An inertial sensor-based system designed to measure and prevent undesired camera rotation during endoscopic sinus surgery

To the Editor:

We present a prototype of an inertial sensor–based system capable of accurately determining camera roll during endoscopic surgeries and a reference-guide strategy that presumably reduces the surgeon’s undesired tilted view during endoscopic sinonasal procedures, a latent factor with negative impact in surgical performance and safety.

Minimally invasive surgery has a steep learning curve because of several drawbacks inherent in the use of an endoscope in contrast to open surgery, such as the indirect view of the operating field and the loss of stereoscopic vision, which alters depth perception. Endoscopic sinus surgery (ESS) and anterior skull-base surgery pose an additional challenge due to the complexity and narrowness of the anatomy, necessitating constant movement of the endoscope to navigate from one zone to another; thus, increasing the difficulty of maintaining a stable visual horizon.

Mastering endoscopic camera operation is essential during the first steps of this learning process and allows surgeons to maintain the visual stability necessary to successfully locate anatomic landmarks while operating. The identification of those landmarks is crucial for spatial orientation and safety in these procedures. During ESS, rigid endoscopic cameras are usually placed inside the nose and held by the surgeon, having rotational freedom in all spatial axes. This freedom and the constant need of camera movement generate an unconscious and often undesired camera rotation that can lead to disorientation. This problem is not solved by surgical intraoperative navigations systems, which are meant to locate the position of the instruments’ tips in relation to preoperative imaging and not to visually aid spatial orientation while operating the camera.

Rotation along the longitudinal axis (x-axis), also known as camera roll, tilts the horizon of the endoscopic image, generating a misalignment between the displayed image and the actual operative field, creating a visuomotor incongruence that makes tool manipulation and localization of anatomic landmarks more difficult.

This undesired camera rotation is a latent factor inherent in the system and has a negative impact on surgical performance by requiring multiple corrections and an extra cognitive effort known as “mental rotation,” increasing operating time and fatigue. Moreover, a tilted view of the operative field increases the risk of endoscopic procedures by favoring wrong judgments regarding the anatomical plane, mostly at angles from 15 degrees to 30 degrees. To prevent this increased risk during surgery, a “gravity-line” strategy has been described recently, emphasizing the importance of keeping the camera in the direction of gravity, in accordance with open surgeries. The effects of this phenomenon on ESS have not been studied.

Materials and methods

The system comprises 3 parts: an inertial sensor placed inside a hermetic box, a computer system with a custom-made software, and a foot pedal to control the software.

The inertial sensor uses the angular acceleration from a 3-axis accelerometer and the angular velocity from a 3-axis gyroscope to provide the spatial orientation through the roll (rotation along the x-axis) and pitch (rotation along the y-axis) angles. The sensor is located inside a hermetic box with a total weight of 26 gm and is capable of obtaining and recording 50 measurements per second. The box can be attached to any endoscopic camera using an articulated holder (Fig. 1A). It is then connected to the computer system, which receives and processes the information.

The software captures the incoming video from the endoscopic system and shows it unmodified on the screen while processing the sensor data and displaying it as overlay graphics by using a circular bar for the roll (Supporting Video 1 and 2). The guides are color-coded by default using green for rotations from 5 degrees to 10 degrees, orange from 10 degrees to 15 degrees, and red over 15 degrees (Fig. 1B-D). However, these settings could be customized as the surgeon desires.

To test the feasibility of the prototype, a pilot prospective, randomized, and observational study in 2 fresh human cadaveric specimens (4 sides) was conducted in the dissection laboratory. Seven participants were enrolled with different degrees of training and exposure to ESS. To determine the intrasubject impact of the reference guides, different tasks selected among parts of a regular ESS were assigned to each participant. Every participant performed the same assigned task on the same side of both specimens. One task was performed without the reference guides and the other with the

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Additional supporting information may be found online in the Supporting Information section at the end of the article.

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guides activated, in a randomized order. Wilcoxon signed-rank sum tests were conducted to compare the roll angles of each task with the reference guides activated against the theoretical mean roll angle of the combined tasks without the guides.

