Original Article
pISSN 2383-5389 / eISSN 2383-8116
Journal of International Society for Simulation Surgery 2015;2(1):13-16 http://dx.doi.org/10.18204/JISSiS.2015.2.1.013

3D Head Modeling using Depth Sensor

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Purpose We conducted a study on the reconstruction of the head's shape in 3D using the ToF depth sensor. A time-of-flight camera (ToF camera) is a range imaging camera system that resolves distance based on the known speed of light, measuring the time-of-flight of a light signal between the camera and the subject for each point of the image. The above method is the safest way of measuring the head shape of plagiocephaly patients in 3D. The texture, appearance and size of the head were reconstructed from the measured data and we used the SDF method for a precise reconstruction.

Materials and Methods To generate a precise model, mesh was generated by using Marching cube and SDF.

Results The ground truth was determined by measuring 10 people of experiment participants for 3 times repetitively and the created 3D model of the same part from this experiment was measured as well.

Measurement of actual head circumference and the reconstructed model were made according to the layer 3 standard and measurement errors were also calculated. As a result, we were able to gain exact results with an average error of 0.9 cm, standard deviation of 0.9, min: 0.2 and max: 1.4.

Conclusion The suggested method was able to complete the 3D model by minimizing errors. This model is very effective in terms of quantitative and objective evaluation. However, measurement range somewhat lacks 3D information for the manufacture of protective helmets, as measurements were made according to the layer 3 standard. As a result, measurement range will need to be widened to facilitate production of more precise and perfectively protective helmets by conducting scans on all head circumferences in the future.

Key Words Modeling · ToF sensor · Medical image processing · Surface Rendering · Positional plagiocephaly.

Received: May 10, 2015 / **Revised:** May 12, 2015 / **Accepted:** May 24, 2015
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Introduction

3D measuring is one of the medical areas receiving the most attention at present.

We conducted measurements using the ToF sensor, a 3D measuring device, and we more effectively conveyed realistic information compared with the past by showing measured data in 3 dimensional format. In addition, we produced a virtual 3D head model in order to help plagiocephaly patients suffering from distortion to the skull, and used the model in the creation of a device to aid the correction of head shape. Previously, in order to produce such assisting devices, medical staffs had to conduct check-ups using X-ray, cephalometry and CT computer tomography to precisely measure head shape. However, radiography on newborn infants between 3 and 18 months of age causes increased social costs and the discomfort. In order to resolve these problems, we recommend the method of producing an exact model of the head's shape using the safe ToF sensor. In addition, The quantitative head shape evaluation method presents a scientific and objective solution.

Materials and Methods

We now describe the method that makes up our system. Fig. 1 provides a workflow of our whole method in block form. It is comprised of the following five components (1, 2, 3, 4).

Signed distance function

Every point cloud is defined as $X \in R^3$ and if the value X is equal to 0, it means it is a surface.

We define f (x) as a level set function and ϕ (x) as a signed distance function. ϕ has positive values at points x inside Ω, it de-

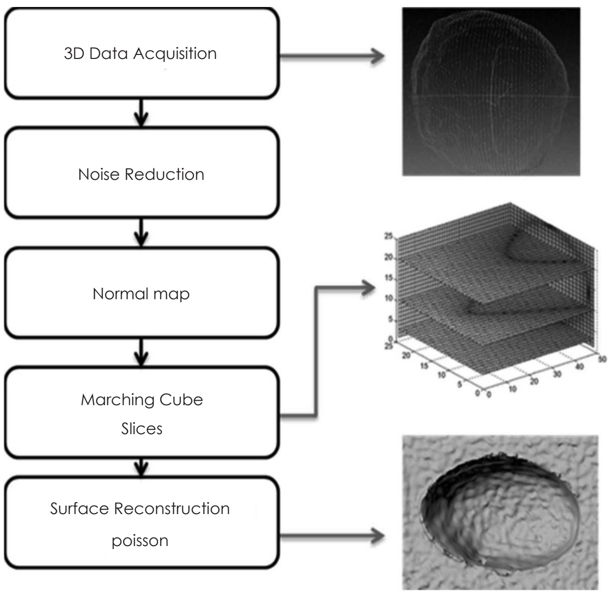

Fig. 1. Flow chart.

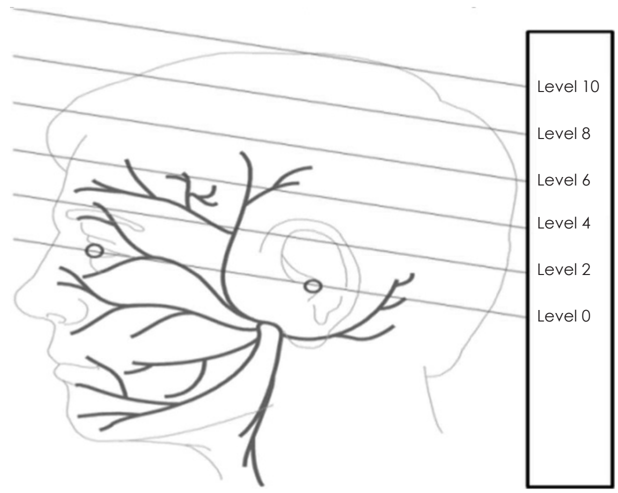

Fig. 2. Head level set.

