An Ophthalmic Anesthesia Training System Using Integrated Capacitive and Hall Effect Sensors

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Abstract—Regional anesthesia delivery for ocular surgery involves insertion of a syringe needle into the orbital space at the proper position and orientation such that ocular structures remain undamaged while avoiding adverse systemic reactions. Additionally, anesthetic fluid must be injected at an appropriate rate to achieve painless and rapid akinesia. Training on human subjects is risky and animal cadavers do not emulate human ocular anatomy. Thus, a training system which closely replicates human ocular anatomical structure and provides real-time qualitative feedback on the effectiveness and safety of the anesthetic procedure would significantly mitigate risks associated with real-life procedures. This paper presents a rapid prototyped, anatomically precise training manikin that detects the proximity and touch of syringe needle to the extraocular muscles and alarms the trainee to avoid injury. The proximity of the needle to the muscle structure is detected using capacitive sensors integrated in the manikin. A Hall-effect sensor based measurement scheme for detection of rate of injection from a syringe has been developed. The specially designed syringe piston provides illusion of fluid flow inside the manikin for the trainee while reducing anesthesia wastage. A Virtual Instrument developed measures the output from capacitive sensing electrodes and Hall-effect sensor and displays it to the trainee through a Graphical User Interface. The proposed capacitive touch and proximity detection schemes have been validated by tests performed on the prototype system. The rate of injection was measured in real-time on a prototype syringe, demonstrating the practical use of the system for medical training purposes.

Keywords—capacitive proximity, ophthalmic anesthesia, training system, rate of injection, Hall-effect sensor.

I. INTRODUCTION

COMPLICATIONS in regional anesthesia delivery in the eye have been widely reported for the clinically practiced techniques such as peribulbar, retrobulbar and sub-Tenon’s [1],[2]. Globe (eye-ball) and optic nerve perforation and retrobulbar hemorrhage constitute some of the commonly reported complications [1]. Additionally, the rate of injection of anesthetic fluid in the intraorbital cavity is known to influence the time taken for onset of akinesia, uniformity of spread of the anesthetic agent and pain perceived by the patient [3],[4]. Fig. 1 illustrates the correct needle position and appropriate trajectory to be followed for a typical anesthetic block with a 2.54 cm needle. It highlights the importance of the insertion position of the needle and the path followed in avoiding damage to the eye-ball and associated muscular structure. Mastering these anesthesia administration techniques require hours of practice either on cadavers or on actual human subjects. Actual human subject based training entails risk to the patient and hence is...
not advisable [5]. Complication rates are as high as 4% in case of peribulbar and retrobulbar techniques [2],[6]. The high incidence rates can be correlated to lack of proper training [2],[7] and human errors [5]. Animal cadavers eyes are not an accurate representation of human ocular anatomy and may not always be readily available. More importantly, determination of nervous, muscular and ocular damage and providing feedback on the quality and effectiveness of the block performed becomes challenging. Hence, a training system that can assess the quality of the performed anesthetic procedure and provide appropriate feedback, can be beneficial in augmenting the anesthetist’s skills.

Manikin based training systems have been shown to be effective in reducing human errors and overall time taken to administer anesthesia, while providing the trainee with a realistic training environment [8],[9]. General anesthesia training manikins do not have any provision for training in ophthalmic blocks [10]. The Ophthalmic Retrobulbar Injection Simulator (ORIS), is a retrobulbar anesthesia simulator that employs expensive, complex and bulky ultrasonic sensing techniques to determine needle position [11]. Moreover, it does not provide qualitative feedback on the anesthetic procedure and proximity to important ocular structures. Capacitive proximity and position detection schemes have been reported to be effective and reliable [12],[13]. Capacitive array sensing based manikin of [14] does not have underlying ocular and orbital anatomy necessary for accurate reproduction of the training environment.

Image or video based methods of calculation of rate of injection require direct line of sight between the image capture device and the syringe [4]. This impairs free movement for the anesthetist who does not perceive an accurate training scenario. A magnetostrictive displacement transducer based method proposed in [15] and the magnetic encoder system used in [16], both, do not resemble practical syringes used by anesthetists on a day-to-day basis. Hence, they are not suitable for realistic training environment. Hall-effect sensor based linear position sensors are known to be compact, rugged and easy to mount [17],[18]. However, determination of position with Hall-effect sensors and magnet presents challenges due to nonlinear nature of sensor output arising from the power-law relationship of magnetic field decay [18],[19]. With suitable calibration, Hall-effect based position sensors can be employed for measurement of rate of injection [20].

