Optical mouse tracking surgical

The computer mouse is a popular pointing device used to control the position of a cursor on a computer display. Sensors used in optical mice enable the contactless measuring of the changes in position over a flat surface. This article describes the application of optical mouse sensors as position sensors in a tracking system – TrEndo – that has been developed at Delft University of Technology and the Academic Medical Centre Amsterdam.

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Minimally invasive surgery (MIS, e.g. laparoscopy) is nowadays widely used for therapeutic purposes. It is well known that MIS has many advantages for the patient, such as reduced morbidity, shorter hospitalisation, better cosmetic result, and earlier return to normal activity. Performing laparoscopic surgery, however, requires unique psychomotor skills that are different from those needed to perform open surgical procedures. To facilitate the learning process, training systems (box trainers and virtual reality (VR) trainers) are being developed. However, these training systems do not provide standardized objective assessment of basic psychomotor MIS skills, which would quantify and qualify competences of the user. Since it is indisputable that a surgeon needs to acquire a certain level of manual dexterity to perform surgery safely, it is necessary to develop an objective score, which can be used to measure the competence of basic MIS skills.

In the literature, it has been demonstrated that motion analysis is a valuable assessment tool in training of basic MIS skills [1]. However, in order to use motion analysis as the assessment tool in both box and VR trainers, a system that tracks and records motions of real MIS instruments is needed.

Tracking system – requirements

The design of a system for tracking MIS instruments should meet the following requirements:

1. Realistic manipulation of the MIS instruments in four degrees of freedom (DOFs).
2. Possibility to use with real MIS instruments (Ø 3-6 mm).
3. Resolution and level of accuracy suitable for reliable assessment.
4. Low-cost and easy to produce, to make it affordable for every (training) hospital.
5. Ready to use – 'plug-and-play' in any standard PC.
6. Small size, to be easily carried and mounted (e.g. on a box trainer).

TrEndo – the prototype

Based on the above requirements, a prototype – TrEndo (Tracking, Endoscopy) – of the tracking system has been developed (Figure 1) [2]. The main principle of the prototype is to measure the movements of the instruments by means of optical sensors, and to mimic the pivoting point by means of a gimbal mechanism. Due to the use of a two-axis gimbal mechanism, TrEndo allows realistic manipulation of real MIS instruments in four DOFs.

sensors for instruments

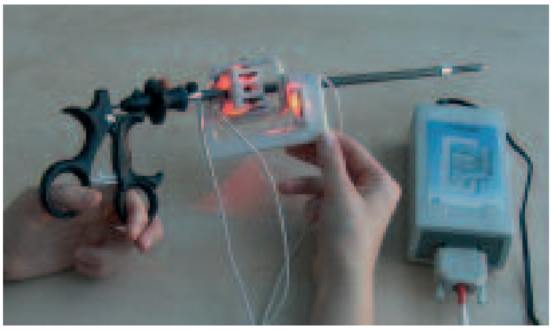

Figure 1. The TrEndo tracking system for guiding and measuring real MIS instruments in training setups.

Optical sensors

The TrEndo system consists of three optical computer mouse sensors (Agilent ADNS-2620), which enable contactless measuring of the real MIS instrument and easy access to the computer through a standard USB port. According to the specification of the manufacturer, the ADSN-2620 sensor tracks motions up to 305 mm/s and its default resolution is 400 counts/inch (16 counts/mm) [3].

There are two sensors placed in the rectangular rigid body of the TrEndo (Figure 2). Sensor 1 measures movements of the MIS instrument in two DOFs: translation along (1st DOF) and rotation around its axis (2nd DOF). Sensor 2, which faces a fixed semicircular surface in the middle ring, measures left-right rotation of the instrument around the incision point (3rd DOF). Sensor 3, which is located on the outer ring of the TrEndo, measures forward-backward rotation of the instrument around the incision point (4th DOF).

Optical mouse sensors measure changes in position over a flat surface by taking pictures (frames) of the surfaces with a small CCD chip at high frame rate [3]. Images of the surface (Figure 3) are acquired through a lens and illumination system. A digital signal processor (DSP) determines from these images the direction and the magnitude of motions using correlation. A stream of *x* and *y* values (given in number of 'sensor counts' that the camera sees) generated by the DSP is sent to the serial peripheral interface. This signal is converted to a USB-signal, which makes that optical mouse sensors are 'plug-and-play'.

