Technical Article

Gesture detection:
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Gesture detection technology in human-machine interfaces is today familiar to users of games consoles such as Nintendo’s Wii and Microsoft’s Xbox. Here, it is capable of detecting any kind of movement with great precision and at a distance of several metres. In this guise, the technology performs impressively – but it is expensive and power-hungry.

The Wii and Microsoft’s Kinect have revealed, however, that people like and quickly adapt to gesture as a means of controlling computing devices. This article now describes a proven way to implement gesture detection using a proximity sensor (the TSL2772 from ams) and three IR LEDs. In contrast to the gesture detection technology in games consoles, this new reference design from ams has a low bill-of-materials (BoM) cost and consumes little power.

Indeed, since many mobile phones already use a low-power proximity sensor to determine when the user has placed the phone next to their head (triggering the system to turn off the display and touchscreen), gesture recognition can be added to these devices for little more than the cost of two additional IR LEDs.

The reference design in this article supports the detection of approximately linear, continuous hand movements from one position to another, at up to 10cm distance from a proximity sensor. Once a gesture has been recognised by the sensor, in software it can be tied to commands that, for instance, turn on the device, raise the volume of a loudspeaker, turn a page of a document, or navigate through a menu.

Where gesture detection enhances a device

Gesture detection is an ideal technology to use when a user cannot or should not use a conventional keyboard, mouse or touchscreen. In medical applications, gesture detection enables healthcare professionals to control a device without the risk of picking up contamination from a keyboard or touchscreen. In an industrial environment, it lets an operator control a computer with gloved hands.

There are today several ways to implement gesture detection. Camera-based designs require an image sensor, complex software, a high-specification processor and a large power budget. Laser-based systems are expensive and potentially power-hungry, and can pose eye-safety risks.
By contrast, the case for designs using IR-LED proximity sensors is that they are low-cost, effective and simple to design. They also consume little power. While they do not offer the range or precision of other technologies, they provide good enough performance for many applications at a fraction of the cost and power.

The gesture system described in this article uses a single proximity sensor, three LEDs and a microcontroller for controlling FETs and making simple calculations. Excluding the MCU, this system consumes around 0.007W. By contrast, Microsoft's Kinect, with two cameras, a laser and a high-speed image-processor ASIC, consumes around 10W.

The BoM cost comparison is also worth noting: for the IR LED-based reference design the cost is around $3 in low production volumes; the Kinect's BoM is estimated at $56 (according to a teardown analysis reported in EE Times). If simple gesture recognition at short range is required, the cost and power advantages of the IR-based approach are overwhelming. It should be said, at the same time, that any device that includes a camera for other reasons can also use it to implement gesture detection. In this case, an IR LED-based system makes sense only if the designer needs to save power.

**What a proximity sensor measures**

In a system using the TSL2772 proximity sensor from ams, the IC itself pulses current through an LED that emits IR light (the TSL2772 proximity sensor is sensitive in the 650nm to 950nm region). This light reflects off an object (in this case the user's hand) back to the proximity sensor. The demonstration board shown in Figure 1 shows three enabled IR LEDs circled in red, a configuration suitable for a rectangular display screen. (The other three LEDs shown on the board, not circled, are not enabled and do not support this gesture recognition application.)

The proximity sensor measures the reflected light intensity (not, as the name of the device might suggest, the distance from the reflector). Since the intensity of reflected light declines the further the reflector is from the light source, intensity is related to distance and may be measured in proximity 'counts' (see Figure 2).
Fig. 1: demonstration board for an IR gesture recognition system. The three enabled LEDs supporting the application are circled in red. The TSL2772 sensor is circled in blue.

Fig. 2: signal output from the proximity sensor on the ams demonstration board (in Figure 1) as a hand is moved over the board. A single IR LED is switched on.
Theory of operation of an IR-based gesture recognition system

While the intensity of the reflected IR light will vary depending on the skin colour of the user, the location of the peak is independent of the reflector, and this peak is a key characteristic used in the reference design.

The location of the peak signal can be approximated by taking the half-power emission angle ($\Theta_L$) of the LED (+/-20 degrees for the LED on the gesture board) and the half-power acceptance angle ($\Theta_S$) of the sensor (+/-60 degrees for the TSL2772), and constructing a triangle between them (see Figure 3).

