Laser Speckle Stereo Imaging System in Biomedical Imaging

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Abstract - Speckle is an optical interference phenomenon generated by the reflection of a highly coherent beam of light (e.g., laser) on a rough surface. This phenomenon has been applied in several research areas, aiming at the characterization of static surfaces or the extraction of properties in dynamic processes. In particular, laser speckle has shown huge potential in the identification of high varying perfusion regions in medical images of skin and brain. The acquisition setup in laser speckle is usually composed by a laser source, a magnifying lens, and one video camera. From the obtained sequence of video frames several image descriptors are calculated to characterize the surface under analysis, using information obtained from the scattered patterns. In recent years a new acquisition perspective in laser speckle was proposed by assembling an acquisition setup using two video cameras, thus producing the so called stereo laser speckle. This new approach is challenging regarding acquisition and imaging processing, introducing several variables to be controlled (distance from the camera lens to the surface, direction and width of the reflected beam of light). In this paper, a revision of recent results in stereo laser speckle is presented, highlighting the challenges in acquisition and image processing. Moreover, a new setup is proposed to test the influence of the identified critical variables in stereo laser speckle to be applied in medical imaging contexts.

Keywords – Laser Speckle Imaging, Stereo Imaging, Image and Video Processing.

I. INTRODUCTION

Despite being a phenomenon that has been theoretically described since the 19th century, the applications of the laser speckle were only possible due to technological advances related to the acquisition systems, sensors and optical components [1], [2].

Speckle is an interference phenomenon resulting from the scattering effect of the wave fronts that are emitted from a rough reflecting surface, when illuminated by a coherent light source. When the coherent light source is the laser, the physical phenomenon is termed as laser speckle [3].

The scattering surface can either be static or presenting micromovements due to some dynamic process able to modify the texture of the reflection surface, which can be characterized by temporal descriptors. The removal of the speckle effect, regarded as noise, is a common process to improve the accuracy of the obtained information in research fields as synthetic aperture radars [4], biomedical imaging ultrasounds [5] and optical coherence imaging [6], in which speckle interference of the reflected wave fronts is filtered. However, the speckle signal can be used to obtain information about the pattern of the reflected front waves.

More recently, in particular regarding the applications in Biomedical Engineering context, perfusion studies related to cortical ischemia [7], blood flow speed [8] and the assessment of burn recovery [9], are pointing laser speckle imagery as a noninvasive, low cost and versatile imaging modality. Moreover, the integration of the dynamic laser speckle signal with the stereo acquisition is seen as a promising technique to advance for a new fusion imaging (by joining the function obtained by speckle and the texture of the surface using the 3D information obtained by stereo imaging) [10].

The possibility of obtaining fusion images by combining the speckle laser technique with stereo acquisition, poses some challenges regarding optimization in the acquisition variables and in hardware assembling [10], [11].

In this work a versatile stereo imaging system for laser speckle is presented, designed to conduct optimization experiments regarding the central variables for stereo laser speckle imaging (distance between cameras, pitch, roll and yaw in each camera, distance to the Region of Interest).

II. METHODS

The implemented acquisition block system it is represented in Fig. 1. This system is composed by two GigE ae1920-25gm cameras, one Gigabit-Ethernet (GS110TP PoE) switch, a hardware trigger generator and a host computer. The stereo acquisition system is divided in two sectors: the trigger generator and the two acquisition cameras.

