Non-radiological Colonoscope Tracking

Image guided Colonoscopy using commercially available Electromagnetic Tracking System

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***Abstract*— A non-radiological method of visualizing the path of a colonoscope using a chain of electromagnetic sensor coils along the biopsy channel of the instrument has been developed. The electromagnetic imaging system has been introduced as an aid to colonoscopy, and reveals a great potential for assisting endoscopists. There is an existing model available on the market by Olympus, ScopeGuide; however, due to cost consideration and other factors concerned, some hospitals may not want to replace existing instruments. This paper discusses about the possibility of using a commercially available electromagnetic tracking system, the Northern Digital Aurora system and presents a simple algorithm employed to find a representation of the colonoscope path. A possibility of reducing the amount of sensor coils used in existing model is also discussed. The visual guidance is expected to provide the user with a sense of assurance, which is often missing in the navigation of colonoscope. The work may be useful in locating the exact position when a lesion is found during the procedure, and to identify a loop when it is formed. It may also be useful as a navigational aid in colonoscopy training and teaching purposes.**

***Keywords*—Conolonoscopy, Electromagnetic Tracking, Surgical Navigation, Image Guided Intervention, Colonoscope Tracking.**

I. INTRODUCTION

It is now widely recognised that colonoscopy is the most commonly used method to investigate suspected colorectal disease and to screen for high-risk individuals [1, 2]. However, studies have shown that colonoscopy remains a technically demanding procedure, which is both difficult to teach and to learn [3]. In performing the procedure, the endoscopist navigates the scope through patient's colon, frequently based on trial-and-error manipulations or based on experience. Loops are invariably formed during colonoscopy, and there are loops in the sigmoid and transverse colon. Further insertion of the instrument into the patient causes the loop to enlarge, which causes pain and achieves no advancement of the instrument tip. The endoscopist needs to pull back the instrument to remove a loop. Lack of full visual guidance during the procedure often is the key bottleneck determining the success of colonoscopy procedure. It causes difficulty in detecting looping due to stiffness of the instrument. [4] The endoscopist occasionally must rely on guesswork. Sedatives are given to patients to reduce physical pain during the procedure due to the uncomfortable nature of the procedure, Risk of perforation may also occur due to mechanical stresses of the colonoscope [5]. Unnecessary trauma can be avoided with the development of a navigational aid.

The use of fluoroscopy has been a common practise in acquiring two-dimensional static images for colonoscopy guidance and to aid in learning of colonoscope intubation techniques. However, exposure to excessive radiation poses a high health risk. Recent developments have shown the advantages of non-radiological techniques for navigation during the procedure [6, 7]. As well electromagnetic approaches have demonstrated a huge potential in surgical navigational field. The application of electromagnetic tracking techniques avoids the 'line-of-sight' problem known in optical tracking, and allows tracking in human body; however, electromagnetic distortions may occur due to metallic objects. Since the visualization of the path of the instrument does not require high accuracy, this technique is preferred.

Research has shown that a set of three generator coils and a series of 15 sensor coils positioned at 12cm intervals along the length of catheter that is inserted down the biopsy channel have been used to display three-dimensional images for navigation [6]. An electromagnetic imager is currently commercially available; 12 sensor coils are embedded into the colonoscope tube along the accessory channel, signals are detected and processed to display a continuous, real time image of the colonoscope [8]. However, rather than replacing or modifying the instruments available in the hospital to a new system, hospitals may prefer a commercially available tracking system that is able to adapt to the current instruments that they are using.

In order to visual and provide guidance in loop removal, the entire path of the colonoscope must be known and a three-dimensional display is required since the loops are formed in three dimensions. The work involves creating a 3D display of shape of scope used in colonoscopy for instrument path tracking, by making use of a commercially available tracking system. It is to facilitate training exercises and aid in visualization during colonoscopy procedures.

II. METHODS

A. *Hardware*

The Aurora electromagnetic tracking system, Northern Digital Inc. is used to produce electromagnetic fields with working volume of 500x500x500mm³. These fields are detected by sensor coil(s) that is inserted down the biopsy channel of the colonoscope. A 5DOF sensor coil is available in size of 8mm x 0.55mm (length x diameter). It is embedded in a flexible chord with 2.3mm diameter.

Commonly used colonoscopes are coming with a dimension of 168cm x 3.2mm (tube length x diameter of biopsy channel). A catheter surrounded with metal coil and polymer coating with a through channel is used as a phantom to simulate the biopsy channel of the colonoscope.

