Automatic guidance of laparoscope based on the region of interest for robot assisted laparoscopic surgery

Lingtao Yu, Hongwei Li, Lingyan Zhao, Sixu Ren and Qing Gu

College of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin, Heilongjiang Province, PR China

ABSTRACT

Background: Minimally invasive surgeries rely on laparoscopic camera views to guide the procedure. Traditionally, an expert surgical assistant operates laparoscopic camera. This process is distracting, and the camera is not always placed in an ideal location. To mitigate these problems, we have developed a laparoscopic automatic navigation method.

Methods: In this article, a way to determining surgery status based on the distance of surgical instruments is presented. Combining with the surgery status, the region of interest (ROI) in laparoscopic image is defined, and related parameters are given in detail. Comprehensive the above content, the method of laparoscopic automatic navigation based on the ROI is proposed.

Results: Finally, introducing the method into a kind of typical minimally invasive laparoscopic surgery robot system (MLSRS), and the method is simulated by using some typical surgical tasks.

Conclusion: The results show that this method is feasible.

KEYWORDS

Laparoscopic surgery; operation status; region of interest; automatic navigation

1. Introduction

Robot assisted surgery is a new type of surgery developed in recent 30 years, which has advantages of little trauma and faster recovery. But surgical robots cannot instead of surgeon, the main role of it is to assist the surgeon during operation and it cannot be called as intelligent robot because of almost no autonomy especially for the robot arm, which clamps laparoscope.[1,2] Because the number of master manipulators is less than slave manipulators, the surgeon must switch control object to adjust the position and pose of laparoscope from time to time, which will prolong the time of surgery and affect the operation efficiency. How to realize the automatic navigation of laparoscope is the first step of surgical robot toward Intelligence.[3,4]

The key problem of laparoscopic automatic navigation is how to determine the operation field. A main way is to confirm user’s intent. Eye gaze tracking is a way to confirm user’s intent. There have been some method be proposed,[5,6] but still have a series of problems, such as high cost, low accuracy and stability.[7] User’s intent can also be expressed by the surgical instruments. King et al. [8] establish a laparoscopic automatic navigation system based on vision, which can automatically centers the camera’s view on the two instruments and alters the zoom level to ensure both tools are in view at all times. Detecting surgical motions/tasks is another way to confirm user’s intent,[9,10] but this work requires additional tracking hardware or access to the robot’s hardware, it cannot be more easily applied to laparoscopic surgery.

In addition, various laparoscopic automatic navigation systems have been developed,[11–13] most of them are not universal, and need a lot of preparation.

The contribution of this article is proposing a new kind of laparoscopic automatic navigation method based on region of interest (ROI) in laparoscopic image, which can realize the accurate window tracking under the intermittent movement. In our articles, user’s intent is expressed by the operation status, so how to detective operation states is the basis of the method. And the definition of ROI is presented combined with the operation states. According to them, our method is proposed. Then, the method introduced into a kind of typical minimally invasive laparoscopic surgery robot system (MLSRS), it is proved to be feasible through simulation and experiment.

CONTACT Lingyan Zhao bliqr163.com College of Mechanical and Electrical Engineering, Harbin Engineering University, No. 145 Nantong Street, Nangang District, Harbin 150001, PR China

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2. Operation status detection method

In the process of surgery, the operation field that surgeons need can be summed up in two cases, one is global field of vision and another is partial field of vision, which corresponding to two different operation status:

1. Do not dealing with the pathological tissue. When the surgeon searching target or the operation at the beginning, usually need a wide range of operation field. This corresponds to global field of vision.

2. Dealing with the pathological tissue. When the surgeon dealing with the pathological tissue, usually need to clearly show the surgical instruments and pathological tissue. This corresponds to partial field of vision.

Surgical tasks commonly used mainly include cutting and peeling tissue, intracorporeal knot tying, extracorporeal knot tying, hemostasis, etc. Taking two of them as examples, as shown in Figure 1, most of the other surgical tasks are around the pathological tissue, so through setting a threshold of space distance between surgical instruments, these two operation states can be simply judged.

