Safety Oriented Laparoscopic Surgery Training System

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Abstract. The discussed training system employs several means for encouraging safe behavior during laparoscopic surgery procedures. The elements of no-fly zones, magnetic position sensing and expert systems are tied together to form a complex system that provides guidance and performance assessment. A 3D reconstruction algorithm is used for the purpose of defining no-fly zones and has been tested in a simulator developed for the purpose of this work. An expert system has been built in cooperation with surgeons that, based on simple rules, can assess the risk of the trainee's actions. Despite the shortcomings of the 3D reconstruction process, the training system performed as expected during experiments. Simple exercises like touching points in 3D space were performed and scored appropriately to whether a no-fly zone has been breached or not. Also simple advice could be provided to the trainee in order to help improve the results.

Keywords: laparoscopic surgery, training, image processing, expert system, fuzzy logic.

1 Introduction

Laparoscopy is a surgical technique, where operating sites within the human body are accessed under the guidance of an endoscopic camera, through special long tools, that are introduced into the body via small incisions - as opposed to open surgery, where one large incision is made and the surgeon has direct access to the tissue and is viewing the operating site with his bare eye. Because of that change of perception of visual and haptic sensations laparoscopy is much more demanding and difficult to master than traditional surgery.

Soon after laparoscopic surgery has been adopted in the 1980's the medical society discovered the need of specificaly designed training programs with objective performance assessment. This need has been addressed by applying simulators, an idea that came from the aviation industry [1,2]. Several such systems [3,4] are available with emphasis on the Virtually Asissted Surgical Trainer (VAST)

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[4] system, which serves as a basis for the training system built for the purpose of this work.

Currently [5,6] the main part of laparoscopic surgeon training is learning to operate the endoscopic camera [7] and instruments by performing excercises on physical models. The main purpose of the system described in this paper is to aid in that process but also enforce safe behaviour during procedures - by informing the trainee about approaching certain predefined zones where the operating instruments shouldn't appear [8,9] as well as providing information about certain features of movements, like speed or roughness. That way the trainee is forced not only to master the basic set of skills but also to operate in a safe manner.

An expert system application has been proposed earlier [9] but has been extended to offer not only advice on improving the skills but also can now provide risk assessment. The expert system is based on a set of rules created in cooperation with surgeons and a fuzzy classification of movements.

2 System

The system contains of a standard laparoscopic setting - a surgical instrument and a camera, which are insterted in to a obscured box. The instrument also has an embedded position sensor, which together with the images from the endoscopic camera provide information for the computer system - as outlined in Figure 1.

An important part of the system is the image processing component, which is reponsible for creating a 3D model of the operating field. It is possible to obtain such a model through application of a certain set of image processing algorithms (an approach called structure-from-motion 3D recovery) directly from a set of 2D images of the operating field, coming from the laparoscopic camera.

2.1 Training

The training is based on simple tasks that trainees have to complete within a specified time. Several types of exercises have been proposed by others [14, 15], the common goal is to practice dexterity, coordination and depth perception. Example exercises are:

- knot tying,
- cutting and suturing,
- picking up objects,
- touching different points on a model.

The trainee's score is calculated with respect to :

- elapsed time,
- length of the path of the instrument tip,
- accuracy,
- hazard,

where the hazard score is related to the events of approaching no-fly zones - hazardous regions, defined at the beginning of each exercise.

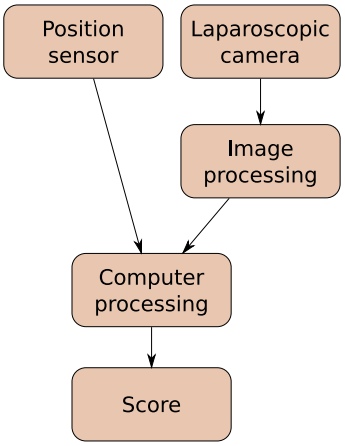


Fig. 1. Components of the training system

2.2 No-Fly Zones

The concept of no-fly zones is an important part of the described system, which just like the idea of applying simulation in surgical training has been borrowed from the aviation industry. In the system presented here the no-fly zones are used to focus the training on the skill of avoiding certain regions of the operating field - just like during normal procedures the surgeon has to avoid irritating or cutting certain anatomical structures (i.e. nerves, vessels).