Figure 1. Setup acquisition.
A. Camera Features

In Table I the camera features are presented. The exposure time is a configuration parameter of central importance in speckle, not only because it must be adjusted to match the short duration of the visible elements of speckle, but also due to its interdependence with the acquisition frame rate. Another central parameter directly related with acquisition frame rate is the electronic shutter operation. In the cameras used in this work only the rolling shutter mode is available, which includes two sub-types (the rolling shutter mode and global reset release shutter mode). These are different reading modes of the camera sensors, which provide a further level of flexibility in the setup parametrization.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>acA1920-25gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum possible resolution</td>
<td>1920 x 1080</td>
</tr>
<tr>
<td>Color</td>
<td>Mono</td>
</tr>
<tr>
<td>Possible Synchronization Modes</td>
<td>Via Hardware trigger</td>
</tr>
<tr>
<td>Exposure time control</td>
<td>Programmable via the camera API</td>
</tr>
<tr>
<td>Camera Power Requirements</td>
<td>Via Ethernet connector - Power over Ethernet (PoE) 802.3af Via I/O connector - 12 VDC</td>
</tr>
<tr>
<td>I/O Lines</td>
<td>1 optocoupled input line</td>
</tr>
<tr>
<td></td>
<td>1 optocoupled output line</td>
</tr>
</tbody>
</table>

B. System Configuration

To achieve a frame rate in the order of 50 frames per second (FPS) (to accomplish the same frame rate as the reference papers for this work and our previous experience in speckle acquisition using one camera) a region-of-interest (ROI) of 960 x 540 resolution was defined to be used in the experimental setup during acquisition. As it can be observed in Table 1, this is not the maximum resolution of these cameras, but this reduction in resolution allows to obtain the maximum frame rate available for a 960 x 540 ROI, thus setting the frame rate close to 50 FPS.

In order to guarantee stereo synchronization of the left and right images, a hardware generated trigger is used to define the instant of acquisition of a frame. In other words, a frame start trigger is generated with a hardware source. The frequency of such signal corresponds to the acquisition frame rate. The actual acquisition of the visual data begins after a predefined delay established by the trigger signal rise, as represented in Fig. 2. This delay is recommended when a hardware trigger is used for image acquisition. As the defined electronic shutter operation mode is the rolling shutter mode, the minimum exposure time (MET) can be calculated using (1).

\[
MET > tRow \times (AOI\_Height - 1) \tag{1}
\]

where:

- \( AOI\_Height \) = height of the ROI defined in the frame
- \( tRow \) = temporal offset from one line to the next

This minimum exposure time value determines when the sensor reading will be taken on all lines at the same time. This value is important to determine the flash window width, that it is represented by the difference between the defined exposure time and the minimum exposure time calculated by (1). The use of a flash window width is necessary to generate a signal to activate a flash light for better illumination of moving objects, whenever necessary. Since the laser speckle is a phenomenon that occurs with a high variation in changing patterns, the electronic shutter operation modes and the exposure time must be tightly controlled, as they can influence the pattern of the laser speckle captured by the cameras. As a security measure, the exposure mode has been set to discard possible triggers while an exposure is in progress.

Since the objective is to obtain a synchronous stereo acquisition, the process of exposing and reading the image sensors must be performed at exactly the same the frame rate and acquisition period. As it can be observed in Fig. 2, the sequence of processes was defined so that the sum of the total start delay (TSD), defined in (2), with the frame readout time, must belong to the HWFSTrig period. The frame readout time value can be obtained by reading the Readout Time Abs parameter.

\[
TSD = ESD + ILRT + DS + FSTD \tag{2}
\]

Where:

- TSD = Total Start Delay
- ESD = Exposure Start Delay
- ILRT = Input Line Response time
- DS = Debouncer Setting
- FSTD = Frame Start Trigger Delay

The PacketTimeout parameter defines how long the filter driver waits for the next expected packet before initiating a resend request [12]. Other important parameter to consider is the FrameRetention, which defines the timeout frame retention timer (in milliseconds). The frame retention timer starts when a leader for a frame is detected. After all frame packets are received the timer resets and the timer will timeout. In case timeout occurs before the...
last packet is received, the buffer for the frame is released and an indication of unsuccessful grab is provided [12].

Regarding the hardware trigger, the frame starts trigger is defined by configuring the time when the signal is high by setting an Arduino Mega timer in PWM mode, where it is configured for the frequency of acquisition.