B. *Software*

Matlab (The MathWorks Inc. Natick, MA. USA) is employed in the study to perform numerical computations with matrices and vectors, to load and read data collected, to display information graphically and to provide graphical user interface.

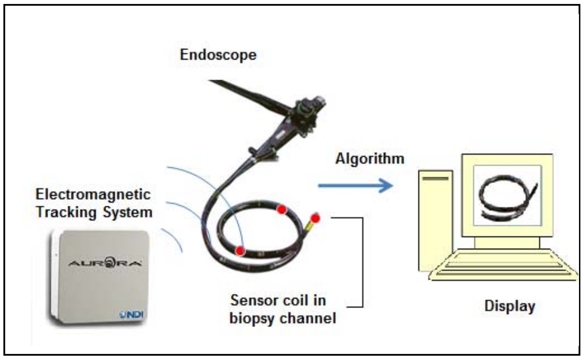

Fig.1: Schematic overview of the Colonoscope Tracking.

C. *Denavit-Hartenberg Local Frames*

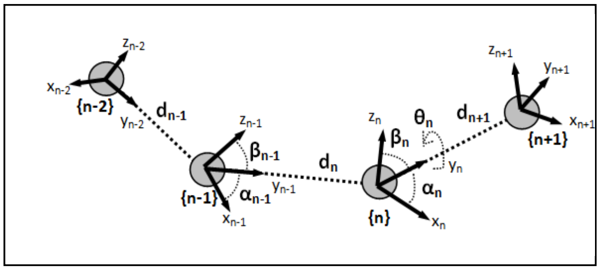

Fig. 2: Points at a pre-defined interval is used to describe the position in terms of the coordinate frame centered at point n-1, two rotations and a translation are composed.

The data points collected at certain interval are modeled using the Denavit-Hartenberg method. For simplicity, the endoscope is modeled as a serial linkage composed of consecutive backbone data points, as shown in Figure 1. The standard Denavit-Hartenberg notation was used to define the location and orientation of joint axes.

joint	**α**	**β**	**θ**	**d**
n-2	α_{n-2}	β_{n-2}	N.A.	d_{n-2}
n-1	α_{n-1}	β_{n-1}	N.A.	d_{n-1}
n	α_n	β_n	N.A.	d_n
n+1	α_{n+1}	β_{n+1}	N.A.	d_{n+1}

Table1: Summary of joints, rotation and translation

A 5DOF sensor coil is used. Translation is computed with Euclidean distance between two consecutive points (x_{n-1}& x_n, y_{n-1}& y_n, z_{n-1}& z_n), which is denoted as d. Angle between x_{n-1} and x_n (rotation about z-axis) is denoted as α_n. Angle between y_{n-1} and y_n (rotation about x-axis) is denoted as β_n. Angle between z_{n-1} and z_n (rotation about y-axis) is not considered as the sensor coil is only of five degree of freedoms.

Translation is only along y-axis for every two consecutive point, which is the Euclidean distance between the two points, i.e. $\sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2 + (z_n - z_{n-1})^2}$.

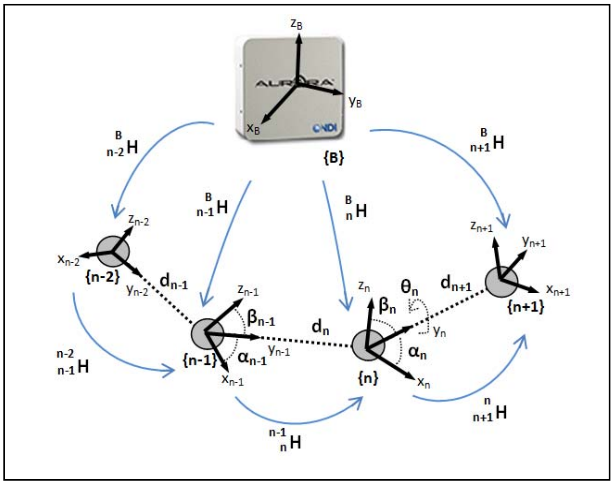

Fig. 3: Homogenous Transformation

$$ {}^{B}_{n+1}H = {}^{B}_{n-2}H \cdot {}^{n-2}_{n-1}H \cdot {}^{n-1}_{n}H \cdot {}^{n}_{n+1}H $$

