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Real-time Quality Feedback System for Screening Colonoscopy

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Real-time Quality Feedback System for Screening Colonoscopy

by

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A THESIS
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Abstract

Colonoscopy is the gold standard method for the diagnosis of colorectal cancer and the identification of precancerous polyps. Unfortunately, there is not yet a metric (formally recommended by consensus guidelines) for the quantification of colonoscopy quality. Though, there are established quality indicators such as the bowel preparation and the withdrawal time; fast withdrawal time is highly correlated with adenoma detection rate. Current metric tools for these parameters are not objective. This limitation leads to the formalization of the present study, which focuses on the development of a real-time, novel colonoscopy evaluation system and the assessment of its clinical efficacy. The proposed tool consists of an embedded system that can automatically measure: a) the quantity of stool and waste matter existing within the patient during a colonoscopy procedure; b) withdrawal velocity; c) image clarity; and d) determination of colonoscope direction and traveling distance. The proposed method can be used to create practice standards for colonoscopy training, or as part of medical skill evaluation.

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List of Abbreviations and Annotations

ACG	American College of Gastroenterology
ASGE	American Society for Gastrointestinal Endoscopy
BBPS	Boston Bowel Preparation Scale
CMA	Canadian Medical Association
CMS	Centers for Medicare and Medicaid Services
CRC	Colorectal Cancer
CSPY	Colonoscopy
DCM	Dolling Camera Motion
GIQuIC	GI Quality Improvement Consortium
HSV	Hue-Saturation-Value
OBPS	Ottawa Bowel Preparation Scale
PQRS	Physician Quality Reporting System
RGB	Red-Green-Blue
STS	Side-to-side

1. Introduction

1.1 Colorectal cancer

The colon or large intestine is the lower part of the digestive system and the rectum is the last part of the colon. When cancer occurs either in a portion of the colon or in the rectum itself, it is generally termed as Colorectal Cancer (CRC) [1].

Every year, more than one million people in the world are diagnosed with CRC. The risk of getting CRC during lifetime is quite high at around 5.1% [2]; thus, this disorder is a major cause of mortality worldwide [3]. Specifically in the USA, CRC represents 10% of cancer deaths; though at a disproportionately higher rate for men than for women. In the USA, 50,830 colorectal cancer-related deaths have been predicted for 2013 [2]. This makes it the second most common cancer in America [4]. Fig. 1 shows CRC incidence in the USA comparatively with other types of cancer.

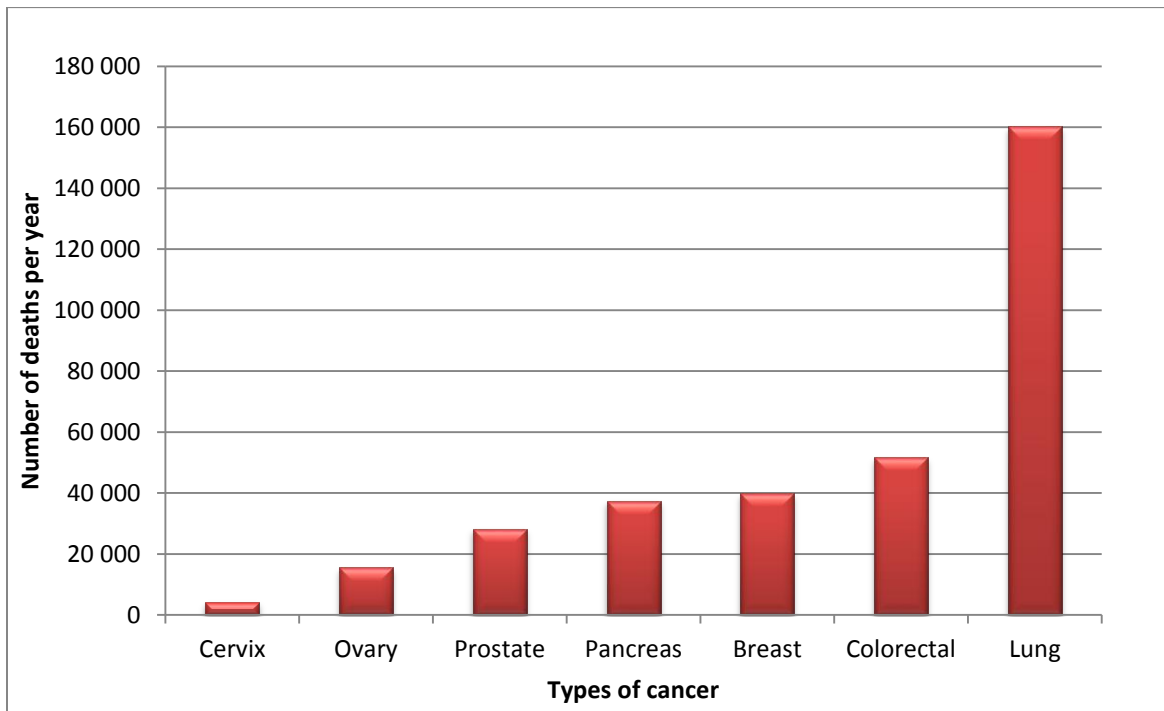


Fig. 1 Cancer mortality in the USA per year [5]

Fortunately, the early detection and treatment through colonoscopy (CSPY) has helped to slowly decrease the number of new cases during the last decade, as reported in early 2007 by the American Cancer Society [4]. The impact of CRC early detection relies on the fact that patients that are diagnosed and treated at the onset of the disease have a 90% better chance to survive after five years than if diagnosed later on. Unfortunately, early CRC diagnosis accounts for just 40% of all CRC cases [4]. For this reason some organizations have been making efforts to better regulate the use of CSPY.

1.2 Colonoscopy as the golden standard for early polyp detection and removal

CSPY is a procedure that allows real-time visualization of the interior of the colon. Additionally, it enables polypectomy (removal of polyps), tissue biopsy and the usage of instruments that can be inserted through the colonoscope [6].

The colonoscope is a flexible tube with a small camera on the tip which transmits a video image from inside the large intestine to a monitor, thus allowing a careful viewing of the colon [7]. During the procedure, the colonoscope is inserted through the anus and gradually maneuvered through the colon.

CSPY can assist doctors in diagnosing a variety of diseases in the colon, from bleeding and ulcers to cancer [8]. More importantly, CSPY is the most effective imaging tool for the early recognition of adenomatous polyps, which are precursors to CRC and is now considered the “gold standard” method of screening for CRC [9].

Currently, regardless of the implementation of sophisticated technology in colonoscopy devices, omission of big polyps and cancers still occurs [10]. Contemporary sensitivity of colonoscopy for detecting polyps of a size larger than 10 mm is 98% [10]. However, there is a miss rate between 15-20% for polyps smaller than 10 mm [11]. For this reason, there is an

ongoing quest for getting best practice standards for this procedure that can help to lower adenomas and neoplastic lesions miss rate.

1.3 The need for quality assessment

According to the American Society for Gastrointestinal Endoscopy (ASGE), upon reaching 50 years old it is advisable for all people to have a colonoscopy, with follow-up tests to be conducted every 10 years, as well [12]. However, if a family member has suffered from colon cancer before, patients should take additional actions, like beginning screening colonoscopy before 50 and having follow-up screenings periodically [12]. Consequently, CSPY has become one of the most common lower digestive tract procedures performed in the United States [7], with approximately 4 million colonoscopies conducted yearly [4].

In clinical practice, CSPY performance is highly variable. Some research studies have highlighted several important drawbacks in CSPY accuracy [13]. It has been also reported that if CSPY could be adequately conducted, it would help to significantly decrease CRC incidence [14].

CSPY effectiveness involves the ability to detect and extract all neoplastic lesions within the colon [13]. However, some limitations to achieve this goal are the inability to reliably intubate the cecum, rapid withdrawal times, and poor bowel preparation [15-17].

The ASGE and the American College of Gastroenterology (ACG) have published guidelines on quality indicators for CSPY procedures [18]. Nevertheless, many indicators cannot be standardized currently as they are too operator-dependent [19-21]. For instance: the documentation of bowel preparation, adenoma detection rate in asymptomatic patients and an average withdrawal time of 6 minutes in procedures with no polypectomy.

1.3.1 Withdrawal time

In the withdrawal phase, the colonoscope is gradually withdrawn while the endoscopist moves the camera from side to side, and often back and forth to completely examine the colorectal mucosa. Fast withdrawal time is closely related to diagnosis uncertainty in some segments of the colon, for example while exploring difficult to access areas of the organ [22]. It has been concluded that withdrawal time is strongly linked to adenomas detection rate [23]. Endoscopists who spend more than 6 minutes for withdrawal have a significantly higher chance to detect adenomas. Unfortunately, just 50% of the endoscopists adhere to such timing [23]. However, withdrawal time is not the only indicator for adenoma detection, individual colonoscope withdrawal technique can influence the adenoma detection rate as well [19].