In this work, we present a new manikin based training system [21] for regional ophthalmic anesthesia techniques to address the above mentioned problems. A low-cost but effective capacitive sensing scheme and measurement system is used to determine the proximity of needle to important ocular structures or appendages. A simple, specially designed piston structure is employed which conceals the anesthetic fluid when the piston is pressed providing the illusion of actual liquid flow through the needle to the trainee. This provides the trainee with an accurate training environment. Additionally, the piston also houses the Hall sensor, hiding it from the view of the trainee, thus providing a maneuverable and compact syringe to practice safe rate of injection. The developed manikin provides an anatomically accurate representation of the orbit, globe, extraocular muscles (EOM) and optic nerve. The skin is made of gel-filled silicone which gives an authentic human tissue appearance thus aiding in creating an actual human subject experience for the trainee. The syringe needle’s proximity or touching of ocular muscles and the rate of injection information is displayed in an intuitive Graphical User Interface based Virtual Instrument (VI).

II. INTELLIGENT OPHTHALMIC ANESTHESIA TRAINING SYSTEM

Fig. 2 shows a simplified overall diagram of the ophthalmic anesthesia training system. The training manikin which includes the orbital structure, muscles and globe structure are 3D
A. Anatomically Accurate Manikin

The manikin which resembles a human face consists of four parts: (a) Orbital structure (b) Silicone Facial structure (c) Globe and extraocular muscle (EOM) structure and (d) Silicone based skin overlay.

1) Orbital Structure: This is an anatomically accurate physical model of the orbit and its associated skeletal features. A polygon model of the human orbital structure along with the globe, ocular muscles was modeled in Autodesk 3DS MAX 2010 (32-bit) [23]. 3DS MAX is a modeling, animation and rendering software. The developed polygon model was dimensionally matched to the human orbit. The dimensional matching was achieved by preparing the polygon model from CT scans of the human orbit. The posterior wall of the structure has a hexagonal mating cavity to insert part (c), which has a similar hexagonal matching structure, as shown in Fig. 3(b). This configuration ensures that the globe and EOM is placed in its correct position and orientation in the orbit during assembly. The orbital structure is mated with a dovetail structure and secured by nuts to ensure rigid assembly.

2) Silicone Facial Structure: The part (b) of the manikin, shown in Fig. 4(a) is made of high hardness silicone rubber, OOMOO 30 manufactured by Smooth-On Inc, with a Shore A hardness of 30. A polygon model of the human face was modeled in 3DS MAX 2010 [23] to closely match the orbital structure of part (a). The polygon model was converted to a Stereo-lithography (STL) model and 3D printed in ZP-151 composite material using Z510 3D printer from 3D Systems. This rapid prototyped physical model of the human face was then used as mold for the OOMOO 30 silicone rubber and cured at room temperature for 24 hours.

3) Globe and Extraocular Muscle Structure: Part (c) consists of a 3D printed model of a polygon model of the globe and extraocular muscles along with the optic nerve, as shown in Fig. 3(c) which was modeled in Autodesk 3DS MAX 2010 (32-bit) [23]. The posterior end of part (c) ends in a hexagonal mating connector, having grooves for drawing electrical connections. The six extraocular muscles of the eye are coated uniformly with a thin layer (≈ 100 µm) of silver conductive ink (SBCI-19 from Constand Indichrom Pvt. Ltd.), to make them electrically conductive.

4) Silicone based skin overlay: Part (d), is a detachable gel filled silicone rubber overlay that closely replicates the look and feel of human tissue and skin as shown in Fig. 4(b). It is made by sandwiching a layer of silicone gel between two layers of silicone rubber using mold and mask making techniques. The silicone used is Dragon Skin Medium 10 from Smooth-On Inc, with a Shore A hardness of 10 with viscosity of 23000 cps. The human face mold of part (b) was used as a positive mold. A negative mold was cast using plaster of Paris from this face mold. The low viscosity silicone rubber is then
Fig. 6. The internal view of the developed training system showing the orbital structure. Shielded cables from the eye structure are connected to the DAS with an interfacing PCB. The DAS is connected via USB to a Laptop-PC running a VI for display of needle proximity and touch information.

poured in the space between the positive and the negative mold and cured at room temperature for 24 hours. The silicone skin overlay thus obtained matches closely with part (b).