![Figure 3: Calculation of the location of peak intensity for the reference design board](image-url)
The approximate location of peak intensity can be calculated as follows:
Location of peak intensity = D/sin(180°-ΘS-ΘL)*sin(90°-ΘL)*cos(90°-ΘS)

**Electrical and mechanical fundamentals**

A proximity sensor and one IR LED can determine an object’s presence in one region. By multiplexing between three IR LEDs, the user can detect presence in three regions.

By synchronizing the proximity sensor with the multiplexer, the microcontroller can assign the sensor’s stream of output signals to each of the three LEDs. This underlies the operation of the gesture recognition system: a linear motion of a reflector over the three LEDs will produce a sequence of three peaks in the proximity sensor’s signal (see Figure 4).

By passing the three proximity signals into a simple algorithm, it is then possible to extract the approximate velocity (speed and angle) of the reflector. The speed and angle data then enable a control program to decide whether the reflections sensed by the TSL2772 represent a sideways or up-and-down movement of a hand.

In the ams reference design, the three IR LEDs are laid out to form a right isosceles triangle with the sensor very close to the middle LED (see Figure 1). This emulates a gesture-sensing system located at the corners of a display screen; it also simplifies the mathematics.

![Gesture board output (top to bottom swipe)](image)

**Fig. 4:** output of gesture board as the user gestures from top to bottom
As the reader can see from Figure 4, the signal peaks occur at different times. The top LED peaks before the other signals, since the hand is moving from top to bottom.

Fig.5: gesture board showing overlaid x and y axes

Because the time of peak signal is independent of the reflector, the peak-to-peak times of the signals contain almost all the information necessary to determine velocity, when plotted against horizontal and vertical axes (see Figure 5).

The time difference between the peaks for the left and middle LEDs can be expressed as follows:

\[ TX = \text{TMID;PEAK-TLEFT;PEAK} = \text{time component in the x axis} \]

And the time difference between the peaks for the top and middle LEDs:

\[ TY = \text{TTOP;PEAK-TMID;PEAK} = \text{time component in the y axis} \]

Let the distance \( D = \text{location of the peak signal} \)

Speed of gesture = \( D/\sqrt{TX^2+TY^2} \)

Angle of gesture = \( \text{atan2}(TY, TX) \)
Note that the equations above are valid in the case of LEDs laid out in a right isosceles triangle, and \( \text{atan2} \) returns the angle of a vector given its components. From a theoretical standpoint this is all the reader needs to determine the speed and angle of a passing hand. In practice, the system continuously generates noise, which can be measured with no hand or reflector near the gesture system. An offset can then be applied to the proximity sensor’s output to eliminate the effect of noise (see Figure 6).

![Output after normalization and signals<4 cut off](image)

**Fig. 6: normalised proximity sensor output, eliminating the effect of noise**

The exact time of the peak might be ambiguous when the dataset does not contain a perfectly smooth set of points, but calculating the centroid (otherwise known as the centre of mass) provides an effective means of establishing a precise effective peak.

The designer can then take these calculated peak times and insert them into the speed and angle equations above. The algorithm then compares these values against a pre-set range of values that
define lateral and longitudinal gestures, and decides whether they represent a gesture or not, and if so, which kind of gesture.

The system may also be designed to recognise an in-and-out gesture, in which the proximity signal for the middle LED will saturate for a prolonged period (typically >300ms).

**Speed limit**
Tests on the ams reference board show that the system loses its ability to recognise movements at speeds above 2m/s. This is no impediment to its use as a gesture recognition system, since it is considerably faster than people would ordinarily expect to gesture. Faster gestures can be recognised by spacing the LEDs and sensor further apart.

**Conclusion**
The demonstration board shown in Figure 1 proves that gesture recognition can be implemented in a system containing just three IR LEDs and a single proximity sensor, the TSL2772 from ams. Carrying a BoM cost of just $3 in low volume, this design enables OEMs to enhance the user interface in applications that are poorly suited to the use of a keyboard, mouse or touchscreen.

A more detailed description of this application, including schematics, flow charts and code, is available online from ams at www.ams.com. Applications engineering assistance in the implementation of the technique described is available locally from ams sales representatives and authorized distributors.

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