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Computer-controlled endoscopic performance assessment system

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Abstract. We have devised an advanced computer-controlled system (ADEPT) for the objective evaluation of endoscopic task performance. The system's hardware consists of a dual gimbal mechanism that accepts a variety of 5.0-mm standard endoscopic instruments for manipulation in a precisely mapped and enclosed work space. The target object consists of a sprung base plate incorporating various tasks. It is covered by a sprung perforated transparent top plate that has to be moved and held in the correct position by the operator to gain access to the various tasks. Standard video endoscope equipment provides the visual interface between the operator and the target-instrument field. Different target modules can be used, and the level of task difficulty can be adjusted by varying the manipulation, elevation, and azimuth angles. The system's software is designed to (a) prompt the surgeon with the information necessary to perform the task, (b) collect and collate data on performance during execution of specified tasks, and (c) save the data for future analysis. The system was alpha and beta tested to ensure that all functions operated correctly.

Key words: Minimal access surgery—Task performance—Psychomotor skills

In minimal access surgery (MAS) the objective assessment of task performance is an essential step in the evaluation of endoscopic psychomotor skills and the development of surgical instruments for endoscopic surgery. The Dundee endoscopic psychomotor tester (DEPT) was developed as an objective means of assessment of endoscopic performance [2]. Studies with DEPT have confirmed that objective evaluation of task performance in an endoscopic field is feasible; these studies have also documented differences in psychomotor abilities between subjects [3]. The system also provides an objective method for evaluation of the task-endoscope interface. However, DEPT only records the performance of single-handed manipulations; it does not take into account such endoscopic skills as two-handed coordination and manual dexterity. As a further limitation, the operator cannot use standard endoscopic instruments—e.g., graspers and needle drivers—when operating the system. Therefore, we set out to eliminate these limitations by devising the advanced computer-controlled system for objective assessment of endoscopic task performance described herein.

Materials and methods

Design considerations

The advanced Dundee endoscopic psychomotor tester (ADEPT) serves as an objective real-time scoring system to eliminate assessor variability. The components of ADEPT include standard endoscopic instruments, an endoscope, and an image display system. This design closely approximates the performance of subjects on the system required for endoscopic manipulations during MAS. ADEPT has been designed to permit the use of different target modules, to allow adjustment of the level of task difficulty, and to accommodate a variety of endoscopic instruments. In addition, ADEPT permits the adjustment of spatial locations of the target, the endoscope, and instruments, all of which are important variables in ergonomic research on task-instrument interface. Finally, the computer recording of the performance in real time enhances the objectivity and reduces the time needed to conduct the tests.

Components of the Advanced Dundee Endoscopic Psychomotor Tester

The system consists of a dual gimbal mechanism that accepts standard endoscopic instruments. The target object consists of a sprung base plate with various positioning tasks and a sprung top plate with access holes. The subject has to manipulate the top plate with one instrument to allow the second instrument to negotiate the task through the access hole. A standard video-endoscope system provides the visual interface between the surgeon and the target-instrument field. A box encloses the system and allows separate access at any point for the instruments and the endoscope (Fig. 1).

Instrument mounting mechanism

Instruments are mounted in a gimbal mechanism to allow the system to track and record the tip positions of two instruments in three-dimensional

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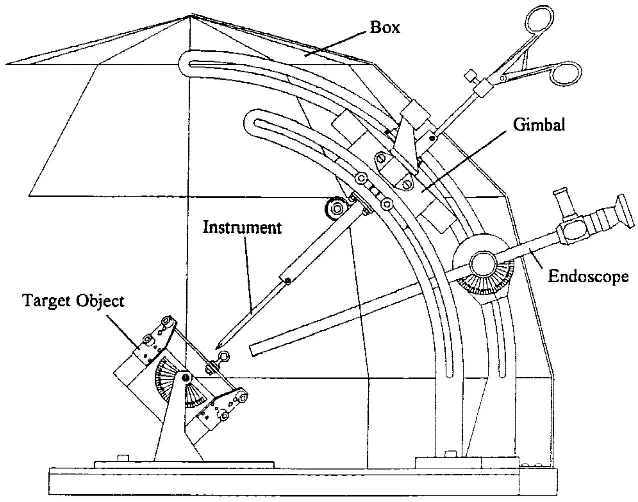

Fig. 1. Diagrammatic representation of The Advanced Dundee Endoscopic Psychomotor Tester (ADEPT).

