Authors' accepted manuscript: International Conference on Applications of Intelligent Systems (APPIS), Las Palmas de Gran Canaria, Spain, 2018.

Analyzing interference between RGB-D cameras for human motion tracking

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Abstract. Multi-camera RGB-D systems are becoming popular as sensor setups in Computer Vision applications but they are prone to cause interference between them, compromising their accuracy. This paper extends previous works on the analysis of the noise introduced by interference with new and more realistic camera configurations and different brands of devices. As expected, the detected noise increases as distance and angle grows, becoming worse when interference is present. Finally, we evaluate the effectiveness of the proposed solutions of using DC vibration motors to mitigate them. The results of this study are being used to assess the effect of interference when applying these setups to human motion tracking.

Keywords. RGB-D cameras, interference, Kinect, Asus, vibration motor, human motion tracking

1. Introduction

Nowadays, RGB-D cameras have become very popular sensors in Computer Vision and Robotics due to their direct and fast sensing of depth at a very affordable prize. Among their shortcomings we find their relatively small field-of-view ($\sim 50^o$) and a limited range of operation ($\sim$1m-3.5m), so it is common to find setups with several devices working jointly to overcome these limitations. Additionally, the combination of multiple devices can avoid blind zones and potentially produce richer and more accurate scene representations. In these configurations, however, since these cameras are active sensors, they may interfere to each other, affecting the quality of the data coming from the overlapped areas. This paper presents an analysis of such interference in relation to the distance and angle to the measured surface. We also evaluate the effectiveness of the existing solutions in the literature [1,2], based on asynchronous vibrations between the cameras to reduce interference. Although a similar analysis has been carried out in [1], we've extended it by also estimating the depth error in a setup with the cameras pointing with a certain angle to a large and flat surface. This has been repeated for several distances, aiming to reproduce the conditions of a more realistic scenario. The experiments reveal that the noise of the measured points increases with distance and it is larger in the case of the camera not being perpendicular to the measured distance. Moreover, interference is shown to affect

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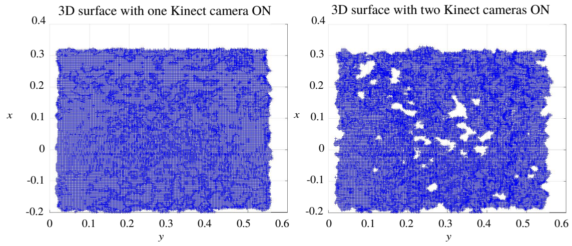

Figure 1. 3D representation of a flat surface (a) without and (b) with interference.

even more to the accuracy of the recorded data, although its effect can be significantly mitigated by using a DC vibration motor attached to one of the cameras. This analysis represents a primary step aimed to evaluate the effect of the interference when applying multiple RGB-D cameras to perform human motion tracking, this being of special interest in disciplines as physiotherapy or rehabilitation. Due to space limitations, though, this further analysis will be addressed in the full version.

2. Background

Kinect-type cameras, as the ones used in this paper, project a known light pattern on the scene that is deformed by the objects within it. This pattern is then captured by an infrared (IR) sensor and compared with the emitted one, hence being able to estimate the *depth* of every pixel according to the pattern deformation. The active nature of this working principle induces interference in the overlapping areas where two or more devices are projecting their patterns at the same time, leading to noisier measurements, outliers and even points not being detected. This can be seen in Figure 1, where a Kinect device (C_1) has scanned a flat surface while another one (C_2) has been set to be directly pointing to the same surface. When C_2 is *on*, the recorded data are noticeably noisier and contain more spurious points (including holes in the surface representation) due to interference.

3. Experiments

In this section we present a quantitative study of the magnitude of the noise introduced by interference in a two-camera setup according to the distance and angle between the cameras and the measured surface. For that, we have set two configurations: i) measuring perpendicularly and ii) with an angle of 45^{o} with respect to the surface. The measurements have been repeated for two different brands of devices: Kinect and Asus.

3.1. Setup and analysis of interference

The cameras for the experiments have been placed on tripods about 30 cm apart while scanning a 2 m×3.5 m wall. Then, we have performed measurements every 25 cm from 1 m to 3.5 m in order to cover most of the range operation of the devices. Finally, this recording has been repeated for the two above-mentioned configurations aiming to evaluate the impact of both the distance and the angle of the surface in the measurements. In