$$ {}^{B}_{n+1}H = {}^{B}_{n}H \cdot {}^{n}_{n+1}H $$

$$ {}^{n}_{n+1}H = {}^{B}_{n}H^{-1} \cdot {}^{B}_{n+1}H $$

$$ {}^{B}_{n}H = {}^{B}_{n-1}H \cdot {}^{n-1}_{n}H $$

$$ {}^{n-1}_{n}H = {}^{B}_{n-1}H^{-1} \cdot {}^{B}_{n}H $$

$$ {}^{B}_{n-1}H = {}^{B}_{n-2}H \cdot {}^{n-2}_{n-1}H $$

$$ {}^{n-2}_{n-1}H = {}^{B}_{n-2}H^{-1} \cdot {}^{B}_{n-1}H $$

The relationships between each point with reference to the base (Electromagnetic tracking system) and between points with reference to each other are established using Denavit-Hartenberg notation. The interval between points, which is denoted as Euclidean distance can be determined by the number of data frames captured continuously or the user-defined flex-chord insertion interval length.

III. ALGORITHMS

By using a single sensor, two different methods can be employed in capturing data; a continuous method, capturing the data frames continuously depending on the pre-set frame rate, or capturing point by point at predetermined interval, upon completion of flex-chord insertion segment by segment.

A. Data Collection at pre-defined interval

Flexcord with the 5DOF sensor coil embedded is inserted into the channel of the phantom, data including position(x, y & z) and orientation (Quarternion format or Euler format) are collected at a pre-defined interval.

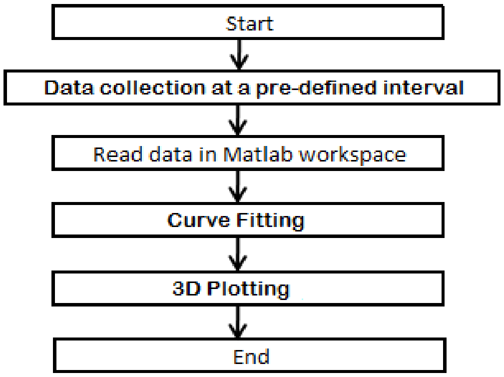

Fig.4 : Flowchart of single sensor insertion method with a pre-defined interval.

Data obtained is in CSV(Comma Separated Value) formatted text file, each line in the text file corresponds to a row in the table. Within a line, there are fields separated by commas, each field corresponds to a table column. Data are collected at a pre-defined interval along the arc length of the instrument; this method is using segment approximation, assuming the Euclidean distance between 2 points is equivalent to the pre-defined interval (arc length). The Euclidean distance is measured to compare with the length of the curve in order to find an optimum interval to minimize the error.

Parametric cubic fitting is used to generate curves using an interval of 50mm and 100mm. The parametric cubic fitting method is only an approximation method, especially as the assumption of equating Euclidean distance with arc length may not be valid. However, due to the mechanical constraint of the instrument and by selecting the optimum interval, accurate results may be reproduced (refer to Fig. 5a & 5b).

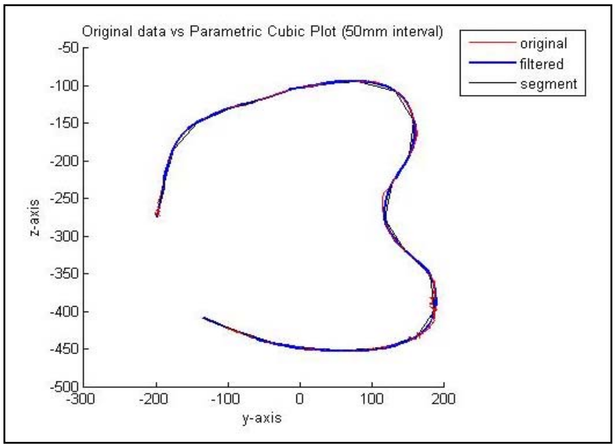

Fig. 5a: Comparison of continuous data with parametric cubic fitted data at 50mm intervals.