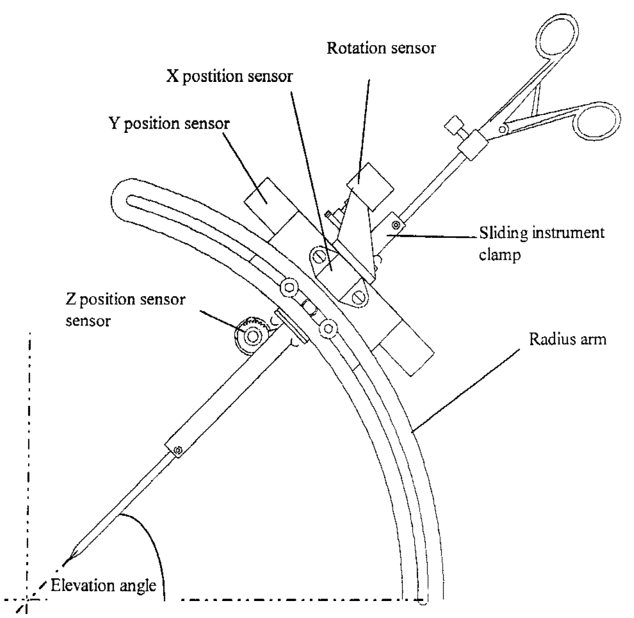

Fig. 2. Diagrammatic representation of instrument mounting mechanism.

space and to detect any additional rotational movement (Fig. 2). The gimbal mechanism was designed with an inner core geared to a potentiometer to detect rotation of the instrument about its axis (θ measurement). A rectangular slider passes through the centre of the core and is coupled to a potentiometer by a rack and spur gear to detect the depth of the instrument along its axis (z measurement). Two potentiometers measure horizontal (x) and vertical (y) measurements. Analogue channels are used to record the output of x, y, z, and θ measurements. The gimbal is mounted on a radius arm to adjust the elevation angle of the instrument by moving the gimbal between 5° and 90° along a radial slot in the arm. The gimbal arm assemblies are mounted on a plate and can be positioned up to 120° apart. Standard 4.8-mm diameter instruments are inserted in the gimbal through a hole along the axis of the slider and then clamped by two grub screws. This enables a variety of instruments to be used and compared against each other.

Endoscope mounting arm

The endoscope is mounted on a radius arm, the centre of which coincides with the system's isocentre (Fig. 3). The endoscope can be positioned

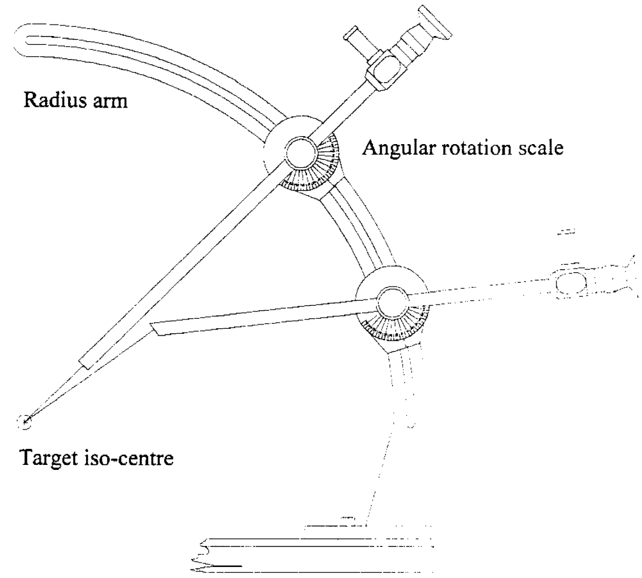

Fig. 3. Diagrammatic representation of endoscope mounting arm.

between 5° and 90° along a radial slot in the radius arm. In addition, the endoscope can be rotated on an angular position scale to enable the system to utilize endoscopes of different directions of view.

