A remote-control, smartphone-based automatic 3D scanning system for fNIRS/DOT applications

Yunjia Xia[1,2], Kui Wang[2], Addison Billing[2,3], Robert J. Cooper[2], Hubin Zhao[1,2*]
[1]*HUB of Intelligent Neuro-engineering (HUBIN), CREATe, Division of Surgery and Interventional Science, UCL, HA7 4LP, London, UK*
[2]*DOT-HUB, Department of Medical Physics and Biomedical Engineering, UCL, WC1E 6BT, London, UK*
[3]*Prediction and Learning Lab, Department of Psychology, University of Cambridge, CB2 3EB*
[*]*Corresponding author e-mail address: hubin.zhao@ucl.ac.uk*

Abstract: We present a remote-control, smartphone-based scanning system that can achieve a full-head 3D scan of an infant within 2 seconds. The scanned images can then be automatically aligned to generate a 3D head surface model.

1. Introduction

Functional Near-Infrared Spectroscopy (fNIRS) changes in the intensity of near infrared light passing through the scalp and brain to calculate the concentration changes of oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR). indicating the hemodynamic activity of the brain. fNIRS and its extension Diffuse Optical Tomography (DOT), allow functional neuroimaging of the human cortex to be cheap, accessible, and easy to use. To apply the fNIRS/DOT devices on subject heads for practical applications, three-dimensional model of the head surface is required to obtain the 3D position of optodes on the scalp relative to the cranial landmarks (i.e., nasion, inion, right/left preauricular points and Cz) [1]. This step is called "spatial registration".

The traditional methods for the spatial registration of fNIRS/DOT devices include electromagnetic digitizer [2,3] and photogrammetry [4–6]. However, both approaches are usually impractical when applied to infants due to their near-constant movements. Recently, a smartphone-based 3D scan method was implemented to quickly acquire the 3D scan of the adult subject [7]. By implementing the depth camera on the smartphones, a depth-resolved image of the subject can be directly acquired without any subsequent processing. Herein, we proposed an iPhone-based 3D scanning device which is capable of scanning an infant simultaneously with five iPhones at different angles within 2 seconds to achieve the highest scan coverage. In addition, an automatic alignment algorithm was proposed to automatically stitch the images acquired from five iPhones into a complete 3D head model.

Fig. 1 (a) The proposed smartphone-based 3D scanning system with the Bluetooth controller. (b) Photograph of the infant phantom.

2. Methods

The photograph of the proposed system is shown in Fig. 1(a). Four used iPhone XR smartphones (total cost ~£740) were fixed symmetrically to a hollow aluminum hoop of diameter ~70 cm. The fifth iPhone was fixed by a flexible phone holder 35 cm above other iPhones and 20 cm from the center of the hoop to obtain a scan of the subject's top head area. The 3D image of the subject can be directly acquired by the Heges 3D scanning app (Cite Heges) that utilized front camera to directly capture the 3D image of the subject based on the principle of structured-light. A custom-designed printed circuit board (PCB), on which integrated with a multi-channel Bluetooth controller (MDBT50, Raytac, China) and a trigger, was designed and fabricated to remotely control (i.e. start and stop) the scan operations of the Heges 3D scanning app [8]. Before the scan began, the hoop was held above the subject's head. Once the scan started, the user rotated the hoop around the subject's head by approximately 60 degrees, allowing the scan to cover most of the head area. The entire scanning session was completed within 2 seconds. The point-clouds acquired with the five iPhones were uploaded to the cloud via Wi-Fi to permit instantaneous processing of the resulting data on a local laptop.

The scanning system can be operated in both "manual mode" and "automatic mode". For manual alignment, the user manually selected at least three pairs of common points from two iPhone scans using CloudCompare and minimized the distance between the point pairs to achieve a rough global alignment between the scans [9]. An Iterative

Closest Point (ICP) algorithm was then implemented to improve the alignment between scans on CloudCompare. The automatic alignment was performed using python with Open3D package [10]. A 3D head template obtained from a previous 3D scan of a phantom wearing the same DOT device was used for global alignment. The Fast Point Feature Histograms (FPFH) feature describing the point cloud's geometric property was calculated separately for both the template and the scans. A Random Sample Consensus (RANSAC) algorithm was implemented to achieve the global alignment of the scans. The roughly aligned scans were further color-filtered, retaining the points with distinctive color characteristics. An ICP algorithm was then performed to achieve a fine alignment between the filtered scans. A 3D-printed infant phantom that contained dummy optodes at precisely known positions (via the CAD model) (Fig. 1(b)) was constructed to evaluate the performance of the system, including the effective scan coverage and actual localization errors attained by the system.

