices

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Abstract. As the technological world has developed exponentially in recent decades, wearable electronics has been a growing industry in both size and significance. Sensors play an important role in these electronics, but research was rarely done on how different sensors play this role and serve different purposes. Thus, this paper focuses on the characteristics, pros and cons, and potential application on wearable electronics of different commonly seen proximity sensors. Namely, infrared sensors, ultrasonic sensors, and binocular vision. The research is done by analyzing different past papers and studies, piercing this information to gather to gain a comprehensive analysis and conclusions. The study reveals the vastly different characteristics of different proximity sensors and their different advantages and disadvantages displayed due to their diverse characteristics. The study also revealed potential applications of different sensors on wearable electronics. It is reasonably induced, from this study, that wearable electronics should adapt to use the most suitable proximity sensor and even use more than one type of sensor to tact the disadvantage of each to maximize its function.

Keywords: Proximity Sensors, Infrared Sensors, Ultrasonic Sensors, Binocular Vision, Wearable Electronics.

1. Introduction

Proximity sensors are everywhere: A door opens when people come near, a car starts buzzing when parking or a robot can run by itself. All the above complex and ingenious functions can be realized thanks to proximity sensors' various inventions and applications. As the industry started to grow and technology got more and more advanced and delicate, the growing demand for proximity sensors with higher precision and portability started to expedite. For example, according to a study conducted in 2022, the global wearable technology market reached $61.3 billion, with the application of consumer electronics, healthcare, enterprise and industrial applications, and other applications [1]. In these applications, proximity sensors take an indispensable role in realizing some of their function, especially for those with accessibility demands. In the preceding analysis, the researcher will introduce four types of commonly used proximity sensors, analyze their pros and cons, and make an overview of the application of proximity sensors in wearable electronics.

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2. Infrared Sensors

2.1. Mechanism of infrared sensors

Infrared sensors sense distance by receiving infrared wave intensity from nearby material, either passively or actively.

A passive infrared sensor (PIR) does not emit any infrared radiation activity from its apparatus by only receiving infrared wavelengths from the surrounding objects. PIR can sense anomalies in the infrared signal surrounding—specifically, heat—and report the change to the system promptly. A Passive infrared sensor realizes its function by having a pyroelectric component (metal and crystal), embedded in an external RLC circuit. PIR sensors respond to changes in heat, which then will send a positive differential change to the system and vice versa. A PIR circuit can detect the surroundings to see if there is any heated object that is traveling through its sensing area. For example, a PIR would work perfectly when it comes to detecting animals and humans. Moreover, passive infrared sensors can also be used as thermometers to determine the approximate temperature of the surrounding object (which is also frequently used for health monitoring purposes). Passive infrared sensors are the most widespread form of IR sensors among all the same kinds [2].

On the other hand, the active infrared sensors work with a different mechanism. The active infrared sensor, like a radar, actively emits electromagnetic radiation (infrared radiation) and detects its returning signal to determine the position of the targeted object. Active IR sensors work in pairs as a photo-coupler: They pair up as an Infrared LED and an Infrared photodiode. The IR LED emits infrared radiation to the destinated object, while the IR photodiode catches its returning radiation. The system will then decide the distance the object is from the sensor by analyzing the returning intensity of the infrared sensed by the photodiode. The pair will work together only emitting/sensing one wavelength of IR to make sure the pairing is accurate.

2.2. Pros and cons of infrared sensors

Infrared sensors have various advantages over other forms of proximity sensors on the market. First, due to the rapid nature of electromagnetic waves, infrared sensors can provide information with a very short response time. The fast response can bring significant benefits, especially, to robotics and autonomous motion-detecting technology as it can provide almost real-time data. Second, the production of pyroelectric components, infrared LEDs, and photodiodes is not expensive. Thus, IR sensors come with a relatively cheap price. This benefits industries or companies that are demanding sensors with higher affordability. Third, IR sensors provide information from conditions that are not visibly available to human eyes. Specifically, nighttime and night vision since IR sensors only sense infrared radiation.

However, infrared sensors also have various critical deficiencies over other forms of proximity sensors this paper covers. First, infrared sensors can be very easily distracted in complicated environments. For example, in an environment containing an overly hot object, the sensor can be overexposed to this singular object and lose the sensitivity to sense the desired object. Moreover, due to the uncertainties in the angle of the radiation emitted and incident into the sensor, the distance to the object and the voltage response from the infrared sensor is not linear, this could result in some impreciseness when sensing distance. Lastly, due to its reliance on heat sensitivity, users must make sure that there are no factors in the circumstance that can hinder the transmission of heat from or to the infrared sensor. Things such as light, dust, smoke, mist, vapor, etc. can all act as factors that can block the transmission of infrared radiation. These factors, when emerge in the detecting surroundings, will directly hinder the effectiveness and sensitivity of the infrared sensor. Thus, the infrared sensor’s limitation on its working surroundings might prevent it from being applied in areas that potentially need distance detection in harsh areas [2].