Target object

The target concept is based upon the main actions involved during endoscopic operations—e.g., grasping and pulling the tissue with the passive instrument while negotiating the task with the active one. To simulate these actions, the operator has to move a top plate held against springs to gain access to one of five tasks mounted on a base plate (Figs. 4 and 5). These tasks involve measurement of two sliders, a joystick, a dial, and a toggle switch. The base plate is made of aluminum coloured in matte black; the top plate consists of semi-transparent frosted acrylic. These finishes eliminate glare during illumination of the target surface by the endoscope. Both plates are mounted on springs to adjust the tension, which, in turn, govern the east of movement of the plates. The target is modular to allow easy removal and replacement with other modules. The target can also be rotated in two planes about the isocentre to obtain a variety of task-instrument relationships.

Box

The box is a dome constructed from 36 panels and mounted on longitudinal spokes. Each panel can be easily removed and replaced with a felt boot, enabling endoscopes and instruments to be inserted at various points on the box surface (Fig. 6).

Software details

The ADEPT software is located in a computer (IBM PC tope) fitted with an analogue-to-digital (A/D) conversion card (Advantech PC Lab Card, model PCL-812 PG, Roldec System plc., Wolverhampton, England). The card has a 25-pin input adapter built to the ADEPT hardware specifications. The software is designed to (a) prompt the surgeon with the information necessary to perform the task, (b) collect and collate data from the executed task, and (c) save the data for future analysis. All three functions are integrated into a single program that can be used easily without any detailed computing knowledge. However, an introduction to the ADEPT hardware is necessary. The program runs from an MS-DOS prompt.

The system is designed so it can be configured by a text-based initiali-

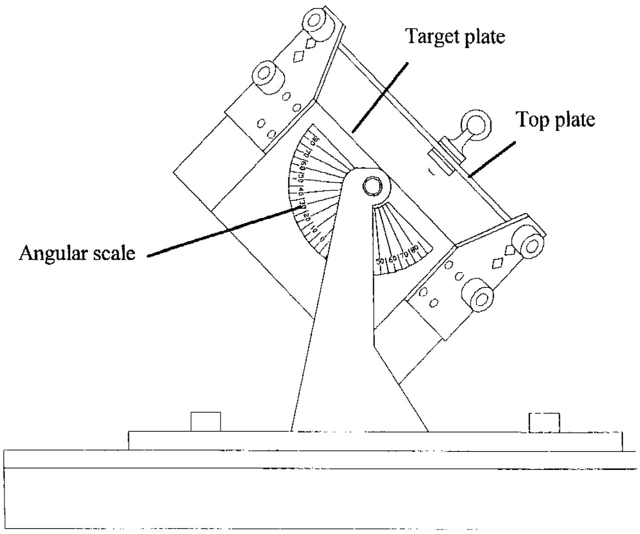

Fig. 4. Side view of target plate.

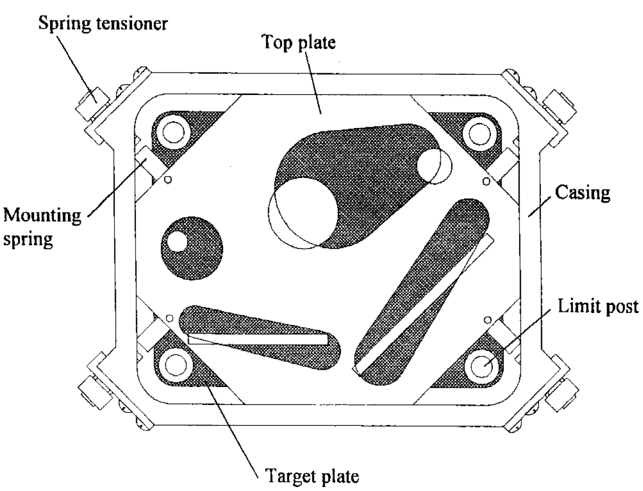

Fig. 5. Top view of target plate.

