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Needle Tip Position Tracking for Eye Anesthesia Practical Simulator Based on Hall-Effect Array Sensor

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Abstract:	Purpose: Eye surgery treatment need to block the eye movement by using anesthesia. The failure of anesthesia causes eye trauma, blindness, and dead. Some eye anesthesia needs to inject anesthesia behind the eye ball through skin. Surgeon must have well skill and experiences. Method: The purpose method is a tracking system based on the array of Hall-effect sensor. The position of the needle is calculated by the neighborhood average value of the nearest sensor and the pose of the sensor. The overall system of eye anesthesia such as eye model, needle tracking system and graphical user interface was described in the paper. Result: Questionnaires has full score at 5 points, which mean very satisfy. There are 10 medical students and one expert physician. The first section which represent the familiar in purposed system with first time testing got average score 3.61 which is quite good level. Next section represents the correctness of the eye phantom dimension and usage of eye phantom. The output score is in the good level. The third section is the interface and tracking performance. The output score is 4.46 quite excellent. In last section, the skill development performance is evaluated with average score 4.43, quite excellent level.

	Conclusion: The needle tip position enough to able performs practical training. The calculation algorithm for needle tip position is performed. The non-planar array sensor is able to calculate the position from the eye phantom frame reference.

Needle Tip Position Tracking for Eye Anesthesia Practical Simulator Based on Hall-Effect Array Sensor

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KEYWORD : Needle Tracking, Hall effect sensor, Eye anesthesia, Practical simulator

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I. INTRODUCTION

Eye vision is one of the most important perception for living. Human eye are soft organ and able to loss the efficient by aging and other effect like air pollution. Chemical and surgery is a treatment for the eye. For the eye surgical treatment, the eye disease such as eye cataract, refractive error, eye muscle disease, macular degeneration, and etc. About 314 million people are visually impaired worldwide, 45 million of them are blind. Most people with visual impairment are older, and females are more at risk at every age, in every part of the world[1].

Almost the surgery need eye anesthesia with a good care with every procedure, because eye are small and sensitive. The cause of failure during the surgery can cause trauma such as hemorrhage, blindness, and able to dead [2]. One of the surgery risk factor because there are no practical system that available for medical doctor. The medical needs to practice their own skill with the patient, since the anatomy of the eye changed in the dead body.

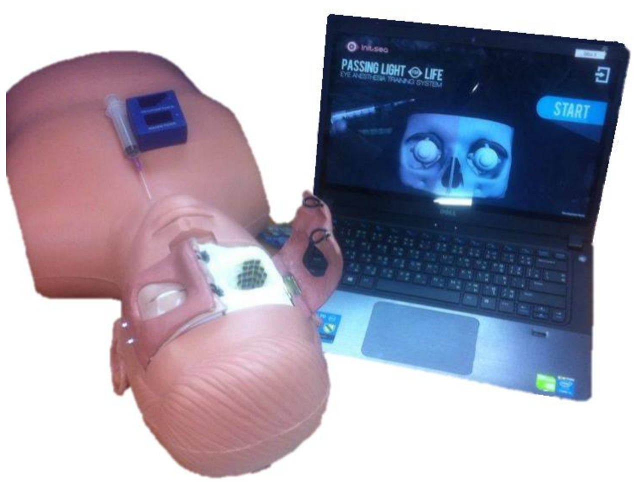

Fig. 1.Eye Anesthesia Practical Simulator

The retrobulbar block is one of the regional anesthesia method. This method inject the anesthesia directly to retrobulbar fat which located in the orbit behind the eye. A needle insert through the skin below the eye or posterior to tarsal plate at one-third of the eye length. After needle is at the half way, the surgeon need to change needle tip direction point up to the retrobulbar area.

There are many modalities of tracking system such as optical tracking system, electromagnetic tracking system, acoustic tracking system, and sensor based tracking system. Optical tracking is the accuracy for tracking device [3], but the problem of line of sight and need of rigid body tool causes the optical tracking is not fit for this application. Acoustic tracking system not has enough accuracy[4]. The electromagnetic tracking system has the limitation in size and the magnetic distortion cause the error.