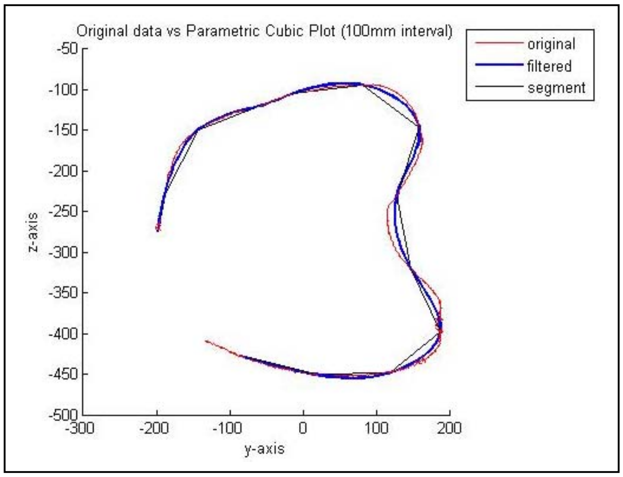

Fig. 5b: Comparison of continuous data with parametric cubic fitted data at 100mm intervals.

B. Continuous Data Collection

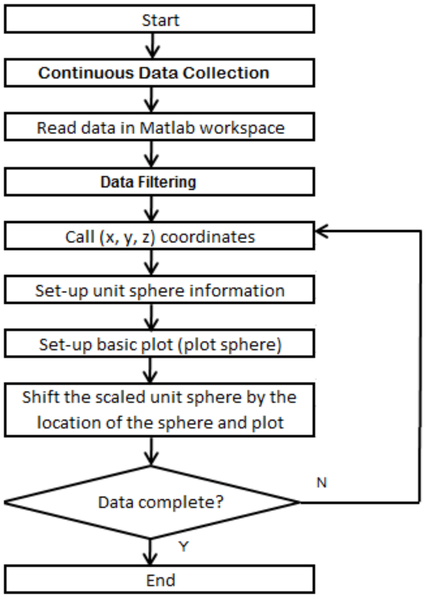

Fig. 6: Flowchart of single sensor continuous insertion method.

Frame data are collected throughout the insertion path. While the Flexcord is inserted into the channel of the phantom, measurements are obtained continuously. Data is smoothened using a moving average filter.

The 3D display is presented by creating a sphere at each measurement. By setting up unit sphere information using a Matlab program written to plot and display the path travelled in 3D. The spherical plot is chosen to create multiple spheres as orientation (rotation information) is not critical in sphere plotting.

Every sphere is plotted based on the coordinates (x, y, z) collected as center point. The number of sphere faces, color map, radius and shading information are determined to construct a 3D solid display of the path travelled by the 5DOF Flexcord via a hollow tube simulating the shape of colonoscope catheter. The 3D solid tube effect is generated by a continuous plot of a sphere followed by shifting the scaled unit sphere to the next location of sphere and plot. Common colon layouts and loops are simulated for 3D shape tracking.

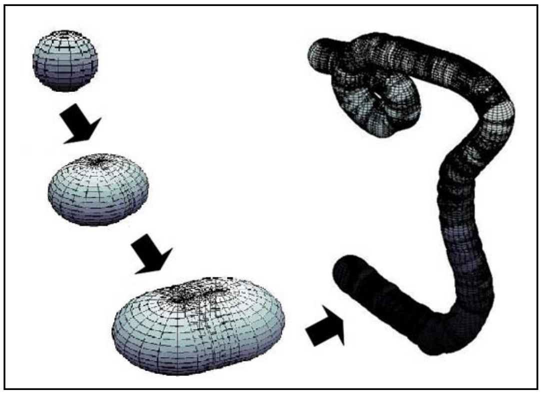

Fig. 7: Progress of 3D shape rendering of the instrument based on the chronicle of its travelling path. The sphere function is used to generate a sphere at the coordinates recorded at each frame to provide a 3D image of the instrument.

C. Comparison between two algorithms

Both algorithms required interruption of the colonoscopy procedure for data collection and 3D image generation. However, the continuous algorithm is relatively faster compared to the data collection at a certain interval. More time is required for the Flexcord insertion process, whereby the endoscopist needs to pause and collect data at every interval travelled by the flex chord. The continuous method does not disturb the continuous insertion process of Flexcord by interrupting data capturing. The data frames are collected throughout, and hence it is relatively faster.