1.3.2 Forward-backward and side-to-side movements

The ideal screening colonoscopy obtains a clear visualization of the complete colon. However, the interior surface of the colon (called the lumen) is topographically complex, with numerous folds (hastra) and turns (flexures). Since the field of view of a typical colonoscope camera is 140 degrees, simply pulling the scope back through the colon will be inadequate to visualize the lumen in its entirety. Thus, side-to-side (STS) and forward and backward movements are required to look behind folds and occasionally retrace steps to look again in places where an adequate view was not obtained. These movements could be an indicator for adenoma detection, since the repetition of these movements might imply that the endoscopist is trying to scope difficult areas within the colon folds [24], which are potential areas where polyps could be missed. Consequently, detection rates might be enhanced by an increased ability to visualize areas behind flexures and folds.

In addition, recent Canadian research studies suggested that while CSPY helps to detect cancer in the left side of the organ, it does not present outstanding results for the right side of the colon, presumably due to hidden adenomas omission [25].

a. Disparity on the detection of right-sided vs. left-sided colonic adenomas

Colonoscopy has been projected as a tool that can help to the reduction of CRC and in consequence of its mortality rate. In order to help on the CRC mortality decrement, colonoscopy serves as an instrument for the detection and extraction of adenomatous polyps, from which most CRC is formed [26]. Recently, some studies have questioned the effectiveness of colonoscopy to prevent CRC on the proximal side of the colon [27]. Comparatively, colonoscopy can prevent 85% of CRC occurrence in the distal (left) side, whereas on the proximal (right) colon the prevention rate is lower, around 56% [27-29].

Several factors have been implicated in the low detection rate of the right-sided CRC. It could be due to poor bowel preparation, or to a low quality in the colonoscopy test, especially since many colonoscopies may not reach the cecum due to tortuosity of the colon, patient discomfort, or incompetence of the endoscopist [30]. On the other hand, it can be suggested that polyps on the right side could have particular molecular features such as rapid cancer propagation whereby cancers may arise in flat lesions or smaller polyps than in the left colon [30, 31].

Cancer in the proximal colon has 3 times more chances to be found in small lesions in comparison to lesions in the distal side of the colon [32, 33]. Evidently, small polyps have a tendency to be located in the proximal side rather than in the distal part of the colon as denoted in Fig. 2. Interestingly enough, most post-colonoscopy cancers are found in this section of the colon as well [32, 34]. Therefore, the lack of scrutiny during colonoscopy to find small polyps

could link quality aspects of colonoscopy with a biological reason to offer an overall explanation for the higher polyp miss rate in the right colon.



Fig. 2 Differences in size and morphology between the carcinoma lesions found in different sections of the colon. On the proximal side of the colon, lesions tend to be nonpolypoid and diminutive compared to the distal side [34]

Between 3.3% - 12.4% cancerous polyps on the proximal side of the colon are found a short time after a colonoscopy [35-37]. Then, small/nonpolypoid advanced adenomas that were missed during colonoscopy can progress to cancer in the future [34, 38, 39]. Fig. 3 shows examples of colorectal neoplasms that can be easily missed during colonoscopy either because of their small size or flat appearance.

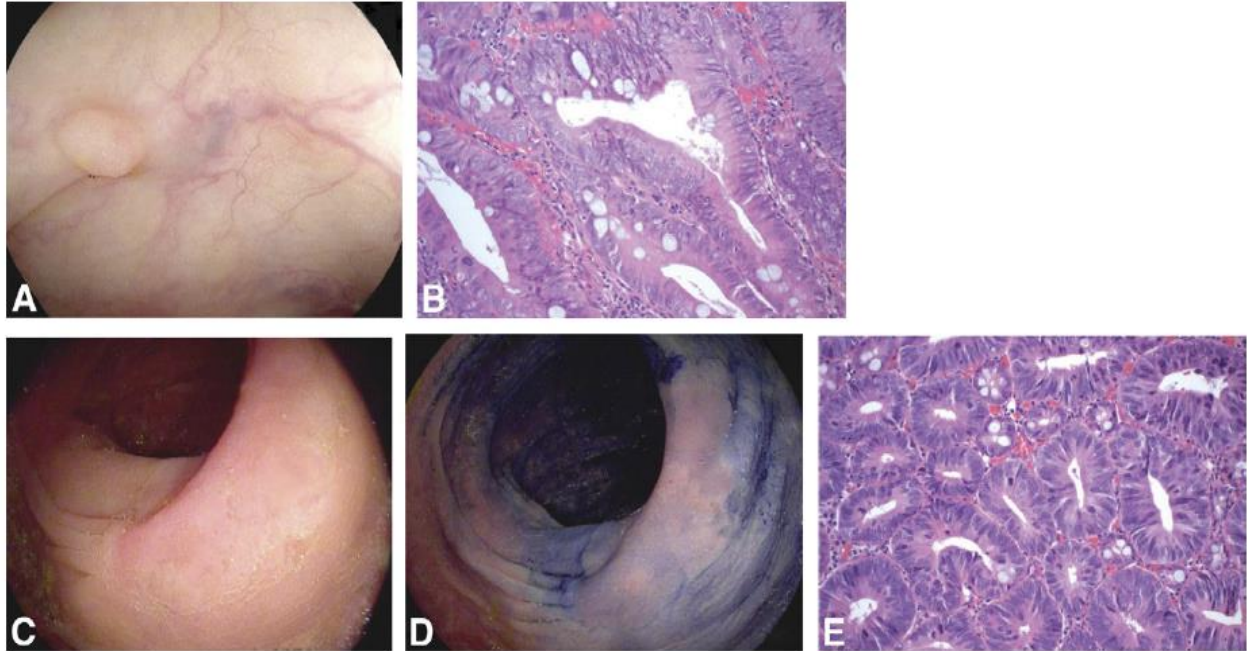


Fig. 3 Nonpolypoid and small polyps are more commonly located in the right side of the colon. (A) Small polyp in the right colon. (B) Histological analysis of polyp “(A)” shows advanced dysplasia. (C) A nonpolypoid lesion in the transverse colon. (D) Lesion “(C)” has been highlighted by chromoendoscopy. (E) Analysis results of lesion “(C)” reports a carcinoma in situ [34]

On the other hand, it can be presumed that the probability of small lesions to turn into carcinogenic adenomas is relatively small. Research articles have reported a percentage ranging between 1.1% to 3.5% [34, 40, 41]. Nevertheless, since most of the colorectal cancer polyps are small, this percentage shouldn't be ignored, as it accounts for approximately 28% of all high-grade dysplasia and cancerous lesions [42].

Most proximal adenomas with early CRC are minuscule or nonpolypoid [40]. Colorectal neoplasms are more difficult to detect during a colonoscopy test when they are very small or they have a nonpolypoid shape; this feature may explain the difference in colorectal neoplasm detection between the proximal and the distal colon [34]. Additional factors such as low

adenoma detection rate by the endoscopist, and inadequate bowel preparation can hinder the detection of adenomas even more [43]. Thus, it is recommendable that endoscopists pay special attention to small polyps on the right side of the colon, and to come up with further improvements on the colonoscopy technique.

The occurrence of CRC after screening colonoscopy is related to the endoscopist's adenoma detection rate, as reported by Kaminski et al. [44]. An inadequate inspection of the mucosa can easily lead to missed nonpolypoid or small lesions, especially because of their subtle appearance. Consequently, it is suggested that endoscopist skills on small and nonpolypoid lesions detection can be improved by colonoscopy training programs. The detection rate among endoscopists reaches as high as 37% [45-47], hence, comprehensive training and educational programs might help to regulate colonoscopy practice and improve the adenoma detection rate by endoscopist [34].

b. Retroflexion

Since the field of view of the colonoscope is typically 140° , polyps may be missed in areas where the scope cannot be moved side to side to visualize. The distal rectum is one such area in particular. In the rectum, at the end of the screening colonoscopy, a retroflexion maneuver is recommended. This involves turning the tip of the scope 180° to view towards the anus from the proximal rectum (Fig. 4). Retroflexion in other areas has been proposed, such as behind colon folds [48] and in the cecum [49], however since the colon wall is thinner outside the rectum the risk of perforation is higher, and thus retroflexion outside the rectum is not routinely performed in screening situations.