B. Capacitive Sensing System

The needle of the syringe is supplied with a 1 kHz sine wave signal \( V_S \). Since the needle is made of stainless steel, it acts as a source of sine wave excitation signal, \( V_S \), as shown in Fig. 5. The muscles which are coated with a conductive material act as capacitive receiver electrodes. Connections are brought-out from each of the conductive electrode with shielded cables and the connection from each muscle is fed to an I-to-V converter (refer Fig. 5) and then to a 12-channel Data Acquisition System (DAS) that digitizes the analog signals from the I-to-V converters at a sampling rate of 10 kHz. This digital data is then fed to a LabVIEW [22] based Virtual Instrument (VI) developed to display the processed data appropriately.

Various capacitances that exist across the muscle electrodes and the needle are shown in Fig. 5. For clarity, they are indicated using three pictures, position-I, position-II and position-III. When the needle is in position-I, as shown in Fig. 5, capacitance \( C_1 \) and \( C_2 \) vary according to the relative position of the needle with respect to the two muscles. In position-I, as the needle moves closer to the Medial Rectus (MR) muscle, \( C_1 \) increases while \( C_2 \) decreases. Thus signal received by the corresponding muscles will also follow same pattern or trend. Similarly, when the needle moves closer to the Inferior Rectus (IR) Muscle \( C_2 \) increases while \( C_1 \) decreases. Therefore \( C_1 \) and \( C_2 \) can be assumed to vary almost in a push-pull manner. \( C_{IM1} \) is negligible with respect to \( C_1 \) and \( C_2 \). This is achieved by ensuring that the muscle surfaces which are close to each other and are physically inaccessible to the needle, are not coated with the conductive material. So, as in position-I, when the needle is in close proximity of MR, the blue proximity indicator of MR is turned on to alarm the user, as indicated in Fig. 5. Similarly, when the needle is the position-II, the capacitances \( C_3 \) and \( C_4 \) are in a push-pull mode. In this position, when the needle is in close proximity to the Superior Oblique (SO) Muscle, the blue proximity indicator for SO is switched on as shown in Fig. 5. Thus, when a syringe needle is inserted, due to change in above mentioned capacitances, the voltages at the corresponding I-to-V converters will also change as a function of the position of the needle and the appropriate proximity indicators are switched on to alert the trainee. When, the needle is in position-III, in contact with MR, a red touch indicator corresponding to Medial Rectus muscle is turned on to indicate needle touch event. This situation is shown in Fig. 5.

The detection of needle touching the globe/eye-ball is carried out from the signals obtained from the muscles. The eye-ball has not been coated with the conductive material to keep the inter-muscle capacitances, \( C_{IM} \) low. The muscle voltages are differentiated with respect to time as shown in Fig. 5 to observe any sharp change common to all muscle voltages due to the needle touching the globe surface. When the system detects a needle touch, the ensuing possible systemic and local complications are immediately displayed to the trainee on a pop-up window.

In order to detect needle touch on optic nerve, the optic nerve can be coated with silver conductive ink and connected to the measurement system. Corresponding output can be monitored to detect optic nerve proximity or touch events.

Fig. 6 shows the eye and extraocular muscle structure mated inside the orbital structure. Shielded cables from the hexagonal mating structures of the eye are connected to the DAS with an interfacing PCB. The entire assembly is placed inside an aluminum enclosure which is grounded to minimize the effects of stray capacitance. The DAS is connected to a Laptop PC which runs a LabVIEW [22] based VI. The VI, shown in Fig. 6 has appropriate proximity and touch indicators corresponding to the extraocular muscles to visually alert the trainee.

C. Hall Effect Based Injection Rate Detector

In order to measure the rate of injection of the anesthetic agent and to facilitate illusion of fluid flow a modified syringe with a specially designed piston as shown in Fig. 7 has been designed. The detection of needle touching the globe/eye-ball is carried out from the signals obtained from the muscles. The eye-ball has not been coated with the conductive material to keep the inter-muscle capacitances, low. The muscle voltages are differentiated with respect to time as shown in Fig. 5 to observe any sharp change common to all muscle voltages due to the needle touching the globe surface. When the system detects a needle touch, the ensuing possible systemic and local complications are immediately displayed to the trainee on a pop-up window.
developed. The needle is blocked permanently to prevent passage of any fluid. Ring magnets are attached to the transparent syringe body. The magnets are concealed by a magnet holder developed. The needle shown in Fig. 7 is a standard 23G needle and the syringe body is a standard commercially available 5ml syringe. The design of the piston is discussed in the following section.

