July 2020

Ambient Light Independent Depth Acquisition Using Switchable IR filter

Ping Tong Chu

Chung Chun Wan

Ambient Light Independent Depth Acquisition Using Switchable IR filter

ABSTRACT

Devices such as smartphones, tablets, etc. are equipped with cameras that have depth-sensing capabilities. The quality of depth acquisition in such devices is often limited by the cost, available physical space for depth-sensing hardware, and by the ambient light conditions in which an image is captured. This disclosure describes a depth-sensing camera system that utilizes a switchable infrared filter. In an IR-cut mode, used when ambient light is of sufficient quality, the filter allows visible light to pass through and cuts off IR. In an IR-pass mode, used in low light conditions, the filter allows IR to pass through while cutting off visible light. The camera system enables high resolution depth acquisition in arbitrary light conditions at low cost and with compact hardware.

KEYWORDS

- IR Filter
- Switchable filter
- Depth camera
- Depth acquisition
- Depth sensing
- Portrait mode
- Infrared projector

BACKGROUND

Many devices such as smartphones, tablets, etc. are equipped with cameras that have depth-sensing capabilities. Depth-sensing is used for applications such as facial recognition, capture of portrait mode images or video, augmented reality (AR) applications such as AR navigation and avatars, etc. The quality of depth acquisition for such applications is an important differentiator for such devices.

For mobile applications, it is important that depth-sensing technologies fulfill certain requirements. For example, the cost of a smartphone is an important user criterion, and it is important that depth-sensing be performed at low cost. Also, many devices have limited available space for depth-sensing hardware which requires that such hardware be compact. In some applications, e.g., portrait photography, a depth image is combined with a color image. The quality of the portrait image is higher when a high-resolution depth map is available. Users use their cameras in varying light conditions, and it is important that depth acquisition be functional under any light condition, including under low-light and strong ambient light situations.

There is no current depth-sensing solution that fulfills all the above requirements. There are multiple depth sensing technologies today, broadly categorized into (1) Stereo; (2) Time Of Flight (ToF); (3) Structured Light; and (4) Light Field, some limitations of which are described below.

1. **Stereo**: In stereo, a long baseline is required and therefore this technology suffers from a size issue due to available device sable space (size issue). Also, a dual-camera is required to compute depth, which adds to the device cost. Still further, if the cameras used in the stereo system are color cameras, the technology does not support low-light situations. Alternatively, two infra-red (IR) cameras and an IR projector can be used; however, such a system does not support strong ambient light situations in which the ambient light overwhelms the light from the IR projector.
2. **Time Of Flight (ToF):** ToF technology requires large pixels on the sensor, making the

resolution small, or necessitating that a large sensor be used which adds to the size and cost. Further, ToF techniques require projecting IR light to the scene and sensing the time it takes for the light to come back, which is imperfect in strong ambient light situations. Also, eye safety mechanisms may be required to ensure that the ToF depth sensing system is eye safe.

3. **Structured Light:** Structured light techniques suffer from similar issues as stereo. Further, the depth resolution obtained with structured light is limited by the density of projected dots. To achieve higher resolution, which requires higher dot count and a higher power laser, additional cost may be incurred, and further eye safety concerns may arise.
4. **Light Field:** In a light-field based system, a special sensor in which two or more pixels are grouped under one micro-lens is used. The sensor outputs multiple subframes, and a depth image is computed using the disparities of the subframes. This technique is low-cost, compact, and provides high-resolution depth data. However, since it uses a color camera, it does not work well under low-light situations.

DESCRIPTION

This disclosure describes depth acquisition techniques that are low cost, compact, high resolution, and work under arbitrary ambient light conditions. A color image sensor is also sensitive to light in the IR spectrum, e.g., 940nm. Although a color image sensor is also sensitive to IR, in a normal color camera, there is a IR-cut filter that eliminates IR light from getting into the sensor. This prevents the creation of a washout effect in the captured picture caused when both color and IR light get into the sensor.