Operation states judgment formula is as follows:

\[
\begin{align*}
L_{AB} &\leq T \quad \text{Dealing with the pathological tissue} \\
L_{AB} &> T \quad \text{Do not dealing with the pathological tissue}
\end{align*}
\]

(1)

Where \(L_{AB}\) stands for the space distance between two surgical instruments, \(T\) stands for the threshold, which is set according to the size of pathological tissue.

3. The definition of region of interest

At present, most of the laparoscope equipped by MLSRS can output HD image (1080P), the image can still stay sharp even though zoom in it, but the surgeon only interested in the parts of the laparoscopic image which we usually called ROI, so we choose the ROI as output image, as shown in Figure 2.

Combining with the surgeon’s demand of the surgical field, the requirements of ROI under different operation status are as follows:

1. When the surgeon is not dealing with the pathological tissue, the surgical instruments are far apart, the ROI contains a wide surgical field, so do not make special requirements.

2. When the surgeon is dealing with the pathological tissue, define the average size of two surgical instruments is between \(S_D\) and \(S_U\).

Supposing the coordination of point \(c\) is \((x_c, y_c)\), the length of straight line \(ab\) is \(L_{ab}\). The center of ROI is \((x_c, y_c)\), the size of ROI is as shown in formula (2).

\[
(w, h) = \begin{cases} 
(KL_{ab}h_{\max}/w_{\max}) & \varepsilon > \varepsilon_{\min} \\
(w_{\max}\varepsilon_{\min}, h_{\max}\varepsilon_{\min}) & \varepsilon \leq \varepsilon_{\min}
\end{cases}
\]

(2)

Where \(\varepsilon = KL_{ab}/w_{\max}\), \(K\) is the width factor of ROI, which need to be set according to the operation environment. \(w_{\max}\) and \(h_{\max}\) are the width and height of original image, respectively.

The proportion of ROI in original image is given as below.

\[
\varepsilon_{\pi} = \begin{cases} 
KL_{ab}/w_{\max}\varepsilon > \varepsilon_{\min} \\
\varepsilon_{\min}\varepsilon \leq \varepsilon_{\min}
\end{cases}
\]

(3)
To guarantee the proportion of core operation area in ROI and reducing the unrelated information in ROI, the width factor \( K \) usually take 1.5 ~ 2.

In order to keep the marks in ROI, the value of \( K \) need to be adjusted according to the slant angle of \( \phi \).

\[
K = \begin{cases} 
    K_c & \sin \phi \leq K_c h_{\text{max}} / w_{\text{max}} \\
    \sin \phi w_{\text{max}} / h_{\text{max}} & \sin \phi > K_c h_{\text{max}} / w_{\text{max}} 
\end{cases}
\] (4)

As shown in formula (4), when all the marks of surgical instrument are within the ROI, \( K \) is equal to the initial value \( K_c \), whereas the value of \( K \) change along with the changes of slope angle \( \phi \).

As shown in Figure 2(b), in order to keep the ROI always within the laparoscopic original image, we define a judgment area. When the ROI and motion judging area have overlap, laparoscope needs to be adjusted; the criterion is given by formula (5).

\[
\begin{align*}
{w + 2|\{x_m| + d_w| < w_{\text{max}}}
\quad & \\
{h + 2|\{y_m| + d_h| < h_{\text{max}}}
\end{align*}
\] (5)

\( d_w \) and \( d_h \) stand for the width of the judgment area on the horizontal and vertical direction. Refer to Figure 3, based on the definition of ROI and its motion state during the navigation and camera imaging model, the values of \( d_w \) and \( d_h \) in camera coordinate systemOc - xCyCzC are given by formula (6).

\[
\begin{align*}
d_w &= K\left(\frac{\Delta x_f z_f}{z} + \frac{|\Delta x_t (x_M + \Delta x_l) f_z|}{z (z_M + \Delta z_M)}\right) \\
d_h &= \frac{kh}{w} \left(\frac{\Delta y_f f_y}{z} + \frac{|\Delta y_t (y_M + \Delta y_l) f_y|}{z (z_M + \Delta z_M)}\right)
\end{align*}
\] (6)