Fig. 4 Retroflexion in the rectum. The colonoscope tip is looped into a J-shape, showing the distal rectum and the scope as it enters the rectum [48]

1.3.3 Bowel preparation

On the other hand, bowel preparation is a very important stage in the colonoscopy procedure and it highly affects CRC screening, cleaning the colon walls from fecal matter for optimal visualization [50]. When bowel preparation is poor it inhibits the detection of small and large polyps. In such situations, clinicians often clean unclear sections of the colon using the water source that is embedded in the colonoscopy system. Thus, poor preparation is one of the biggest obstacles to colonoscopy effectiveness. Fig. 5 demonstrates a clean colon (left) in comparison to colonic segments with poor bowel preparation (middle and right). In the poorly prepared colon, small or even moderately sized polyps can be obscured by stool and turbid fluid.



Fig. 5 Left: Bowel segment with good preparation. Middle and right: Poorly prepared bowel segments

ASGE/ACG have also recommended that quality of bowel preparation should be registered in the final report after each individual screening [6]. Unfortunately, there is not yet a metric formally recommended by means of guidelines. This is because all three presently introduced scales for bowel preparation measurements are considered to be subjective, they depend purely on the colonoscopist's appreciation of cleanliness.

These three scales use subjective terms for grading, such as “excellent,” “good,” “fair” and “poor” [50]. Although these scales have been a welcome tool for assessing quality of preparation, their subjective nature illustrates the need for a standard quality measurement. These scales are: the Aronchick, the Ottawa and the Boston scales [51].

a. Quantification scales for bowel preparation

Aronchick scale

The Aronchick Scale evaluates the quality of the colonoscopy according to the percentage of colon surface that is clearly visible [52]. The scale rates bowel preparation as “excellent” when more than 95% of the surface is seen and there is only a small amount of clear liquid. The preparation is “good” if large amounts of clear liquid cover 5% to 25% of the surface allowing the visualization of 90% of the surface. It is “fair” if there is some semisolid stool that could be washed away but still more than 90% of the surface is perceptible. Finally, the bowel preparation is “poor” when semisolid stool cannot be suctioned or washed away and it is possible to see less than 90% of the surface only [52].

Ottawa scale

The Ottawa Bowel Preparation Scale (OBPS) evaluates each segment of the colon (right colon, mid colon and rectosigmoid) regarding the presence of fecal matter. The sum of all segment scores provides a total score for the bowel preparation [51]. This scale calculates cleanliness and

fluid volume independently. Cleanliness is graded from 0 to 4 in each of the three segments of the colon. The obtained 3 numbers are added to indicate total cleanliness. On the other hand, fluid quantity is an overall value for the entire colon ranging from 0 to 2 [53]. OBPS assigns a total score of 0 to an excellent preparation where no fluid is on the colon surface. Conversely, it assigns 14 overall points (12 for poor cleanliness and 2 for large fluid quantity) to a poor preparation containing large amount of fluid in each of the three segments [52].

The criteria for cleanliness of each segment in the Ottawa scale are as follows:

- ☐ Excellent (0): the mucosa is completely visible, there is almost no stool. Although there can be fluid, it should be clear.
- ☐ Good (1): there is stool and non-transparent fluid, but colon wall is still clearly visible and it does not require washing and suctioning.
- ☐ Fair (2): there is turbid fluid and stool hindering the visualization of the mucosa. However, mucosal detail becomes visible by suctioning but not washing.
- ☐ Poor (3): there is stool on the mucosa. By suctioning and washing a fair image of the mucosa can be retrieved.
- ☐ Inadequate (4): It is not possible to see the colon properly even after washing and suctioning.

Weighing for the presence of fluid is: 0 for small; 1 for moderate; and finally, 2 for large amount of fluid [52].

Boston Scale

The Boston Bowel Preparation Scale (BBPS) is a 10-point scale that assesses bowel preparation with the indication that it has to be done during colonoscope withdrawal, which occurs strictly after the completion of all cleansing maneuvers [50]. In this scale, similarly to the scales discussed above, subjective terms, such as “excellent”, “good”, “fair”, “poor” and

“unsatisfactory” are inferred. 4-point (from 0 to 3) scoring system is applied to each of the 3 different segments of the colon. The maximum BBPS score for a perfectly clean colon without any residual liquid is 9, and the minimum BBPS score for an unprepared colon is 0. Conversely, if the procedure has to be aborted due to insufficient preparation, all the segments are assigned a score of 0 [50].

1.3.4 Quality assurance as a way to regulate insurance policies in the USA

GIQuIC (GI Quality Improvement Consortium) is an initiative to electronically submit information of colonoscopy procedures in order to determine the most important quality standards in colonoscopy [54]. Doctors, hospitals and universities in the USA, are taking part on this call by electronically reporting quality standards for colonoscopy [54].

The objective of the GIQuIC is offering an organized and systematic method to gather information about colonoscopy practices in order to improve them. In addition, GIQuIC offers a way to analyze the collected information to establish guidelines on colonoscopy quality measurements. This database is useful for endoscopists that want to practice colonoscopy with the highest standards, since they can compare their performance with other endoscopists in the program, identifying their own gaps and finding ways to approach them.

The currently existing quality measurements for colonoscopy resulted from the alliance between the ACG and the ASGE and their publications in 2006 [54]. GIQuIC has adopted some of these measurements like the adenoma detection, intubation rate, and the bowel preparation. However, new measurements could be established by tracking endoscopists' performance around the country. New measurements could contribute to improve the quality of colonoscopy, but it would be important to consider whether these new measurements would have a repercussion in the cost-benefit of the colonoscopy practice.

To date, there are already 10 parameters in the GIQuIC registry:

1. History and physical documentation
2. Inform of consent, stating the possible complications
3. Optimal bowel preparation
4. Instructions of patient discharge
5. Documentation of the ASA category (the patient general physical health)
6. Documentation of all indications
7. Cecal intubation rate with proper documenting pictures
8. Adenoma detection rate
9. Withdrawal time
10. Adverse events [54]

Since a pay-for-performance policy has been introduced in the US, it is necessary that the information concerning medical procedures can be distributed to associations in charge of tracking quality practices [55]. Capable physicians could benefit from insurance companies with compensations given for insuring the best medical care for patients [55].

On the other hand, the Centers for Medicare and Medicaid Services (CMS) which are part of the United States Department of Health, have implemented the Physician Quality Reporting System (PQRS) for a doctor to get an economic compensation based on his expertise [56]. S/he needs to submit a report where it is specified that at least 3 quality indications were met during the medical procedure that s/he conducted [56]. Unfortunately, for colonoscopy, just 2 quality indicators exist at the moment:

1. CRC average-risk patients should have a colonoscopy test periodically, in order to avoid CRC occurrence;

2. The doctor should participate in a database Registry that demands reporting quality measurements during colonoscopy [57].

Therefore, endoscopists haven't been able to participate in this pay-for-performance practice. However, it's only a matter of time before more indicators are approved, since the ACG and ASGE have recommended already some other quality indicators for colonoscopy, retrieved from the GIQuIC database for the National Quality Forum to evaluate them [58].

Insurance agencies will make public all the information collected in the PQRS, including the measurements that should be taken into account to guarantee the good quality of colonoscopy. It is intended to publish this data in a website, and disclose the name of the doctors that participated in the PQRS program [59].

From 2015 forward, Medicare (the US health insurance program) will begin to take action on reducing compensations for doctors that decided to skip the PQRS. By 2016, the payment reduction will be of 2%, increasing quickly year by year till it reaches the 10% [59]. At the same time, incentive rewards will be provided as follows in the next years:

- ☐ 2013 – 0.5%
- ☐ 2014 – 0.5%
- ☐ 2015 – 1.5%
- ☐ 2016 – 2% [57]

1.3.5 Pay-for-performance policy in Canada

It is challenging for health institutions and governmental agencies to decide how to distribute economic resources for different medical procedures. That is why a cost-benefit comparison guarantees the optimal use of resources on healthcare services. Decisions in the health sector should be based on an economical evaluation [60].

CRC screening is a cost-effective measure in patients with an average risk to get CRC [60]. Among recommendable CRC screening tests that happen to be cost-effective are: either a fecal immunochemical test every year, or a colonoscopy every 10 years. Both increase monetary benefits to the health system in Canada [60].

Another way to optimize costs in the healthcare area is through the regulation of a procedure with certain standards that have to be met. In this manner, the quality of a medical procedure would be able to accomplish high levels of performance after some time.

