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ANALYSIS ON TELEPOINTER TRACKING METHODS FOR ENDOSCOPIC IMAGES

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ABSTRACT

Recently, the growth of endoscopic surgery for accelerating the operation performance with minimum pain regardless of the distance limitations becomes the crucial agenda for enhancing the health care qualities. Therefore, telemedicine is one of the best alternatives to break the limitation. On top of that, telepointer is a well-known supported tool for remote guided used in telemedicine as well as to facilitate the inexperienced physician at the remote place during surgery operation. The function of telepointer is to label the tissues and organs of interest (TOB). However, the non-rigid shape and movement of tissues and organs lead to lose the pointer track. Unfortunately, there are only a few studies has been done on telepointer tracking, especially for endoscopic application. In this paper, we analyzed three methods to keep track the TOB and maintenance the pointer towards the TOB by using feature matching approached as an observation data. Therefore, our aim is to evaluate the most effective method of telepointer tracking. Three techniques have been compared, which are least square method (LMS), Delaunay triangulation with line intersection (DT) and maximum probability keypoints with scale circles intersection (PMAX). Simulation results show that the most effective technique is PMAX with average mean error distance MED lower than six pixels followed by DT and LMS. Hence, the tracking system will allow the physician to track the pointer better especially in noisy environment.

Keywords: telepointer, tracking, endoscopic image, T-test.

INTRODUCTION

Endoscopic surgery is introduced with the aim to reduce the side-effect of open surgery. This surgery can only be performed by a surgeon, who is an expert in handling the endoscopic surgery instruments. However, there is a lack of experienced and expert surgeon in Malaysia to handle the endoscopic instruments, especially in the rural areas [1] [2]. One of the alternatives that can be implemented to address the problem is by utilizing telemedicine communication technology. It offers synchronized transmission of voice, video and image for effective communication between the junior and experts surgeon.

In emergency case, telemedicine technique can be used to guide the junior surgeon in performing endoscopic surgery for critical patient. Nevertheless, the main drawback of the recent techniques in telemedicine system is the lack of non-verbal communication such as facial expression, hand gesture and body movement.

Therefore, the application of pointer technology in telemedicine, especially during endoscopic surgery is very important because it can be used to relay the expert's hand gesture information to mark the tissues and organs of interest (TOB). As a result, the location of the tissues and organs that need to be treated and investigated can be detected immediately and accurately even by the junior surgeon [3]. There are various telepointer modalities such as cursor, laser, sketching and virtual hand [4], but even for the state-of-art telepointer technology failed to keeps track the TOB movements. The TOB image tracking is a complicated process because of homogeneous tissues and internal organs (Figure-1(a)) as well as inconsistent illumination (Figure-1(b)) that makes it difficult to be distinguished from its surroundings. In addition, the non-rigid nature of TOB (Figure-1(c)) increases the complexity of the tracking process. Therefore, the main objective of this study is to keep tracks the TOB movement for time series endoscopic videos.

In computer vision system, a robust estimation method must be able to measure the movement parameters accurately [5] [6], by selecting the reference keypoints (TR) carefully from the final pool of matched keypoints. Therefore, failure to choose the right keypoints will reduce the reliability of observed data and thus, produces inaccurate estimation. Hence, the selection of right TR is an important process so that reliable input can be obtained to represent the actual movement model.

In order to identify the best selection and estimation techniques, this paper evaluates the effectiveness of three selection and estimation methods, which are 1) Least Square Method (LMS), 2) Delaunay Triangulation with line intersection and 3) The maximum probability keypoint with scale circle intersection.