Where \( \Delta x_t = \frac{v_t}{\phi} \sin \frac{\psi_t}{2}, \Delta z_t = \frac{v_t}{\phi} \cos \frac{\psi_t}{2}, \Delta y_t = \frac{v_t}{\phi} \sin \frac{\psi_t}{2}, \Delta z_l = \frac{v_l}{\phi} \cos \frac{\psi_l}{2}, f_s \) and \( f_y \) are the focal length of the laparoscope. \( f_c \) and \( f_t \) are the focal lengths of the laparoscope. \( \phi_t \) and \( \phi_v \) are the visual range angle of laparoscope. \( v_t \) and \( v_v \) are the speed of surgical instruments in in the horizontal and vertical direction. Point M is the center of point A and B.

**4. The process of laparoscopic automatic navigation**

The flow chart of laparoscopic automatic navigation is shown as Figure 4. First, system collects the original image of laparoscope and acquires the size and position of surgical instruments in laparoscopic image. The parameters of ROI are calculated based on the definition of it. Then the ROI is amplified output to the screen. Next, the laparoscopic motion parameters are calculated, if they are not zero, keep the surgical instruments and move laparoscope, if they are zero, it means that the laparoscope do not need to move. Throughout the laparoscopic automatic navigation, image acquisition and output still be performed.[14]

**5. Experiment and discussion**

Base on the manipulator of a kind of typical MLSRS (as shown in Figure 5), three kind of trajectories, which belong to the surgical task of intracorporeal knot tying are adopted to prove the feasibility of this method.

Considering trajectory detection error and joint movement errors, MATLAB is used to simulate and analyze this method. As shown in Figures 6, 7, the simulation results show that: for each kind of trajectory, keeping ROI within the original image of laparoscope only need adjust the laparoscopic posture and position 3~4 times. Through point-to-point movement, this method can complete automatic navigation, which effectively avoids the influence of continuous movement of laparoscope.

In this article, we also consider the automatic navigation effect under different laparoscopic visual angle. For each kind of trajectory, this method is simulated 10 times. The average adjustment times of laparoscopic pose is shown in Table 1.

The results show that: for laparoscope with different visual angle, the adjustment times of laparoscopic pose is less than one, which means it is determined by the instrument trajectories and have little relationships with the laparoscopic visual angle. This method is suitable for most kinds of HD laparoscope.
**Figure 4.** The flow chart of laparoscopic automatic navigation.

**Figure 5.** Manipulator with laparoscope.

**Figure 6.** The visual process of simulation: (a) trajectory 1, (b) trajectory 2, and (c) trajectory 3.

**Figure 7.** The moving range of ROI: (a) trajectory 1, (b) trajectory 2, and (c) trajectory 3.
6. Conclusions

For the problem of switching control object to adjust the operation field during the robot assisted laparoscopic surgery, a method of laparoscopic automatic navigation based on ROI is proposed. Applying the method to a kind of typical MLSRS, MATLAB is used to simulate and analyze this method; the visual process of automatic navigation is presented. We also simulate this method based on the laparoscope with different visual angle, which shows this method is suitable for most kind of HD laparoscope. This method avoids the image dithering and blurring caused by frequent movement of laparoscope, which has a couple of advantages.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Table 1. The automatic navigation effect under different laparoscopic visual angle (unit: times).

| Visual angle | Trajectory 1 | Trajectory 2 | Trajectory 3 |
|--------------|--------------|--------------|--------------|
| 0°           | 3.3          | 2.8          | 2.0          |
| 5°           | 3.2          | 3.1          | 2.1          |
| 10°          | 3.0          | 3.4          | 2.0          |
| 15°          | 3.2          | 3.1          | 2.2          |
| 20°          | 3.1          | 3.3          | 2.1          |
| 25°          | 3.0          | 3.4          | 2.2          |
| 30°          | 3.0          | 3.5          | 2.4          |
| 35°          | 3.1          | 3.9          | 2.7          |
| 40°          | 3.4          | 3.8          | 2.6          |
| 45°          |              |              |              |

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