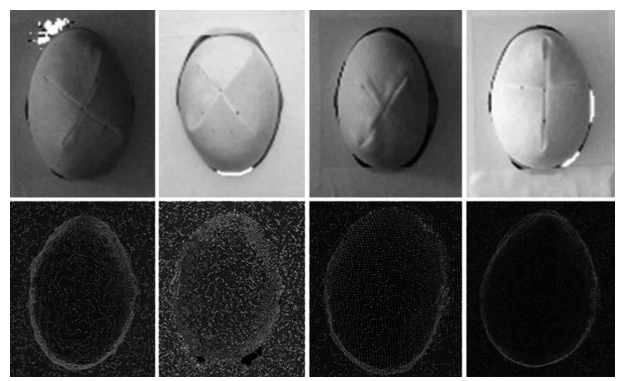

Fig. 3. Top: head top capture image. Bottom: Head Top Point Cloud.

creases in value as x approaches the boundary of Ω where the signed distance function is zero, and it takes negative values outside of Ω (1, 2, 3).

We now define the distance from a point $\vec{X}$ to a set ∂Ω and d($\vec{X}$)=0 for a given point $\vec{X}$. If the boundary set ∂Ω closest to $\vec{X}$ is found, we now call this point as $\vec{x}_C$.

Then, we get d($\vec{x}$)=| $\vec{x}-\vec{x}_C$ |

$$d(\vec{x}) = \min_{\vec{x}_C \in \partial\Omega}(|\vec{x} - \vec{x}_C|) \quad (1)$$

$$\emptyset(\vec{X}) = \begin{cases} -d(\vec{x}) & \vec{x} \in \Omega D_- \\ 0 & \vec{x} \in \Omega D_0 \\ d(\vec{x}) & \vec{x} \in \Omega D_+ \end{cases} \quad (2)$$

Furthermore, the signed distance function has a remarkable characteristics such as

$|\nabla\phi(X)| = 1$.

$$\vec{x}_C = -\vec{x} - \phi(\vec{x})\vec{N} \quad (3)$$

The formula $\vec{x}_C$ above is to calculate the closet point on the interface, where $\vec{N}$ is the local unit normal at $\vec{x}$[4].

Level set

If the linking of straight line segments based on the Sellion point and Tragion standard for establishing the head's line of reference is called Level 0 and the point when the imaginary line crossing Level 0 passes by the edge of the head is designated as Level 10, then 10 horizontal lines can be obtained between Level 0 and Level 10. Here, we measured the surface area of the head based on the part equivalent to Level 3 (Fig. 2) (5, 6, 7).

The reference point for level 3 is generally around the top of the ear and eyebrow, so we made a square aiding plane and conducted measurements in 3D.

The aiding plane was used for the purpose of confining the location of Level 3 after modelling and usage for determining whether the camera and head crossed during measurement (Fig. 3).

This is an image of the square aiding board installed in the spot equivalent to Level 3 of the head, and this is the result of 2D projection of the image in which this is converted into a 3D point cloud (Fig. 3) (8, 9, 10, 11).

Experiment and conditions

We measured the level 4 section of the heads of the 10 experiment participants. The results of measurements are considered as a ground truth and original circumference was measured based on a model made using 3D measured data. Moreover, ground truth was measured 5 times in order to reduce the error

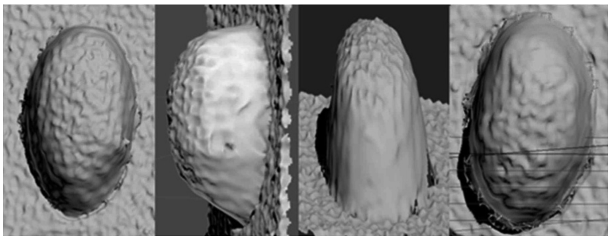

Fig. 4. ① Head Top view, ② Side view, ③ Front view, ④ measurement view.

Unit: Cm

Number	Ground truth	Head circumference	Error
1	62.82	61.5	1.32
2	59.74	58.7	1.04
3	58.7	58.5	0.2
4	61.12	59.7	1.42
5	62.56	61.5	1.06
6	60.32	59.6	0.72
7	61.98	60.5	1.48
8	61.5	60.1	1.4
9	60.92	60.7	0.22
10	62.25	61.8	0.45

rate of the experiment, and for head circumference, original circumference was measured using a 3D measurement tool based on a model calculated following the modelling.

Results

The results of measurement on the original circumference based on the aiding plane Level 3 show an error rate of around 0.2-14 mm (Table 1, Fig. 4).

Discussion

There is room for improvement in measurement error in accordance with figures generally permitted in the medical field. These errors may be viewed as a result of an accumulation of sensor errors, noise, algorithm errors and measurement errors. If these errors are reduced, we would be able to reach the level of producing precise head aid devices. Also it is anticipated that measurement standards will also become more accurate.

Conclusion

In this paper, we gathered data using a 3D surface measurement sensor and created a 3D model. This model has three main advantages.

Firstly, it was able to precisely detect changes in head shape by way of 3D reconstruction. This is cheaper than previous methods in terms of social costs and this made possible to use infrared (IR), which causes no harm to the body even after repeated measurement.

Secondly, it is for the creation of customized aid devices. The exact surface area of the head must be known in order to create such devices according to the size and symptoms. The surface measurement method proposed in this paper can be seen as a precise method.

Thirdly, it makes objective evaluation possible. Previously, qualitative methods were often used to evaluate the posture of the head. The method presented in this paper was able to evaluate the head's rate of change using data by continuously saving data throughout the process of changes to head shape. In the future, methods capable of reducing measurement errors will be devised and a development will be made to create models for the entire surface of the face rather than the creation of 3D models for between levels 3 and 10.

Acknowledgements

This research was supported by the MKE (The Ministry of Knowledge Economy), Korea and Microsoft Research, under IS/SW Creative research program supervised by the NIPA (National IT Industry Promotion Agency) (NIPA-2014-H0510-14-1034).

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