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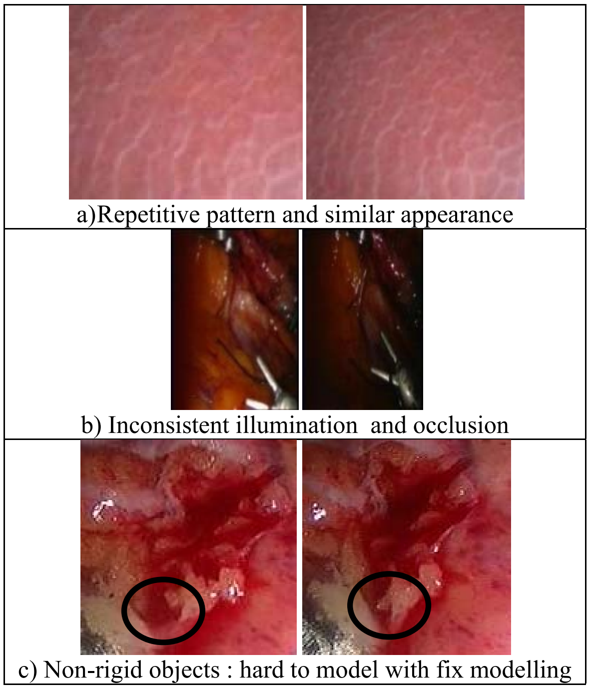

Figure-1. The challenges of telepointer tracking for endoscopic images.

METHODOLOGY

Generally, this study consists of four modules as depicted in Figure-2. The details of each module are outlined as below:

a) Pre-processing: It is done to enhance the quality of raw images by suppressing the unwanted noise as well as enhancing the relevant features. The process is performed by smoothing the images using Gaussian smoothing technique. Prior to that, conversion of the color model from RGB to grayscale is done to reduce the computational complexity.

b) Feature extraction: This module is carried out using a modified method of centers surrounded by extreme (STAR) detector [7], which produces the highest number of detected feature points compared to the other detectors. Furthermore, description of the feature points are represented by using vector set of log ratio [8].

c) Feature matching: The aim of this module is to maintain the image registration. In our previous work, we have proposed matching algorithm using probability approach by utilizing the powerful t-test hypothesis testing t-test [8]. For robust implementation, the matching module is improved by investigating the actual movement characteristics of the tissues and organs. As a result, new procedures were introduced which are; 1) segmented region used in normality test for each LRD and 2) probability-distance test. The test only considers ten nearest candidate keypoints from the current keypoint. The probability-distance, F_{PD} is defined as

$$F_{PD} = (PA * e^{-(\alpha * dist)} \mid PA \geq 0.005) \quad (1)$$

$$PA = (P1 + P2) \quad (2)$$

where, *PA* is an acceptable probability obtained from the t-test hypothesis testing. α is set to 0.5 and *dist* is the Euclidean distances between the reference keypoint with feature point candidates. The final matched keypoints are used as input to the telepointer tracking module.

d) Telepointer tracking: The goal of this module is to identify the new location of TOB which has moved from its original location. This module has two sub-processes. The first process is designed to remove false matched keypoints by using geometric constraint technique [9]. In fact, there exists a few mismatched keypoints even though we have tried to minimize it during matching module. As a result, only the true matched keypoints are selected as TR and at the same time, it improves the reliability of TOB movement trajectory. Figure-3 shows an example of geometric constraint on the internal organ.

The second process is to estimate telepointer location by tracking the TOB movement. This step is a combination of two steps, which are the selection of TR and calculation of new telepointer location.

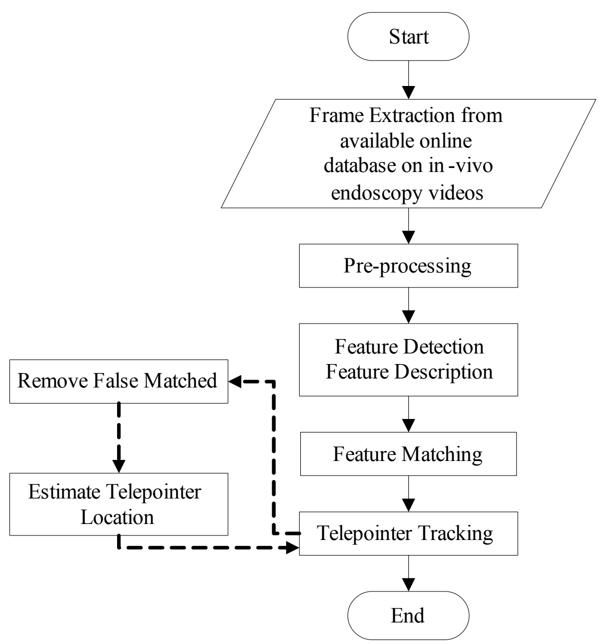

Figure-2. Flowchart of the proposed telepointer tracking system.