Our purpose method is based on the Hall-effect array sensor. The Figure 1 Shown the overall system. This system is reverse the approach of electromagnetic. The sensor located around the orbit received the magnetic field form the modified needle and calculate the electrical signal to get position of the needle tip.

The remaining of the paper is organized as following. In the next section, we outline some fundamental background and related research. Section III our solutions for the eye anesthesia practical simulator. In section IV, Hardware and set up experiments is described. The experimental of practical tested by medical student. In last section, we conclude the paper and discuss some future work.

II. RELATED RESEARCH AND FUNDAMENTALS

Opthalamic anesthesia training system has not widely developed. Conventional method to study these skills is learning by observation, lecturing, porcine testing and eye phantom without feedback. There are few exist system for ophthalmic anesthesia such as EyeSi, ORIS and our previous work, INITSEA. EyeSI Surgical is a virtual reality simulator for intraocular surgical training by VRmagic[5]. In this platform, the surgeon has to look through the microscope. This system allow surgeon to insert the needle in a graphical simulation with no force feedback and there is no regional anesthesia in their software. In[6], ORIS or the Ophthalmic Retrobulbar Injection Simulator is an another virtual reality with human eye phantom. This system tracks the needle by using the acoustic tracking system. Unfortunately, this platform has low accuracy which the error approximately 6.35 millimeters. George et al. propose approach the ophthalmic anesthesia using integrated capacitive and Hall-effect sensor[7]. This platform used the modified needle and capacitive electrodes to detect the organ touching. The use of the Hall-effect sensor schemes for injection rate of the syringes. This system detect only when the tip of the needle touch the electrode at the surface of the organ. In real use, only detection of the tool is not enough to see the movement of the needle, so the surgeon can't understand much how to control their hand and needle direction. For our previous work, Intelligent Needle Insertion Training System for Eye Anesthesia, INITSEA[8,9], is the platform for retrobulbar block using NDI Aurora, electromagnetic field tracking device. This system shows the position and orientation of the needle, which modified to be an inductance coil. The size of this system is too big for practice, but the position and orientation can read accurately. HERBERT R. JONES et al [10] discussed magnetic position and orientation tracking system.

III. HALL EFFECT SENSOR TRACKING SYTEM

Hall-effect array sensor is developed to solve the line of sight problem, steerable needle, and non-modified needle. The feature of this system is capable to track the object, which can generate magnetic field. This purposed method aims to track the position of the needle tip in eye anesthesia application. This platform has 6 main parts including Hall-effect array sensor, signal acquisition, position calculation, modified needle, eye orbit phantom and Graphical User Interface. Firstly, Hall-effect array sensor is a specific part that designed to measure the magnetic field from the needle tip. This part consists of the circuit board to gather signal and sensor, which attached in 3D position of eye orbit phantom. Secondly, the signal acquisition is the part that gathers the signal from the hall-effect array sensor. After the signal is collected, the position of the needle is being calculated in the computational part. Next, magnetizer is used to turn needle to magnetism source. An eye phantom is the mockup of the eye orbit and the sensor attachment location. Lastly, the interface between eye tracking simulator and modified needle is displayed in graphical user interface.

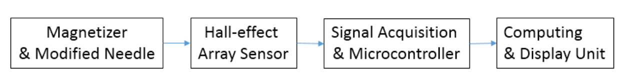

Fig. 2. System Process Diagram

The position display of the needle in the eye orbit has a flow which visualized in Figure 2. Firstly, the modified needle is magnetized by the magnetizer. After the needle became the magnetic source, the magnetic field is measure by the Hall-effect array sensor. Next, all of sensors are collected by signal acquisition part, and then collected signal is calculated to a position of the needle tip. Finally, the position of the needle tip is displayed in graphical user interface.

A. Hall-effect array sensor

Hall-effect sensor is one of the magnetic sensors used for positioning and level sensing. The Hall-Effect Sensor consists of a thin rectangular p-type semiconductor material that pass current. When placed a device within magnetic field, the flux lines will deflect the charge carriers, electrons and holes in semiconductor material. The Lorentz force does the charge carrier movement. These ratiometric Hall effect sensor ICs provide a voltage output that is proportional to the applied magnetic field. They feature a quiescent voltage output of 50% of the supply voltage. The output voltage will rise when the intensity from South Pole is higher while it will decrease when intensity from North Pole is increasing.