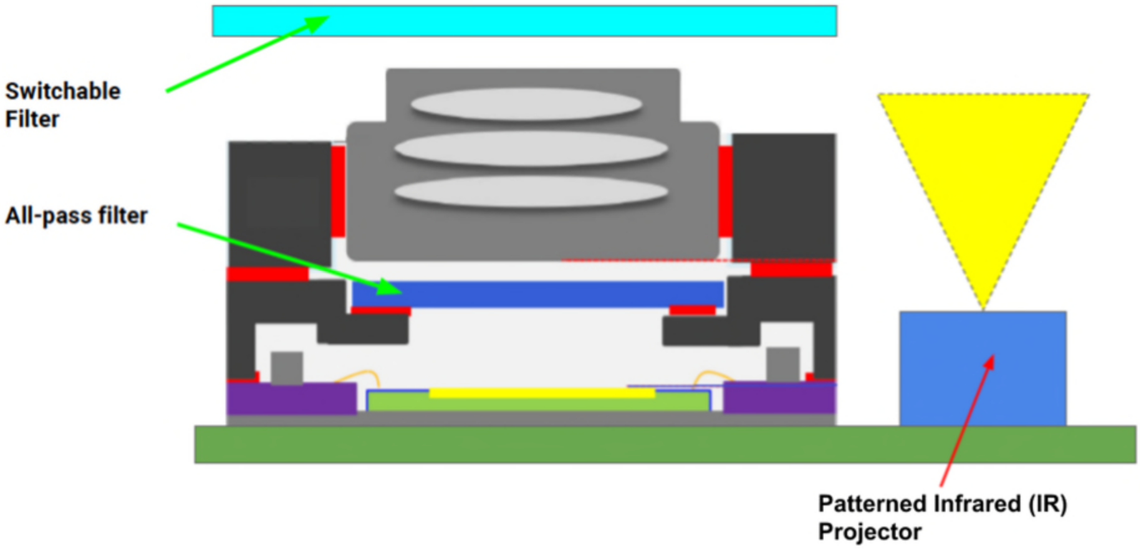

Fig 1: Camera system with switchable filter

Fig. 1 illustrates a schematic of a camera system with a switchable filter, per techniques of this disclosure. Per the described techniques, the camera is provided with a dual- or quad-PD sensor. Instead of an IR-cut filter (as in a conventional camera), the camera uses an all-pass filter. The system also includes a switchable filter and an IR projector e.g., a patterned infrared projector as shown in Fig. 1, or a simple flood projector. The switchable filter includes two different types of filters - an IR cut filter and an IR pass filter.

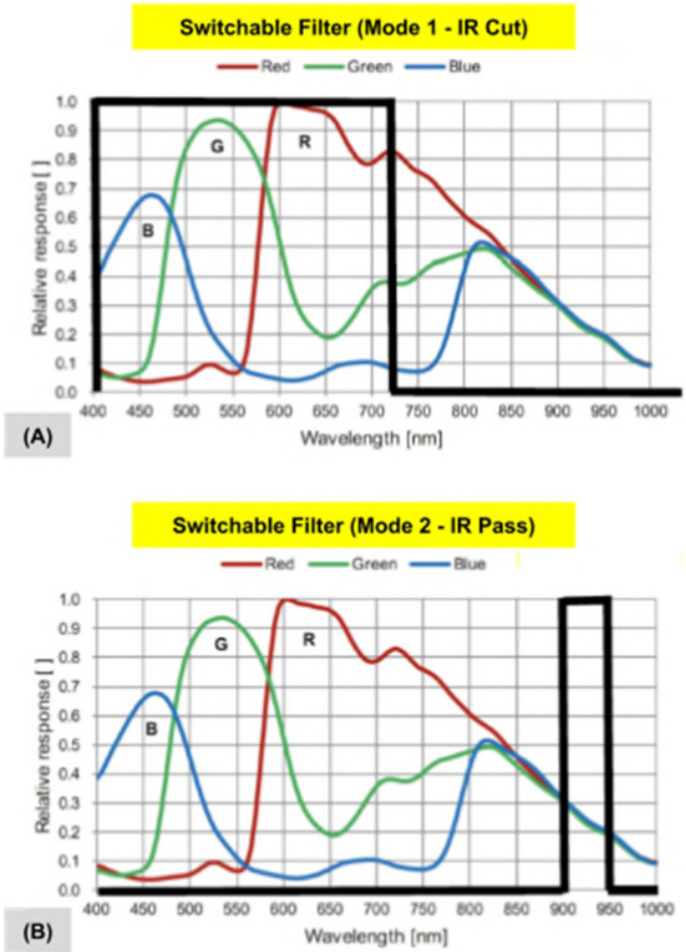

Fig. 2: (A) Mode 1 - IR Cut; (B) Mode 2 - IR Pass

Fig. 2 illustrates two different modes of operation of the camera. In a first mode, the filter is configured to pass color light only, as shown in Fig. 2(A). In a second mode, the filter is configured to pass IR light only, as shown in Fig. 2 (B). For example, mode switching can be performed via a mechanical lever that swaps the filters.

When capturing a scene where the ambient light is strong, the switchable filter is in the first mode in which the IR cut filter is in place and the projector is off. In this case, the subframes (e.g., four subframes) as captured by the sensor can be used for depth map generation in addition to output a high-resolution color image .

When capturing a scene under low-light conditions, the switchable filter is in the second mode in which the IR pass filter is in place and the projector is on. In this case, the scene is illuminated by the projector that provides additional light. The camera can now take in the IR light and captures multiple IR subframes (e.g., four subframes) that are used to generate depth. A high-resolution IR image can also be output in this case.

The described techniques for depth acquisition work under arbitrary lighting conditions, while being low cost, compact, and high resolution. Further, in the first mode, the camera used to capture RGB and depth images are the same and in the second mode, the camera used to take the IR and depth images are the same. In both cases, since the optical axes are the same, combining color and depth or IR and depth requires no re-projection thus eliminating image artifacts due to re-projection.

The described techniques can work with a flood IR projector or a patterned IR projector and can be implemented for sensors of different resolutions, with any number of sub-pixels under one micro-lens and with lenses of different fields-of-view. While the foregoing discussion refers to an example implementation of the switchable filter, it can be implemented in other ways. The techniques are suitable for both fixed focus and auto focus cameras and work with or without optical image stabilization (OIS). The described depth acquisition techniques can be implemented in a smartphone, tablet, laptop, smart display, or any other device that performs depth acquisition.

CONCLUSION

This disclosure describes a depth-sensing camera system that utilizes a switchable infrared filter. In an IR-cut mode, used when ambient light is of sufficient quality, the filter allows visible light to pass through and cuts off IR. In an IR-pass mode, used in low light conditions, the filter allows IR to pass through while cutting off visible light. The camera system enables high resolution depth acquisition in arbitrary light conditions at low cost and with compact hardware.

REFERENCES

1. Learning to Predict Depth on the Pixel 3 Phones