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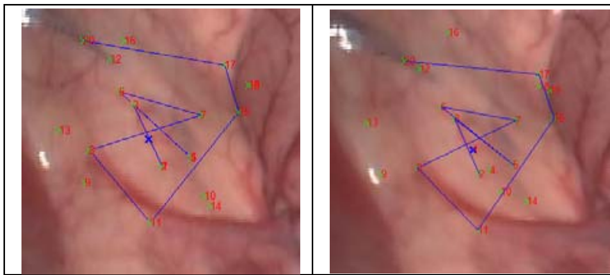


a) Previous frame | b) Current frame

Figure-3. Blue 'x' is the initial telepointer location. Green 'x' is the nearest final matched keypoints to the initial telepointer location. Keypoints that attached to the blue line are considered as true matched.

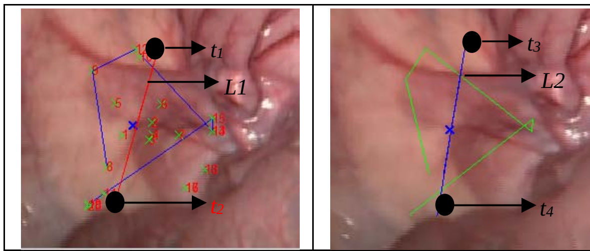
A. Least Square Method (LMS)

LMS method is a statistical technique used to obtain the best fit line of the data points. A straight line is obtained by minimizing the number of error between the data points and average point. Basically, this method aims to reduce the mismatched keypoint error in the data set.

In this study, the LMS technique produces four new point locations, t_1, t_2 t_3 and t_4 as illustrated in Figure-4, where *L1* and *L2* represent the best fit line for the previous and current frames. Next, we estimated the TOB movement by using transformation matrix as in equation (3).

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \lambda \cos\theta & -\lambda \sin\theta \\ \lambda \sin\theta & \lambda \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix} \quad (3)$$

Where (x', y') and (x, y) are the locations of telepointer during current and previous frames, respectively. While λ and θ represent the scale and rotation parameters, respectively. Meanwhile, t_x and t_y are the shift parameters on the x and y axes, respectively. To extract the movement parameters in equation (3), we overlaid L2 on top of the previous frame (Figure-5). Both of the lines are projected until it crosses each other.



a) Previous frame Blue 'x' is the initial telepointer location. | b) Current frame Blue 'x' indicate the telepointer ground truth.

Figure-4. Green 'x' is the final matched keypoints, which is a neighbour to the initial telepointer location. Noted that, the blue and green lines represent the geometric constraint.

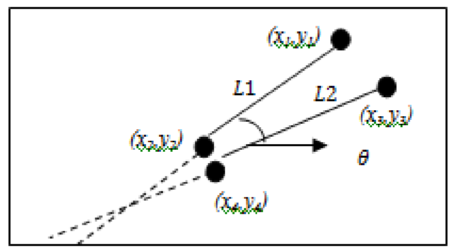


Figure-5. Illustration of overlaid L2 on the top of L1.

After that, the slopes for each line, which are represented by m_{L1} and m_{L2} are calculated? The angle between L1 and L2 are derived from equation (4). While, λ is obtained from geometric constraint calculation where the shift parameters are calculated as in equation (5).

$$\theta = \tan^{-1}\left|\frac{m_{L1} - m_{L2}}{1 + m_{L1} m_{L2}}\right| \quad (4)$$

$$t_x = x_1 - x_3 \text{ and } t_y = y_1 - y_3 \quad (5)$$

Finally, all the known parameters of the movement are inserted into equation (3) to find the new location of telepointer.

