OptoSkin: Novel LIDAR Touch Sensors for Detection of Touch and Pressure within Wave guides

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Abstract

We propose OptoSkin, a novel type of sensor for touch and pressure detection. It is based on direct Time-of-Flight (dToF) measurements of light propagated within wave guides due to Total Internal Reflection (TIR). It shows great potential for applications like robotic sensor skins for being compact, cheap and easy to fabricate.

1. Introduction

Touch sensors are ubiquitous among us (e.g. used as switches for turning on and off lamps, touch screens in mobile devices, etc.). Usually, touch sensors are based on capacitive and resistive technologies. Standard capacitive touchscreens rely on a precise grid of conductive electrodes, typically made of Indium Tin Oxide (ITO), which is fragile and difficult to apply on curved or irregular surfaces without compromising conductivity, which is crucial for touch detection. Opposed to these electrode-based sensors, new types of touch sensors that exploit light behaviour to detect touch and pressure have surged. We present the OptoSkin sensor [1], a novel system that is composed of multiple time-of-flight (ToF) sensors and a quasi-two-dimensional optical waveguide (Figure 1).

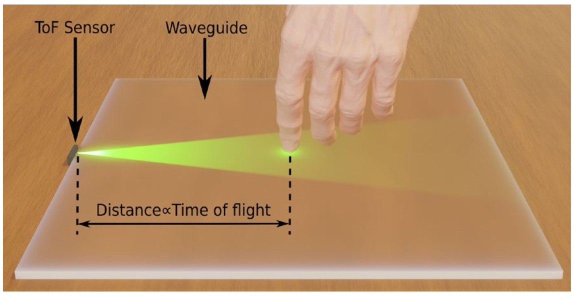

Figure 1. OptoSkin setup.

2. Sensing Principle

ToF sensors measure the distance between the sensor and an object by measuring the travel time of an emitted signal. Optical ToF sensors are composed of a light-emitting component and a photo-sensor component. We use direct time-of-flight (dToF) sensors that directly measure the travel time of the pulsed light with a single-photon-counting avalanche diode (SPAD). As a SPAD can measure the time of single events, the measurement must be repeated to be statistically reliable, outputting histograms of counted events along time. These histograms are processed to choose the time t_{ToF} associated with the round-trip time of the flight from the sensor to the object and the distance d is computed as

$$d = \frac{tToF}{2}c$$

where c is the speed of light.

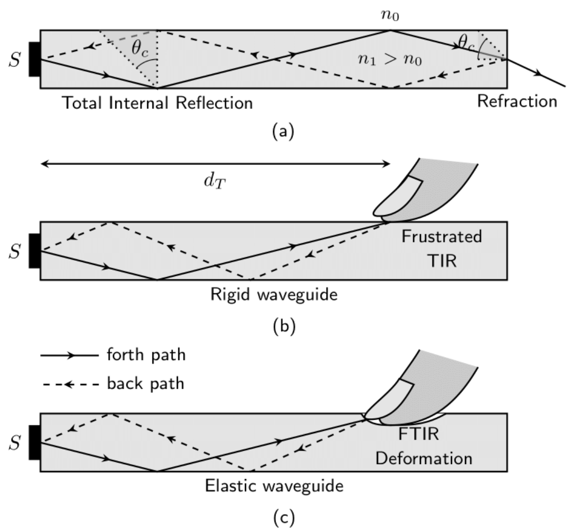

Figure 2. OptoSkin sensing principle diagram.

When light enters a medium with higher refractive index, it bends towards the normal of the surface due to refraction. Depending on the angle of incidence when exiting the medium, total internal reflection (TIR) might happen and light is completely reflected back into the higher refractive index medium, without refracting. Optical waveguides are physical structures that guide light inside by leveraging TIR. In the proposed OptoSkin setup, the dToF sensor is attached to the wave guide, light is propagated inside by TIR and reaches the end of the optical waveguide.

Part of the light is refracted outside and part is reflected back to be propagated back (Figure 2(a)).

