A cost effective 12-cameras scanning system based on close-range photogrammetry, for precise 3D digital models of human body.

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Abstract.
In this paper a precise, cost effective and non-invasive body scanning system based on close-range photogrammetry, suitable for applications in medical and biomedical field, has been design and implemented. The system consist of 12 compact digital cameras, mounted on a rigid frame which allow to keep constant the B/H ratio. An high intensity led lighting system, integrated with the rigid frame, ensures a perfect and homogenous illumination of the subject with the minimum encumbrance. A modified firmware was installed on each device, in order to perform the synchronized remote release, driven by a remote control. The data transmission to the computer, is carried out wirelessly through the SD cards in the cameras. Furthermore, a robust internal and external camera calibration process, which allows to increase the performances of the body scanning system in terms of precision of the digital models, has been presented.

Keywords: Body scanning system, Close-range photogrammetry, camera calibration, High precision.

1 Introduction

The photogrammetric body scanning systems are very useful in numerous precise applications such as in medical and biomedical field [1], as well as in forensic field [2], because they are rapid, economic and non-invasive [3], [4], [5]. In order to be a valuable tool for these applications, the body scanning system have to returns precise digital models [6], evaluated in terms of repeatability. With this purpose, in a previous work [7] a body scanning system with 8 compact digital cameras was implemented, while in the present paper an improved 12-cameras body scanning system, based on close-range stereo photogrammetry, capable to return high precision 3D models of the human bodies and suitable for applications in medical and biomedical field, has been presented.

2 Materials and methods

The proposed body scanning system consist of 12 compact digital cameras (Canon Power Shot A480) with 3648x2736 Pixel resolution (Pixel size 1.69 10^{-3} mm), suitable for a photogrammetric multi-camera system, for the size (Dimensions = 92 x 62 x 31 mm) and weight (140 g). The Canon Power Shot A480 sensor is a CCD 1/2.3", which is very small but represents a compromise having an acceptable precision and the lowest cost of equipment. The cameras were mounted in pairs on a rigid frame, with a B distance between the cameras of 120mm, and the H distance of the object of 600mm, having B/H of 0.2. An integrated high intensity led lighting system, allows to ensure an homogenous illumination of the subject. Finally, a modified firmware was installed on each device to synchronize the shots of the cameras in order to reduce the problems related to the involuntary subject movements [8]. The data transmission to the computer, was carried out through the wireless SD cards installed on the cameras.

3 Camera calibration

The camera calibration is a very important process that enable to model a camera and obtain a photogrammetric digital model with high precision. The calibration process includes an internal camera calibration, that allow to take into account the distortion induced by the lens into the images, and an external camera calibration, that enable to calculate the position and the orientation of each camera in the World Coordinate System (WCS). The cameras of the proposed body scanning system were calibrated with a two-step internal calibration process as showed in the previous work [7], while the external camera calibration was carried out in the present work with an original solid calibrator and a photogrammetric software which detects the points in the source photos and align them employing a SIFT like approach, in order to reconstruct the dense surface (3D digital model) using the pair-wise depth map computation algorithm [9]. The images of the calibrator were elaborated through the photogrammetric software and the coordinates of the principal point X0, Y0, Z0 in WCS and the angles Yaw (ω), Pitch (φ) and Roll (ϰ) which individuate the orientation of the focal plane in WCS, were calculated. As the cameras are mounted on a rigid frame, their relative position in WCS is constant, thus the external camera parameters can be used to perform the "ground control".

4 Results and discussion

In order to state the precision of the proposed body scanning system, two analysis were carried out. The first one aims to state the precision of the calculation of the cameras position in the world coordinate system, while the second one, aims to state the precision of the 3D digital model obtained for both static object and real human body.

Precision of the cameras position calculation. The precision of the calculation of the cameras coordinate in the WCS, has been carried out employing the solid calibrator. Four different scans of the calibrator were performed, and four set of cameras position (s0, s1, s2 and s3), were calculated using the alignment algorithm of the photogrammetric software [9].Then, the four clouds of points, constituting the computed positions of the 12 cameras, in four subsequent acquisitions, were aligned with rigid translations and rotations, using the Procrustes algorithm. Finally, the four sets of data s0, s1, s2 and s3 were compared in pairs, in order to calculate the distances between the positions estimated for each camera, in the four acquisitions. This distances represent the error in calculation the cameras position in the WCS and, therefore, can be considered as a measure of precision. This analysis showed that the errors in the cameras position calculation is within the range from 0.37mm to 5.26mm with an average error of 2.87mm mm.

