Tobii white paper
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Why next-generation surgical systems will include eye tracking

To simplify surgical workflows, facilitate skills transfer, and enable additional safety features

Abstract

Bringing a new medical device to market is often the result of years of collaboration. Commercialization relies on long-term relationships, financial investment, niche technology, and an ability to stay the course through lengthy certification processes.

Throughout product development, medical technology companies manage the balance of innovation, cost, and feasibility. Most technology components provide a purpose, but they also need to be affordable and fit with the overall design of a device. Before adding new technology to medical-device architectures, its value needs to be proven.

This paper describes how eye tracking enables surgeons to control robots, pan, scroll, and select objects with the movement of their eyes — keeping their hands on the controls and attention on the patient. We show how this technology can simplify surgical workflows, facilitate skills transfer, enable additional safety features, and why it will be included in next-generation medical devices.

Is this white paper for you?

The use of eye tracking in industrial and professional environments is broad. Given that the technology measures human physical attributes — head and eye movements — the healthcare sector, and medical devices in particular, has been an early adopter of the technology.

Emerging solutions include systems for controlling surgical robots as well as devices for assessing and treating neurological diseases and vision impairments. One medical technology company has successfully commercialized a system that records eye movements to generate brain-disease assessment reports. Another has developed a tablet-like device that not only tests for vision impairments but also treats them.

> ***If your working scenarios include people, machines, interfaces between the two, and some value in what the person is looking at, then eye tracking could be a catalyst for innovation in your product development.***

Much of the content of this paper is generic and could be of interest to any organization developing professional products. However, from an application point of view, it addresses the use of eye tracking in medical devices, and specifically those used in surgical procedures.

The fundamental principles of eye tracking and how to embed this technology in a device are, however, the same no matter what your industry. If your working scenarios include people, machines, interfaces between the two, and some value in what the person is looking at, then eye tracking could be a catalyst for innovation in your product development.

So, yes, you should read this white paper if you are developing medical devices for surgical procedures. Again yes, if you design products for highly regulated industries. And yes again, if you are wondering how eye tracking could help improve your product interface.

Once you've read this paper, you should know:

- A little bit about the history of eye tracking.
- That eye tracking is a sensor technology, and its value lies in leveraging the data it delivers.
- The basic concepts of eye tracking, how it fits into a device, and how the technology calculates gaze points and other useful metrics.
- The value of eye tracking in medical devices and how applications can leverage this technology to simplify surgical workflows, facilitate skills transfer, and add new safety features.
- What to look for in a supplier of eye tracking technology, and in the design of eye tracking components.

Sensors, the small giants in smart systems

Eye tracking is a sensor technology that follows what a person is looking at, converting their gaze and attention into a data stream. Similar to other sensor technologies, such as touch and heat, eye tracking delivers data. What makes sensor technologies valuable is what you do with that data.

Interior climate management is a prime example of a smart system that relies on sensors. Heat sensors placed throughout a building provide data to a centralized controller application. The controller makes decisions about whether to adjust the settings on air-conditioning units, for example, sending self-healing instructions to all elements of the system. Human interaction is reduced to monitoring and responding to high-level warnings. The solution is simple yet powerful and provides a valuable service with optimum use of resources and minimal downtime.

Smart waste management systems exemplify the innovation that occurs when diverse technologies combine. These systems work by equipping trash cans with a compressor so that they can hold more refuse. Sensors assess when the container is full and use basic cellular components to request a pickup from the local collection depot. The result is no overfull containers and optimized collection.

The sensors at the foundation of these innovations supply the data that is crucial for decision making and system automation. In isolation, the data may not be that valuable. But, like the smart trash-can, something happens when sensor data and other technologies combine. Suddenly, the combination becomes valuable because it transforms data into insights — for data-driven decision making and laying the foundations of smart systems. Figure 1 illustrates how raw eye tracking sensor data is processed to deliver insights that medical devices can leverage.