2.3. Applications of infrared sensors in wearable electronics

The fast-response nature of infrared sensor allows wearable electronics to realize different function that requires rapid response. According to Deutsche Telekom Laboratories, Germany, for example, infrared sensor arrays are applied to use as sensors in wearable electronics to detect surrounding hand gestures. Due to its fast response and accuracy when sensing objects that are actively emitting infrared radiation (such as a human hand), infrared sensor arrays can very easily detect human hand gestures and give real-time responses to their input. In this research, the researcher utilized this notion and sensed hand gestures to control the color palette on an iPhone. This technology, according to the German team, can be applied to wearable electronics such as watches, bands, and pendants [3, 4].

3. Ultrasonic Sensors

3.1. Mechanism of ultrasonic sensors

Differing from the infrared sensors, the ultrasonic proximity sensors (US proximity sensor) use ultrasound frequencies—frequencies above the range that can be heard from human years—to determine the sensor's distance from an obstacle or an object. An ultrasonic transmitter in the US sensing apparatus will emit an ultrasonic sound wave at a certain frequency [5]. The apparatus that transforms the digital signal of sending away ultrasonic waves to an analog ultrasonic wave that vibrates on a material is called a transductor. A transductor is a device for controlling alternating current and it turns the digital alternating current with a certain frequency of sound. The frequency used for ultrasonic sensors varies. But, for example, the frequency used commonly in car parking radar is often 48kHz [6]. After the transducer emits the wave, the ultrasonic wave will then be transmitted to the targeted object, and bounce, or in other words echo back to the US sensing apparatus. A receiver will then pick up the sound transmitted and received by the ultrasonic receiver of the apparatus. Because sound waves travel much slower (at 340 m/s), the system will record the Time of Flight (ToF) to determine the distance of the object from the US sensing [2]. For example, if an object is 1 meter away from the sensing apparatus, the time it would take for the ultrasonic wave to travel to and back from the object would be around 5.9 ms, and if the sound took 35.3 ms to travel, then the object is approximately 6 meters away.

3.2. Pros and cons of ultrasonic sensors

Ultrasonic proximity sensors have various advantages over their counterparts, but they also display deficiencies that their competitors might not encounter. On one side, US proximity sensors offer a considerably accurate margin of error in their sensing results, when compared to the infrared sensor. The ultrasonic sensors can sense distance up to the precision of 1 centimeter in a distance of up to 6 meters [2]. The preciseness gives possibilities when applying ultrasonic sensors to products that require relatively accurate results. Moreover, ultrasonic proximity sensors are also advantageous at map building of obstacles in complicated circumstances and environments. Since sound is emitted as a form of wave, they get back to the sensor after they already scanned through an area. A study published in IEEE by Marioli et. Al. demonstrated a simple map scanning and building method using ultrasonic sensing technology [5, 7]. Lastly, unlike infrared sensors, ultrasonic sensors are almost completely insensitive to the potential factors in the common surroundings that can very easily disturb the infrared sensor, such as light, dust, smoke, mist, vapor, etc. This empowers ultrasonic sensors to work in special conditions that other sensors such as infrared and binoculars cannot—these conditions might also be very common in people's lives or might be very common in hazardous conditions [8].

On the other hand, ultrasonic sensors also display various disadvantages. Firstly, the transmission of sound waves requires a certain amount of time. For example, referring to the calculation made earlier in this passage when sensing an object that is 6 meters away, the sensing process needs about 35 ms to discover and record the number. This time is significant compared to other sensing methods, and it drastically increases the response time of the machine or system to changes in distance. This disadvantage refrains robotics or machines that require fast response time to changes from using US proximity sensors [2]. Moreover, like infrared sensors, the US proximity sensors can sometimes also be prone to noise and disturbance from the surroundings. Other daily objects that we encounter in daily life that use ultrasonic technologies, such as the speed gates for traffic, or the proximity sensors when you

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are parking a car, might as well either block or disturb the distance sensed from the real distance. This disadvantage might bring concerns about application of the ultrasonic sensors in daily life.