1) Modified Piston of the Syringe: The modified piston shown in Fig. 8 consists of an opaque hollow cylindrical chamber (C) connected to the atmosphere through a ball valve (BV) on one end as shown in Fig. 8(a). The other end of the piston has a rubber seal as usual but with a hole (H) that connects the cylindrical chamber (C) to the syringe body chamber (S). The ball valve consists of a steel ball (B) sliding in a cylindrical valve chamber (VC) leading to the atmospheric outlet (AO) as indicated in Fig. 8. The outlet of the syringe is blocked with a cyanoacrylate based water resistant adhesive, preventing passage of fluid through the needle outside the syringe body.

A fluid is initially filled in the syringe chamber S. The system was tested for water, brine solution and anesthetic fluid, any of which can be used for training purposes.

The syringe piston is inserted into the syringe body with the needle tip facing downwards. In this condition, steel ball S slides through VC towards C due to gravity. This will open up AO to atmosphere. When the syringe piston is pushed inside syringe chamber S, the air entrapped inside chamber C of piston, escapes to the atmosphere through AO and the fluid inside S enters C as shown in Fig. 8(b). Since the piston is made of an opaque material, the fluid remains concealed from the view of the trainee and he feels as if the fluid has been ejected through the needle, whereas it is actually stored inside chamber C of the piston as illustrated in Fig. 8(b). Similarly, when the piston is pulled back, while performing aspiration, the fluid reenters syringe chamber S from C.

However, when the syringe is held with the needle facing upwards, steel ball B slides through VC towards AO due to gravity, closing AO as shown in Fig. 8(c). Now, the chambers consisting of S and C, form a completely air tight chamber, since all the outlets are blocked. Therefore, in this position, the piston cannot be pushed inside the syringe body. This prevents leakage of anesthetic fluid from the system, while giving a realistic training environment to the trainee due to the illusion of fluid flow. As shown in Fig. 9, the new piston also houses a Hall Effect sensor SS49E from Honeywell. The detection axis of the Hall sensor is aligned to the direction of movement of the piston. The wires connected to the sensor are provided with a strain relief and taken out from the piston body to the measurement system as illustrated in Fig. 9.

2) Magnet Holder: A magnet holder has been fabricated that houses a set of three Nd-Fe-B ring magnets of outer diameter 25.4 mm, inner diameter of 19.05 mm and thickness of 2.38 mm each. This holder is fitted on the syringe body as shown in Fig. 7. The surface magnetic flux density of each magnet is 2635 Gauss. The magnets are axially magnetized with poles on the flat face. The three magnets are stacked on top of each other with their magnetization axis parallel to the axis of the Hall sensor. Since, the piston of the syringe body is free to rotate about the central axis (Z) as shown in Fig. 9; the Hall sensor detection axis can transcribe a circle of fixed radii around Z-axis, while always remaining parallel to the central axis. The magnetic field produced by the ring magnet is uniform over this circle. Hence, the rotation of the piston or the syringe body about the central axis does not produce any change in Hall

Fig. 8. (a) Needle facing downwards. Flow of air through AO to atmosphere enabled as ball valve moves down. (b) Fluid entry into piston chamber creating the illusion of liquid ejection from needle. (c) Needle facing upwards. Formation of air tight chamber inside piston and syringe body due to ball valve action is visible.

Fig. 9. The Hall Effect sensor with strain relief for cables. Hall detection axis is parallel to the cylindrical axis of piston. The Hall sensor is connected to a DAS. A block diagram of the measurement setup implemented in the VI is shown.
sensor output signal. Therefore, the trainee can freely rotate the piston (as in a typical syringe) or the syringe body as may be required for adjusting the bevel direction of the needle. The block diagram of the measurement scheme is shown in Fig. 9. The Hall sensor inside the piston is powered by a stabilized +5V power supply and output of the Hall sensor is fed to one of the analog input channels of a National Instruments USB 6211 16-bit DAS.