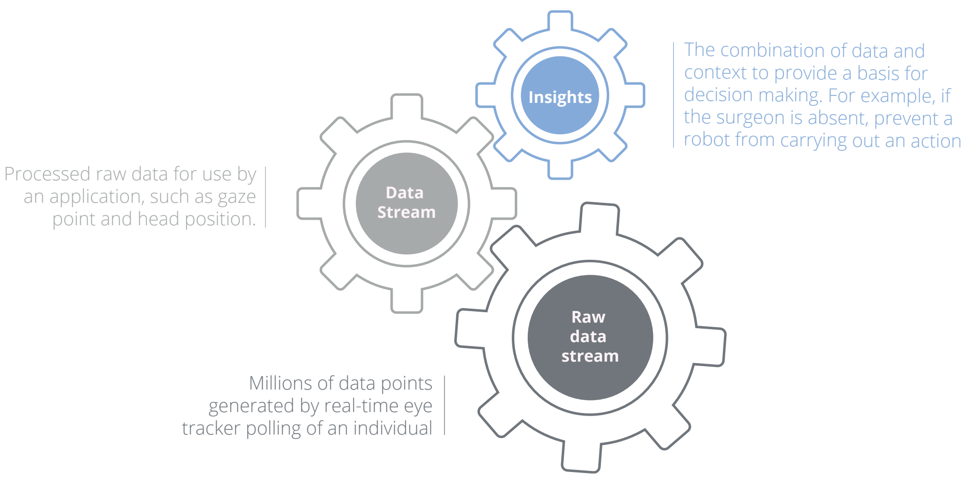

Figure 1: From raw data to insights for smart systems

Eye tracking then and now

The roots of eye tracking date back to The Progressive Era of the late 1800s and early 1900s. At the time, some scientists and psychologists were working to understand the mechanics of reading. Initially believing that the process was a smooth one, these pioneers soon discovered that people read in a series of stops and scans referred to as fixations and saccades.

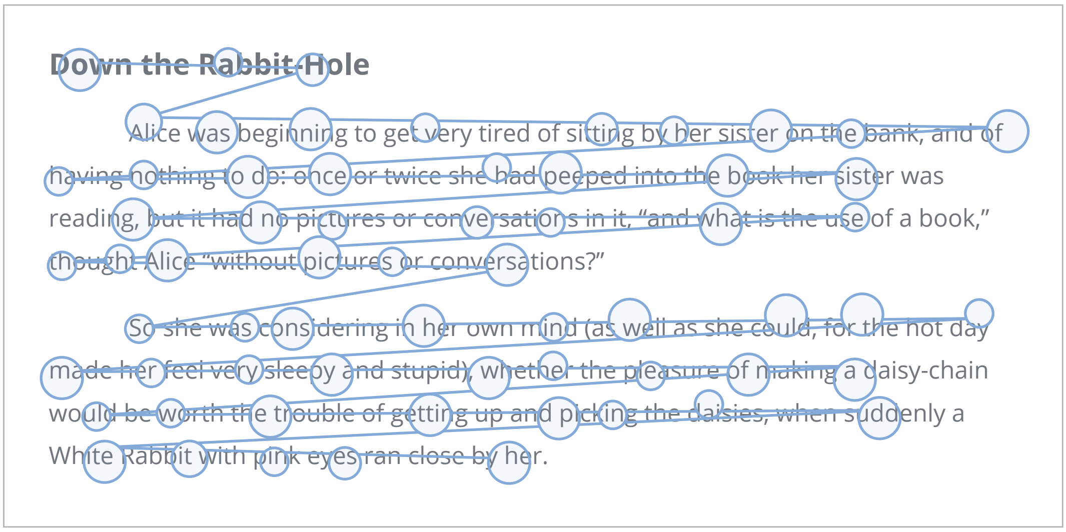

Figure 2: *typical reading pattern comprising fixations (dots) and saccades (lines between the dots)*

The technologies used to make these discoveries were rudimentary and invasive. People willing to partake in the studies were required to wear a cup-like molding over their eyes. A hole in the cup enabled them to see, and a pointer attached to it traced marks on paper.