According to the Canadian Medical Association (CMA) it is sought to have a health system transformation in Canada [61]. One of the actions suggested consists of giving incentives as a way to assure quality. Thanks to a quality report program, doctors would be able to document their performance and receive economic benefits in the future [61].

Currently, some provinces have already adopted a pay-for-performance system, i.e.: Nova Scotia, Ontario, Manitoba, Alberta and British Columbia [61]. Of these provinces, Ontario doctors already get special bonus if they achieve specific performance levels in preventive actions on colorectal cancer [61].

There are several reasons to participate in quality assurance programs in Canada, including:

1. Regulatory agencies have already started to demand quality measurements
2. Stipends for healthcare providers will be dependent to their performance
3. Patients will be aware of quality metrics and will be asking for reports from doctors
4. Doctors will be satisfied from delivering the best health services possible to their patients

[61]

1.4 Colonoscopy market

Currently, there are many marketable products for the diagnosis and treatment of gastrointestinal diseases offered by hundreds of companies. Thus, this kind of equipment represents one of the most important medical products for global commercialization [4].

As a result of education and training in endoscopic surgery, the high-level technology available in this area, and the large number of gastrointestinal surgeries conducted all around the world, the gastrointestinal sector had a value of \$14.6 billion in 2011 [4]. Moreover, by 2016 this amount will increase to \$18.3 billion [4] as presented in Fig. 6. Endoscopes and similar techniques contribute to half of the total gastrointestinal sales, with an amount equivalent to \$7.6 billion in 2011 [4]. However, as part of the gastrointestinal market, the endoscopy segment is estimated to keep rising at a 4.7% growth, reaching \$9.5 billion by 2016 [4].

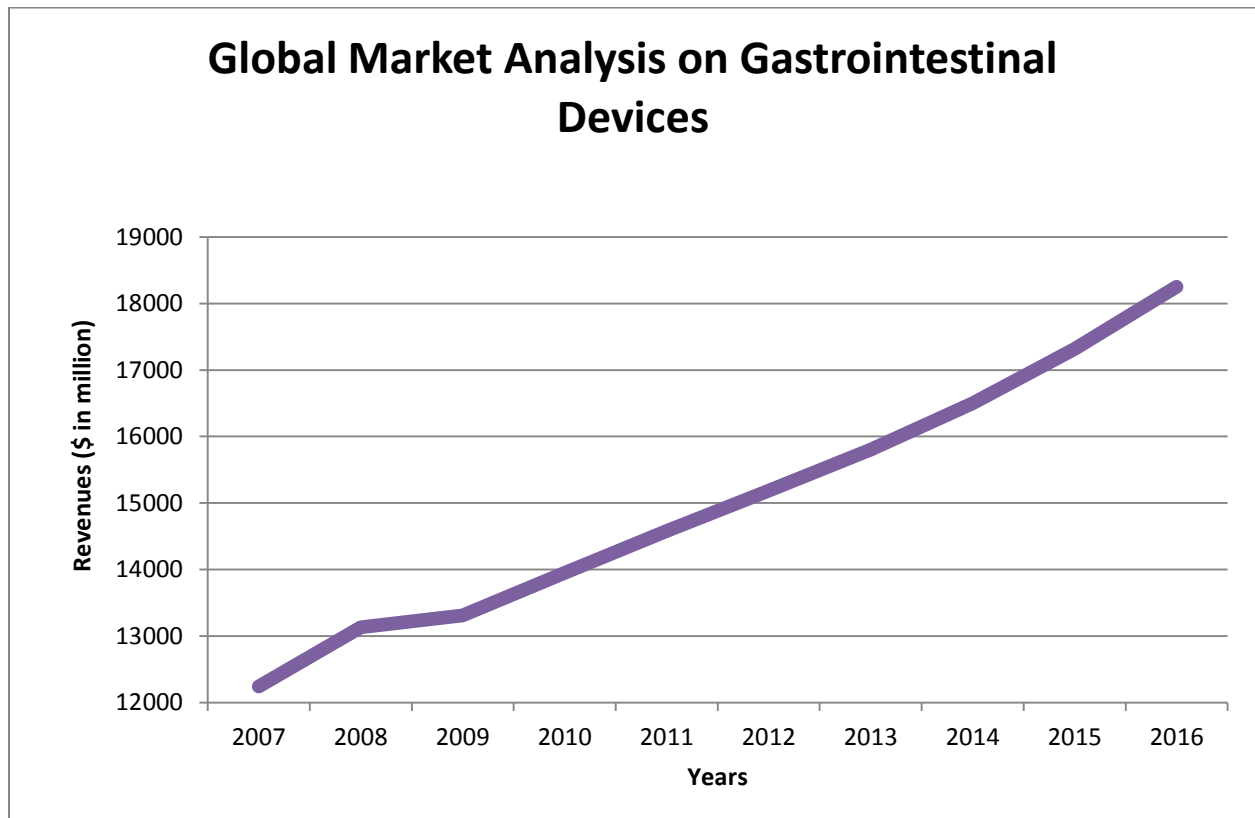


Fig. 6 Global Gastrointestinal Equipment and Device Market Analysis, 2007-2016 [4]

To summarize Table 1 presents a global view of CRC market.

Parameter	Value
Market age	Growth stage
Market size (2011)	\$14.6 billion
Potential revenues (2016)	\$18.2 billion
Compound annual growth rate (2007-2016)	4.5%
Price sensitivity	Moderate
Number of commercialized products	More than 10
Competitors (active market competitors in 2011)	More than 17
Degree of competition	Moderate
Degree of technical change	High
Market concentration (percent of 2011 market controlled by top competitor)	65.0%

Table 1 Global view of Colorectal Cancer market [4]

At the moment, there are many companies in the GI devices market providing tools to diagnose, monitor and treat GI diseases as shown in Fig. 7. The highly competitive market for GI products is constantly evolving with new technological innovations.

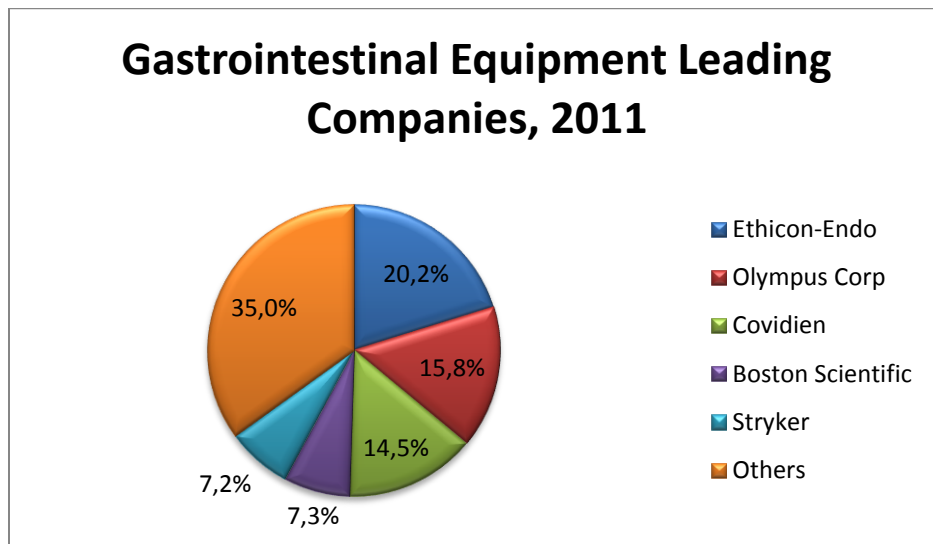


Fig. 7 General description of companies working in technology development for GI diseases

[4]

The companies shown above are leaders in the development of medical technologies. They design, manufacture, and commercialize devices in the gastroenterology field, and can be considered as potential licensees of a technology for quantifying the quality of colonoscopy. In addition, there are other large companies that may be interested in such technology. The names of some leading gastrointestinal companies are cited in Table 2 along with their location.

Company	Location
Covidien PLC	Dublin, Ireland
Olympus Corporation	Tokyo, Japon
Boston Scientific	Natick, MA, USA
Conmed Corporation	Utica, New York, USA
Fujinon	Wayne, New Jersey, USA
Given Imaging	Yoqneam, Israel
Johnson & Johnson	New Brunswick, NJ, USA
Stryker	Kalamazoo, MI, USA
Welch Allyn	Skaneateles Falls, NY, USA

Table 2 Leading companies in gastrointestinal products that could be potential purchasers of our technology

On the other hand, there are also smaller companies working on projects slightly related to the quality assurance in medical tests that could also be potential distributors of such kinds of equipment:

- Medicsight, is located in the UK. This company focuses on the colorectal and lung cancer. This company has launched software that facilitates the identification of colon and lung diseases.
- OnPoint (Licensed MRI quality assurance software from Mayo Clinic). This company is located in Virginia, USA. OnPoint offers a product that automatically registers certain quality control parameters that are required by the American College of Radiology. This product offers the ability to introduce real time commands, analyses information and presents results to assure that patients are diagnosed based on high quality images.

