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Synchronization of a New Light-Flashing Shield with an External-Triggered Camera

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Abstract

In this letter, we describe a new light-flashing shield to be used at flash-based imaging or event-based vision tasks performed in environments with poor light conditions. The shield incorporates a multiplexer that permits to set the operation mode, the nominal current, the pulse-width and the trigger sensitivity of up-to 2 high-brightness LEDs by means of a single I2C bus. A trigger conditioning circuit permits to synchronize the LEDs light and an Intel RealSense d455 camera to obtain a set of clear images while the LEDs are illuminated, being this feature the main novelty and contribution of this work in order to provide light on-demand in visual-based tasks performed in environments with poor light conditions. Images obtained during real tests prove the correct synchronization between the light-flashing shield and the camera.

Index Terms

Light-Flashing Shield, External-Triggered Camera, Synchronization, Image Capture, Poor Light Conditions

I. INTRODUCTION

With the flourishing technological advances, the efficiency of vision-based tasks (VBTs) (e.g. autonomous navigation, surveillance, etc) has been significantly enhanced [1]–[4], yet environments with poor light conditions stand as a major challenge since such conditions worsen the sensors performance and reliability.

Developing new sensors technologies, such as bio-inspired retinas [5], [6], event-based cameras [7], [8], photon avalanche diode arrays [9], and the heterojunction of different semiconductors [10], is a solution adopted to enhance VBTs in the absence of proper light conditions [11]–[13]. On the other hand, due to their implementation easiness and relative low application costs, image processing techniques, as iterative statistic 3D-points alignment [14], artificial neural networks [15], and different LIDAR data treatments [16], have been a more preferred option that had equally demonstrated to improve VBTs in obscured scenarios.

To our best criteria, to illuminate the environment while simultaneously applying image processing techniques [17], [18] seems to be a more convenient solution to overcome the aforementioned challenge nevertheless, in most of the cases, the light source remains lit which increases energy consumption. We present a light-flashing shield to provide an artificial I2C-modulated light source *on-demand*, i.e. only when the VBT requires it, for flash-based imaging or event-based vision tasks. The shield incorporates a trigger attenuation circuit to synchronize a global shutter camera and up-to 2 high-brightness LEDs in *flash mode* which stands out as its main feature.

The sequel of the letter is outlined as follows: Section II provides a description of the Intel RealSense d455 camera and the light-flashing shield, Section III is devoted to the characterization of the shield signals, and the results of experimental tests that validate the synchronization between the lighting board and the camera are presented in Section IV. The conclusions are given in Section V.

II. LIGHT-FLASHING SHIELD DESCRIPTION

The conception of the Light-Flashing Shield (shown at the top of Fig. 1) relies on the idea that, for some applications, it may be necessary to obtain the environmental information only when required. In this sense, the camera should punctually take the images on-demand while the ambience is illuminated properly.

According to the literature reports [19]–[21] and the camera supplier [22], the global shutter Intel RealSense d455 camera can be externally triggered and work synchronously with other devices which makes it perfect for the current application case. In its so-called *synchronization mode*, the camera burst a number of frames (from 1 to 255) at the Native Frame Rate (NFR in fps) when an 1.8 V trigger signal with a pulse width $t_w \geq 100\mu\text{s}$ is received. The NFR limits the trigger frequency f_T , such that $0 < f_T < \text{NFR}/2$ and $\text{NFR} \in \{6, 15, 30, 60, 90\}$.

The shield design is based on the TPS61050 Integrated Circuit (IC) commonly used to modulate, by means of an I2C