The format of the array in this proposed system is flexible. Normally, the Hall-effect array sensor is place as a planar array in three axis to tracking the position of the object. Our purpose attaches the sensor, which based on the anatomy structure, which is non-planar pattern. Each sensor has a specific position and orientation as shown in Figure 3. This position and orientation is used for calculated the position of the needle tip.

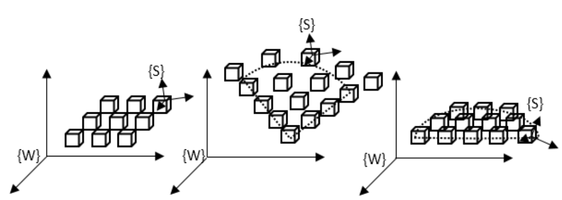

Fig. 3. Non-Planar array Sensor Position and Orientation

The magnetic source is necessary for the Hall-effect sensor to representative of the tool tip. However, the standard needle of the syringe is made from the stainless steel, which is a low magnetism capability, so the modified needle is changed from the stainless steel material into ferromagnetic steel needle which being used from the past. The ferromagnetic material is able to induce more magnetism than a stainless steel material. The magnetizer is made from two magnets that align in the parallel with the different pole. The gap between two magnets is the magnetic field. When a modified is applied in the magnetizer the needle become temporary magnet. Keep that in mind, there are two poles for the magnetizer, North Pole and South Pole. The applied needle is measured the based value of magnet with calibration of hall-effect sensor. The measured value is being use for calculate the distance between the needle tip and surface. The value of the sensor is depended from the distance of the emitter and receiver and the shape of the magnetic source. Unfortunately, the needle tip has a sharp end, so the magnetic field has a similar to circular field from the source.

The array sensor has many sensors, so the data from each sensor is collected by multiplexer, which is controlled by microcontroller. All the sensor data is acquainted and is sent to the computing unit. Hall-effect array sensor tracking system in this purposed used A1324 from Allegro Micro system, Hall-effect sensor. This model of sensor has high sensitivity at 5 millivolts per gauss. This sensor has a linear output and usually used in displacement measurement, angular position, and current measurement [11,12]. Industrial and automotive designed of this sensor provided the temperature-stable sensor and Low-noise output. For the data selector, Multiplexer, MAX4619, has High-speed at 25 ns. For data selector. The CMOS Analog is fit for read the data in analog, which match for the ratiometric sensor.

B. Eye Orbit Phantom

Developed sensing system is integrated into the special designed of eye orbit phantom. An eye phantom has 3 major parts, eye anatomy structure, sensor socket, and human-like skin attachment. Eye phantom depicts the eye anatomy, which include the eye muscles, eye globe, optical nerve, and eye orbit.

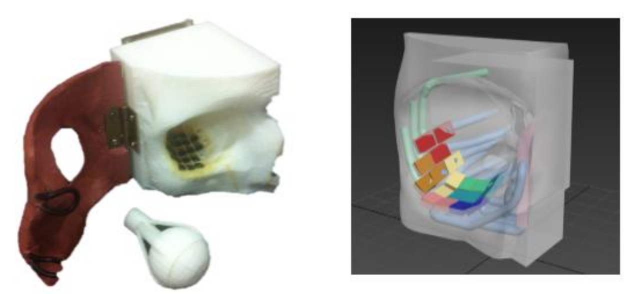

Fig. 4. Eye Phantom with integrated Hall-effect Array Sensor

This entire structure anatomy dimension is very important for practical simulator, because the physicians used their own experiences to control the needle with exist anatomy of the eye orbit. 3D model is created by 3D CT-scan dataset and preprocessing to smooth the surface and to clear some noise. From the conventional retrobulbar block, the sensor is attached around possible workspace area of the operation.

The 3D model is modified to have array of sensor sockets. The position and orientation of the sensor is based on the eye phantom frame. The socket is designed to fit with the sensor shape and able to wire the electrical cord link to backside of the phantom. 3D printing produces the designed phantom that shown in the figure 4. After the sensor is put into the design socket, the electrical transparent epoxy to prevent the short circuit between the needle tip and IC solder pad. The last past is mask installation for skin attachment. The force resistance during the insertion is the one sense that makes the physician adjust the force and needle direction. The artificial skin is made to have a resistance like in real human, but it is not described in this paper.

