Validation of a 3D computerised method for accurately measuring insertion depth of different sections of the colon during flexible endoscopy

[1]Rowland RS, [2]Bell GD, [3]Dogramadzi S, [3]Allen C

[1]RMR Systems Limited, Kirton, Suffolk, [2]Faculty of Medical Sciences, Sunderland University, [3]Dept of Electrical and Electronic Engineering, Newcastle University

Summary

The 'Bladen system', first described in 1993, is a non-radiological method of imaging the path of an endoscope using magnetic fields. We recently reported a new computer system (the 'RMR system') in which a more realistic endoscope could be produced using stored data from the Bladen system (Rowland and Bell 1998).

In this presentation we validate refinements to the RMR system which permit us to measure not only the total depth of insertion but the approximate length of any section of the large intestine during colonoscopy or flexible sigmoidoscopy to an accuracy of 0.5 cm. The analysis of data captured during examinations of the colon using a variety of endoscopes should aid the design, manufacture and testing of instruments which cause less discomfort and are easier to use.

Introduction

Our group have been using a non-radiological method for real time 3D imaging of the path of the endoscope around the colon for the last 6 years (Bladen et al., 1993, Saunders et al., 1995, Williams et al., 1997). The 'RMR system' (Figure 1) is a new method for the computerised imaging of the endoscope (Rowland and Bell 1998) using data stored by the Bladen system (Bladen et al., 1993). We have made further improvements to the system which include the facility to measure the length of any segment of either a colonoscope or a flexible sigmoidoscope as it is passed around the patient's bowel.

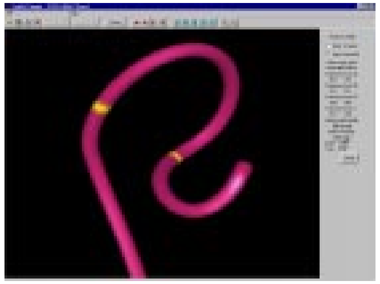

Figure 1 - The RMR System

Methods and results

Endoscope representation

As previously described (Rowland and Bell 1998), the data defining the shape of the endoscope is a series of 3D coordinates - the positions of the sensors - together with orientation angles and a list of actual distances between these sensors measuring along the endoscope itself. Taking consecutive sensors and the known distance between them, the coordinates and orientation of each are fed to an algorithm which returns an arbitrary number of straight-line segments that may be joined to approximate a curve. A wireframe model is initially built up in this way by drawing lines joining the calculated vertices of each segment. The methods used to determine lengths rely on the interactive selection and analysis of these vertices.

Anatomical position

When an image file is first loaded, the 3D coordinates of three marker positions are read from the data file. These represent the positions of fixed points on the patient and are used for reference. Markers 1, 2 and 3 approximate the positions of the splenic flexure, hepatic flexure and anus respectively.

Distance calculation

As noted above, distances may be calculated in two ways –

- Straight line distance between any two points on the instrument and/or reference markers
- The distance between two points on the instrument measuring along the instrument itself

In the former case, a simple algorithm is used to calculate the straight line distance between two points based on their coordinates. Distances between two points measuring along the instrument itself are calculated as follows:

The data includes the relative spacing (in cm) of all sensors. From this data, the absolute distance of each sensor from the instrument tip may be determined. Suppose, for sensors *1..n* that these absolute distances are $d_1, d_2 \ldots d_n$ etc. The model calculation algorithm previously described (Rowland and Bell 1998) produces an arbitrary number (m) of straight-line segments approximating the curve following the instrument path between two adjacent sensors, say a and b (in the current version of the system, m=20). The approximate length, l, in centimetres of each straight line segment between sensors a and b is then given by

$$l = (d_b - d_a) / m$$

When an image is displayed for length calculation, the position of the operator's mouse-clicks on the instrument are interpreted to identify the corresponding straight-line segment vertices. Using the above calculation, we can obtain the approximate path length between the two points.

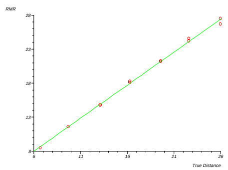

Figure 2 - Correlation between true and estimated distance, markers 1 & 2

Validation of distance calculation

To validate the combined accuracy of the Bladen imager and the RMR graphics system, the following series of experiments was carried out.

Straight line distance validation

The correlation between true experimentally measured distances and those estimated by the above system between markers 1 and 2 is shown in Figure 2 while that for between either markers 2 and 3 or 3 and 1 are shown in Figure 3.

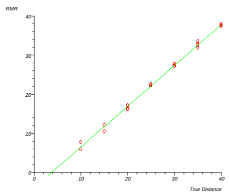

Figure 3 - Correlation between true and estimated distance, markers 1 &3, 2 & 3

Validation of insertion depth

A model colon had a transparent plastic cannular inserted so that the magnetic sensor catheter could be passed up it and hence into the model colon for a varying distance. The catheters used in the imaging system all have 12 sensors. Starting at the catheter tip, the distances between the sensors were 5, 7.5, 10, 12.5, 12.5, 15, 15, 15, 15, 15, and 15 cms respectively. With the Bladen system running, the sensor catheter was gradually inserted into the model colon. Ten readings were taken as each sensor passed marker number 3 at the colon model's anus. Duplicate readings were obtained by repeating the measuring as the fully inserted catheter was withdrawn. The excellent correlation between the true and estimated distances from the anus to the tip of the catheter are shown in Figure 4.

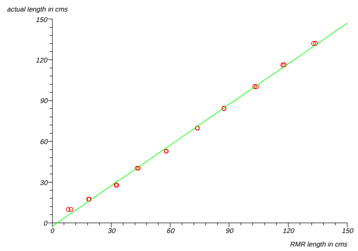

Figure 4 - Correlation between true and calculated insertion depth

Validation of distance between any two points

We used the same positional data files to measure the distance from the last visible sensor inside the colon model to the catheter tip and correlated this with the known true distances between the relevant sensors during the insertion and withdrawal phase. An almost perfect correlation was obtained as shown in Figure 5. Finally, although for convenience we opted to select the actual sensor positions for our correlation experiment, we confirmed that as there were, in this case, 20 possible vertices to select between each sensor we could easily and reproducibly measure any distance along the endoscope to an accuracy of 0.25, 0.375, 0.5, 0.625 or 0.75 cms depending on the actual distance between the sensors. This arbitrary figure of 20 subdivisions could easily be tailored within the RMR system to give greater precision.

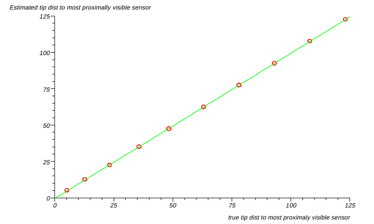

Figure 5 - Correlation between true and calculated distance between the tip of sensor catheter and most proximally visible sensor inside colon model

Discussion

The experiments confirm the accuracy of the system in terms of measuring distances between fixed markers as well as the insertion length of the chain of sensors along the sensor catheter. The exciting new finding is the capacity to accurately measure in 3D the exact length of any section of the endoscope by simply clicking on the desired segment with the mouse. We have several hundred stored files of previous colonoscopies and flexible sigmoidoscopies and over the next year it is our intention to interrogate this data with the RMR system. We are currently, inter alia, looking at differences between male and female patients, the effect on bowel length of using a stiffening overtube, and the comparative performance of different instruments. The present system will allow up to 15 sensors whereas we are currently only using a chain of 12. We are now working on methods of producing even smaller sensors, which if placed closer together in the distal bending segment of the endoscope, would also allow accurate estimation of the angle of tip deflection.

References

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