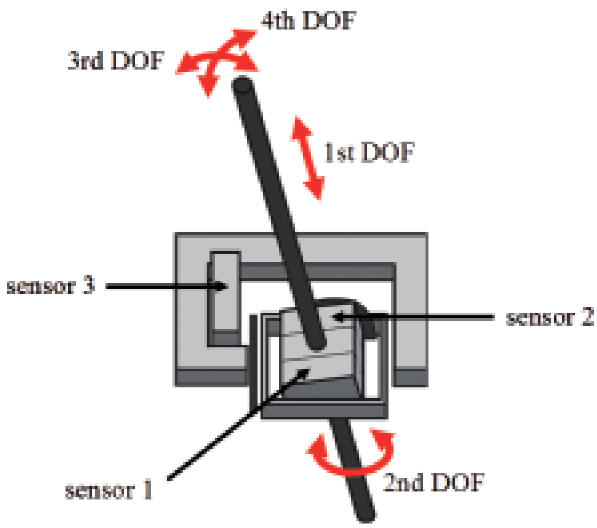

Figure 2. A schematic drawing of the TrEndo tracking system. The two-axis gimbal mechanism allows manipulation of the MIS instrument in four degrees of freedom. Sensor 1 measures the translation (1st DOF) and rotation (2nd DOF) of the MIS instrument around its axis. Sensor 2 measures left-right (3rd DOF) rotation of the instrument around the incision point. Sensor 3 measures forward-backward (4th DOF) rotation of the instrument around the incision point.

Before the TrEndo was developed, several conditions that affect the accuracy and the resolution of the optical sensor have been investigated.

Optical sensor – tests

The accuracy and resolution of the optical sensor changes when the conditions change under which the sensor works [3]. The following conditions are critical for the optical sensor:

1. Distance between lens and tracked object.
2. Velocity of the movements.
3. Surface characteristics of the tracked object.

Tests of the ADSN-2620 sensor were performed using a computer-driven CNC milling machine. The milling machine allows making precise movements (up to 1 μm)

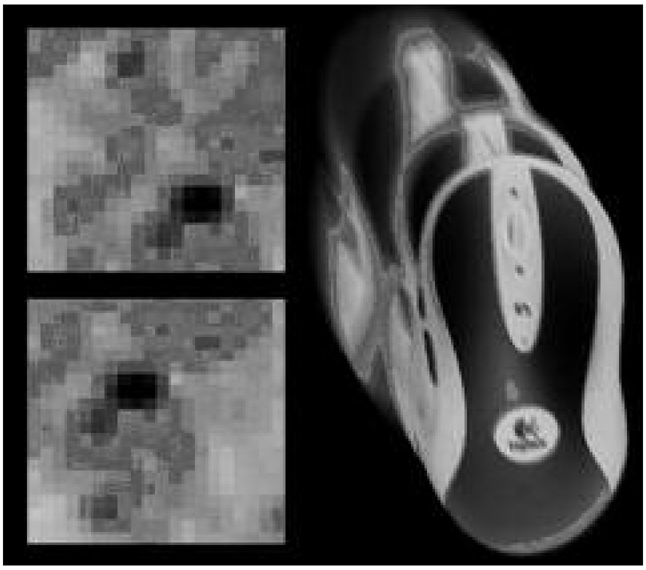

Figure 3. Example of what the optical mouse sensor 'sees' on a surface (resolution 16 x 16 pixels). Details from top left image are compared with details from left down image. The differences in positions between images give information about the position of the mouse. In this case, the mouse is moving down to the right and the image is moving up to the left. (from: Logitech, The MXTM Optical Engine, www.ellenperry.com/logitech_epd/i_tech.html)

with different velocities, and accurate control of the position in *x*, *y*, and *z* directions. The sensor was mounted on the arm of the milling machine and moved 50 mm forward and backward. The relative error was calculated as:

$$Error = \frac{d_{dif} \cdot 100}{d_{total}} \ [\%]$$

Where d_{dif} is the difference between the initial and return position measured by the sensor given in sensor counts and d_{total} is the whole measured distance in sensor counts. The following tests were performed:

1. The optimal distance lens-object:
   During these tests, the distance between tracked surface and lens was changed within the range 2.2-4.5 mm. The measurements were performed at a constant velocity of 1000 mm/min and with sand paper with 1000 parts/inch^2.
2. The velocity:
   These tests were performed for five different velocities: 200, 500, 1000, 3500, and 6000 mm/min. The measurements were performed with a constant distance lens-object of 2.4 mm and sand paper with 1000 parts/inch^2.
3. The surface characteristics:
   The surface was investigated using four different groups of surfaces: different metals (aluminium blasted with glass beads, stainless steal blasted with glass beads, and sandblasted brass), sand papers (2000, 1000, 400, 240 and 40 parts/inch^2), one-colour prints, and two-colour prints (printed on the laser printer). These measurements were done with a constant distance lens-object of 2.4 mm and a velocity of movements of 1000 mm/min.