C. Needle Tip Position Calculation

The needle is display in 3D workspace with the Cartesian coordination. This refers to the needle tip and internal value and pose of the sensor. Sensor is collected its pose as 6 parameter, x-y-z axis and x-y-z rotation. The needle tip position calculation is divided into three parts, signal preprocessing, tip position calculation, and compare the needle tip with eye 3D model.

The collected signal is filtered with low pass filter of FIR. The moving average window extracts the noise out from the system. The sampling rate is set to relate with the user application. The sampling rate is set at 10 Hz. At last, the computing unit searches for the sensor that return highest value. The highest measured value sensor means the needle tip close to the sensor. The aim of using only highest value sensor is to reduce the computation, which also include the value from the second measured value sensor. The distance of the needle tip to the sensor is calculated from the signal value. The distance of the selected sensor is calculated in the equation 1

$$Distance_i = \frac{C}{Sval_i} \quad (1)$$

The $Distance_i$ parameter is a perpendicular distance between sensor and needle tip. The $Sval_i$ is the sensor value. C is sensor coefficient which gain by preliminary result. The $Distance_i$ is referenced with the sensor frame. In order to represent the needle tip with eye phantom reference, the needle tip distance must transform by the homogenous matrix from the eye origin. The following equation 2 described the needle tip position in the eye phantom frame.

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{needle\_tip} = \begin{bmatrix} Rot(\alpha,\beta,\gamma) & Pos(x,y,z) \\ \tilde{0} & 1 \end{bmatrix}_{sensor,i} \begin{bmatrix} 0 \\ 0 \\ Distance_i \\ 1 \end{bmatrix} \quad (2)$$

The position of the needle is calculated by using the transformation matrix of highest value sensor multiply by translation matrix of that sensor with calculated $Distance_i$. The position and orientation of the sensor provided by CAD designed of eye phantom. This purposed system is cannot calculate the orientation of the needle, because only the tip of the needle is not enough to calculated the orientation and the rotation matrix inside the transformation matrix shown the orientation of the sensor not the needle tip. The highest value may have closely level, so the position from the the second measured value sensor are used and weight with the highest value as following equation 3.

$$pos(x,y,z)_{weight_{pos}} = W_1 \cdot [pos(x,y,z)]_1 + W_2 \cdot [pos(x,y,z)]_2 + W_3 \cdot [pos(x,y,z)]_3 \quad (3)$$

The position of the needle tip has weight value from the nearest value sensor. The weight of the sensor depends on the result from the experiment.

D. Needle Hit Detection

The alarming of the needle tip with the artificial area is the determination of distance between the needle tip and the artificial point. This feature used to alarm the physician to avoid the danger area in the eye orbit and this function is also used to indicate that the needle tip is in the goal position, retrobulbar injection area. Alarming is separate into two layer, alarm and hit. The Euclidean distance, $\vec{D}$ between the needle tip and specified point or area is calculated following equation 4

$$\vec{D} = \sqrt[2]{(x_m - x_p)^2 + (y_m - y_p)^2 + (y_m - y_p)^2} \quad (4)$$

The m stand for the marker and p stand for predefined point. The determination condition used the simple math comparing. For example, if the Euclidean distance is in the alarming range, the alarming is warning condition. On the same way, if the Euclidean is less than threshold distance, it means the needle hit.

E. Graphical User Interface

The graphical user interface is used for display the needle tip and eye anatomy in the 3D simulation. Developed software has two main pages, the configuration pages and needle tracking display. First part of the software need the user to configure the communication port and select the side of eye phantom, left or right phantom eye. Then the software is connected to the microcontroller to collect the data from the Hall-effect array sensor and calculated the needle tip position. Next, the display part show selected eye anatomical with the needle tip position. There are two-view mode, the projection view and first person view. The figure 5 shown the GUI display.