1.5 State of the art

1.5.1 Critical review of existing patents

Relevant publications that present a system to measure the quality of colonoscopy have been disseminated by the Mayo Foundation group [24, 62, 63]. The most relevant patents on quality metrics for colonoscopy are listed below:

□ PATENT #US7,894,648 B2

“Colonoscopy video processing for quality metrics determination”

The system proposed in patent # US7,894,648 B2 achieves real-time analysis and feedback to aid the endoscopist towards optimal inspection and improve the overall quality of colonoscopy during the procedure.

This system displays metrics for colonoscopy procedures such as: a) colonoscope withdrawal time, b) clear withdrawal time, wherein the clear withdrawal time is representative of the withdrawal time less the duration of non-informative images, c) number of camera motion direction changes, d) ratio of the number of camera motion direction changes to clear withdrawal time, and e) close-global inspection ratio, wherein the close-global inspection ratio is representative of the ratio of the colon wall view images to the colon lumen view images; and an output coupled to the processor for outputting the computed quality metrics. In addition, the analyzed information is also based on audio recording, during which the physician indicates the location of the endoscope in the colon.

In patent # US7,894,648 B2, affine model, which represents motion in 6 different parameters [64], is applied to estimate camera motions between two consecutive frames. Among the camera motions, Dolling Camera Motion (DCM) is mainly examined because it is directly related to the

forward and backward camera movement. The positive DCM value means forward movement and the negative DCM value means backward movement.

□ PATENT #US20120033062 A1

“Method and device for examining or imaging an interior surface of a cavity”

In this patent a method for the formation of a complete image of the colon is described. This method consists of capturing partial images of the colon and then putting them together. If an area of the colon couldn't be captured adequately, this system can provide the operator with information about the location of this missing area.

Another aspect of this system is the identification and the replacement of blurry images. In the event that an image is fuzzy or otherwise unsuitable for the reconstruction of the single integrated image, a processing device alerts the physician so that one or more additional images may be acquired to replace the unsuitable image. In addition, automatic detection of colon segments is proposed.

The determination of the position of the colonoscope is also considered herein. The endoscope may have a sensor or transducer for communicating the position (such as the location and/or orientation) of the imaging device to a processing device. Examples of such positioning sensor include magnetic positioning sensors, RF positioning sensors, or optical positioning sensors. The objective of having such position information is to be able to better determine how to integrate images, since the joining images can be improved based on the imaging device's position and on information about a particular geometry of the segment of the colon the imaging device is in.

□ PATENT # WO2010060039 A2

“Colonoscopy tracking and evaluation system”

This invention is a method and apparatus for tracking and evaluating a colonoscopy procedure and for providing a real-time visualization and evaluation during the procedure.

The tracking input receives position data representative of the location and/or of the orientation of the endoscope within the patient's colon during the procedure. Its guidance system can generate visualization that represents the colon in three-dimensions (3D) and can provide feedback about regions of the colon which have been missed or have been poorly viewed. The final goal is to generate a colon model reconstruction. The reconstruction is performed using the collected points taken from the determination of the colonoscope position values during an exam. The reconstructed 3D surface of the colon can be used to detect abnormalities such as polyps. In addition, using a 3D surface reconstruction system the uniformity of the colon wall can be used as a metric for proper insufflation, which is an important part of colonoscopic tests.

This technology also provides a method for detecting the direction of view based on the analysis of regions of interest. For instance, each video image is partitioned into regions and each region is evaluated based on image intensity using the assumption that the far field is darker than the near field. Together, the intensity regions can be used to determine the direction of viewing along with the depth of viewing.

The introduction of "trackers" through the access port of the endoscope to the tip of it helps for tracking the endoscope. Another input is from a patient reference tracker that is taped to the patient. A magnetic reference is attached to the patient table in order to generate a magnetic field signal which the tracker system uses to determine the position of the colonoscope and the patient via reference tracker during the procedure. In addition to the magnetic tracking system, a mechanical tracing (e.g., shape tape) and imaging (e.g. fluoroscopy) is also proposed. Finally,

determining “forward” and “backward” directions using an accelerometer at or near the tip of the colonoscope is also considered.

Putting together all these approaches, this system displays metrics for colonoscopy procedures that include metrics vectors such as distance, size, shape and texture of the colon, which can all be visualized in a virtual colon model.

Table 3 shows a comparison among colonoscopy assessment technologies described above.

Parameter		#US7,894,648 B2	# WO2010060039 A2	#US20120033062 A1
Yes/No	Description			
Objective		To achieve real-time analysis and feedback to aid the endoscopist towards the inspection of the colon.	To evaluate a colonoscopy procedure and give feedback of regions that have been poorly viewed. To provide a 3D colon model reconstruction.	To capture partial images of the colon and by gathering them be able to form a complete image of the colon.
Determination of forward and backward movements		Y The implementation of an affine model to estimate camera motions between two consecutive frames. The Dolling Camera Motion (DCM) positive value indicates forward movement; negative value indicates backward movement.	Y Endoscope tracking method consists of the introduction of “trackers” through the access port of the endoscope to the tip of it. Another input is from the patient reference tracker that is taped to the patient. A magnetic reference is attached to the patient table in order to generate a magnetic field. An alternate approach would be mechanical tracing (shape tape) or imaging (fluoroscopy). For detecting the	Y The endoscope may have a sensor or transducer for communicating the position. Examples of such sensors are magnetic, RF or optical positioning sensors.

				direction of view, each video is portioned into regions. These are evaluated based on image intensity using the assumption that the far field is darker than the near field. Together the intensity regions can be used to determine the direction of view along with the depth of viewing.		
Withdrawal time calculation	Y	The system identifies a boundary between endoscope insertion and withdrawal phases. The boundary frame between the insertion and withdrawal phases has the highest accumulated DCM value.	N		N	
Blurry frame identification/ Non-informative frame filtration	Y	It performs lumen identification to decide whether a frame is informative.	Y	The system uses regional sharpness to determine the quality of the image data, higher sharpness indicates less blurry data.	Y	The system aims to identify and replace blurry images. When a partial image is unsuitable for the reconstruction of a single joined image of the colon, a processing device alerts the physician to take an additional image.

Scanning Speed Calculation	N		N		Y	The system set a key point in two images. Then, it calculates the scanning speed by dividing the distance by the time that has passed between two images. Another method proposed is by measuring the size change of a geometric feature from one image to another.
Stool detection	N		Y		N	
Calculation of additional parameters	Y	The analyzed information is also based on audio recording where the physician indicates the location of the endoscope in the colon.	Y	The system displays a color indicator of image quality.	Y	The automatic detection of colon segments and the calculation of the total time spent in every segment. To offer a tool for comparing new images with old images retrieved from the memory to identify changes in the interior surface of the colon.

Table 3 Comparison of colonoscopy assessment technologies

On the other hand, with the technology that has been already developed in the Low Frequency Laboratory at University of Calgary, there has been a substantial progress on a system called the Colometer, a novel approach to measuring CSPY quality. It combines velocity and image blurring as an output metric. The Colometer offers important advantages with respect to withdrawal time monitoring, which is the metric presented by Mayo Foundation research group. If the Colometer could be validated as competitive equivalent with respect to measuring the

withdrawal time, then the reporting quality of colonoscopy would become simpler, cheaper and faster, in addition to being more reliable as it would be automatic and unalterable. It is also user-friendly, avoids complex calculations and requires almost no effort from the clinical staff. In addition, our automated method for stool analysis will likely be more easily correlated with the Ottawa Scale scores, which is the main bowel preparation scale used in Canada, as opposed to the Mayo Foundation's system in patent # US7,894,648 B2 that uses the Boston Bowel Preparation Scale.

1.5.2 The Colometer

The Colometer is a real-time feedback tool for colonoscopic procedures. It offers an indicator for image velocity and blurriness that is displayed on the endoscopist's monitor in real-time. This tool it is also capable of showing a summarized report after each screening test [65].

It is calculated that the number of blurry images contained in a video ranges from 37% to 60% of total video length [66], depending on different factors including the endoscopist's skills and the level of bowel preparation in every patient. Several different methods have been proposed for the assessment of colonoscopy videos blurriness [67-69]. However, there is no report of an algorithm for real-time implementation. The Colometer approach for blurriness measurement consists of an instant calculation of the image variance in a frame-by-frame evaluation setup.