$$S = \left(\frac{k_t}{t}, \frac{k_s}{s}, k_A \cdot A, k_H \cdot H\right) \tag{1}$$

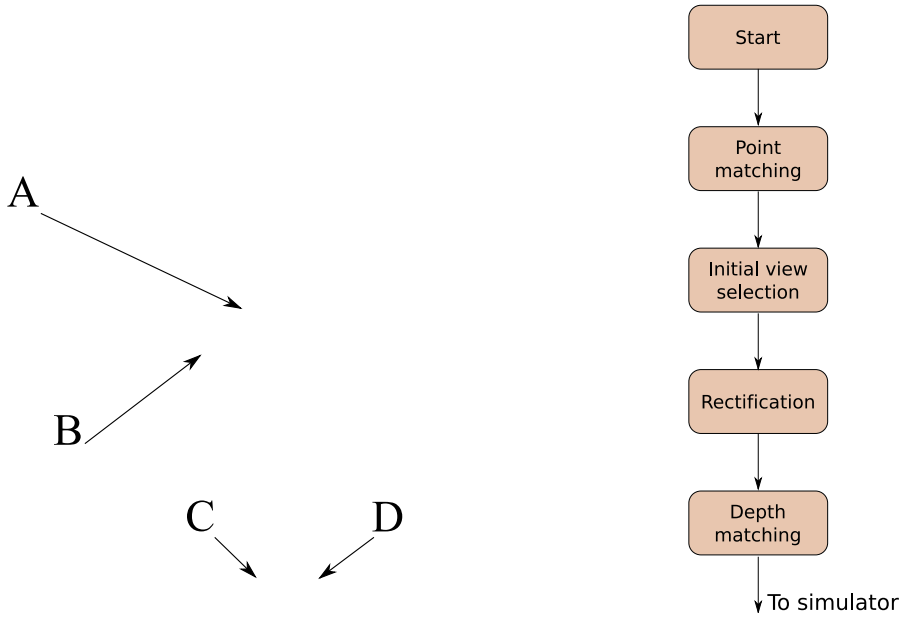
with

$$H = -\frac{2R_H}{|d(H_c, T)| + R_H} + 1, \tag{2}$$

and $d(H_c, T)$ being the distance between the center of the no-fly zone (approximated by a sphere) H_c and the instrument tip T.

A simulator of the system has been developed and used to evaluate the performance of the proposed concepts. As it is shown in Figure 2(a) the simulator contains several elements - an instrument, image of the operating field, no-fly zone proximity indicator and the H measure indicator. An example of applying the modified scoring function in a training drill is shown in Figure 2.

The no-fly zones are located in the 3D space of the operating field. To achieve that a 3D model of the operating field has to be obtained first. It has been shown [10] that an application of structure-from-motion computer vision algorithms (also outlined in Figure 2(b)) can be used for that purpose.



(a) Simulator of the system, running in Matlab. A - tip of the instrument, B - no-fly zone location, C - H measure indicator, D - no-fly zone proximity indicator

(b) Image processing steps

Fig. 2. Simulator and the image processing pipeline

2.3 Expert System

In order to build a usable training system some expert knowledge and fuzzy set theory has been embedded into the described system [11,12]. This knowledge is expressed in a number of rules, similar to the following:

- if (speed is F-) and (smoothness is S+) and (distance is D+) then (Risk is R-),
- if (speed is F+) and (smoothness is S-) and (distance is D-) then (Risk is R+),
- if (speed is F+) or (smoothness is S+) or (distance is D+) then (Risk is R+),
- if (speed is F+) then (Risk is R+),
- if (smoothness is S-) then (Risk is R+),
- if (distance is D-) then (Risk is R+),

where F^+, S^+ and D^+ are fuzzy sets containing movements that are, respectively, fast, smooth and distant from no-fly zones.