When another medium comes in contact with the waveguide interface, like a human finger, it interferes with TIR and prompts light rays to refract and leave the wave guide. This phenomenon is known as Frustrated Total Internal Reflection (FTIR), and has been previously used in multi-touch screen sensing or force sensors. When the material inducing FTIR is partly diffuse, it will scatter light in various directions, making some of the scattered light reenter the wave guide and travel back towards the sensor. Distance to the touch point is calculated according to ttouch (Figure 2(b)). In addition, if the material of the waveguide is elastic, it is deformed on contact, changing its physical shape. In that case, the angle of incidence of the light, which previously created TIR, will be greater with respect to the normal at the locally modified surface, and might cause light to refract outside the wave guide. Similarly to before, if the material causing the deformation is partly diffuse it will scatter light back, reentering the medium and arriving back to the sensor (Figure 2(c)).

The touch location is reconstructed from the captured histogram, where touch is detected due to reflected light at the touch point because of FTIR. We create a sensor-centered likelihood heat map of touch by projecting the captured histogram on the surface of the planar waveguide, taking into account the angular coverage of the dToF sensor that depends on the Field-of-View (FoV) and Field-of-Illumination (FoI). Assuming a very thin wave guide, the measured distance values (d) and the angular coverage (θ) of the dToF sensor represent polar coordinates $P_{d,\theta} = (d, \theta)$. For a reconstruction of the likelihood heatmap, these values are transformed to cartesian coordinates $C_{x,y}$:

$$P_{d,\theta} \rightarrow C_{x,y} : x = d\cos(\theta), y = d\sin(\theta) .$$

3. Simulation

The sensing principle of OptoSkin has been evaluated initially through physically-based simulation, allowing us to demonstrate the sensing principle under perfect and controllable conditions. The waveguide materials are transparent, without scattering or absorption and the output histogram of the dToF sensor is simulated using *mitransient* [2], a modified version of Mitsuba 3 rendering software adapted for transient light transport. Simulations facilitate the investigation of OptoSkin configurations. For instance, Figure (3) shows the reconstructed touch by using multiple dToF sensors.

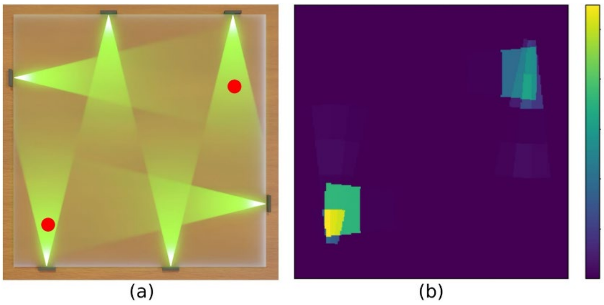

Figure 3. (a) Simulation and (b) tactile map reconstruction of two touches (red dots).

4. Demonstrators

We create three experimental setups to test the sensing principle in under real conditions:

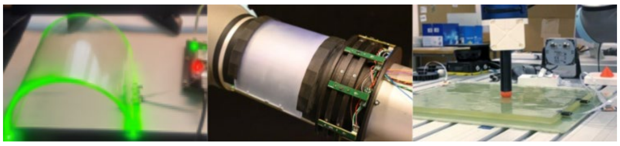

Figure 4. OptoSkin real demonstrators.

5. Conclusions

We have demonstrated the fundamental principle of OptoSkin touch sensor based on ToF sensors and quasi-planar optical waveguides through simulation and demonstrators. We have developed three different prototypes, each with unique features, to showcase the versatility and applicability of our approach. The key advantages of our proposed sensor is the electrode-free surface and the simplicity of the OptoSkin sensor, making it compact, cheap and easy to fabricate.

Acknowledgements

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References

[1] E. Bacher et al., "OptoSkin: Novel LIDAR Touch Sensors for Detection of Touch and Pressure Within Wave Guides," in IEEE Sensors Journal, vol. 24, no. 20, pp. 33268-33280, 15 Oct.15, 2024, doi: 10.1109/JSEN.2024.3443615.

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