Precision of the 3D digital models. Two scans were carried out with the aim to state the precision of the result: the first one was carried out with a static object while the second one with a living subject. In Fig. 1 have been reported the 3D digital models of both, mannequin (left) and human body (right), obtained with the proposed body scanning system.

Fig. 1: Three-dimensional digital models obtained with the proposed body scanning system.

In order to state the precision of the digital models, the distances among the positions of a set of 14 coded target printed on the photogrammetric body, calculated in 3 different scans for each subject, were calculated. This analysis showed that the errors for the mannequin model is within the range from 0.03mm to 0.18mm with an average error of 0.10±0.05mm, while the errors for the human body model is within the range from 0.01mm to 0.20mm with an average error of 0.05±0.05mm. The results given by the analysis on the positioning precision of the cameras in the WCS are encouraging and state the high precision that can be achieved with the internal and external calibration processes. In fact, the maximum relative error of the cameras position calculation is about 5mm, which represents a percentage error less than 1%, on the H distance between the cameras and the subject. Furthermore, this error does not affect in the same way, the precision of the 3D digital model. In fact, for the models obtained, the error calculated on the relative position of the considered target, is one or two orders of magnitude smaller and ranging from 0.01mm to 0.20mm.

5 Conclusions

In the present work a low-cost and 12 cameras body scanning system, based on close range stereo photogrammetry has been presented. The system has proved to be suitable for precise applications such as those in the medical and biomedical field, because is not invasive, rapid and very precise. In fact, the analysis conducted, have shown that the processes of internal and external cameras calibration, allowed to obtain 3D digital models with precision ranging from 0.01mm to 0.20mm, for both static objects such as a mannequin, and for living human subjects.

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References

[1] Galantucci, L.M., Percoco, G., Angelelli, G., Lopez, C., Introna, F., Liuzzi, C., De Donno, A., 2006. Reverse engineering techniques applied to a human skull, for CAD 3D reconstruction and physical replication by rapid prototyping, Journal of Medical Engineering & Technology 30, pp. 102-11

[2] De Donno, A., Carlucci, D., Introna, F., 2008. The use of infrared rays for identification purposes, Journal of Forensic Identification, pp. 193-202.

[3] Galantucci, L.M., Percoco, G., Dal Maso, U., 2008. Coded targets and hybrid grids for photogrammetric 3D digitisation of human faces, Virtual and Physical Prototyping 3, Vol. 3, Issue 3, pp. 167–176.

[4] Galantucci, L.M., 2010. New challenges for reverse engineering in facial treatments: How can the new 3D non-invasive surface measures support diagnoses and cures?, Virtual and Physical Prototyping 5, pp. 3-12.

[5] Deli, R., Di Gioia, E., Galantucci, L.M., Percoco, G., 2011. Accurate Facial Morphologic Measurements Using a 3-Camera Photogrammetric Method, Journal of Craniofacial Surgery 22, pp. 54-59.

[6] Fourie, Z., Damstra, J., Gerrits, P. O., Ren, Y., 2011. Evaluation of anthropometric accuracy and reliability using different three-dimensional scanning systems, Forensic Science International 207, pp. 127-134.

[7] Pesce M., Galantucci L. M., Percoco G., Lavecchia F., 2014. A low-cost multi camera 3D scanning system for quality measurement of non-static subjects, In: 3rd CIRP Global Web Conference. PROCEDIA CIRP, Elevier Science BV, ISSN: 2212-8271, Napoli, 3-5/6/2014

[8] Jones, P., Rioux, M., 1997. Three-dimensional surface anthropometry: Applications to the human body, Optics and Lasers in Engineering 28, pp. 89-117.

[9] AgiSoft Photoscan. Algorithms used for the 3D dense surface reconstruction. http://www.agisoft.com/forum/index.php?topic=89.0 (accessed November 03, 2014).