B. Delaunay triangulation with line intersection (DT)

DT method is performed by utilizing shape information in the form of geometric triangular. Basically, DT method assumes all the correspondence keypoints as a node in network. The nodes are interconnected to each other by a straight line to produce small triangle regions where the nodes connection must fulfill the Delaunay criterion, which is every circumcircle can only contain one triangle. It cannot contain other triangles or points inside the circle. Keypoints that satisfied the criterion are considered as the best and unique keypoints for object

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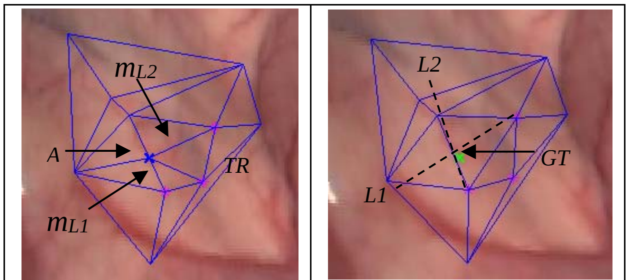
modelling [10]. In this study, only two nearest keypoints from the initial telepointer location (*A*) are chosen as the TR.



a) Previous frame | b) Current frame

Figure-6. Blue 'x' is the initial telepointer location. Magenta '*' is the reference keypoints. Green 'x' indicates the telepointer ground truth.

Then, the new telepointer location can be calculated by using line intersection as shown in Figure-6. Firstly, we derived the line equations for *L1* and *L2* by calculating the slopes, m_{L1} and m_{L2}, where

$$m_{L1} = m'_{L1} \text{ and } m_{L2} = m'_{L2} \tag{6}$$

Secondly, we calculated y-intercepts (c_1 and c_2) for line *L1* and *L2*. Ideally, the intersection will occurr when the coordinate of both lines are at the same location (x_3,y_3). Hence, the new location for the telepointer is obtained by rearranging the line equations for *L1* and *L2* as;

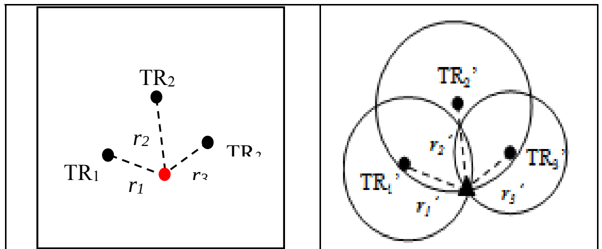
$$m'_{L1}\, x_3 + c_1 = m'_{L2}\, x_3 + c_2 \tag{7}$$

C. The maximum probability keypoint with scale circle intersection (PMAX)

In this study, probability-distance approach is used to measure the similarity degree between two correspondence keypoints. The highest F_{PD} reflects the highest confidence where both keypoints are similar with high reliability to represent the TOB movement accurately. Due to that, *h* pairs of correspondence keypoints are selected as TR. From investigation, it is found that *h* = 4 is enough to represent the TOB movement.

Afterwards, we applied circle intersection to estimate the new telepointer location. Let define r_1, r_2, ... , r_h as the Euclidean distance between TR_1, TR_2, ... , TR_h, respectively with initial telepointer location at the previous frame. Based on the information, *h* circles centered on the correspondence keypoints TR1', TR2' and TR_h' (Figure-7) are drawn at the current frame.

To adapt with various scales, radius $r_{1'}$, $r_{2'}$, ... , $r_{h'}$ are multiplied with scale factor *k*, which is defined as the median of ratio distance between TR keypoints at both current and previous frames. The intersection between *h* circles are considered as the new telepointer location.



a) Previous frame | b) Current frame

Figure-7. An example of circle intersection with *h*=3. Red circle is the initial telepointer location and black triangle indicates the new telepointer estimated location.