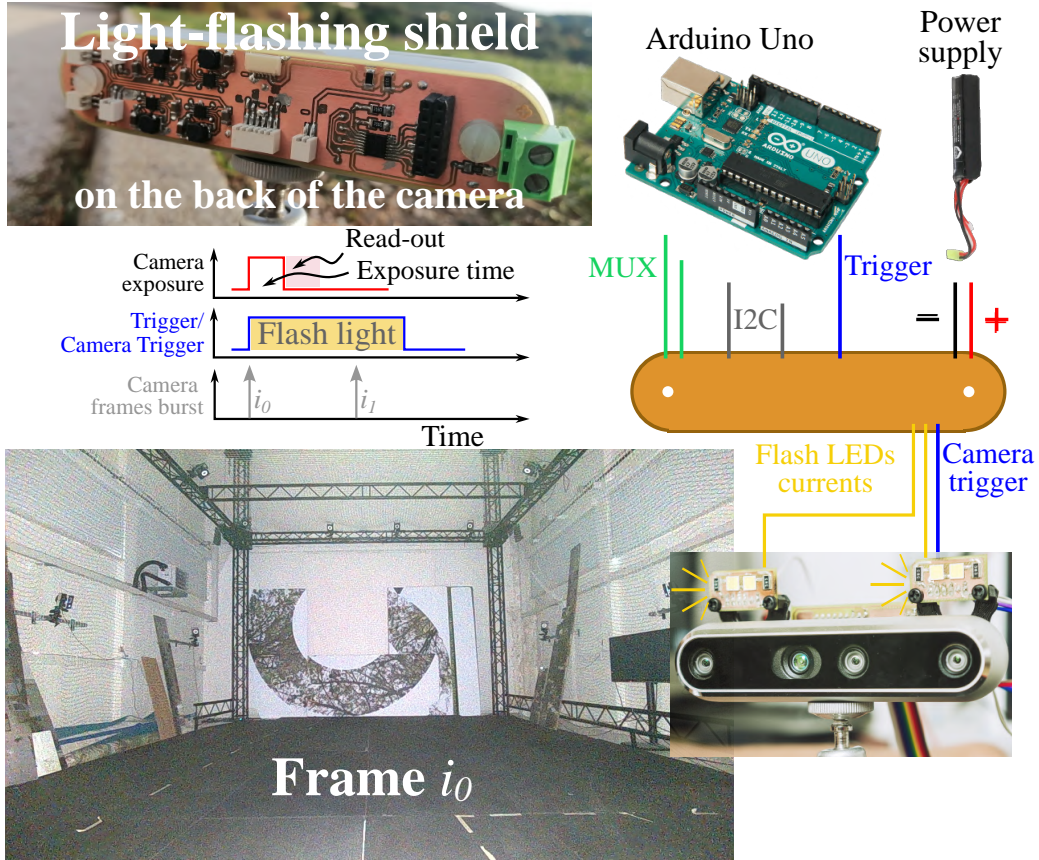


Fig. 1: Light-Flashing shield installation alongside the signals routing diagram and the camera reaction to an external trigger event.

communication bus at 100 kHz, the current of high-brightness LEDs incorporated in mobile phones [23]. This IC enables two different operation modes: i) *torch mode* and ii) *flash mode*.

In *torch mode*, the LED is lit and its current is driven to the torch current i_t . A *low dimming sub-mode* is equally enabled. In this sub-mode the device employs a 122-Hz fixed frequency PWM whose duty cycle is defined in order to achieve a mean dim current i_d according to the values shown in Table I.

In *flash mode*, the device drives the LED current from i_t to the flash current i_f once an external 5 V trigger signal is received. The response of the LED with respect to the trigger signal can be selected to be: i) level sensitive (the LED strobe pulse follows the external trigger pulse and the duration of the flash is limited by a safety time t_s so that in the case that the pulse width of the external trigger exceeds t_s , the LED will be turned off) or ii) rising-edge sensitive (the LED strobe is triggered by the rising edge of the external trigger signal and the LED remains lit during a given time defined by t_s , meanwhile, the device ignores any other trigger signal). The allowed i_f and t_s values are shown in Table I. In both modes, the maximal LED voltage is limited to 5.25V.

TABLE I: I2C-modifiable parameters of the LED lights according to the operational mode

Torch mode parameters		Flash mode parameters	
Torch current i_t [mA]	Dim current i_d [mA]	Flash current i_f [mA]	Safety time t_s [ms]
0	$0.8\% \times i_t$	150	32.8
50	$1.6\% \times i_t$	200	65.6
75	$2.3\% \times i_t$	300	98.4
100	$3.1\% \times i_t$	400	131.2
150	$3.9\% \times i_t$	500	⋮
200	$4.7\% \times i_t$	700	951.2
250	$6.3\% \times i_t$	900	984
	$8.6\% \times i_t$	1200	1016.8
Sub-operational mode		Trigger Sensitivity	
Normal Torch	Low Dimming	Level	Rising-edge