IV. EXPERIMENT SET-UP

A. Experiment

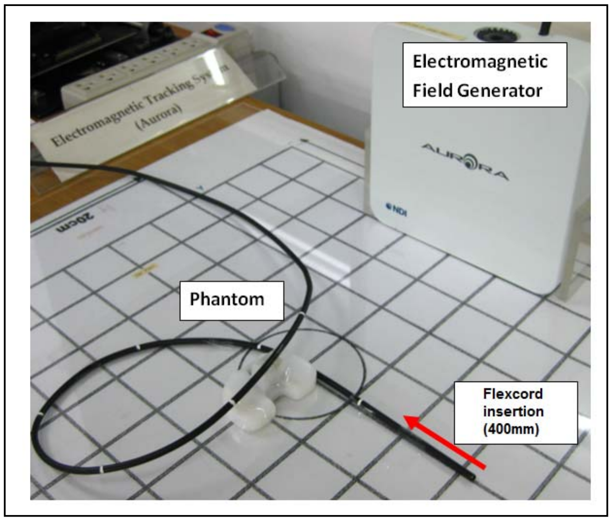

Fig. 8: Experiment set-up to simulate intubation process with different loops formation

Experiments were performed to show the 3D display of the instrument based on the continuous single sensor insertion algorithm. A phantom was used to simulate 4 examples of common loops formed [9] during the intubation process, namely Alpha loop, Deep Transverse loop, Gamma loop and Spiral loop.

The phantom is placed within the work space of the electromagnetic field. The field generator of the system generates the required electromagnetic fields. The Flexcord equipped with a sensor coil is inserted into the channel of the phantom. When the sensor coil in the electromagnetic field produces a small current, position and orientation of the sensor coil is tracked and recorded. The objective is to track the shape of the simulated loop. The data collected are filtered and displayed in 3D.

B. *Results*

The filtered data filtered are plotted in a 3D work space; the displays are compared with the simulated loops as shown in Fig. 10. The obtained data are later used for a 3D image plotting based on the above discussed spherical method.

The box plots shown in Fig. 9, depict the error distribution: the lower boundary (25th percentile) to upper boundary (75th percentile) of each box, shown in red. The range is indicating a good signal to noise ratio. The medians (50th percentile) of the data are almost constant throughout the tested case. The medians value of approximately zero is an indication of an unbiased visualization, confirming that most of the smoothened data do not deviate much from the original data. This measure provides a rough indication of the tendency of filtered data bias from the original data, which in this case is unbiased.

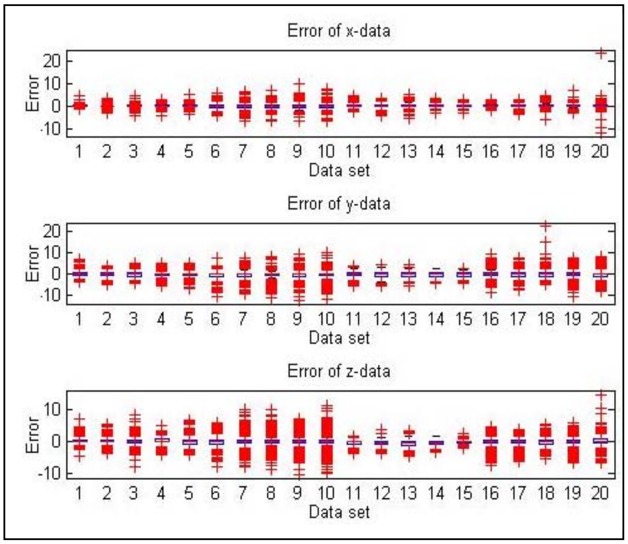

Fig. 9: Box plots of error measured between original and filtered data indicating a good signal-to-noise ratio

Results as shown in Fig. 11 present a clear visualization of the shape of the loops. A 3D display or a planar display can be selected for image guidance.

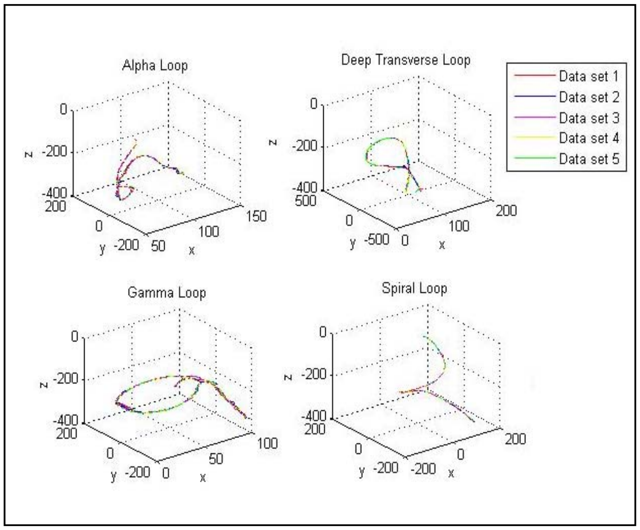

Fig.10: Data are collected based on loops simulated shows consistency of the results