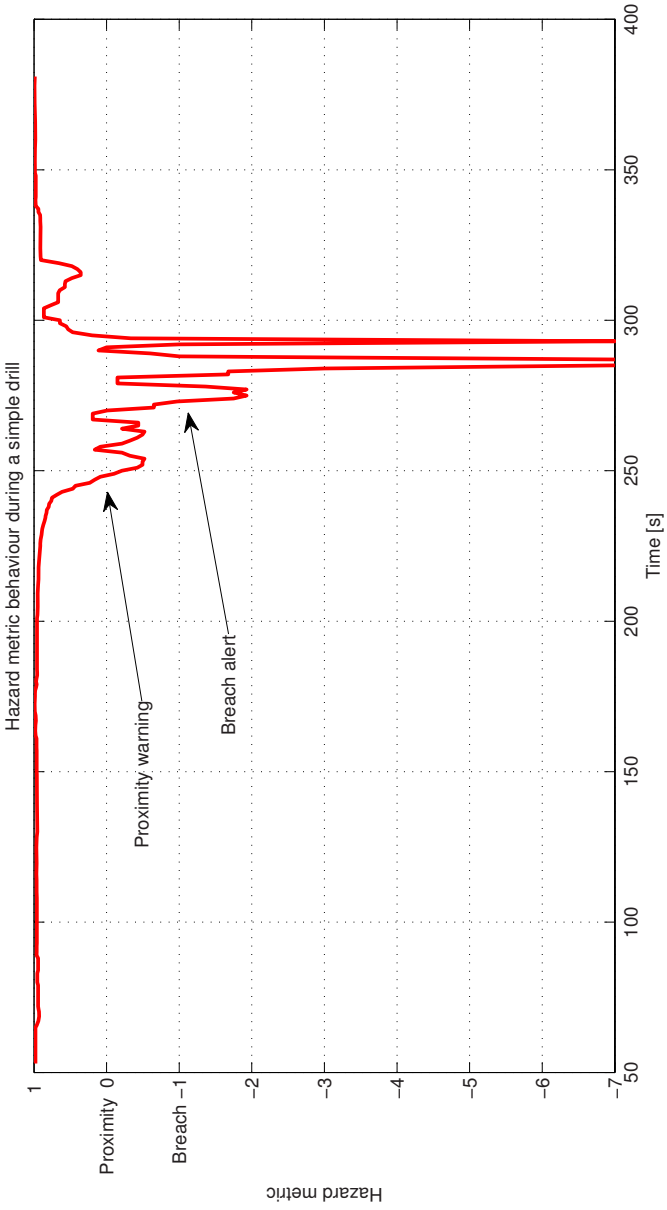
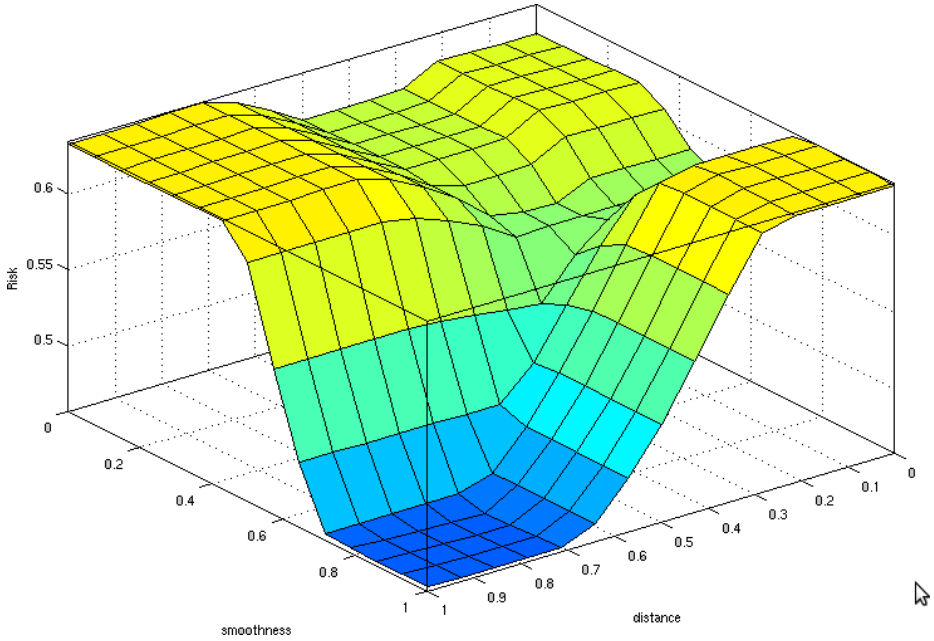
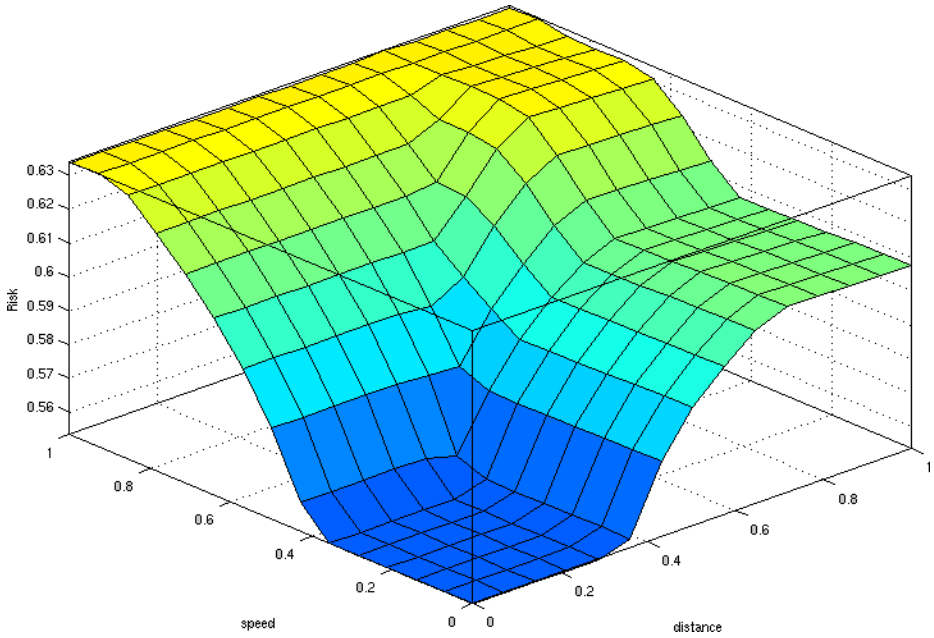