D. Rate of Injection Measurement Scheme

As the piston is moved, the distance between the Hall sensor and the magnets change. Thus the magnetic field strength experienced by the Hall sensor changes according to the position of the piston in relation to the syringe body. As a result the output of the Hall sensor is a function of the piston position and in turn, the volume of liquid expelled in ml. The Hall sensor output signal is sampled at the rate of 10 kHz. The measurement signal is then fed to a calibration curve to determine the position of the piston with respect to the syringe body. The signal acquired using the DAS is processed in the developed VI. First, it is filtered using a 3rd order Low Pass Butterworth filter having a cutoff frequency 5 Hz. This signal is then fed to a calibration curve to determine the position of the piston with respect to the syringe body. The output of Hall sensor is directly calibrated to provide the volume of liquid $P$ in the syringe chamber body $S$ in ml. The value of $P$ thus obtained is truncated suitably considering the fact that the Hall-sensor output was calibrated at intervals of 0.2 ml. Therefore, to reduce the effect of truncation in the signal, it is passed through a moving average smoothing filter of sample length 20 as indicated in Fig. 9. The rate of injection ($R$) is then calculated by computing the difference in volume between successive samples and multiplying it by the sampling rate. Additionally, if $R$ exceeds a positive preset threshold value, the system detects aspiration of the piston, which is considered as an important step in anesthesia administration.

A prototype of the syringe assembly was built using Rapid Prototyping (RP) technique and the measurement scheme was implemented in the VI developed. The Hall-sensor output voltage was calibrated to the volume of liquid in the piston (in ml) by moving the piston manually to change the volume of the piston by increments 0.2 ml from 0 ml to 5 ml. For each position of the piston, the Hall-sensor output voltage was observed and an inverse exponential curve of (1) was fit to it as shown in Fig. 10. In (1), $y$ is the output voltage from the Hall sensor in volt and $x$ is the volume of liquid in the syringe (or position of the piston multiplied by the cross-sectional area of the syringe body) in ml. The worst case relative error in fit was found to be less than 0.05%.

$$y = 2.529 - 0.07021e^{-0.598x}$$

The relative error in measurement of position (volume), $P$, is shown in Fig. 11. Worst case relative error in measurement
of position was found to be less than 2.5%. Therefore, the worst-case relative error in computation of difference in \( P \) between successive samples (\( dP \)) will be 5%. Since, the error in \( dt \) is negligible, the worst-case relative error in measurement of rate of injection (\( dP/dt \)) in ml/sec will not exceed 5%.

E. Video Recording and Playback

The system is equipped with a Zebronics Clarion Plus 25 megapixel camera. The camera allows the automatic capture of video of the entire training session which aids the trainee as future reference for playback purposes. It is attached to the head-side of the mannequin with an air suction cup arrangement as shown in Fig. 12. The neck of the camera is adjustable to allow easy access and positioning of the camera. The camera is connected to the PC via USB and the VI records the video of the entire training session in 640x480 pixel resolution at 15 frames/sec and is stored as an AVI file with Microsoft Video 1 compression filter applied. The video feed is also made available to the trainee in real-time on the VI front-panel as is seen in Fig. 12.

III. RESULTS

Practicality of the proposed capacitive sensor and syringe injection rate detector system were tested on a prototype training system shown in Fig. 12. The trainee is seen injecting the anesthetic agent into the orbital cavity of the manikin with the specially designed syringe. The manikin is connected to the Laptop-PC running the VI which displays the proximity and touch indications along with the rate of injection in ml/min. Fig. 13 shows the capacitively coupled electrode (fitted in the muscle) voltages measured by the DAS when the needle (standard 23 Gauge, 2.54cm) of the syringe is manually moved along a semicircular path around the lateral orbital rim starting from the Superior Rectus Muscle (SR) to the Lateral Rectus Muscle (LR) and then to the Inferior Oblique Muscle (IO) and back to Lateral Rectus Muscle (LR) with the needle inserted 1.25 cm into the orbital cavity as shown in Fig. 13(a).