sation file that describes the tasks in terms of prompts issued and tolerances allowed for successful task completion. Thus, the device can be tuned by the operator based on experimental feedback rather than requiring recoding at the source level.

Operator prompting

The system works by presenting English-language prompts on the screen. Information is always displayed in the same location and in large text. Individual tasks are described by an entry in the configuration file. Target movement for instrument tasks is expressed as numbers corresponding to those engraved on the hardware. The following tasks are included on the current version:

- *Sliders.* The surgeon has to move the slider at least one unit from its current position to a randomly determined new position.
- *Dial.* The surgeon has to rotate the dial at least one unit from its current position to a randomly determined new position.
- *Toggle switch.* The surgeon must toggle a self-returning switch on and off a randomly determined number of times (between two and five).
- *Joystick.* The surgeon has to move the joystick at least one radius from its current position to a randomly determined new position.

The task is deemed to be successfully performed when the operator has

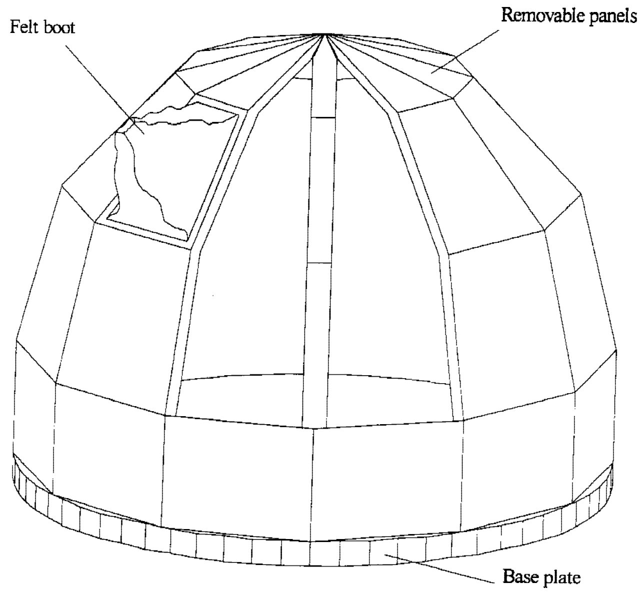

Fig. 6. Box made of removable panels.

completed the task within the tolerance limits and the allocated time defined in the system configuration file.

Data collection

Data collection is automatically initiated by the prompted task process. The system's timer is initiated automatically when either instrument is moved forward from its real stop and stops, when either the time runs out, or when both instruments are withdrawn to their stops. The system also monitors the time that instruments are in contact with the sides of front plate holes (instrument error time) and the time that the real plate is in contact with the corner pins (plate error time). These contact errors are notified by digital output channels to the A/D card. The software records instrument positions at 10th-s intervals, giving x, y, z, and θ measurements for each of the two instruments. Before and after timed sequences, the system calculates the position of the current task in order to set the task or assess its success. Analogue output channels are used to calculate positions of the sliders, the joystick, and the dial; a digital output channel is used for the toggle switch. Data for a task segment is held in computer RAM during the task, and appropriate calculations are made at the end when the data are written to the relevant file and onto the screen.

Data saving

Program data are saved in a disk-based text file after each run, to limit the amount of memory required to run the program. The file is in plain ASCII text to make it accessible to a variety of programs. Coordinate data for x, y, z, and θ of each instrument are listed at 10th-s intervals, so that the data are always available for subsequent processing and evaluation in more specialised data analysis packages to provide the detailed trajectory of the instruments.