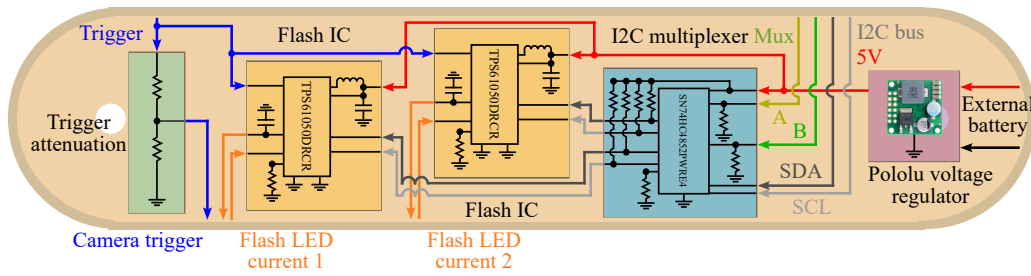


Fig. 2: Simplified block diagram of the circuitry embedded on the Light-Flashing shield.

Since 2 ICs are available on the shield, which permits to drive up-to 2 high-brightness LEDs individually, and due to fixed address of the IC, a 4:1, 2-channels analog multiplexer SN74HC4852 [24] was mounted to address the single I2C bus (SDA and SCL signals) to a given IC. One last feature of the light board is the trigger distribution and attenuation circuitry that permits to use a single 5 V trigger signal, to attenuate it properly and to distribute it, synchronously, to the 2 ICs and the camera. To power the shield, a 5 V, 5.5 A Step-Down Pololu Voltage Regulator [25] is installed such that an external power source is still required to provide energy.

The content of this section is summarized in Fig. 2 where a simplified block diagram of the circuitry is provided.

III. LIGHT-FLASHING SHIELD CHARACTERIZATION

Several isolated tests were performed to ensure the proper behavior of the different parts. Regarding the multiplexer, its 2 input channels are connected to the I2C bus (SDA and SCL lines) and addressed to a specific IC by means of 2 digital inputs, A and B. Two digital square signals were provided to A and B, at different frequencies f_A and f_B , to test the response of the device while both SDA and SCL lines were connected to 5 V. Some results of the test are partially shown in Fig. 3 where the response of the 2 SDA output channels when $(f_A, f_B) = (90, 45)$ Hz, and the response of the 2 SCL output channels when $(f_A, f_B) = (2, 1)$ Hz are depicted. For both sets of frequencies (f_A, f_B) and from the output channels, a negligible mean commutation time of 9 ns was found.

The trigger attenuation circuit was tested such that the frequency of the 5V digital trigger f_T was set at 45 Hz with two different pulse widths $t_w = 11.1$ ms and $t_w = 100$ μ s (Fig. 4). We did not find a significant delay between the distributed triggers, furthermore, the camera trigger was correctly attenuated to 1.8 ± 0.1 V.

We performed several test to verify the behavior of the IC and the LED. In this regard, Fig. 5 shows the LED current, alongside the 5V digital trigger and the I2C signals (SDA and SCL). It is straightforward to recognize a proper torch mode operation at first, right-after, one can appreciate the LED operating in low dimming mode and the PWM working principle (details in Fig. 5b). In torch mode, the device clearly ignores the trigger signal and remains lit at the corresponding current i_t or i_d . Flash mode was proved afterwards, in this short test, one can appreciate the differences in the flash light behavior related to the trigger sensitivity (Level or Rising-edge), in both cases, the safety time was set to 131.2 ms while $f_T = 8$ Hz and $t_w = 50$ ms were set as the trigger parameters.