Modern eye tracking technologies are unobtrusive and follow the stops and scans of a person's eye movements precisely. The output is a data stream that includes many useful metrics, such as a person's head pose, how often they blink, the position of their eyes, as well as the data about where they are looking.

During the early days, scientists made additional findings related to the impact of intent on eye movement. In testing, participants were shown a photograph and asked to answer a question. Results revealed that participants exhibited similar gaze patterns for a given question, but the patterns varied greatly from one question to the next.

A similar discovery was made by scientists in the 1930s. By this time, researchers were using cameras to record light reflections shone onto a person's cornea. Results confirmed earlier theories that our eye movements relate to the task at hand, and that reading patterns vary among people and even vary for the same person.

The approach adopted by those early researchers remains the foundation of modern eye tracking. The most commonly used technique in today's remote eye tracking is pupil center corneal reflection (PCCR). Near-infrared light creates reflections on a person's eyes. This type of light is practically invisible, making the technology nonintrusive. A camera still records the reflections, but modern components and processing elements can fit into the bezel of a screen or the rim of a pair of glasses, and are powerful enough to capture and process detailed eye movements such as fractions of a millisecond variations in pupil size.

Over the past two decades, the application of eye tracking has broadened significantly for several reasons:

- The pioneering work carried out by companies such as Tobii, leading to the development of nonintrusive eye tracking.
- The ever-rising capacity of electronic components, enabling the use of eye tracking data in real-time applications.
- Advances in materials leading to nano form-factors, enabling discrete eye tracking components that can be embedded in a wide variety of devices.

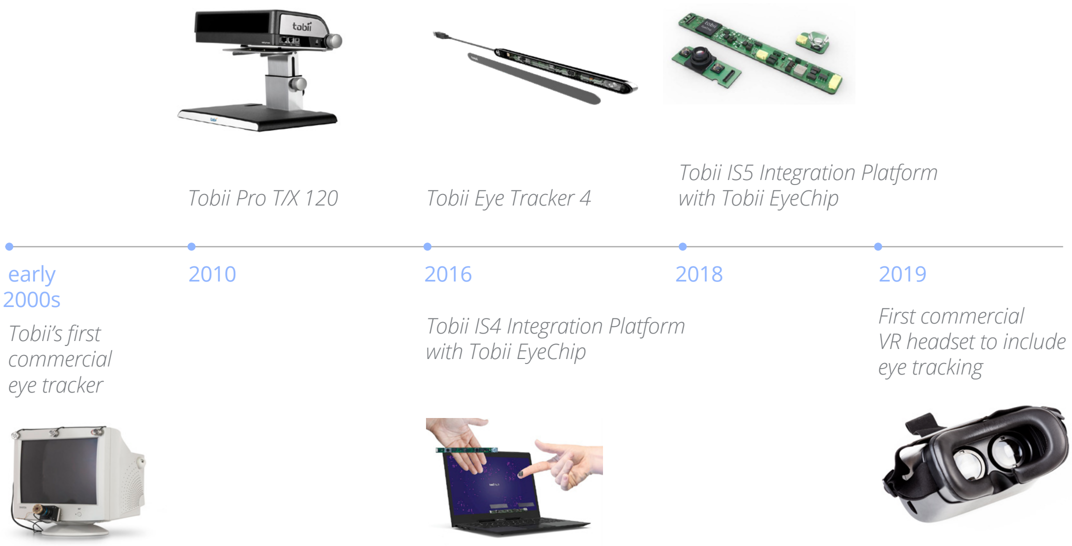

Figure 3: Two decades of Tobii products

What is eye tracking?

Eye tracking is a sensor technology that follows a person's eye movements, converting what they are looking at into a data stream.