System function

A specific software program allows the surgeon to adjust the manipulation, azimuth, and elevation angles of instruments. The manipulation angle is the angle between the two instruments; the azimuth angle describes the angle between either instrument and the optical axis of the endoscope. The elevation angle of the instrument is defined as the angle between the instrument and the horizontal plane [1]. The program also permits the adjustment of the angle between the optical axis of the endoscope and target surface. A text configuration file enables the operator to change the level of task difficulty by modifying the time limit and the tolerance level of task accuracy.

Each test run consists of a number of tasks identified by the configuration file. The order in which tasks are addressed is by random sequence generated by the system software. To ensure that all subjects are examined alike, surgeons have to follow instructions displayed on the computer screen. The task entails manipulation of the top plate with one instrument to allow the second instrument to negotiate the target through the access hole. A full run is completed when the subject has negotiated all tasks. The program outputs statistics to the screen and to a file. The endpoints for each task are as follows:

- *The execution time*(*s*): The time from moving either instrument from the back stop until both instruments are returned to the back stop or the time limit is reached.
- *Instrument error time*(*s*): The time that instruments are in contact with the sides of front plate holes.
- *Plate error time*(*s*): The time that the rear plate is in contact with the corner pins.
- *Flight trajectory* (*units*): The x, y, z, and θ coordinates.
- *Task completion* (*yes or no*): The task is deemed to be completed when the operator has performed the task within the tolerance limits and the allocated time defined in the system configuration file.
- *Task success* (*yes or no*): The task is deemed to be completed when the subject has completed it with no instrument or plate errors.
- In addition, a *summary set for all tasks* includes: total execution time, total instrument time error, total plate time error, number of completed tasks, and number of successful tasks. Three-dimensional mapping of flight trajectory for each instrument can be obtained from the analysis of x, y, z, and θ coordinates.

Results

Following development and assembly, the ADEPT was alpha tested and then released to the Surgical Skills Unit for beta testing to ensure that all functions operated correctly. There is a reasonable degree of fault tolerance built in—for example, to prevent accidental erasure of data files. The software is not designed to be heavily fault-tolerant in terms of misuse. It is assumed that the operator follows the instructions provided by the software, especially with respect to the configuration file.

Initial experiments showed that the software program can accurately adjust the angles of instruments and endoscopes. The level of difficulty is easily controlled by modifying the text configuration file or changing the spring tension on the target plates. ADEPT was confirmed to be fully operational with a variety of standard endoscopic instruments, endoscopes, and image display systems. Administration of a full run takes <10 min.

Discussion

ADEPT provides an objective real-time scoring system since all subjects are assessed alike in terms of the nature of the test and instructions displayed on the screen. Aspects of face validity of ADEPT include the use of an endoscope, an image display system, and standard endoscopic instruments. Instrument movement in the gimbal mechanism has the same degrees of freedom as endoscopic instruments through the access port, so that the negotiation of target plates mimics basic endoscopic surgical manipulations.

There are important applications of ADEPT in the development of instruments and for ergonomic research related to MAS. New designs of handles and jaws can be assessed by their influence on task performance using ADEPT. The ergonomics of task performance can also be studied by analysing x, y, z, and θ coordinates on performing different surgical tasks, such as knot-tying and bowel-suturing. In addition, ADEPT can be utilized in the assessment of endoscope-task interface and image display modalities.

The psychomotor performance on ADEPT is likely to be dependent on hand-to-eye coordination, spatial perception, two-handed coordination, arm-hand steadiness, and manual dexterity. On the other hand, ADEPT does not evaluate differing abilities between right and left hands, as ADEPT does [3].

ADEPT-measures a combination of skills specific to endoscopic surgical manipulations, whereas established psychomotor tests in current use measure only a specific ability related to each test. Studies on the predictive validity of operative performance in MAS using ADEPT are in progress. These studies may prove to be helpful in the selection of candidates for training in endoscopic surgery.

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