There four information sections as following number in above figure, section 1 is view selection panel, and section 2 is the alarm section that shows the needle status. If alarm show green signal mean the needle is in the injection area and ready to perform injection, whereas the yellow or red signal show warning and hit status. Third section show the position of the needle tip with the eye phantom reference frame. Last section shown the display view of needle tip and eye 3D simulation that sync between hard ware and software. This software is done by Unity software in C# Language.

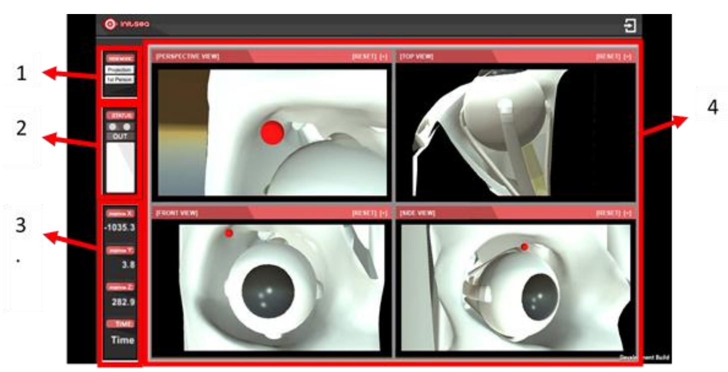

Fig. 5. GUI Display of Eye anesthesia practical simulator

IV. Eye Anesthesia Simulator Testing

The experimentation of this simulator follows the conventional method of the retrobulbar block. Note that, expert physician consultants did all system evaluation. The development and parameter tuning is under physician guidance. The medical student and expert physician is subject data in the test experiment. Medical student is trained only in the lecture before start test with developed simulator. There are 3 steps to be done in the experimentation. First, insert the needle to half way and then change the direction to the retrobulbar area. Next, the injection is performed. Last step, pull out the needle that similar to the enter pathway. In each experiment, the test failed when the simulator alarm hit and false injection area. The test time is also counted. After the experiment had done, test person has to answer questionnaire in the forms. The questionnaire is separated into 4 sections consisted of simulator familiar, medical skill and experiences, graphical user interface, and system satisfaction. Each sub question has full score at 5 points, which mean very satisfy. There are 10 medical students and one expert physician.

V. Results & Conclusions

Skillful physician finish the retrobulbar block process with average times 13 seconds where as the medical student that passed the testing done the process by 27.64 seconds. The success rate of the 50 tests from 10 medical students is 38%. The results show that the surgeons without experience have the high failure. There are many types of failure such as hit muscle, hit eye orbit, hit optic nerve, and inject in the wrong area.

There are four different topic in the questionnaire was described. The result was shown in the table 1. The first section which represent the familiar in purposed system with first time testing got average score 3.61 which is quite good level. Next section represents the correctness of the eye phantom dimension and usage of eye phantom. The output score is 4.12, which is in the good level. The third section is the interface and tracking performance. The output score is 4.46 quite excellent. In last section, the skill development performance is evaluated with average score 4.43, quite excellent level.

In summary, the design of the eye anesthesia practical simulator based on Hall-effect array sensor was described in this paper. This purposed method provided the user to track the needle tip without any special add-on equipment to interfere the conventional method of eye anesthesia. Because of the normally needle is steerable, so the tracking of this method is fit more than other rigid-body tracking system.

familiar in purposed system	(5)
user-system familiar	3.8
learning time made confidence to user	3.9
enough time for familiar with the system	3.5
system comfortable	4.2
practical system is similar to real and reliable	3.6
system is ease to practice like in real patient	2.7

a.)

correctness of the eye phantom dimension and usage of eye phantom	(5)
eye phantom size similar to the real eye	3.9
the artificial skin give the resistance similar to the real skin	3.5
overall phantom look similar to the real human	3.8
model phantom comfortable	4.6
phantom made more understand in skill practicing	4.8

b.)

interface and tracking performance	(5)
3D eye graphic similar to the real object	4.4
response time is realtime	4.3
Graphic Beautiful	4.6
graphical understanding	4.2
GUI made more understand in skill practicing	4.8

c.)

skill development performance	(5)
system satisfy	4.3
gain practice from the simulator	4.6
encourage physician the harmful of failure in the process	4.7
made user more careful	4.6
gain skill experience from the simulator	4.6
gain knowledge more than in practice with real patient	4.1
this system is suitable for eye anesthesia practice	4.3

d.)

