Autogain approach for use with time-of-flight examination in minimal invasive surgery

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Abstract:

Distance measuring time-of-flight cameras are already widely used in many sectors. It is easily understood that 3D views are a big gain for minimal invasive surgery, improving both, precision and convenience of such threatments. For that reason the development of the use of TOF-cameras in minimal invasive surgery has been intensified. Before commercial products can be realized there are still hurdes to overcome.

One of those hurdes is reaching a sufficient accuracy of the distance measureing process. So far, under best conditions TOF-cameras reach a distance accuracy of 3-4 mm for distances up to 50 cm. Outside the best conditions the distance measurements rapidly looses accuracy, thus it is essential to operate the TOF-cameras in best conditions. One important parameter that influences the precision is the amount of received light and with it integration time, which is the time the CCD-sensor receives light.

Our measurements show that a certain amount of photons is needed in order to obtain a certain precision due to statistical processes in photon absorption in the CCD-sensor of the camera. On the other side the amount of charge that a CCD-pixel is able to store during the integration time is limited due to the capacity of the pixel. The limit in charge-storage directly translates into a limit of maximum detectable photons before the pixel gets saturated. It is therefore necessary to adjust integration time in such a way that the 'right' amount of photons reaches the pixel. That means if the reflectivity of or the distance to the target changes, the integration time needs to be readjusted.

In order to avoid inconveniences for the surgeon, which the need to adjust integration time manually would cause, it is necessary to develop algorithms that fulfil this task automatically (autogain).

The algorithm is divided into two main parts, a measurement and rating part and the adjustment part. The first parts reads the output amplitudes of some pixels and then compares it to the 'target' amplitude which is known to give accurate measurement results. If the output amplitude leaves a certain region around the target amplitude, the adjustment part gets activated and changes the integration time in order to match the target amplitude again. For the adjustment part the main requirements are a fast and precise adjustment. One would expect that with increased integration time also the amplitudes increases. This is only true up to a certain point, beyond this point an increase of integration time even causes a decrease of the amplitude, which is caused by saturation effects. Up to now different approaches have been tested to find the right integration time within a maximum of 10-15 frames which results in 1-4 seconds, depending on the frame rate of the used camera.

In the current approach a reference integration-time - amplitude curve is used to calculate a matching integration time, as our experiments showed that varying distances and reflectivities cause the curve to scale by a constant factor. The knowledge of this factor allows to jump directly to the appropriate integration time, without the need to do any intermediate steps. The reference curve usually needs only to be obtained once for every camera-endoscope setup.
The method is however limited to a region of about 1 meter around the distance where the reference curve was obtained, as the curves are only in first approximation scaled by a constant factor. With bigger differences in distance the non-linearities grow and limit the accuracy of the method.
With help of the described procedure it is possible to speed up the autogain process. Experiments have shown that manually adjusting the integration time typically takes 3-10 seconds, depending on how much the integration time needs to be changed. First automatic approaches took about 10-20 seconds. Our method typically needs 9-12 frames to adjust to the right integration time, 3 frames under good conditions (only small adjustment needed), which typically results in 1-3 seconds and for good conditions below 1 second.