On the other hand, velocity change monitoring integrated within the Colometer is a practical tool used to evaluate the adequate time spent to properly examine the colon. Presently, clinicians cannot have a feedback of this metrics until the end of the screening test and, therefore, this feedback does not influence the quality of the procedure. The Colometer offers such real-

time feedback for the doctor during colonoscopy and a final summary report for patient awareness after the procedure, which can objectively assess its quality.

The Colometer also displays summative statistics in a final report. This report includes the withdrawal time, percentage of clear visualization, and an image dynamics-time graph. The objective of this graph is to alert the endoscopist when s/he is going too fast during colonoscope withdrawals. Finally, the Colometer can be easily implemented in any colonoscope with a digital video output, since it employs widely available video processing technology.

In order to have an overall evaluation of colonoscopy procedures, the general objective in the Low Frequency Instrumentation Lab is providing simple-to-use software that could present precise results about colonoscopy quality in an easy way, and then document them into a database. These metrics include quality of image and withdrawal velocity that the Colometer system already provides, in addition to the quantification of bowel preparation and colonoscope direction monitoring.

1.6 Aim of the thesis

Despite the fact that CSPY is widely practiced nowadays, an established standard for measuring the quality of colonoscopies is still missing. Such system could allow for the continuous improvement of CSPY practices. That is why the objective of this study is to propose an evaluation system to improve the quality of CSPY, thus providing three major outputs: 1) real-time visual feedback indication of image changing velocity and image blurriness to the endoscopist; 2) automated summative statistical report provided following the completion of the CSPY, including withdrawal time, percentage time of adequate visualization, and a novel graph of dynamics over time that also includes monitoring of colonoscope direction; and an 3) automated stool coverage analysis for the documentation of bowel preparation. All these outputs

can be obtained automatically. Therefore, this method could allow future CSPY quality control in the daily medical practice.

1.7 Hypothesis

A universal, automated, real-time, feedback-based, and non-operator-dependent method can be designed, which could provide information about the dynamics and level of bowel preparation and will be particularly useful to systematize colonoscopy performance among different centers and medical professionals, thus standardizing colonoscopy delivery services.

2. Methods

2.1 The Colometer: frame analysis

The conceptual block diagram of the entire Colometer system is shown in Fig. 8. Initially, a high-speed analog video acquisition device (VCE-Express, Imperx, Boca Raton, FL, United States) was connected to an EPX-1 colonoscope (Pentax Canada, Mississauga, Ontario) through its S-video port before a standard colonoscopic procedure to enable a real-time video acquisition. A high-performance laptop workstation (Thinkpad W520, Lenovo Canada, North York, Ontario) equipped with Matlab 7.14 (The Mathworks, Inc., MA, United States) was employed to interface with the video acquisition unit and to allow a real-time video processing of the colonoscopy video stream at sampling frequency of 30 frames per second.

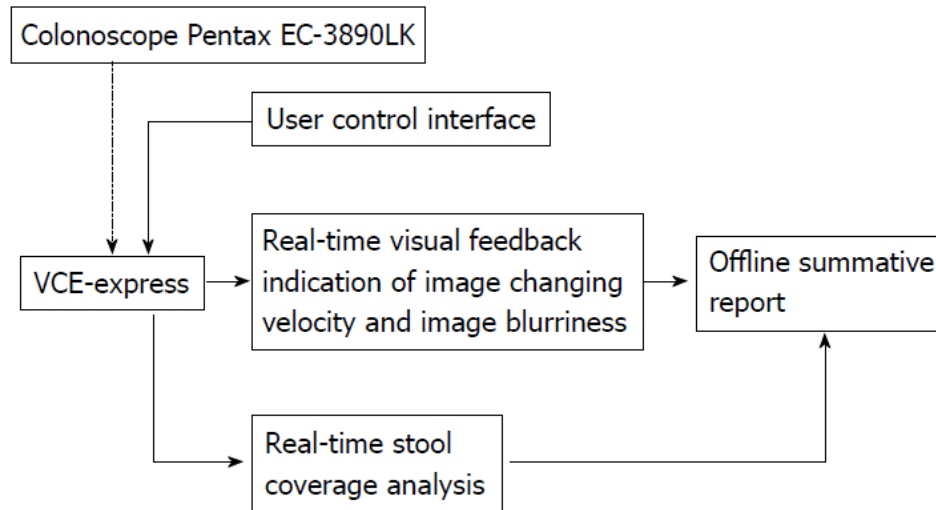


Fig. 8 Conceptual block diagram of the proposed Colometer system

A real-time visual feedback of the colonoscopy image changing velocity and image blurriness was embedded within this video utilizing Matlab (Image Processing Toolbox™). A custom-design user control interface was developed on the workstation using Matlab (MathWorks, Natick, MA, United States) to allow the user to control the real-time feedback indicator and to provide an offline summative report.

a. Real-time visual feedback system

In this study, a total of 14 screening colonoscopy videos from a single endoscopy unit (Foothills Medical Campus, Calgary Zone, Alberta Health Services, Calgary, Canada) were collected, processed, and rated in a real time fashion. The colonoscopy videos were completely anonymized videos without any patient or endoscopist information on the images, filenames, or in the file metadata. The videos were acquired for a quality assurance exercise (practice audit), and was thus exempt from consent requirements. Three other experienced gastroenterologists reviewed these videos in a blinded fashion and rated the withdrawal velocity, image quality, and colon preparation of each (scored 1-5; 1, poor; 3, average; 5, excellent) as well as overall quality

on the same scale. The automated quality ratings were compared to the averaged endoscopist quality ratings.

Image changing velocity measurement

In an image sequence that contains a moving object, a color change in the image background is perceived when the object moves [70], and the background is darker in the immediate preceding image. This represents a change in the image pixel value between one frame and the next. In essence, frame differencing process is about subtracting the actual image from the previous one in a pixel by pixel operation, and saving the absolute value [71].

In general, the dynamics of moving objects in a video sequence can be assessed by frame differencing technique. If the temporal changes of pixel intensity have changed in a successive sequence of frames, it had to be due to the changing dynamics of objects within the image [72]. Once we have calculated the absolute difference between pixels in consecutive images, we can get a proportion of velocities of a moving object in the whole video recording [73]. For instance, by comparing the absolute values of the difference between one frame and another, we can have an estimation of the average difference value. If a value in the video recording frame is above this mean value, then we can conclude that in this specific frame, the velocity of the object is faster. However, in order to set a threshold value from which the velocity can be estimated, we have to analyze the image content.

Most frame differencing methods offer low computational complexity, which was the main constraint when designing the system to operate in real-time [74]. Since the frame differencing technique is contrast-based and the colonoscopic image contrast can be manually adjusted according to endoscopist's preference, a normalized approach was chosen to eliminate this problem.

Initially, overall minimum and maximum values of velocity changes for all 14 videos were determined in real time with 30 ms time delay. Subsequently, two different threshold ranges between these values were selected corresponding to an adequate and rapid withdrawal speeds. These ranges were further optimized to achieve agreement with the average rating from the gastroenterologists (Fig. 9).

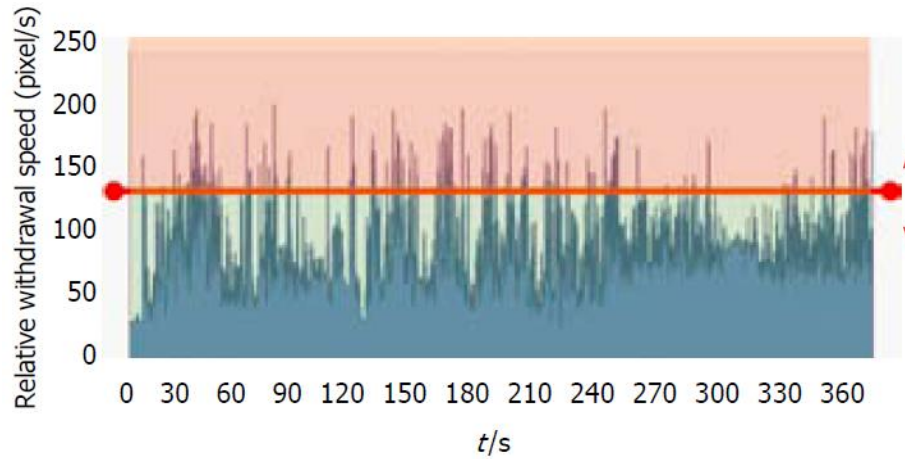


Fig. 9 Relative withdrawal speed over time. Red line is the speed threshold configured by the endoscopists

Image blurriness measurement

When an image is clear, there is a remarkable contrast between the image boundaries and the rest of the pixels in the image. In this case, the image perimeter pixels are either very light or very dark and, in general, there is a large interval between these pixel values and the average pixel value of the image. Contrastingly, in a blurry image, the difference among pixel values is not considerably large and, in general, all pixels (including the image edge) are close to the average pixel value. Based on this, when an image is clearer, the variance of the whole image is greater as well [75].

