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Camera Capture and Frame-Rate Synchronization in a Multi-Camera System

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Abstract:

This publication describes methods and techniques that align auto exposures, frame length times, frames-per-second frequencies, and frame length lines, in a user equipment, such as a smartphone, that utilizes a multi-camera system. In one aspect, the multi-camera system contains one front-facing red-green-blue (RGB) camera and two front-facing infrared (IR) cameras. When a user utilizes the multi-camera system consisting of RGB camera(s) and IR camera(s) it may be referred to as RGB and IR depth (RGBIRD) image capturing. Although this publication illustrates RGBIRD image capturing with a smartphone with a multi-camera system that contains one RGB camera and two IR cameras, the same methods and techniques may be applied to a multi-camera system with one RGB camera and one IR camera, with one RGB camera and two IR cameras, with two RGB cameras and two IR cameras, with two RGB cameras and three IR cameras, any other combination of RGB and IR cameras, and any combination of cameras with different physical specifications.

Keywords:

Camera, image capturing, multi-camera system, red-green-blue camera, RGB camera, infrared camera, IR camera, RGB and IR depth, RGBIRD, automatic exposure, auto exposure, AE, synchronization, frame-rate synchronization, frame length line, FLL, frames per second, FPS, vertical synchronization, VSYNC.

Background:

An original design manufacturer may embed multiple cameras and sensors in or on a user equipment (UE), such as a smartphone, as is illustrated in Figure 1.

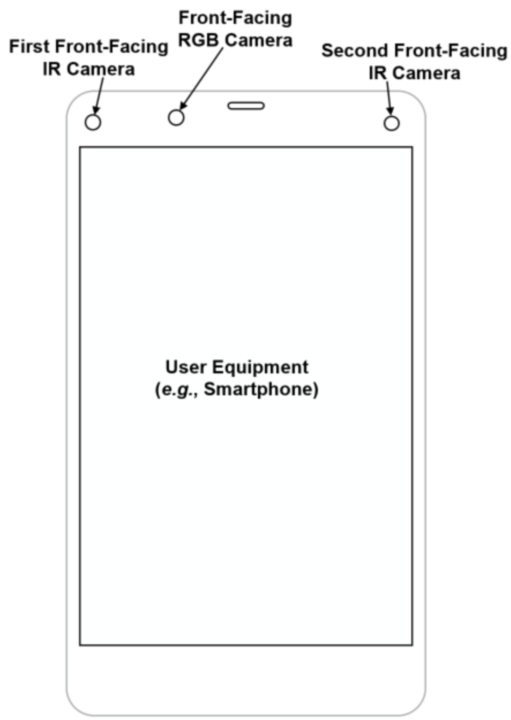

Figure 1

Figure 1 illustrates an example smartphone that has two front-facing infrared (IR) cameras and one front-facing red-green-blue (RGB) camera. Depending on the type of the activity, a user may use only the front-facing RGB camera, one front-facing IR camera, both front-facing IR cameras, and/or all front-facing cameras. When the user utilizes all three illustrated cameras in Figure 1, the operation mode may be referred to as front-facing RGB and IR depth (RGBIRD) image capturing.

In an RGBIRD operation mode, the three illustrated cameras in Figure 1 create three data pipelines for the three cameras using hardware that realize (achieve) a timing synchronization between image sensors of the three cameras. For each transmitted image frame, the hardware of the smartphone generates a vertical synchronization (V_{sync}) signal to align the three image sensors.

The hardware of the smartphone enables each camera to capture images at different frames-per-second (FPS) frequency. An auto-exposure (AE) algorithm determines the FPS and/or the frame length time (FLT) captured by each camera. Once the AE algorithm changes the FPS (*e.g.*, from 39 FPS to 41 FPS) and/or changes the FLT, the image sensors of the IR cameras and the image sensor of the RGB camera need to synchronously respond to the changed FPS and/or frame FLT to capture the determined FPS and/or FLT. The physical specifications of the RGB image sensor, however, differ from the physical specifications of the IR image sensors. A frame structure of an image captured by a camera consists of several horizontal lines, known as frame length lines (FLLs). Nevertheless, the hardware configurations of FLLs of the RGB camera differ from the hardware configurations of FLLs of the IR cameras. Therefore, it is desirable to have a technological solution that synchronizes the FLLs of each camera to increase the quality of an image captured using a multi-camera system.