Data from the sensor were recorded with a sample frequency of 10 Hz on a PC.

Optical sensor – results

The tests of the optical sensor have shown that the following characteristics give the smallest errors (totally lower than 5%):

1. Distance of 2.25-3 mm between lens and tracked object.
2. Velocity of movements up to 5000 mm/min (in MIS, velocities higher than 5000 mm/min are achieved only when the surgeon pulls out the instrument from the patient's body).
3. Rough surfaces or patterned surfaces.

Calibration of the TrEndo

The level of accuracy and sensitivity of the TrEndo was measured again using the CNC milling machine. During the calibration, a brass stick (which imitated the MIS instrument) was connected to the arm of the milling machine. The TrEndo was mounted on a box fixed to the table of the milling machine. Calibration was performed with various velocities and independently for each DOF.

The smallest displacement during translation of the MIS instrument that can be measured by the TrEndo is 60 µm. For the rotation of the instrument around its axis, the smallest measured angle is 1.27°. The smallest angle recognised by the TrEndo in left-right and forward-backward rotations of the instrument around incision point is 0.23°. Furthermore, the total error (for all four DOFs) appeared to be smaller than 5%. Therefore, the accuracy of the TrEndo is higher than 95%.

TrEndo in MIS training setup – tests

Gynaecologists, residents, and interns from various hospitals in the Netherlands participated in this study.

Participants were divided into three groups: experts (gynaecologists with experience of more than 100 laparoscopic procedures), residents (gynaecological residents with an experience of 10-100 laparoscopic procedures), and novices (interns with no previous experience in laparoscopic procedures). The feasibility of using the TrEndo in MIS training setups was investigated by comparing the performance of subjects with different levels of experience, performing a simple, one-hand positioning task in a box trainer. Movements of the MIS instrument were tracked with the TrEndo with a sample frequency of 100 Hz and were analysed. Three kinematic parameters (time, path length, and depth perception, which was determined by the total distance traveled by the instrument along its axis) were used for assessing the performance of all subjects.

TrEndo in MIS training setup – results

Nine experts, eighteen residents, and five novices participated in this study. Figure 4 presents typical instrument trajectories for an expert and a novice performing the positioning task. Experts needed 30% ($p>0.05$) less time to perform the task than residents and 53% ($p<0.01$) less time than novices. Residents needed 33% ($p<0.01$) less time than novices. Experts' mean path length was 28% ($p<0.05$) shorter than the mean path length of residents, and 32% ($p<0.01$) shorter than the mean path length of novices. Residents' mean path length was 6% ($p>0.05$) shorter than novices' path length. Experts' mean depth perception was 28% ($p>0.05$) better than the residents' depth perception,

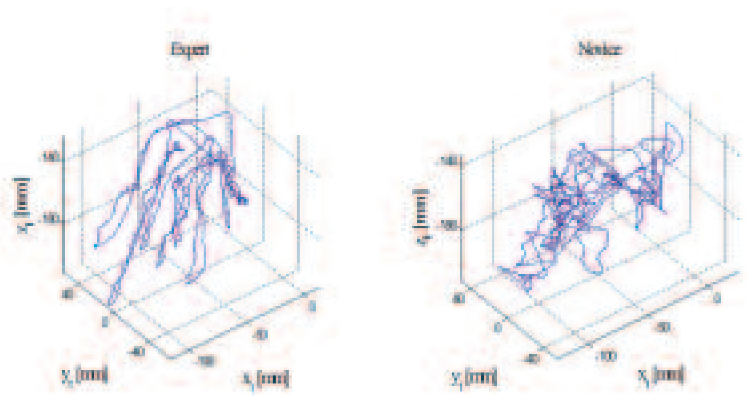

Figure 4. Typical instrument trajectories of an expert (left) and a novice (right) performing the positioning task. This figure shows that the motions of the expert separate eight points more distinctly than the motions of the novice.

and 32% ($p>0.05$) better than novices'. Residents' depth perception was 6% ($p>0.05$) better compared to the novices' depth perception.

Conclusions

TrEndo, a system for tracking real MIS instruments in training setups has been developed. Due to the use of a gimbal mechanism and optical sensors from a computer mouse, the TrEndo is an affordable and easy to produce tracking system. Since differences in performance of subjects with a different level of experience in MIS can be distinguished, it seems feasible to use the TrEndo as a tracking system in MIS training setups. The experiments performed using a milling machine and in the MIS training setup show that optical mouse sensors are suitable to be used as displacement sensors for MIS instruments.

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Information

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