Colonoscopy videos often contain many blurry (out-of-focus) frames due to frequent shifts of camera positions while moving along the colon. Current endoscopes are equipped with a single, wide-angle lens that cannot be focused [76]. Sharpness, brightness and contrast of the image are optimized using the endoscopist's skills. In addition, the tip of the colonoscope during the procedure can be temporally buried in mucosa or closely face the colonic wall, which also results in blurry images. It is estimated that the average number of blurry frames in a colonoscopy video is 37%. However, that number can reach as high as 60%, depending on endoscopists, patients and colon preparation [24]. Numerous methods have been proposed to assess blurriness in colonoscopy videos. However, a real-time algorithm for blurriness measurement for the colonoscopy video has not yet been implemented. A variance metric calculated as the variance of the whole image was utilized to measure the blurriness of the video frames in our real-time application [77]. During blurry video sequence, information about the image changing velocity is not important and thus was not calculated. Fig. 10 shows a comparison between focused and blurred snapshots from a colonoscopy withdrawal video.

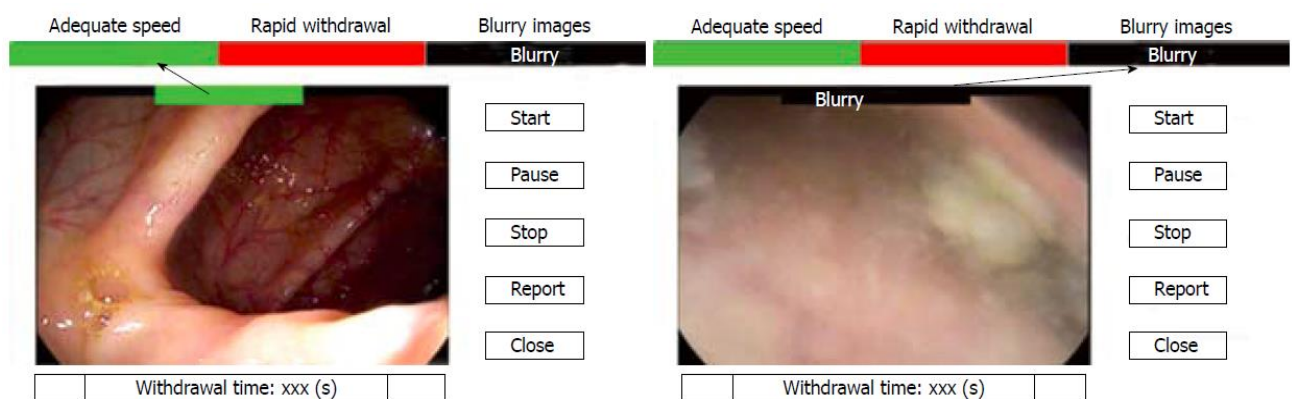


Fig. 10 A sample frame with focused (left) and poor image clarity. Text indicators “adequate speed”, “rapid withdrawal”, “blurry”, were embedded into the video in a real-time to provide a visual feedback to the endoscopist

b. Statistical analysis

Based on these thresholds, a summative statistics report following each colonoscopy could be provided, including withdrawal time, percentage time with adequate visualization, and a novel graph of image changing dynamics over time. Such a graph may allow endoscopists to see through which portion of the colon the withdrawal was too fast. An example of a summative Colometer report is given as an example in Fig 11. Moving average filter was used to smooth the velocity data for every 20 seconds. The peaks in the image changing dynamics graph indicate the period with frequent abrupt image changes during scoping. The slope of the line on this dynamics-time graph reveals useful information about the acceleration of the scoping sequences. Using this information missed colonic segments could be estimated. Comparisons of continuous variables were performed using the Student's t-test and correlations of sequential data employed Spearman's correlation. Free-margin multirater Kappa statistics were calculated for inter-rater variability [78]. A level of $p < 0.05$ was used to determine statistical significance.

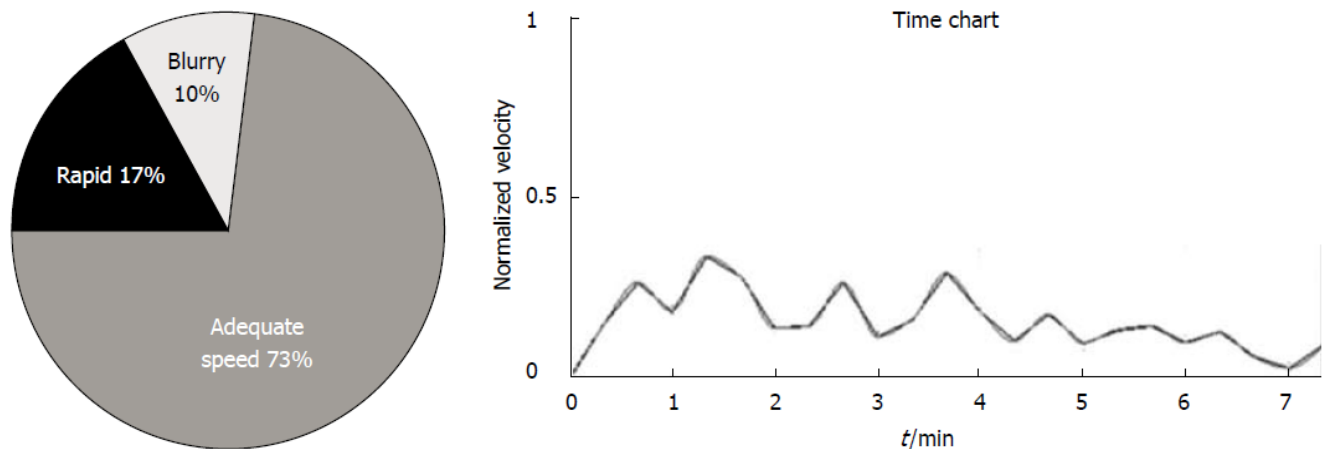


Fig. 11 An automatically generated chart providing % of time of adequate speed in a colonoscopy procedure (left) and chart showing filtered velocity over time (right)

2.2 Stool detection

A key factor to be considered in the process of developing a colon cleansing evaluation system is the level of cleanliness in the colon. In the present study the evaluation of the level of cleanliness was based on the Ottawa scale. The developed algorithm to perform stool detection utilizes color recognition, which is a major approach in feature segmentation [79].

Matlab software was selected for the implementation of the algorithm because of its friendly interface and the advantage of having an image processing toolbox, in which image recognition by color and shape is facilitated. This algorithm was tested in a set of 13 videos, which were acquired in the McPhail Colon Cancer Screening Center in Foothills Hospital. The colonoscopy videos were anonymized videos without any patient and endoscopist information.

Finally, a correlation was performed between the Ottawa 5 point-scoring system and the percentage of stool in the colon retrieved by the proposed software.

a. Color detection

The elements for characterizing an image are color, shape and texture. Of the above mentioned factors, color is the most important feature to segment images [79].

Hue-Saturation-Value color model (HSV) is a method to define color according to its three basic features:

- 1) Hue
- 2) Saturation; and
- 3) Lightness [80].

Hue represents a specific tone of color. Saturation is the estimation of the purity of hue and is related to the intensity of the latter. When a color is completely saturated it excludes any

gray from its content. Conversely, when the saturation is low, a color turns entirely into gray. The lightness component determines if the color turns lighter or darker [81].

HSV color space is shown on Fig. 12. The values for the hue component range from 0° to 360° , where red is set at 0° and black at 360° . For saturation and lightness, the values range from 0 to 1 [82]. From these 3 components, hue expresses the main characteristic of a color [82]. For instance, in the present study, hue represents the highest contrast between the colon wall and the stool in comparison with the other 2 components. Once the ranges in the HSV color space have been set for a specific target object, only the pixels in the image that are within these limits are extracted.