Description:

This publication describes methods and techniques that align FLTs in a UE, such as a smartphone, that utilizes a multi-camera system. In one aspect, the multi-camera system contains one front-facing RGB camera and two front-facing IR cameras. When a user utilizes the multi-camera system including of RGB camera(s) and IR camera(s) it may be referred to as RGB and IR depth (RGBIRD) image capturing. Although this publication illustrates RGBIRD image capturing with a smartphone with a multi-camera system that contains one RGB camera and two IR cameras, the same methods and techniques may be applied to a multi-camera system with one RGB camera and one IR camera, with one RGB camera and two IR cameras, with two RGB cameras and two IR cameras, with two RGB cameras and three IR cameras, any other combination of RGB and IR cameras, and/or any combination of cameras with different physical specifications.

Figure 2 helps illustrate an algorithm that synchronizes frame lengths of one RGB camera and two IR cameras in a multi-camera system.

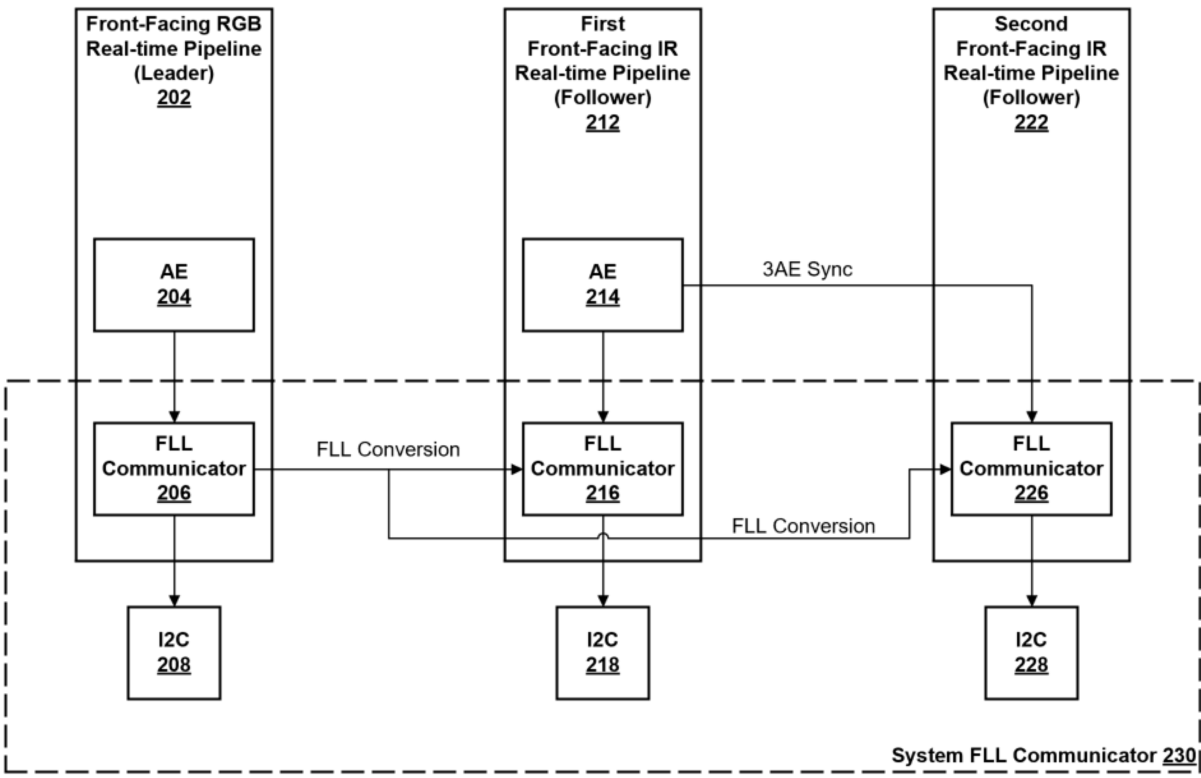

Figure 2

In the multi-camera system illustrated in Figure 2, a front-facing RGB real-time pipeline 202 (RGB 202) is a leader (primary), a first front-facing IR real-time pipeline 212 (first IR 212) is a follower (secondary), and a second front-facing IR real-time pipeline 222 (second IR 222) is also a follower (secondary).

The algorithm uses the relation given in Formula 1 to calculate the FLT. Formula 1 expresses the FLT as a mathematical function, annotated as F_{FLT}:

$$F_{FLT}[in\ seconds] = \frac{FLL_{RGB} \cdot Line\_Length\_PCK}{PCK} \quad (1)$$

where FLL_{RGB} stands for frame length line of the RGB sensor, PCK stands for Pixel Clock, and Line_Length_PCK represents the number of PCK in one FLL_{RGB}.

Alternatively, the algorithm may calculate a mathematical function of FLL_{RGB} when FLT is known, as is demonstrated in Formula 2.

$$FLL_{RGB} = \frac{F_{FLT} \cdot PCK}{Line\_Length\_PCK} \quad (2)$$