Table 1. Average score in each topic of questionaire

This hall-effect array sensor offered the local tracking in the minimal area. The needle tip position enough to able performs practical training. The calculation algorithm for needle tip position is performed. The non-planar array sensor is able to calculate the position from the eye phantom frame reference. The weighting position of highest value and second and third high value improve the position stable. The alarming of the needle tip with the artificial area is the determination of the distance between the needle tip and the artificial point.

The anatomical structure is created from real human data, so the dimension is corrected. The eye model is modified to have a socket for the sensor with the specific medical application. In the eye anesthesia application, the distance limitation of the sensor and needle is neglected due to the distance of the eye globe and eye orbit is narrow and cover all the workspace in eye anesthesia application. 3D printing creates eye phantom. GUI of this simulator displays the navigation of the needle t ip and eye 3D simulation. There are two modes view to display, perspective view and first person view.

From the questionnaire, the medical students and expert physician satisfy the performance of overall system including familiar in purposed system, correctness of the eye phantom dimension and usage of eye phantom, interface and tracking performance, and skill development performance.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: The authors declare that they have no conflict of interest. **Ethical approval:** For this type of study formal consent is not required. **The following statement should be included:** This articles does not contain patient data.

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Figure

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Figure2

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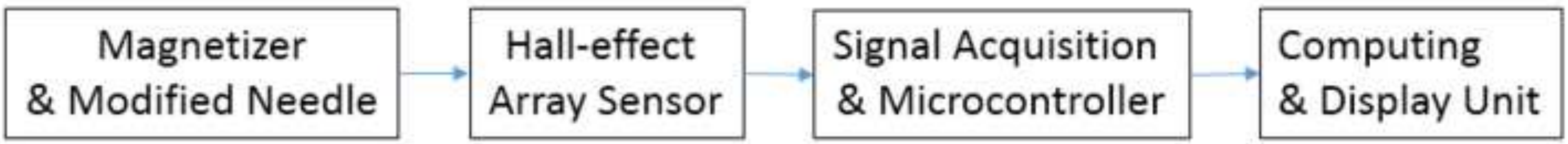