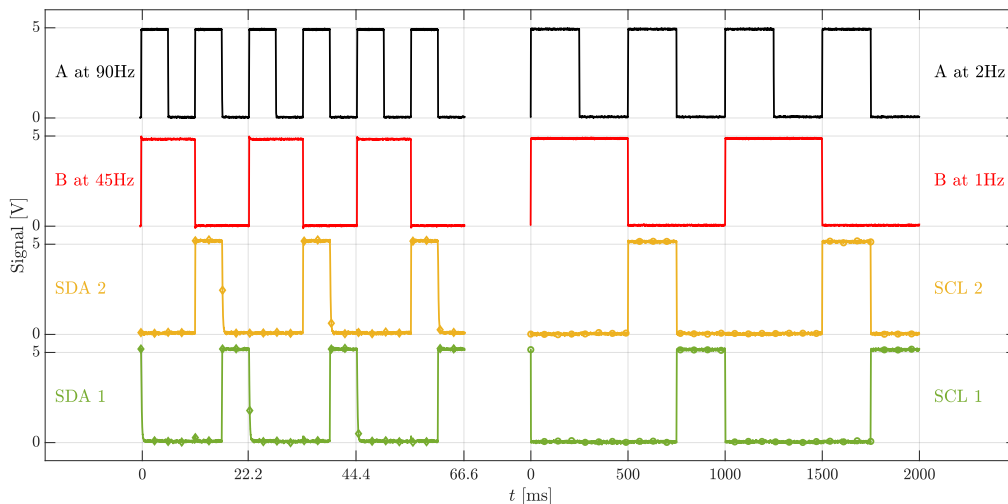


Fig. 3: Multiplexer response: Left) SDA channel at $f_A = 90$ Hz and $f_B = 45$ Hz. Right) SCL channel at $f_A = 2$ Hz and $f_B = 1$ Hz

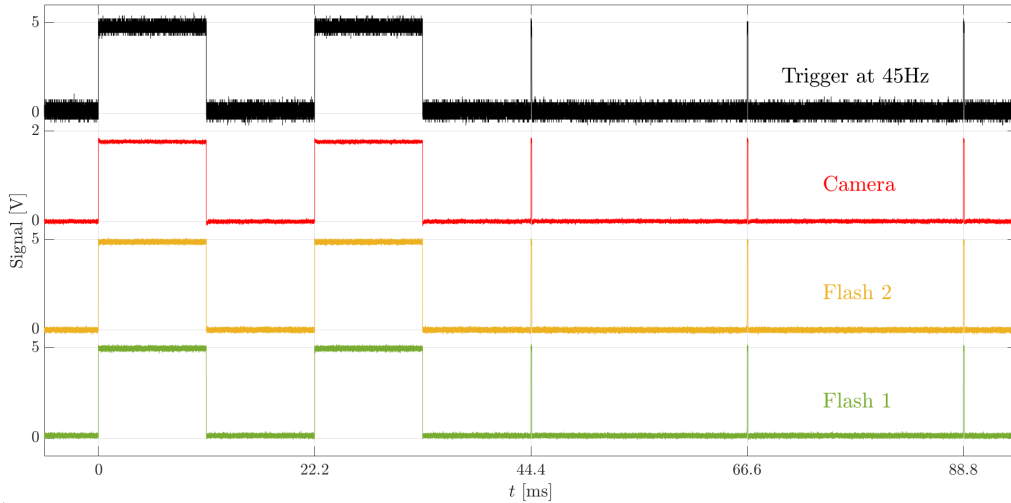


Fig. 4: Triggers response at $f_T = 45\text{Hz}$: Left) Pulse width $t_w = 11.1\text{ms}$. Right) Pulse width $t_w = 100\mu\text{s}$.

From the data set obtained during the IC test, we found that the LED current was properly regulated to the desired current with a $\pm 10\%$ error as described by the supplier and, as witnessed in Fig. 5b and Fig. 5c, adjusting the parameters of the LED light (including turning on the device) takes, approximately, $640\ \mu\text{s}$. On the other hand, a programming time of $304\ \mu\text{s}$ is needed to turn off the device.

IV. SYNCHRONIZATION TESTS AND RESULTS

The light-flashing shield was installed behind the camera as illustrate in Fig. 1. As it can be appreciated in Figs. 1 and 2, the LEDs are not included on the light-flashing shield, a connector allows to use different high-brightness LEDs without modifying the shield and positioning them as needed, see the IC datasheet [23] for further details on the selection of the LEDs. We used two white LUXEON TX high-brightness LEDs with a forward voltage of $2.8\ \text{V}$ and a maximal current of $1.5\ \text{A}$ [26]. The two LEDs were mounted over the camera as shown in Fig. 1, and properly connected to the light-flashing shield. For sake of simplicity, an Arduino Uno board was used to program the ICs, to control the multiplexer and to generate the trigger signal nonetheless, the light-flashing shield is compatible with several 5V-development boards featuring at least one I2C interface.