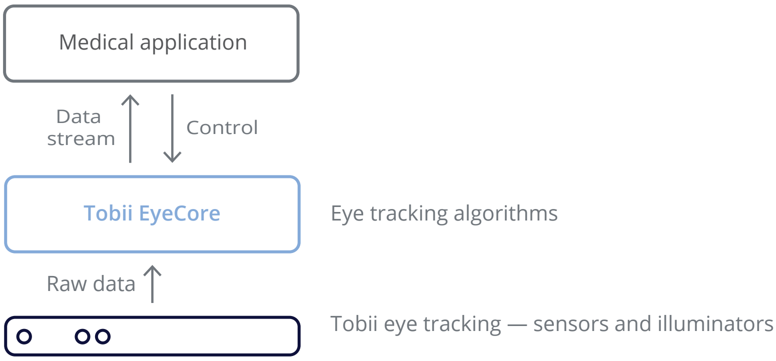

Figure 4: logical view of the main components of a Tobii eye tracking solution

Eye tracking components deliver raw data to a functionally-separated processing unit, which in turn delivers a data stream in real-time to a high-level application, such as a control system for a surgical robot or hands-free navigation in a medical information system.

Eye tracking comes in several different solution types, including:

- Screen-based (integrated) — components are embedded in the user interface, usually in the bottom bezel of a screen.
- Screen-based (peripheral) — components are embedded in a peripheral that is mounted on a screen and connected to the host machine via, for example, a USB port.
- Near-eye — components are embedded inside the device such as in a head-mounted display, an ophthalmology machine, or an application-specific console, where the user's eyes are up close to the machine.
- Wearable — components are embedded in the device, such as in the rim of a pair of glasses.

Eye tracking components typically include a camera, light sources, and a processing unit. The light sources illuminate the eye causing highly visible reflections, and the camera captures an image of the eye showing these reflections. The image captured by the camera is used to identify the reflection of the light source on the cornea (glint) and in the pupil. The eye tracker calculates a vector formed by the angle between the cornea and pupil reflections — the direction of this vector, combined with other geometrical features of the reflections, is used to calculate gaze direction.

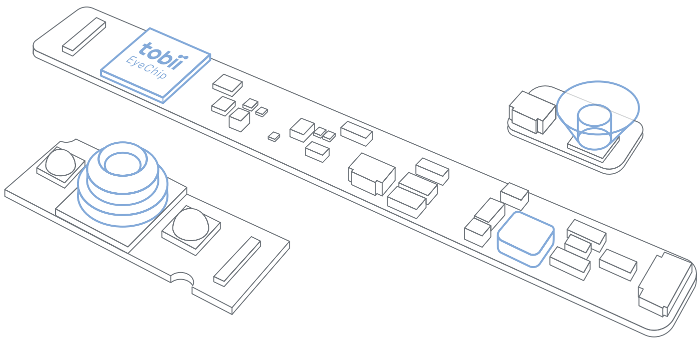

Figure 5: eye tracking components

Screen-based solutions

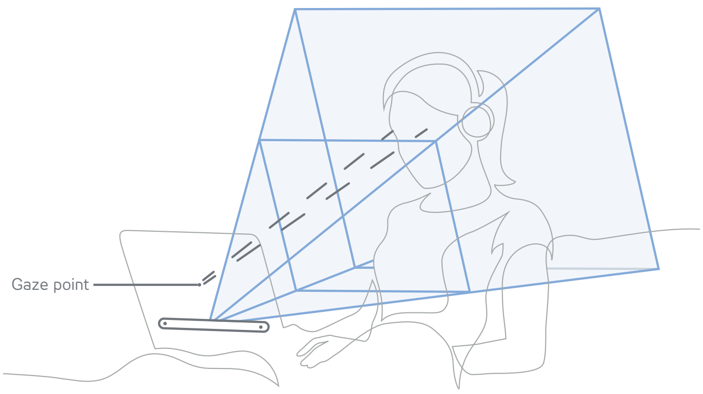

Figure 6: screen-based eye tracking

For screen-based eye tracking, components are embedded in the display interface, in the bottom bezel, or as a mounted peripheral.

Eye tracking leverages how our eyes work to determine where a person is looking. The gaze point can be calculated from the visual axis — the line from the fovea (the part of the eye that renders visual attention) through the center of the pupil to the object.

What eye tracking can calculate, is the optical axis — the extended line from the center of the eye through the center of the pupil to the screen. Personal calibration takes care of the delta — angle kappa — between the optical and visual axes.