Figure3

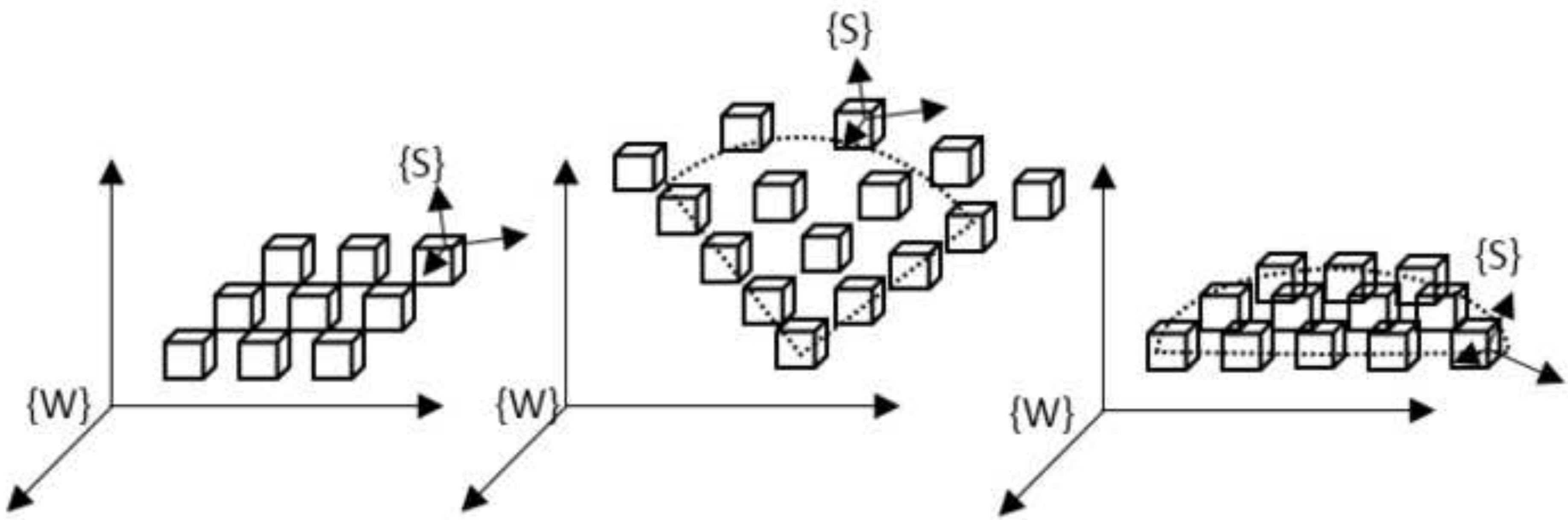

Figure4

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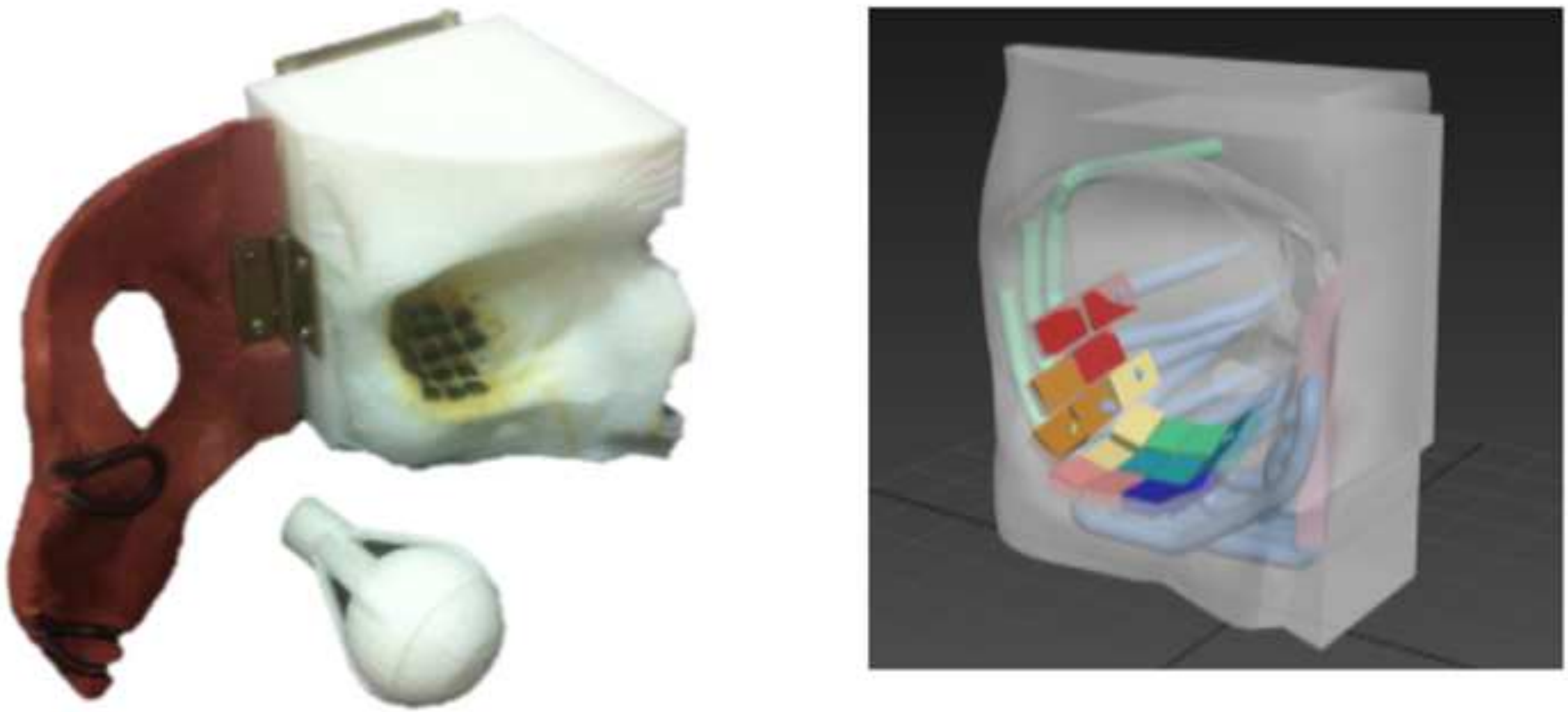