C. Acquisition Process

The flowchart of the implemented acquisition system or the synchronous stereo images is illustrated in Fig. 3. The acquisition methodology is initiated by the above mentioned process of setting the parameters. After this first step, the command for the initialization of the acquisition process during a predefined period is executed. Afterwards, the signal generation begins by sending the order to grab the frame. The control of the acquisition period is carried out through a timer, that is started right after the hardware trigger start order. To guarantee the frame synchronization between the two cameras, a validation function checks each “successful acquisition” to confirm whether the acquisition of camera 1 occurred at the same time of the camera 2. After this verification the stereo image data is saved.

As soon as the acquisition process is finished, the conversion of the acquired frames begins, so that this information can be stored in a .tiff file.

The synchronous stereo acquisition process is represented in Fig. 3.

![Flow diagram of acquisition process.](image)

### III. RESULTS

The main result in the scope of this work is the system itself, from whom the generic configuration is presented in Fig. 1. The results intend to validate the acquisition setup and to confirm that it is fully operational to capture a laser speckle phenomenon.

The setup was developed in order to test distinct acquisition parameters (e.g. distance between cameras, pitch, roll and yaw in each camera, distance to the ROI) and to optimize stereo laser speckle acquisitions.

<table>
<thead>
<tr>
<th>#Frame</th>
<th>Left camera - Acquisition time [s]</th>
<th>Right camera - Acquisition time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,0000</td>
<td>0,0000</td>
</tr>
<tr>
<td>100</td>
<td>3,2987</td>
<td>3,2987</td>
</tr>
<tr>
<td>200</td>
<td>6,6307</td>
<td>6,6307</td>
</tr>
<tr>
<td>300</td>
<td>9,9627</td>
<td>9,9627</td>
</tr>
<tr>
<td>400</td>
<td>13,2947</td>
<td>13,2947</td>
</tr>
<tr>
<td>500</td>
<td>16,6267</td>
<td>16,6267</td>
</tr>
<tr>
<td>600</td>
<td>19,9587</td>
<td>19,9587</td>
</tr>
<tr>
<td>700</td>
<td>23,2907</td>
<td>23,2907</td>
</tr>
<tr>
<td>800</td>
<td>26,6227</td>
<td>26,6227</td>
</tr>
<tr>
<td>900</td>
<td>29,9547</td>
<td>29,9547</td>
</tr>
</tbody>
</table>

In Table II one can observe the acquisition times of the left and right cameras during one speckle acquisition experiment.

In this experiment, one test of isquemia-perfusion in the arm (as described in [3]) was conducted in order to test the system by using an experimental condition similar to the ones we intend to apply in next works with stereo speckle for skin imaging.

As observed from the results shown in Table II, the systems allows perfect synchronization between cameras, which is crucial in the process of stereo laser speckle process. From these results, taking into account the number of frames and time interval, it can be confirmed that the frame period is constant and equal to 33ms.

As a future work, several experimental conditions during speckle experiments will be tested to define the optimal prototype of the system, considering the level of characterization and discrimination of the speckle images, as a quality factor.
IV. CONCLUSION

The speckle laser imaging technique has been shown to be very versatile, and has great advantages in the area of medical imaging since it applies non-ionizing radiation and is non-invasive.

More recently, the use of two video cameras to carry out stereo acquisition has shown to be very promising, but at the same time it raises many technical questions, for example related to the timing of the acquisitions, and the definition of parameters of the stereo acquisition setup that ideally has to be designed for the specific context type and optimized under cost functions that include the output of the image processing algorithms and quality of relevant features.

This work presents an acquisition setup for stereo laser speckle, and the synchronization of video acquisitions for the proposed setup is tested. The presented results will allow to use the setup to test other variables whose variation may influence the image processing, and, ultimately, the consistency of the obtained results.

ACKNOWLEDGMENT

This work is funded by Portuguese national funds provided by Fundação para a Ciência e Tecnologia (FCT) through national funds and when applicable co-funded EU funds under the projects UIDB/EEA/50008/2020, UIDP/EEA/50008/2020 and UIDB/05704/2020 and UIDP/05704/2020.

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