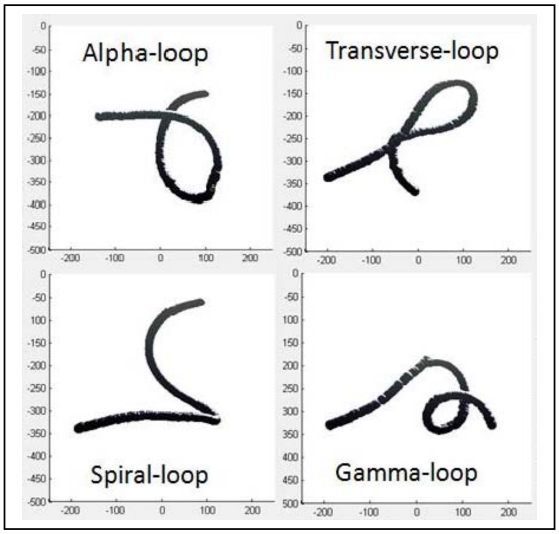

Fig. 11: 3D Display presents a clear visual guidance showing shape of simulated loops represented by gray shading.

V. DISCUSSION

Current work discussed here requires an interruption of the procedure for data collection and the method is not operational in real-time. Previous research [6&7] utilized 15 sensors to provide a real-time display. There is a limitation of 8 sensors (4 ports with accommodation of 2 sensor coils each) that can be detected with the electromagnetic system used. The dimension of the biopsy channel appears to be another constraint in accommodating large amount of sensors. The possibility of reducing the number of sensors should be explored; the algorithm to predict the transformation between 2 frames with a large interval should be explored to use minimal sensors for real-time navigation. This may be an improvement to current endoscope navigation systems available in the market.

The work space constraint of the electromagnetic system can be utilized to provide information about the sensor location. An additional sensor may be embedded at the tip of the instrument to provide information about its location. The distance from the field generator to the patient can be used as parameter to mark and construct a virtual grid. The indication of the sensor at the tip can be visualized and located once any lesions or abnormalities are detected by the camera at the instrument tip.

VI. CONCLUSION

Colonoscopy has become an important screening procedure for colorectal cancer investigation and the demand for it continues to grow. Learning and teaching has always been a difficult process for both trainers and trainees [3] due to lack of visualization of the instrument. Loops tend to form during the procedure, and detection of loop formation and information on the shape of loop formed may provide guidance for endoscopists in loop removal, in order to complete the procedure.

Limited visualization at the tip of the instrument presents another concern in determining the exact location of the tip within the human body. Upon detection of a lesion or abnormalities in the colon, it would be useful to provide information on the location of lesion or abnormalities found, which helps the endoscopist to determine where the problem is located accurately.

Conventional methods of utilizing Fluoroscopy present a radiation risk to both patient and endoscopist. Currently available endoscope navigation systems are considerable cost factors and some hospitals may be reluctant in recruit this expensive solution.

By using a commercially available electromagnetic tracking system, with a sensor coil inserted through the biopsy channel to track the path of the instrument seems to be an economical solution to this issue. It can be adapted to use in parallel with existing colonoscopes available in the hospital without any modification. Matlab program is used to provide a Graphical User Interface for the ease of users.

The work discussed here is able to present information of loops formed in a 3D graphical display. This information may be useful for teaching and training of colonoscopy. Information about loops can be communicated using visual methods. Upon detection of the type of loop formed, correct measures may be applied to remove the loop without having to guess or working blindly. This may reduce unnecessary pain caused to the patient due to force exerted when the loop is further enlarged.

Bending that may increase the possibility in damaging the instrument can be avoided by the ability to visualize the instrument path. Possibility of perforation caused by a damaged instrument may be reduced, unnecessary trauma can be avoided.

ACKNOWLEDGMENT

This work was supported by BART LAB, Faculty of Engineering, Mahidol University, Thailand.

The author would like to thank Prof. Dr. Jackrit Suthakorn for his patience and valuable advices on the work, and the team of Bart Lab for the facilities and the help rendered throughout the work.

The author would like to thank Prof. Dr. Knut Möller for his advices.

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