Angle kappa, which is somewhere in the region of 5°, varies for each individual. For some applications, an assumed angle kappa is good enough, but for others, where best possible accuracy is required, eye tracking needs to be calibrated for each user.

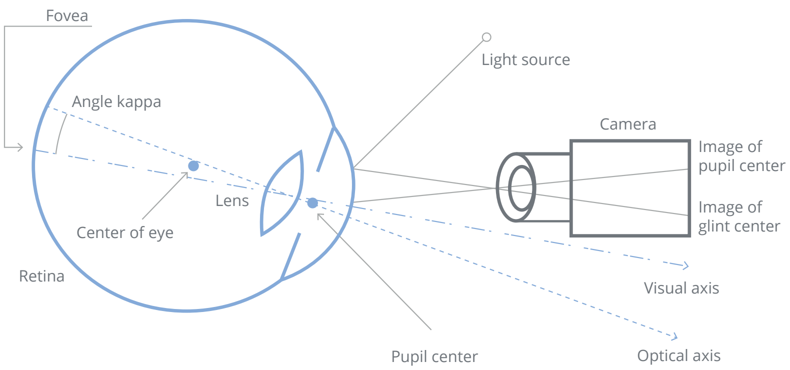

Figure 7: The human eye and basic eye tracking

Near-eye solution

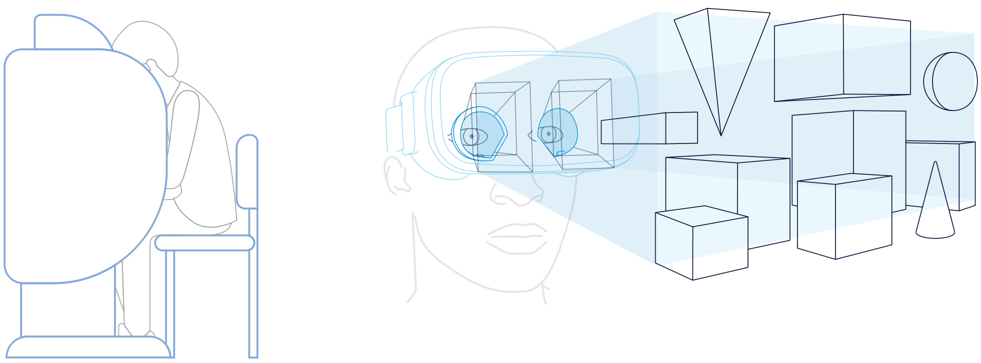

Figure 8: examples of near-eye solutions include VR headsets and surgical consoles

For near-eye solutions, as in a VR head-mounted display or a console, eye tracker components are often integrated into a ring structure between the user's eyes and the screen. Several illuminators creating multiple glints ensure accuracy. Otherwise, the process of calculating the gaze point and other useful data is more or less the same as screen-based.

AR glasses bridge the gap between total immersion in a virtual world and reality. While it's possible to classify such devices as near-eye solutions, for this paper, the next section on wearables covers eye tracking for such devices.