**Results**

A total of 18 tasks (surgical steps) during 49 minutes and 3 seconds with a mean duration of 3 minutes and 12 seconds per task, were compared. The only parameter used in the comparisons was the variation of the camera roll over time.

Globally, the mean rotation was 18 degrees in all tasks without guides and 7.8 degrees with the guides on. This translates to a camera roll reduction of 52.2% ± 18.3%, with a maximum of 84.4% (p < 0.05) Task C in participant 4, an inexperienced surgeon (C-4; Fig. 2) and a minimum of 20.8% (p < 0.05) Task D in participant 6, an expert surgeon (D-6; Fig. 2). The impact of the reference guides was statistically significant in all the comparisons (p < 0.05).

The percentage of time during the tasks without the reference guides where the camera roll was above 15 degrees was 59.1% and 11.1% with the guides activated. Thus, we found 86.8% in rotation time reduction above this threshold using the guides.

**Discussion**

The tasks performed with hidden reference guides showed that camera roll is indeed inherent in camera operation. The intensity of this phenomenon, nonetheless, could be affected by experience in endoscopic procedures.

On the other hand, the strategy of using reference guides seemed to be very effective at reducing this rotation and helped all participants to reduce substantially the amount

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**Figure 1.** (A) Example of the location of the hermetic box with the inertial sensor (black arrow) in a regular endoscopic camera. (B-D) Appearance of the reference system at different stages. (B) Green color for rotations from 5 degrees to 10 degrees. (C) Orange for rotations from 10 degrees to 15 degrees. (D) Red color for rotations over 15 degrees.

**Figure 2.** Mean rotation in every task-participant pair with and without the reference guides.
of time when the rotation was above 15 degrees, aiding experienced surgeons at achieving 100% of the task below this threshold. The mean reduction, as expected, was higher in participants with less exposure to endoscopic sinonasal surgery. Furthermore, a larger potential effect could be expected with further training, because the system has its own learning curve.

The guides seem to benefit novice surgeons by making them aware of a rotation that otherwise would occur unnoticed. This could facilitate the localization of anatomic landmarks necessary for spatial orientation that would be more challenging in tilted fields and serve as a valuable camera operation learning tool. Conversely, senior surgeons with enough experience to stay oriented even with a certain degree of angular rotation (as a result of mental compensation), can benefit from the guides in procedures where no references are available and surgical orientation may be limited; for instance, in patients with distorted anatomy or previous operations.

Different systems have been published that attempt to maintain a stable horizon by automatically rotating the image in flexible endoscopes. This problem, to a lesser extent, also occurs with rigid scopes, but it seems to have only aroused interest among laparoscopists. There is an immense knowledge gap in the literature regarding this issue in the field of rhinology, which reflects a low interest that might also indicate an underestimation of the possible negative effects of this phenomenon.

Intraoperative orientation has been a matter of concern since endoscopic approaches were first used. In the past few years, new strategies based in augmented reality have been developed, fusing computer-generated images of the patient’s imaging data with a real-time endoscopic view of the surgical field, providing 3-dimensional visual cues to aid spatial orientation. This promising technology has not yet seen widespread implementation, probably due to its recentness and elevated prices. Our new proposed system is not meant to be a substitute for any of the previously mentioned devices but an addition designed to tackle a different aspect of the disorientation problem that can work in conjunction with them.

Despite all this technological advancement, orientation is still a complicated subject to assess because of its subjective nature, which makes it difficult to describe, measure, and quantify. The implications and effects of disorientation during endoscopic surgery are poorly understood and often related to contributing factors of systematic error that could lead to intraoperative complications. The proposed system gives researchers a new measuring tool to try to understand camera operational dynamics as contributing factors in disorientation.

To summarize, we have developed a device that can accurately recognize camera roll and a reference-guide system to reduce it during ESS. Unnoticed camera roll and the consequent image misalignment are inherent in camera operation. This latent factor can combine with others in a chain of errors leading to complications in ESS and probably in endoscopic skull-base surgery as well. Therefore, a system dedicated to studying and preventing this factor would probably increase the safety of endoscopic procedures. Further studies are needed to probe the clinical benefits in a larger scale of this new accessory to the conventional scopes.

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