3. Results

Preliminary experiments on the infant phantom showed that this system can access 98.99% of the head surface area of our 6-month-old infant head phantom, with an acquisition time of less than 2 seconds. The average 3D Euclidean error between the optodes position of the 3D model and the true position obtained by our scanning system with manual alignment was 7.40 mm. The average 3D Euclidean error of the optodes positions obtained by our scanning system with automatic alignment was 9.30 mm. Fig. 2(a) displays the distribution of errors across the optodes for the manual alignment and automatic alignment. The accuracy of the generated 3D head model in illustrated in Fig. 2(b).

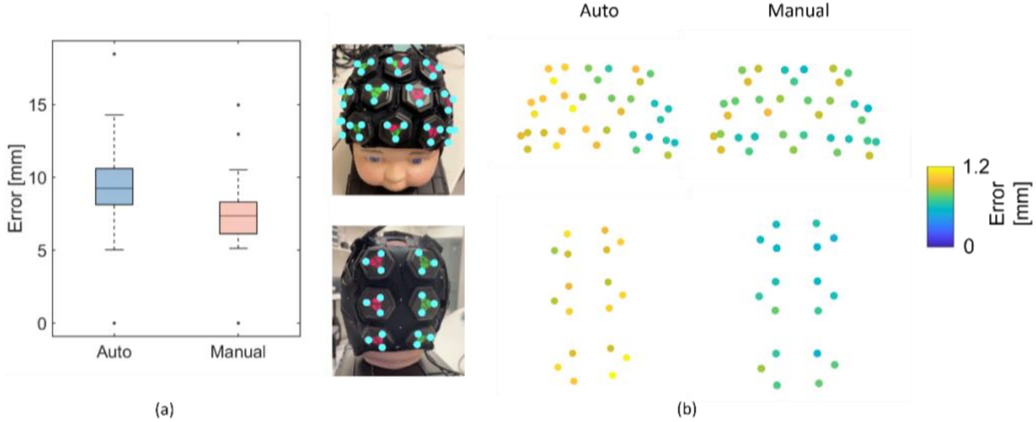

Fig. 2 (a) Localization errors for the optode positions obtained with the smartphone scanning system using automatic alignment and manual alignment. Boxplots represent the distribution of the errors across optode positions. Bottom and top edges of the box indicate the 25th and 75th percentile, while the central mark indicates the median. Outliers are depicted as dots. (b) Error of the smartphone scanning system model from the original phantom. Euclidean errors are represented with a color code on each optodes. Each value indicates the Euclidean distance between an optode on the original phantom and the corresponding optode on the system acquired model.

4. Conclusion

While further refinement and real-world testing is clearly required, the proposed remote-control, low-cost, smartphone-based 3D scanning system can achieve a full-head 3D scan and yield optode positioning error of 7.40 mm in less than 2 seconds. This performance can be further improved through the application of superior alignment and model procedures. We therefore believe that this approach has the potential to provide an efficient, accurate, practical, low cost, and universally application approach to fNIRS/DOT registration.

References

[1] D. Tsuzuki and I. Dan, "Spatial registration for functional near-infrared spectroscopy: From channel position on the scalp to cortical location in individual and group analyses," Neuroimage 85, 92–103 (2014).

[2] S. Wijeakumar et al., "Validating a new methodology for optical probe design and image registration in fNIRS studies," Neuroimage 106, 86–100 (2015).

[3] R. Vitório et al., "Brain activity response to cues during gait in Parkinson's disease: A study protocol," PLoS One 17, e0275894 (2022).

[4] E. E. Vidal-Rosas, et al., "Evaluating a new generation of wearable high-density diffuse optical tomography technology via retinotopic mapping of the adult visual cortex," Neurophotonics 8, 1 - 24 (2021).

[5] X.-S. Hu et al., "Photogrammetry-based stereoscopic optode registration method for functional near-infrared spectroscopy," J Biomed Opt 25, (2020).

[6] E. M. Frijia, et al., "Functional imaging of the developing brain with wearable high-density diffuse optical tomography: A new benchmark for infant neuroimaging outside the scanner environment," Neuroimage 225, 117490 (2021).

[7] I. Mazzonetto et al., "Smartphone-based photogrammetry provides improved localization and registration of scalp-mounted neuroimaging sensors," Sci Rep 12, 10862 (2022).

[8] "Heges — the iOS 3D Scanner app | using FaceID or LiDAR to make scans," https://hege.sh/.

[9] "CloudCompare," http://www.cloudcompare.org/.

[10] Q.-Y. Zhou, J. Park, and V. Koltun, "Open3D: A Modern Library for 3D Data Processing," (2018).