Wearables

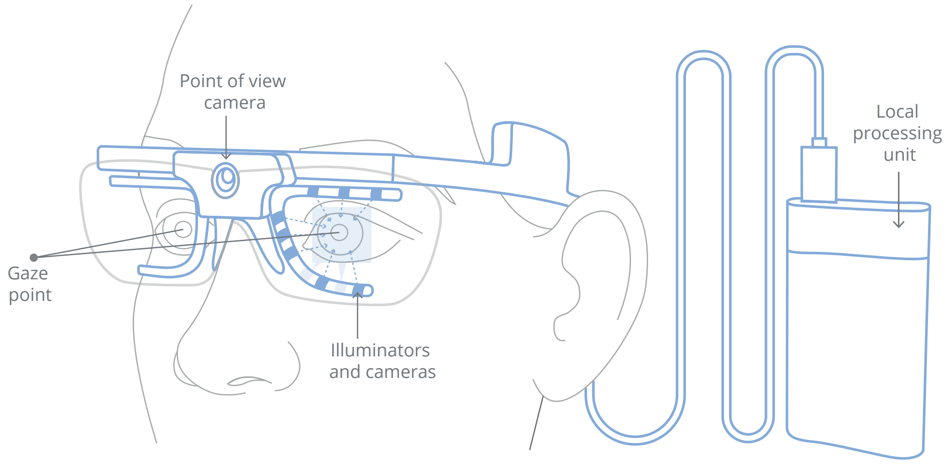

Figure 9: wearable eye tracking glasses

The structure of a wearable, such as the frame of a pair of glasses, houses the eye tracker components. Processing and calculation of data streams are similar to the other architectures. To maximize mobility, wearables often require a small unit to process and temporarily store raw data captured by the eye tracker. Data collection for use in analysis is one of the primary applications of eye tracking in a wearable.

Providing medical devices with insights usually requires gaze data and context to be combined. For example, a surgeon's gaze can be described by (x,y) coordinates on a screen. In isolation, this data may not be that useful unless you are researching the eye movements of surgeons. An application that can map the coordinates (gaze data) to an object on the screen (context) generates insights. In a surgical procedure, that insight might be a specific area of the patient's tissue, unusual bleeding, or a surgical instrument. For screen-based, near-eye, and some wearable solutions, the eye tracking platform provides the gaze data, and the processing unit of the device or host machine provides the context. Some of the use cases for wearables, however, are screenless — no additional device or computer is present to provide context. In such cases, the wearable itself needs to be equipped with a point of view camera to capture context.

The data stream

Eye tracking generates a data stream that includes a variety of metrics. Gaze point is probably the most useful measurement, but there are many more, including eye position, pupil size, head pose, blink rate, and eye openness. By combining this data with context, applications running on a medical device can deliver added value in the form of simplified workflows, skills transfer, and new safety features.

The value of eye tracking in medical devices

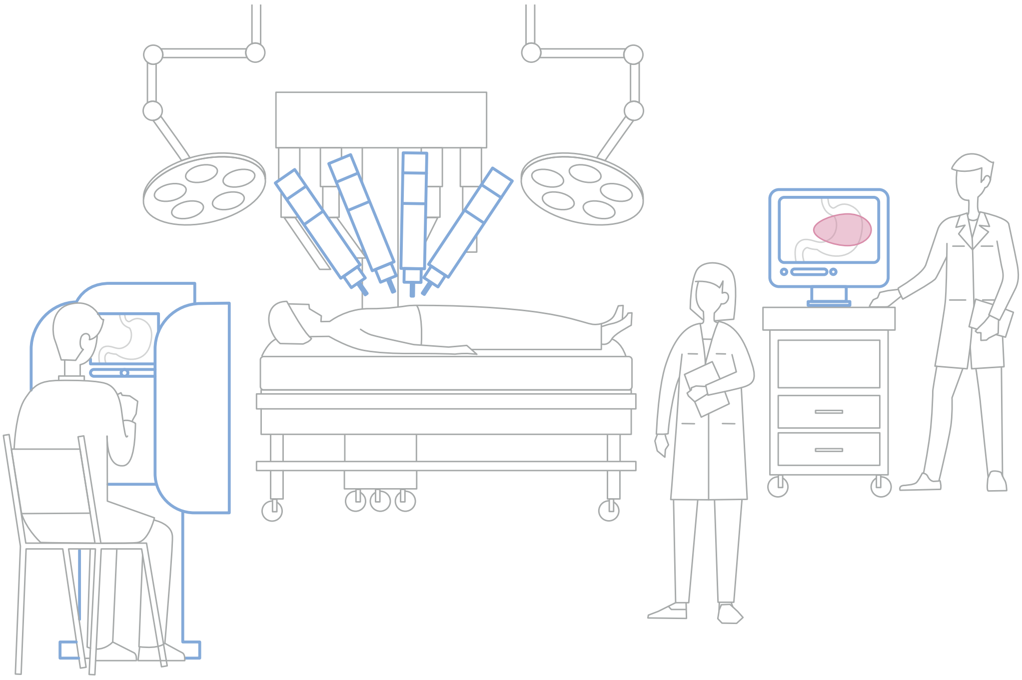

Figure 10: Eye tracking enables other clinical staff to see what the surgeon is looking at

The benefits of robot-assisted surgery reach far beyond the individual patient. Minimally invasive surgery reduces complications for patients, resulting in rapid recovery and shorter hospital stays. Surgeons control robots from ergonomically designed consoles that provide wellbeing and long-term health benefits for staff.