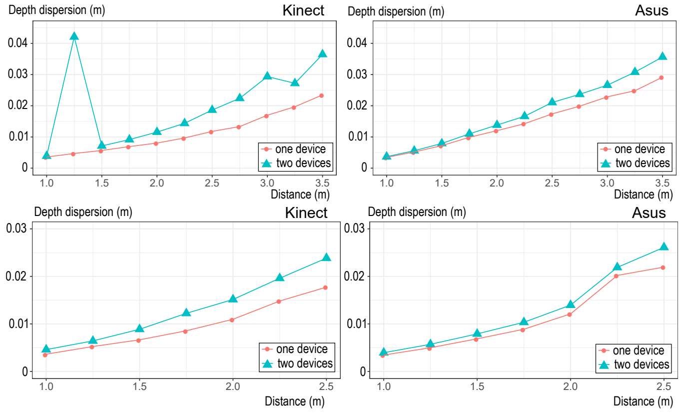

Figure 2. Depth noise with and without interference for the Kinect and Asus devices (top: perpendicular, bottom at 45^o).

the following, the data recorded by device C_1 is employed as the control sample whilst device C_2 only serves to create interference and, therefore, the information it provides is not saved. Thus, similarly to the example presented in Section 2, at each distance, two measurements are grabbed, corresponding to the data from C_1 while C_2 is *off* and *on*. Then, the noise of the depth data is estimated by first computing the covariance matrix of the 3D points recorded by C_1 and subsequently computing its Singular Value Decomposition (SVD) to get its eigenvalues. The square root of the smallest eigenvalue represents the standard deviation of the measurements in the dimension perpendicular to the wall's surface, being considered the *depth noise* in this work.

Figure 2 (top) shows the average depth noise (for the (*left*) Kinect and (*right*) Asus devices) in a set of recorded frames for each of the considered distances with the cameras pointing perpendicularly to the surface. As can be seen, the noise ranges from 4 mm (at a distance of 1 m) to around 25 mm near the end of the working range when C_2 is *off* (in red), while interference caused by C_2 increases the noise in all the distances (in blue). Note that there is a peak in the graph at 1.25 m in the case of the Kinect devices, probably caused by daylight interference to camera C_1 in that particular setup, although, it seemed not to affect the Asus devices.

Besides, the results reveal that the Kinect devices are affected more strongly by interference than the Asus ones, placing the latter in a favorable position to be used as sensors. Similarly, Figure 2 (bottom) represents the same noise when the cameras are placed with an angle of 45^o with respect to the surface. In this case, we only show the results for distances from 1 m to 2.5 m since, for larger distances, data were highly inaccurate in both situations due to the pronounced inclination of the measured plane. Again, the influence of interference is clearly visible in the figure, specially for the Kinect sensors.

3.2. Interference reduction

In order to mitigate the effect of interference in the measurements, we have followed the solutions presented in [1,2] by attaching a DC vibration motor to one of the cameras and computing the noise in the depth data again. Since the IR light emitter and the sensor

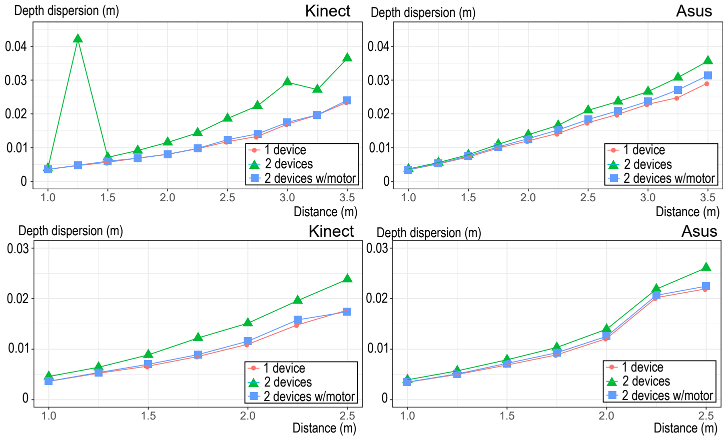

Figure 3. Influence of the motor on the depth dispersion regarding the distance (top: perpendicular, bottom at 45^{o}).

are rigidly connected and move jointly in a single device, inducing vibrations avoids the camera to detect the pattern projected by other devices. The results of the experiments reveal the efficacy of this solution, as the noise produced by interference is almost completely removed in every setup (Figure 3), hence improving the accuracy of the multi-camera system when they are pointing to the same scene.

4. Conclusion

This paper has analyzed the influence of interference between RGB-D cameras in the accuracy of their measurements, one of the main problems of using multiple depth cameras to measure the same scene. For that, we have conducted a series of experiments with the cameras at different distances and angles with respect a large flat surface, trying to simulate realistic conditions of scanning. The experiments reveal that the depth noise increases as distance grows and it is higher when the camera optical axis is not perpendicular to the surface. Not only that, the effect of interference from other devices is clearly noticeable in form of noisier points, increasing the number of outliers and holes in the detected 3D point cloud. Besides, Asus cameras seem to be less affected by interference than Kinect ones. Finally, we have evaluated the effectiveness of the proposed solutions in the literature based on DC vibration motors and validated their capability of alleviating the effects of interference. This analysis and evaluation is being employed to perform a further study about the influence of interference in performing human motion tracking.

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