3.3. Applications of ultrasonic sensors in wearable electronics

Just like many other sensors, ultrasonic is a relatively effective way of detecting distance from obstacles and can indeed act as a proximity sensor on wearable electronics quite effectively. Ultrasonic sensors can be made into a considerably small size. A Taiwanese group invented a pot-like sensor using ultrasonic technology and concatenated the size into only 7.5 mm in radius (15 mm in diameter). A proximity sensor of this size could be contained very well in wearable electronics and given its precision, can be very effective in giving precise distance readings when encountering a close or intermediate-close object [6]. As mentioned in the 'Pros and Cons' session, ultrasonic sensors have great stability when there is a factor disturbing the transmission of electromagnetic waves. Thus, ultrasonic sensors are a relatively reliable way of sensing distance on wearable electronics for people with accessibility issues. Other than wearable electronics that emit ultrasonic waves to the outside, a research group in Canada and Saudi Arabia also uses ultrasonic technology that emits a sound wave to the inside to detect the extension and compression of muscular tissue. Here, the mechanics of ToF acts similar to a strain gauge. When the tension of the muscular tissue changes, the ToF changes, and thus the movement is measured. This application could be used for real-time hand gesture detection, for people with accessibility needs [9].

4. Binocular Vision

4.1. Mechanism of binocular vision

Binocular vision, essentially, is a proximity-sensing mechanism that is based on the application of visible lights. Robotic binocular vision features a similar perception of 3-dimensional space from 2-dimensional images, like the mechanism of the human eyes. Binocular vision features 2 cameras separated by a small amount of distance. When observing a 3-dimensional object, the difference in distance between the 2 cameras will induce a slight deviation in the vision of the cameras, which is represented as the unmatched of pixels in the picture. The pixels are represented by matric, and then the differences are calculated and derived from matrixes. Then, using the triangulation principle, the device would be able to model the object and calculate the distance from the device to the object. Utilization of binocular vision requires preceding calibration, often using a checkered board [10].

4.2. Pros and cons of binocular vision

Compared to other sensing methods, binocular vision has its advantages and challenges. On one side, binoculars indeed have various advantages over other proximity detection methods that other apparatus might not have the chance to achieve. To start with, binocular vision enables the device to see and analyze a wide range of 2-dimensional features. Although binocular vision, in its essential, also realizes its function by using electromagnetic waves (visible lights), the binocular feature allows it to reconstruct a three-dimensional image, and then analyze its depth [11]. This is a huge advantage compared to the infrared and ultrasonic detectors, which can only give a one-dimensional value of distance perpendicular to the sensor. This creates huge advantages for the binocular vision to be applied to realize more advanced functions.

However, binocular vision also has its huge downsides compared to infrared and ultrasonic proximity sensors. To start with, binocular vision requires a stricter working environment than both infrared and ultrasonic sensors. Since binocular vision works completely dependent on visible light, what humans cannot see, binocular cameras can also not see. That is to say, the whole binocular camera notion will not work under fog, mist, smoke, or even too low or too high light intensity on the targeted object. This gives binocular vision a strict working environment and limited application scope. Second, in cooperation with two HD cameras, binocular vision is much more costly than the two alternatives

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mentioned. In this case, proximity detectors based on binocular vision become a costly but sophisticated alternative.

4.3. Application of binocular vision in wearable electronics

Binocular vision proximity sensors may have many benefits when applied to wearable electronics. However, due to its novelty and relatively low portability, there is not much such product currently on the market for analysis. One potential field of application on wearable electronics is to use machine binocular vision as a replacement for human binocular vision (our eyes) to help visually impaired minorities. A Chinese study from 2018 proposed a solution by using the features of binocular vision sensing to assist visually impaired users. In this study, the visual image is collected through binocular cameras, uploaded to a convolutional neural network for analysis, and then the object detected by the neural network is returned to the assisted user in real time. In this process, binocular proximity sensing plays an important role in analyzation as it enhances the accuracy of the stereo image collected and provides users with a more reliable response [12].

5. Conclusion

In conclusion, this article reviewed three types of proximity sensors, including infrared, ultrasonic, and binocular vision sensors. Their mechanism varied from receiving radiation, ToF, or perceiving differences in pictures. Each sensor has its advantages and disadvantages, and potential applications in wearable electronics were introduced. IR sensors are fast, cheap, and have night vision capabilities but are affected by surrounding disturbances. Ultrasonic sensors are precise, have a wide range of vision, and can work in harsh environments, but have slow response times and are prone to ultrasonic interference. Binocular vision sensors can render 3D scenes but are costly and sensitive to harsh conditions. They can also work with and assist visually impaired users. All in all, proximity sensor plays a very important role in wearable electronics, but all of the sensors have their pros and cons. Consumers should make appropriate choices suitable for their products when choosing their sensors. The above passage could work as a comprehensive analysis that could potentially become a reference to this decision-making. It is also necessary, in the future, for the industry to explore not only on using a singular technology but also focusing on combining different technologies (in this case, sensors) to maximize their functionality.

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