As seen in Fig. 13(b), \( V_{SR} \) initially rises because of insertion of needle into the orbital cavity, reaching peak when the needle is completely inserted. The needle is then moved towards LR and hence \( V_{LR} \) increases while \( V_{SR} \) decreases. \( V_{LR} \) reaches peak when the needle passes over the muscle thus aligned parallel in close proximity to it. As it moves away from LR towards IO, it is seen that \( V_{LR} \) decreases steadily while \( V_{IO} \) starts increasing reaching peak when the needle is aligned to the muscle and closest in proximity to it. When the needle is traversed back through the same path towards LR again, \( V_{LR} \) starts increasing. Fig. 13(c) also shows the ratio of \( V_{LR}/V_{SR} \) and \( V_{LR}/V_{IO} \). The Proximity Indicator of LR activated when either \( V_{LR}/V_{SR} \) or \( V_{LR}/V_{IO} \) exceeded the \( V_{PRATIO} \) threshold value. Similar results were obtained for other muscles.

Fig. 14 shows the results of the Muscle Touch detection system. The results were obtained while the IO muscle was touched shown in Fig. 14(inset). The Medial Rectus muscle (MR) serves as reference muscle for the detection scheme, since it is physically impossible to touch MR and IO simultaneously . It is seen from Fig. 14 that when IO is touched, the voltage \( V_{IO} \) crosses the \( V_{TOUCH} \) threshold.
Fig. 15. Needle proximity and touch detection scheme test results showing normalized peak amplitude of muscle voltages for when each muscle was approached by the needle at approximately 1 mm or it was touched. Suitable thresholds $V_T$ and $V_P$ can be used to detect touch and proximity of syringe needle respectively.

The ratio of $V_{IO}/V_{MR}$ crosses the $V_{TRATIO}$ threshold as indicated in Fig. 14. Hence it can be concluded that IO has been touched by the needle syringe and the IO touch indicator is activated.

A test was conducted to validate the robustness of the needle proximity and touch detection schemes. For detection of needle touch, normalized peak muscle voltages corresponding to all muscles are recorded while one muscle is touched at a time for 10 trials each. The results of this test are shown in the top row of Fig. 15. It is clearly seen, that when a particular muscle is touched by the needle the normalized peak amplitude of that muscle is much higher than the normalized voltages on the other muscles for all 10 trials in the 6 muscles. Hence, if the normalized muscle voltage of a particular muscle exceeds the $V_T$ threshold, that muscle is touched by the needle as shown in Fig. 15 top row. It is also observed that when a particular muscle is touched, the muscles immediately close to it have the highest normalized amplitude indicating that the inter muscle capacitance between adjacent muscle is higher than other muscles, as is expected.

For each of the 6 muscles, the needle of the syringe was brought approximately 1 mm from the muscle surface and the voltages from all the muscles were recorded for 10 trials. The normalized peak voltages of each of the muscle when a particular muscle is approached by the needle for the 10 trials are shown in Fig. 15 bottom row. It can be seen that the peak normalized muscle voltage of the approached muscle is higher than the rest of the muscles in all 6 cases. If the normalized muscle voltage is above the threshold $V_P$, that muscle is in close proximity of the syringe needle. It is also observed that the muscles adjacent to the one being approached by the needle exhibit the highest muscle voltage after the muscle being approached. This can be attributed to fact that the inter-muscle capacitance, $C_{IM}$, between these muscles will be higher than other muscles due to their close proximity. For example, in Fig. 15 bottom row, when the needle is brought close to the Superior Oblique (SO) muscle, the muscle with the highest amplitude in the 10 trials is SO and the next highest voltage is that of Medial Rectus (MR). As is seen in Fig. 5, SO and MR muscles are adjacent to each other.

Fig. 16 illustrates the results from globe touch detection algorithm. When the globe is touched with the syringe needle, the derivative of the voltage signals ($V_D$) from the muscle electrodes, as shown in Fig. 16, experiences a positive spike due to a sudden rise in electrode voltages from all the muscles. When the voltage crosses the threshold $V_{POS}$, the Globe Touch indicator is turned on. Similarly, when the needle is withdrawn,
TABLE I. COMPARISON OF RELEVANT TRAINING SYSTEMS WITH THE PROPOSED SYSTEM