Fig. 3. Graves Disease workflow in Taverna



(a) Smoothness vs. distance



(b) Speed vs. distance

Fig. 4. Risk function in terms of smoothness, speed and distance

The main goal of the expert system is assessment of the risk involved with the actions taken by the trainee, an example of the risk output in terms of movement speed, smoothness and no-fly zone distance is shown in Figure 4. Additionally the system can offer advice (i.e. can tell the trainee that the movements are too fast, too rough, etc.), based on the movement classification, to help the trainee in improving missing skills.

Further detail on classification of movements and expert advice offered by the system has been given in [9].

3 Conclusions

The main focus of the system described in this paper is enforcing safe behaviour during laparoscopic procedures. Several means are used to achieve that goal - application of computer simulation, no-fly zones, expert system. The trainee's performance can be scored adequately and advice on how to improve can be offered. The concepts brought together in this system have been tested and can serve as a tool in laparoscopic training programs.

The image processing part (used mainly for the purpose of locating the no-fly zones in the 3D space of the operating field) of the system needs further attention, but already shows promising results. Especially models that are poorly textured produce 3D representations biased with a significant error. Stereo matching algorithms that deal with such textureless objects are available and they will be examined for application in future versions of the proposed system.

In future versions of the system it will be interesting to add a parameter describing the visibility of the instrument, as well as it's distance from anatomical structures, not only from the no-fly zones. That way better guidance and risk assessment will be offered.

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