An auto exposure (AE) 204 of the RGB 202 determines the FLL_{RGB}. The algorithm synchronizes frame lengths of the first IR 212 and the second IR 222 based on the FLL_{RGB} and the AE output of the RGB 202 to account for hardware differences between the IR cameras and the RGB camera. Then, concurrently and in real-time, an FLL communicator 206 of the RGB 202 sends the FLL_{RGB} value to an FLL communicator 216 of the first IR 212 and an FLL communicator 226 of the second IR 222, as is illustrated in Figure 2. A system FLL communicator 230 enables an FLL_{RGB} conversion to the FLL of the first IR 212 and the FLL of the second IR 222 utilizing an inter-integrated circuit (I^2C or I2C) communication protocol, as is illustrated by I2C 208, I2C 218, and I2C 228 of Figure 2. Note that the I2C communication protocol controls the image sensors and is independent of the FLL conversion.

The algorithm helps meet the condition given in Formula 3 to optimize a vertical synchronization (V_{sync}) signal of the hardware of the smartphone:

$$T_{RGB} = \Delta t + T_{IR} \quad (3)$$

where T_{RGB} stands for the F_{FLT} of the RGB 202, T_{IR} stands for the F_{FLT} of the IR 212 and the IR 222, and Δt stands for an acceptable time difference that does not adversely affect V_{sync} (a built-in tolerance).

Using Formula 1, Formula 2, and Formula 3, the algorithm can calculate an FLL value for the first IR camera and the second IR camera, herein annotated as FLL_{IR}. For example, assume the value of the FLL_{RGB} is "x;" Formula 4 demonstrates how the algorithm calculates the FLL_{IR}.

$$FLL_{IR} = F_{FLL_{RGB}}[F_{FLT}(x) + \Delta t] \quad (4)$$

In conclusion, the described methods, techniques, and algorithms enable the multi-camera system that includes RGB and IR cameras to effectively synchronize in real-time the auto-exposure output, the frame length times, the frame-per-second frequencies, and the frame length lines of the RGB camera and the IR cameras to enhance RGBIRD image capturing.

References:

[1] Patent Publication: US20180309919A1. Methods and apparatus for controlling exposure and synchronization of image sensors. Filing Date: April 19, 2017.

[2] Patent Publication: US20180213141A1. Methods and apparatus for synchronizing camera flash and sensor blanking. Filing Date: April 18, 2017.