<table>
<thead>
<tr>
<th>Device /Method</th>
<th>Features</th>
<th>Shortcomings</th>
<th>Price(USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EyeSi [24]</td>
<td>This is a Virtual Reality (VR) based system to train Vitreoretinal surgery, Phacoemulsification, Capsulorrhexis etc</td>
<td>As this is based on VR, no physical models or anatomical features are available. Hence tactile feedback is missing, which is a very useful feature for surgical training. This system does not provide training for regional ophthalmic anesthesia procedures.</td>
<td>80000-100000</td>
</tr>
<tr>
<td>ORIS[11]</td>
<td>Ultrasound Based 3D Needle tracking for Retrobulbar Blocks</td>
<td>3D location accuracy of this device is poor (6.35 mm), which is insufficient for accurate needle proximity sensing and to avoid ocular damage.</td>
<td>Obsolete</td>
</tr>
<tr>
<td>Human Cadavers</td>
<td>It can give good training experience due to authenticity of anatomical features.</td>
<td>These are not reusable and perishable. Indication of needle location or proximity/touch to ocular structures can NOT be obtained.</td>
<td>Not Available</td>
</tr>
<tr>
<td>Proposed system</td>
<td>Capacitive Needle proximity and touch detection to Extraocular muscles and globe. Hall-Effect sensor based rate of injection measurement and aspiration detection. The developed system can be used for Retrobulbar and Peribulbar blocks.</td>
<td>Certain manufacturing steps such as coating of muscles with conductive ink and preparation of connections from the same require manual skilled effort to accomplish.</td>
<td>1500-2000*</td>
</tr>
</tbody>
</table>

# This is the initial prototyping cost. It can be further brought down if the number manufactured is large.

a negative going spike can be observed, which when exceeds the $V_{NEG}$ threshold, the Globe Touch indicator is turned off.

Fig. 17 shows the graph of the computed position and the rate of injection measured in real-time from the rapid prototyped syringe. It is seen that when syringe is aspirated, the volume (ml) increases, indicating an intake of fluid into the syringe, which is detected by the VI.

From the tests conducted on the prototype system, it is found that the developed training system can sense if a muscle is touched by a needle, it can also give a reliable output and indication if the needle is about to touch or is in close proximity of any of the muscles. It can also sense touch of the globe by the needle. Additionally, the rate of injection is measured with Hall-effect sensors attached to the specially designed piston. Thus, the trainee can get accurate information about his performance in real-time during the training process. This will help in making the training procedure more effective and less cumbersome compared to conventional training methods which practically gives no such intelligent feedback to the trainee. TABLE I presents a comparison of the relevant training systems/methodologies available in literature with the proposed system. It clearly shows that the proposed system provides training in ophthalmic anesthesia while being the lowest in cost. Sixty post graduate students and residents of ophthalmology were asked to train on the system without the direct supervision of a trainer. The VI recorded and stored the entire training session of each trainee and a system qualitative score assigned to them. The automatic grading system penalized the trainee for any procedure that might lead to complications and rewarded the trainee for every correct procedure followed. Over a period of repetitive 2-3 trials, the scores of the majority of trainees showed improvement indicating the efficacy of the system.

IV. CONCLUSION

An intelligent ophthalmic regional anesthesia training system was presented. This system, which looks and feels like a human subject, aids in training of safe regional block administration prior to practicing on live patients. A prototype of the system was built and tested. In the prototype, muscles of the eye were coated with a conductive paint which served as capacitive electrodes while a specially designed syringe with its needle connected to a 1 kHz sine wave source acts as excitation signal. The syringe piston along with the syringe body has been developed. A ball valve assembly in the system prevents anesthetic fluid from being ejected from the syringe while ensuring that the visual feel of the liquid being ejected is retained, thus providing the trainee with a training experience which is close to reality. Ring magnets attached to the syringe body along with Hall-effect sensors placed on the movable piston determine the rate of injection of the anesthetic fluid. A Virtual Instrument (VI) developed in LabVIEW platform detects the touch and proximity of the syringe needle to the extraocular or globe and the rate of injection in real-time. The proximity and touch detection scheme was tested and validated. The VI developed is able to detect the approach of the needle to the muscles and correctly identify when the needle is in close proximity of the muscle. When the needle touches a muscle, the VI detects the touch correctly and alarms the user of the condition. The globe touch detection scheme is able to detect the needle touch on the eyeball without employing any direct electrode on the globe. The Hall-effect sensor based measurement scheme provides position of the piston with respect to the syringe body. The rate of injection is calculated from the position information. For practical training purposes, the developed system performs

![Graph of computed position and rate of injection in ml/min obtained from the prototype in real-time.](image-url)
well within acceptable limits. Hence, the system can be used as an effective training device for ophthalmic regional block administration.

REFERENCES