SIMULATION RESULTS AND DISCUSSIONS

Data set and ground truth

To evaluate the algorithms performance, each algorithm was tested with five pairs of image that consist of translation, rotation, scaling, liver and heartbeat movements. The images were extracted from publicly available online database of in-vivo endoscopy videos [11]. Each pair contains 20 dummy initial telepointer locations, which is selected randomly. The ground truth has been labelled manually by the researchers.

Performance measurement

The effectiveness of the algorithms is evaluated by using Mean Error Distance (MED), which is defined as;

$$MED = \frac{\sum_{1}^{G} M(x,y) - GT(x,y)}{G} \tag{8}$$

where *M*(*x,y*) is an estimated telepointer location and *GT*(*x,y*) is the ground truth location. *GT* denotes the total numbers of initial telepointer.

RESULTS

The quantitative outputs were compared between the three techniques and the results are shown in Figure-8. Generally, the MED values reflect the precision and accuracy of the telepointer location. The lowest MED value indicates the best telepointer tracking technique.

From the graph, LMS is the worst technique with high value of MED. It is because LMS assumed that tissues and organs move uniformly in the local environments. In fact, the movements are not uniform, even though the movements are quite similar. Therefore, LMS technique failed to represent the actual tissues and organs movement accurately.

The application of DT improves MED where most of the movements have MED value bigger than 10 pixels error. However, the liver movement produced a high MED value which is almost 35 pixels. This is considered as inaccurate because of windows 7 and 8 limitation where the smallest size of cursor is 32x32 pixels [12] [13].

Interestingly, PMAX technique showed drastic improvement to the MED value, with MED less than 10 pixels. Moreover, the translation and scale movements have less than 5 pixels error. This is because the keypoint with the highest probability value has the highest reliability to represent the actual movement of tissues and internal organs.

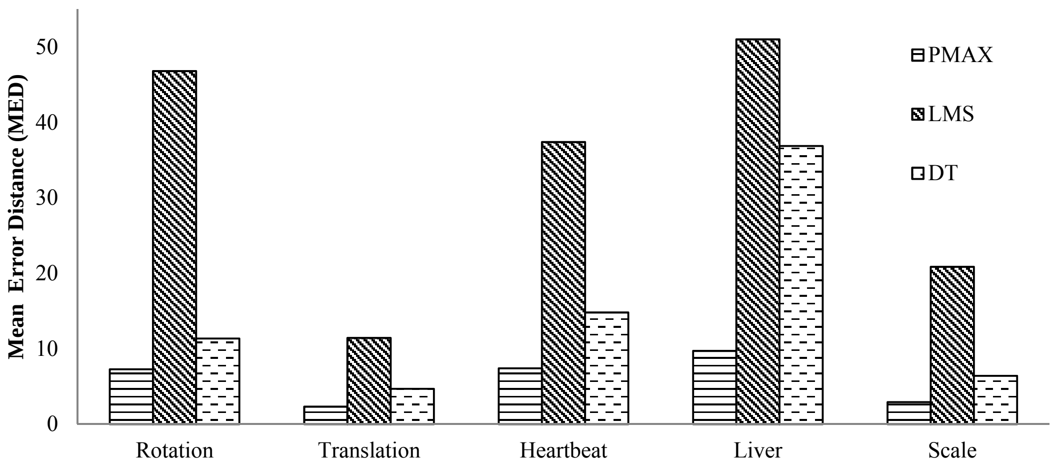


Figure-8. Quantitative comparisons between three telepointer tracking techniques.

CONCLUSIONS

This study was undertaken to evaluate the most appropriate technique for telepointer tracking. In this paper, we have compared three telepointer tracking methods which are LMS, DT and PMAX. PMAX is the best technique for telepointer tracking by producing the lowest MED, followed by DT and LMS. PMAX is a probability-based approach to identify the best observation, which will be applied to circle intersection of various scale radius to estimate the new location. As for future work, a multiple-model can be included [14] so that each region will have its own modelling instead of relying on a single model.

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