DIFFERENT OPTICAL TECHNIQUES FOR SENSING OF FINGERPRINTS

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Abstract: Quite a few fingerprint sensors are on the market today and fall into mainly three categories: optical, semiconductor, and ultrasound sensors. Optical sensors are considered to have a high degree of stability and reliability. This article discusses various techniques in use in optical fingerprint sensors.

1. INTRODUCTION

Optical fingerprint sensors are usually based on total internal reflection of light. The principle of total internal reflection can be applied in two different ways to create a sensor. The first kind is an absorptive sensor and the second one is scattering-type.

2. ABSORPTIVE TYPE SENSORS

The finger is placed on the surface of a glass prism and light is incident through another face of the prism. The angle of incidence is greater than the critical angle and hence all of the light is totally internally reflected from the valleys of the finger. The ridges, however, absorb most of the light. This way the valleys appear bright and the ridges appear dark. This results in a high contrast fingerprint image. Such a sensor has been described by Caulfield et. al. in their U.S. Patent 3,716,301. It consists of a 45-90-45 degree prism which is illuminated from one of the smaller faces. Without the finger, the light is totally internally reflected at the hypotenuse surface and comes out from the other face. When the finger is in contact with the hypotenuse surface, the ridges absorb the light and the valleys reflect the light creating a high contrast fingerprint image which is captured by the camera. Fig.1 illustrates the geometry of the sensor.

This sensor, however, suffered from trapezoidal distortion which was later corrected by Bahuguna et.al. in their U.S. Patents 5,629,764 in 1997 by holographic means and then miniaturized in 1999 in U.S. Patent 5,892,599. Fig.2 illustrates the geometry of the sensor by Bahuguna et. al. It essentially consists of a 45-90-45 degree prism on which a special thin holographic grating is glued. The rays are incident through the hypotenuse surface and illuminate the finger which is in contact with the grating. The rays which hit the ridges are absorbed by the skin and the valleys totally reflect the light. The reflected rays are bent by the grating in a direction normal to the grating and finally exit through the other smaller face after totally reflected at the hypotenuse surface.
This way the image of the finger print appears parallel to the camera lens, as shown in the figure, thus eliminating the trapezoidal distortion. Also, since the distance from all object points from the camera is the same, the image is well focused.

U.S. Patent 5,650,842 by Maase et. al also describes an absorptive type of sensor using a telecentric camera system.

3. SCATTERING TYPE SENSOR

Again, like in the absorptive sensor, the finger is placed on the glass surface of a prism. The incident light, however, is almost normal to the finger. The viewing angle, in this case, is greater than the critical angle. Light from the ridges is scattered in all directions and is received by the optical system whose optical axis is inclined at an angle greater than the critical angle. The light from the valleys, in glass, is confined to a cone whose semi-angle is equal to the critical angle and hence is not received by the camera. This results in a high contrast image of the fingerprint; the valleys appearing dark in this case and the ridges bright.

Igaki et. al. (1992) came up with such a sensor which is free from trapezoidal distortion. In their method, the rays from the ridges are bent by a holographic grating and then collected by a lens as shown in Fig. 3.

This way the final image is projected normal to the camera. The image, however, is laterally shifted with respect to the actual finger and somewhat aberrated principally caused by the holographic grating. Additional optics is needed to correct the aberrations. Fig. 3 illustrates the geometry of the sensor.

U.S. Patent 6,324,020 by Teng et.al describes a sensor which uses a prism with reduced trapezoidal distortion and is shown in Fig. 4. Due to refraction, the image of the fingerprint is pulled toward the camera as
shown by the dotted line inside the prism. The inventors have selected various parameters such as the angle $\gamma$ of the prism, refractive index of the prism and the direction of viewing $\delta$ in such a way to make the distance from all points in the image plane, to the camera, to be essentially the same. This in turn reduces the trapezoidal distortion to a bare minimum.

\[
(n^2 - \sin^2 \delta)^{1/2}(\cot \gamma)(\sin \delta) + \sin^2 \delta = 1
\]

Where $n$ is the refractive index of the prism, $\gamma$ is the angle between the viewing surface and the surface touching the finger and $\delta$ is the angle which the lens-plane makes with the viewing surface.

Hamamatsu came up with a sensor using an aligned fiber optic conduit and is illustrated in Fig. 5. In this device, one end of the conduit is preferably cut at $45^0$. The finger is placed on the inclined face and illuminated from light sources around the finger. The scattered light from the ridges is transmitted to the other end which is attached to a CCD. Very little light from the valleys, however, reaches the other end. Some of it is reflected within the air gap and some of it is transmitted through the sides of the fiber and out of it. This way a high contrast image is formed. It should be noted that there is no lens between the finger and the CCD other than the conduit.

To capture the entire fingerprint a tapered conduit is taken with the wider end cut at $45^0$. A distinct advantage of a fiber optic sensor is that it does not need a lens for imaging. Moreover the resolution is only limited by the diameter of the fibers or the resolution of the CCD. Moreover it is quite compact and rugged.

**4. MINIATURE SENSORS**

The present trend is to miniaturize the sensor. Metz et. al. built a miniature sensor which used a holographic grating to direct the reflected rays from the finger onto a CCD without an imaging lens. Since total internal reflection was not used, the contrast is relatively weaker. Moreover because of substantial thickness if the substrate of the
grating, the sharpness of the image may not be as good.

More recently, Bahuguna filed a patent in 2008 (under examination) which uses total internal reflection in combination with an interference band pass filter. The laser diode sources illuminate the finger from the sides. The central wavelength of the laser diodes is lower than the band pass wavelength of the filter. It is a known fact that changing the angle of incidence shifts the band pass to the shorter side of the spectrum. In other words the band pass shifts to lower wavelength. Since ridges scatter light in all directions, some of the rays whose incident angles are a match for the shifted band pass will transmit through the filter. The laser diode wavelength is properly selected with respect to the band pass wavelength to achieve this goal.

The principle itself has been demonstrated in the lab using a camera. Technology permitting, the filter and the grating can be directly fabricated on the CCD as shown in Fig. 6. This would result in an ultra thin optical fingerprint sensor. Alternatively the holographic grating could be eliminated altogether leaving just the filter coating on the CCD.

REFERENCES