Next-generation devices enabled with eye tracking will deliver new incentives for hospital administrations in the form of simplified workflows for clinical staff, the ability to transfer skills from experienced surgeons to trainees, and the addition of safety features that benefit patients and staff alike.

Simplify surgical workflows

- Control a surgical robot using gaze — relieves load on busy hands and alleviates the need for assistance from other clinical staff.
- Use head or eye movements to select objects, zoom in and out, click, scroll and pan, and move the cursor or focus point.
- Share the surgeon's screen combined with gaze on additional monitors, facilitating communication among clinical staff in the theater, and enhancing understanding for other real-time observers.

Surgeons rely on their hands. Even with robot-assisted procedures, sitting at ergonomically-designed workstations, the load on a surgeon's hands remains high. Embedding eye tracking in medical devices alleviates some of that load, simplifying workflow because it enables surgeons to control robots, move the surgical camera, or pan, zoom, and select objects on the screen directly with their gaze. In some scenarios, the surgical camera maybe operated by an assistant staff member. Adding eye tracking to a medical device provides the surgeon with full control to manipulate the camera as needed, removing the burden of communication, instructing someone else how and when to move the camera.

While eye tracking creates a new input method, because it is an embedded technology, it doesn't introduce yet another physical controller, such as a mouse, joystick, or rollerball. By removing the need for surgeons to move their hands from one control device to another, eye tracking simplifies workflow during procedures.

Streaming the surgeon's gaze together with the feed from the surgical camera on additional monitors throughout the theater, provides clinical staff with useful insights. Workflow can be simplified because clinical staff can use this extra insight to prepare for the next steps.

Facilitate skills transfer

- Combine eye tracking data with visuals captured by the surgical camera to create valuable learning material.
- Gaze insight may help trainees gain a deeper understanding of the surgeon's actions, such as when they handle additional machinery and check the patient's vital signs.
- Heatmaps and gaze plots may also be of use for post-op analysis.

Becoming a surgeon requires many years of education and a ton of experience. As surgeons become proficient, learning becomes intuitive. People learn by doing, by making mistakes, and by devising shortcuts, best practices, and methodologies to ensure the best outcomes. This type of on-the-job know-how makes experienced surgeons highly valuable. It is also one of the hardest skills to transfer.

One way to facilitate skills transfer is to combine eye tracking data and the surgical camera feed recorded during a procedure with a narration by the surgeon. The visuals and observations about the patient and what actions the surgeon takes in different scenarios could become a valuable training asset. To follow up, you could create an application that uses eye tracking to monitor trainees during testing of their acquired knowledge. Trainee performance could be rated based on how closely they emulate the eye movements of the experienced surgeon, and how they improve over time.

The combined feed of a surgeon's gaze and live images captured by the surgical camera provide in-depth insight into the surgeon's actions — creating useful content for trainees observing the procedure from an adjacent room or remotely.

Implement additional safety features

- Prevent a surgical robot from acting if the surgeon is not focused.
- Take action if the cognitive load of the operator becomes excessive — based on enlarged pupil size and a low blink rate.
- Take action if the operator is showing signs of drowsiness — leveraging data related to eye-openness and blink rate.
- Disable a machine if the operator is impaired — leverages data related to pupil size.

Patient and staff safety are critical factors for every health service. Eye tracking can provide the data to implement additional safety handles — assuring that, for example, the surgeon is focused on a specific point before allowing a robot to carry out a critical operation.

Using a surgeon's gaze to control the collimator of an X-ray machine, for example, can dramatically reduce the lifetime risk of radiation exposure from fixed and mobile C-arm procedures for patients and clinical staff.