The overall assembly was placed at the entrance of the flight arena of the ISM laboratory ($L \times W \times H = 6 \times 8 \times 6\ \text{m}$) and the arena was darkened. The camera was plugged to a computer running the Intel RealSense Viewer application where the NFR was set to 15 fps. We enabled the auto-exposure feature inside the application and turned on the camera in order to let the software find the proper expose time in these dark conditions. Once this parameter was set by the application, we disabled the auto-exposure feature and enabled the synchronization mode of the camera such that 2 frames per trigger could be obtained as depicted in Fig. 6a. Fig. 6b shows the darkened flight arena as perceived by the camera after setting the expose time as described. On the

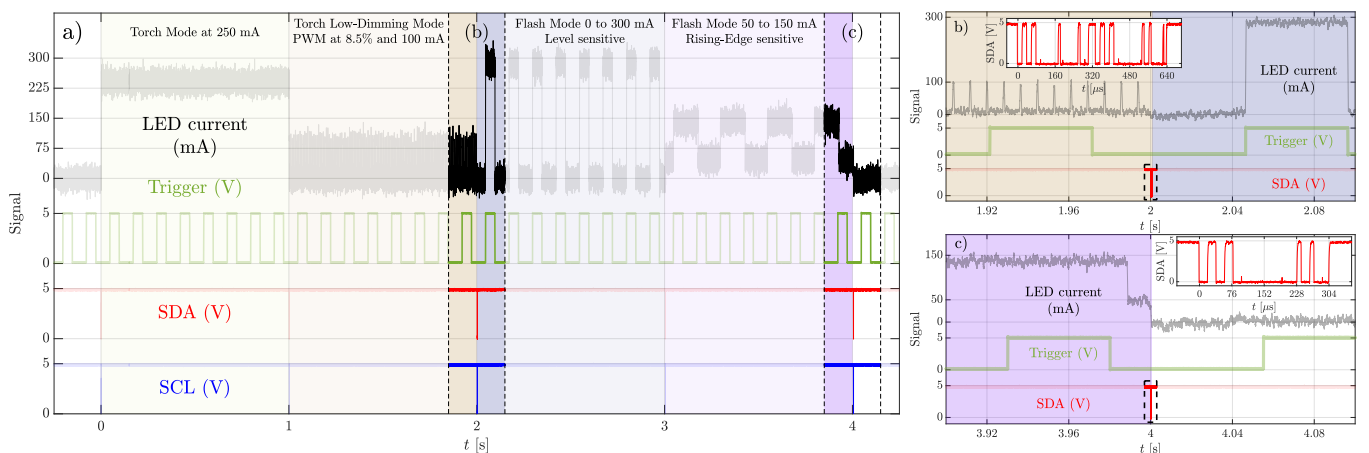


Fig. 5: Left) Response of a single LED current performing in torch and flash modes. LED parameters written on top. Right) Programming time zoom-in plots.