Figure5

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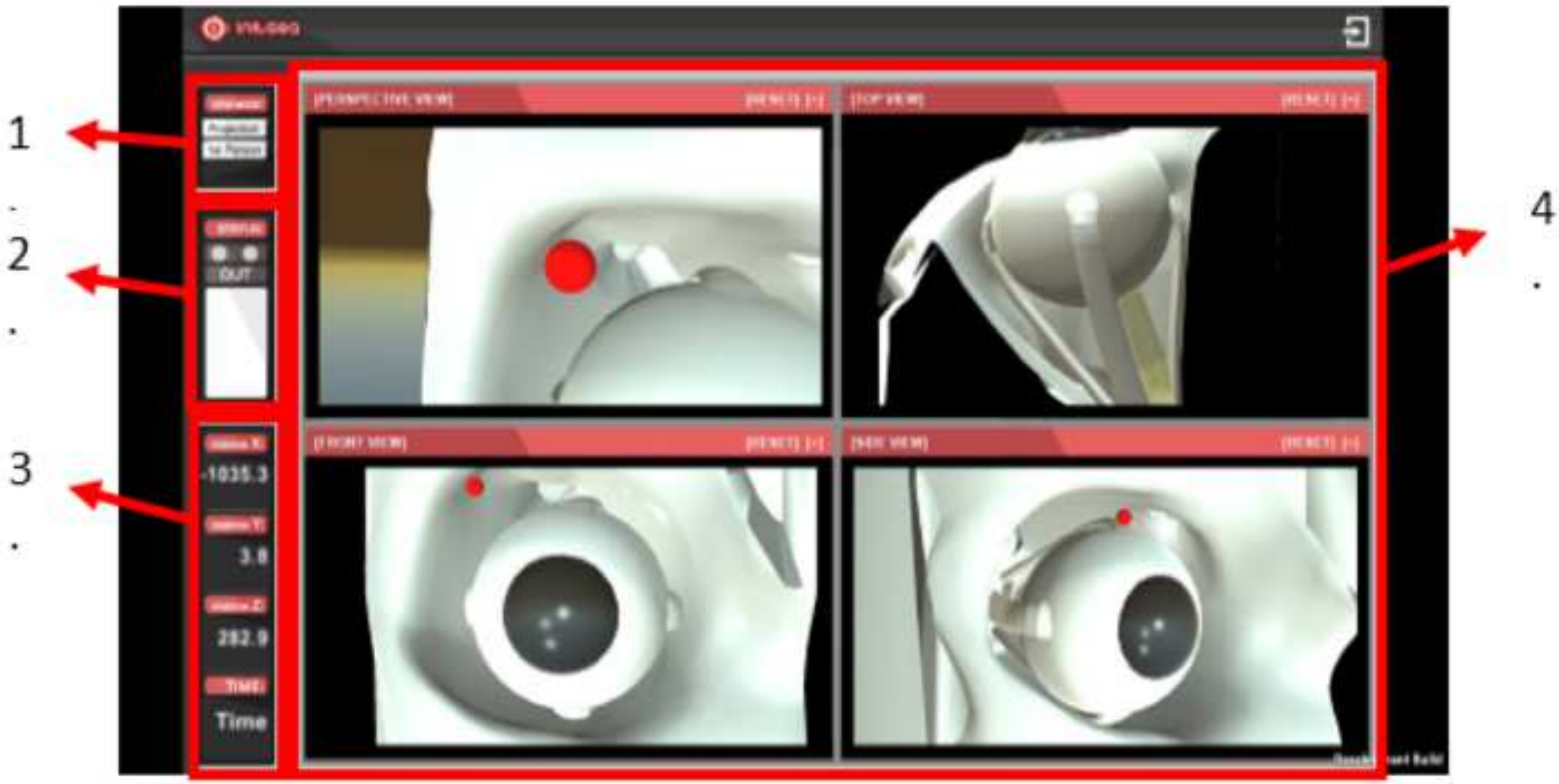

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d.)

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