Eye tracking data can be leveraged to disable machinery when, for example, cognitive load is too high, if the surgeon is under the influence, or if their blinking pattern indicates drowsiness.

Choosing an eye tracking supplier

Medical technology companies operate with novel business models and a highly-targeted customer base. There are few blueprints, a high degree of innovative design, and technology choices are numerous.

Adding a disruptive technology to an innovative business emphasizes the need for suppliers to be flexible, provide support throughout many years of development, and collaborate with other suppliers in different domains to ease integration for the device developer and maximize the benefits that come with cross-pollination.

Perhaps the most significant challenge to bring an affordable medical device to market is regulatory compliance. Knowledge of the lengthy certification process and the ability to stay the course are essential supplier attributes.

The system architecture of a new medical device component should follow the principles of functional separation to achieve the desired safety level. A suitable decomposition of subsystems calls for flexibility in the eye tracking hardware and processing elements so that the overall device design is secured without adding undesired complexity. Proper functional separation supports, for example, optimum placement of data processing elements. They can be embedded on a chip or executed on a host according to the needs of the device. The eye tracking technology should provide options to cater for various system designs, so that the resulting medical device achieves the right balance of safety, performance, complexity, functionality, and cost.

To be considered as a candidate for next-generation medical devices, any component needs to have proven value and designed according to best practices for quality and functional separation. For eye tracking, some, additional criteria apply:

- Universal application — provide accurate data independent of lighting conditions, presence of glasses, eye shape, ethnicity, cornea thickness, contact lenses, dirt, makeup, or smudges.
- Fit-for-purpose data — most surgical applications require eye tracking in the range 30-90 Hz to ensure that the granularity of data generated fits the use case.
- Accuracy — to ensure that calculated values for parameters such as gaze point, eye position, pupil size, head pose, blink rate, and eye openness can be leveraged in real-time.
- Latency — eye tracking components need to deliver real-time processing that ensures lean communication with other parts of the system and user responsiveness.
- Modularity — to fit available hardware designs, especially true for near-eye solutions where space is often more limited than conventional displays

Conclusion

It takes many years to bring a new medical device to market. It requires financing, long-term partnerships, and the ability to stay the course through the many hurdles of certification, development, tests, and trials. Eye tracking will be embedded in next-generation medical devices because it raises their value by simplifying workflows, facilitating skills transfer, and enabling new safety features.

By enabling surgeons to control robots, pan, scroll, and select objects with their eye movements, eye tracking helps to keep surgical hands on the controls of the device and attention on the patient. In doing so, eye tracking relieves some of the in-theater communication burden as well as the need for clinical staff to assist in procedures.

The data eye tracking generates, can be leveraged to produce intuitive training assets and new applications for competence assessment. The technology makes it possible to share what a surgeon is looking at with other clinical staff in the operating theatre as well as remote observers.

Eye tracking provides the necessary data to implement safety handles in medical devices. Ensuring, for example, that robots only act when the surgeon is focused, and that precautions are in place to alert when cognitive load is high, or the surgeon is showing signs of drowsiness or impairment.

For eye tracking to be of practical use in next-generation medical devices, it needs to adhere to design best-practices for functional separation and resource optimization, as well as be:

- Universal — to serve all users, eye types, and lighting conditions.
- Fit for purpose — with granular data.
- Modular — to fit available space.
- Accurate — to deliver trustworthy data.
- Fast — for use in real-time applications and meet latency requirements.

The foundation of eye tracking dates back to the turn of the 20th century. Much of the development of modern, nonintrusive eye tracking, however, has occurred after the turn of this century — owing to advances made in materials and computational power and Tobii's leadership in the field.

Tobii in brief

Founded in 2001, Tobii is the global leader in eye tracking and pioneer of attention computing. We serve partners and customers from our headquarters in Stockholm and offices in Asia, Europe, and North America. Listed on Nasdaq Stockholm (TOBII) in 2015, we currently employ over 600 people and hold around 700 patents.

Contact us

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