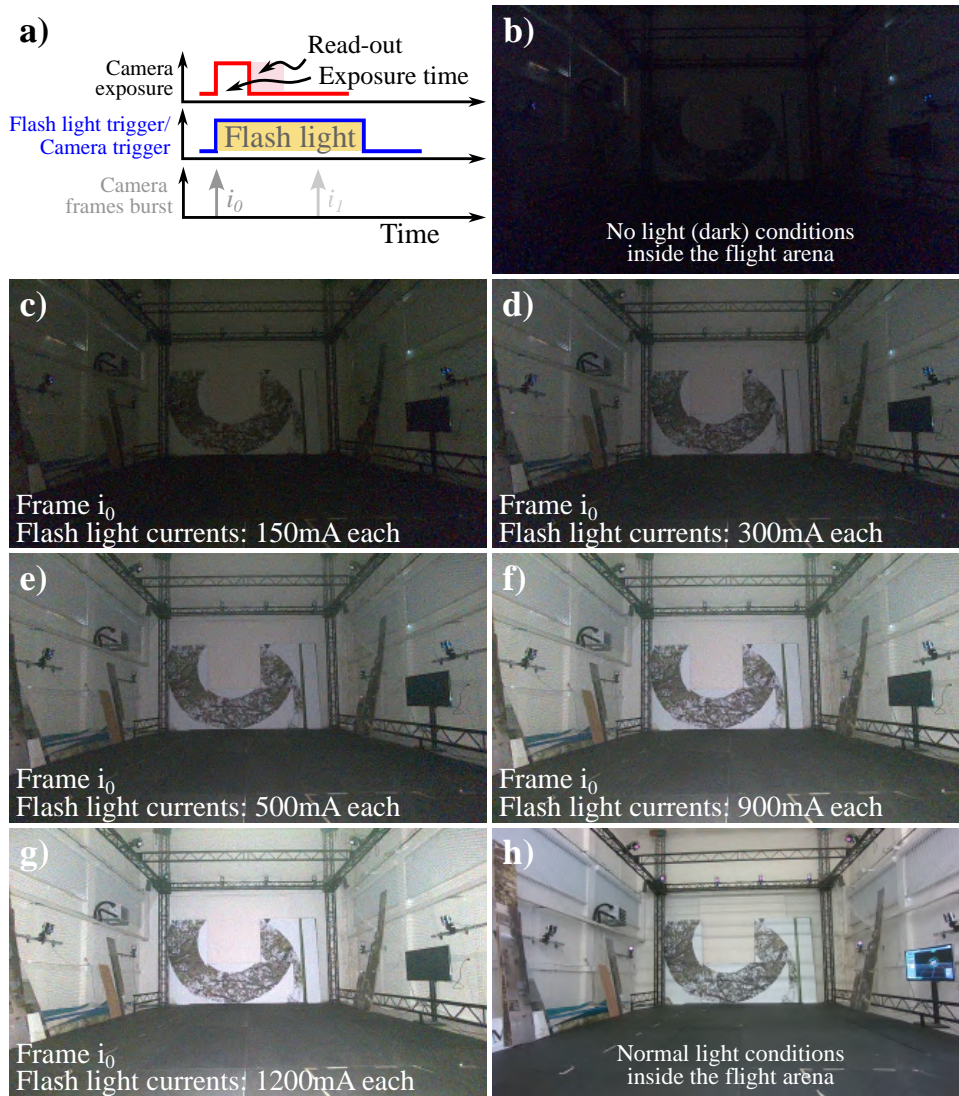


Fig. 6: Images captured thanks to the synchronization between the light-flashing shield and the camera by means of the Arduino Uno and the Intel RealSense Viewer Application: resolution 1280×720 .

other hand, Fig. 6h shows the normal lighting conditions of the flight arena as captured by the camera. The parameters of the camera, in order to improve the quality of the images, may be a matter of especial attention yet, we considered the parameters set by the auto-exposure feature acceptable for the current case.

Since $NFR=15$ fps, the time reserved to obtain each frame was approximately 66.66 ms such that for capturing 2 frames 133.33 ms were required. With base on the latter, the digital trigger frequency f_T was fixed at 1 Hz with a pulse width $t_w = 150$ ms. The light-flashing shield and the camera were thus tested in such a manner that we defined a 1 minute routine in which the camera was capturing images while the flash currents were changed each 12 s, such that the 5 flash currents distributed during the 1 minute routine were 150, 300, 500, 900 and 1200 mA. The corresponding results are presented from Fig. 6c to Fig. 6g where the first frames of the 2-frames burst are introduced.

From Fig. 6 and the data obtained, we appreciated a correct synchronization between the light-flashing shield and the camera since the clarity and quality of the images provided at the first frame of each 2-frames burst were clearly enhanced w.r.t. the images captured in dark conditions. As appreciated in Fig. 6, the image clarity highly depends on the intensity of the flash lights. For a space with similar dimensions to those of the flight arena, 2 high-brightness LEDs flashing at 500 mA seem to provide just enough luminous flux to light the scene, yet at a flash current of 1200 mA, the images captured are similar to those taken in normal light conditions. A further detailed study of the images quality, depending on the needs of the VBT, may be required. Regarding Fig. 6c and Fig. 6d, flashing at low current may not be enough to illuminate properly environments similar the flight arena, yet flashing at low current may result appropriate to illuminate smaller rooms or environments and to avoid any issue related to an excess of illumination. **A video of a performed test can be found at <https://youtu.be/ktmm2IT6ctU>.**

V. CONCLUDING REMARKS

In this letter, we have presented a new light-flashing shield synchronized with an external-triggered camera to obtain clear images of the scenario in dark environments. This synchronous mode to capture images may result specially useful in practical event-based applications, flash-based imaging, VBTs developed in environments with poor light conditions or in different tasks where a light source is required only on-demand which may lead to reduce the energy consumption.

Future works include the improvement of the overall design of the shield such as the distribution of the elements and the signals routing. Two more TPS61050 ICs will be embedded on the shield so up-to 4 high-intensity LEDs could be used. A detailed characterization of the luminous flux, the energy consumption and efficiency, will be provided in further reports. A set of different test to validate the shield compatibility with different cameras is also considered. Lastly, the implementation of the shield in a practical application remains equally as a part of the upcoming work.

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