The spectral characteristics of a camera sensor and its lighting conditions determine the level of color in an image [83]. The use of the HSV color model is suitable for the present study because it is more consistent and efficient than the Red-Green-Blue color space (RGB) while working on color detection, since the hue component remains immune to lighting behavior conditions. This means that the hue histogram, which provides the values for each one of the HSV color space components in an image, remains about the same regardless the change of the illumination level [83].

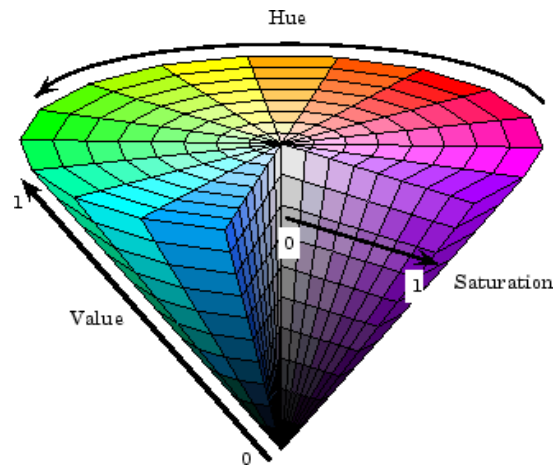


Fig. 12 HSV Color Space [83]

b. Post-processing and quantification

The post-processing and quantification algorithm includes the following steps:

1. Increasing the contrast of the RGB image in order to discriminate better between the colon wall and the stool matter on it.
2. Separating the three color components of the HSV color space. As a result of that partition, hue, saturation and lightness components are separately quantified. The target color is defined by limiting the range of these component values as follows: $H_{min} < H < H_{max}$, $S_{min} < S < S_{max}$ and $L_{min} < L < L_{max}$, where min and max are the maximum and minimum values, respectively [84]. The examined color is detected in the image if the pixel color lays within the boundaries of the HSV zone. These values should be previously identified from the HSV histograms. One histogram for each one of the components in the HSV color space was computed.
3. Every small object that has less than a certain number of pixels is removed from the image in order to avoid saturating the screen and allowing only the segmentation of areas that considerably contribute to the percentage that is displayed.
4. A morphological closing is performed on the grayscale image. The ratio of the black pixels, (which represent the pixels of stool) over the total number of pixels in the matrix is calculated. With this method the percentage output of pixels of stool is computed.
5. The perimeter of the detected area is overlaid on the original image to examine the correctness of the detection.

Fig. 13 shows the output of the proposed software. At the top, the percentage of stool matter in the image is indicated. The contour around the area with poor bowel preparation is also displayed. The complete procedure is explained as a flow chart in Fig. 14.

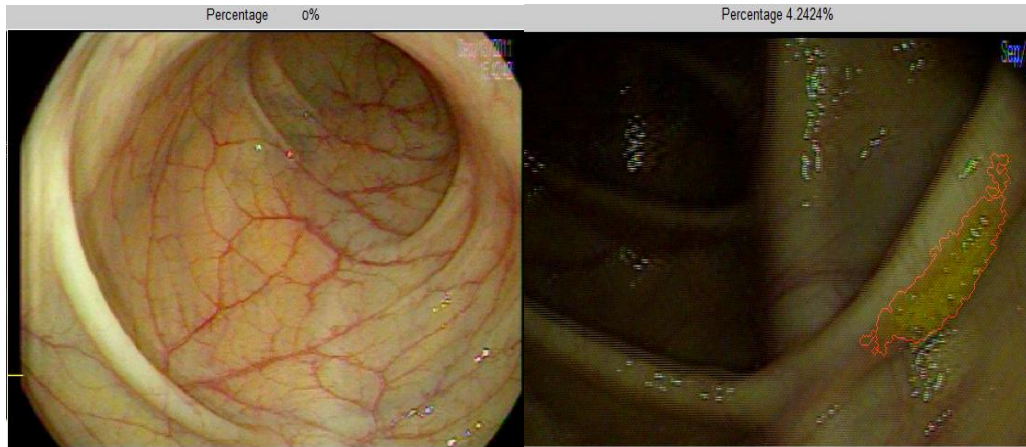


Fig. 13 Output of the software. Left: A clean colon where no percentage of stool was recognized. Right: Colon with stool where the target area is highlighted

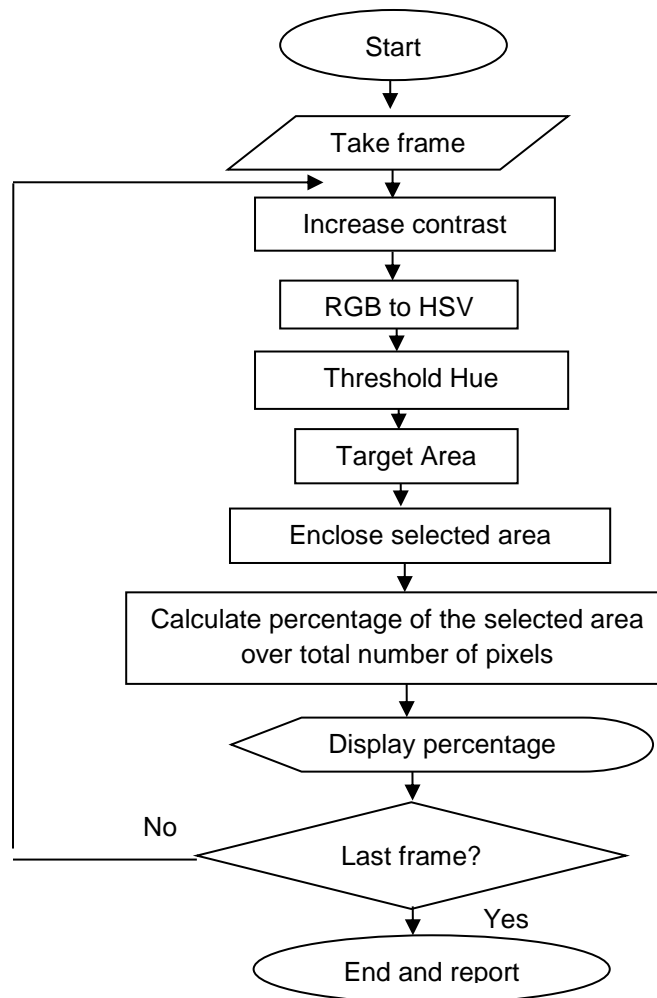


Fig. 14 Algorithm for stool detection

c. Ottawa scale integration

Thirteen complete colonoscopy videos have been graded by a professionally licensed academic endoscopist, and each of the 3 segments in the colon (right colon, mid colon and rectosigmoid) was marked according to the Ottawa scale. For the preliminary analysis the value for the quantity of fluid was not taken into consideration, since the fluid recognition stage has not been yet implemented in the proposed software.

All videos were analyzed in Matlab, at 30 frames per second. All of them had different time durations, ranging from 4 to 8 minutes. The percentage of stool in each of the frames was retrieved from each of the colon segments. From the collected data, the mean of the percentages of stool and the standard deviation for each of the three colonic segments in the 13 colonoscopic videos were calculated.

2.3 The electromechanical tracking device

The proposed idea consists of an embedded system external to the colonoscope that can automatically determine the colonoscope direction and the distance traveled, following by summative statistics of these metrics, including the ratio of forward and backward movements during withdrawal time. This information can thus be used as a method for objectively evaluating the quality of a colonoscopic procedure.

This system is a device that includes one or several electromechanical tracking sensors that sense the movement of the colonoscope when the colonoscope cord passes through the middle section of the device. A rotational support was designed to be affixed to the surgical bed; this allows the positioning of the tracking device to facilitate its manipulation by the doctor.

This is an embedded system intended for the automatic acquisition of parametric values that can be easily correlated to the quality of a colonoscopic procedure. In general, it is

anticipated that in order to have a high-quality colonoscopy test, the withdrawal time length and the carefulness when inspecting the colon mucosa should be evaluated. Currently, the ASGE and ACG suggest that the inspection during withdrawal phase should be completed in an average time of 6 minutes [69]. When it gets difficult to approach certain areas in the lumen, moving the colonoscope side-to-side and forward and backward allows the clinician to have better visualization of the region and to capture more convenient images for evaluation. Then, these movements can be recorded as metrics to evaluate how diligent the doctor is when examining the mucosa.

This device measures the travelled forward and backward distance when it is in direct contact with the colonoscope cord which freely moves along a rigid section in the middle of the proposed tracking device. The generated forward and backward movement is recorded by electromechanical sensors within the device. Fig. 15 depicts the electromechanical tracking device that includes two rotating wheels 11' that are calculatedly positioned leaving a space 13' in between. This space allows the placement of the colonoscope within the tracking device.

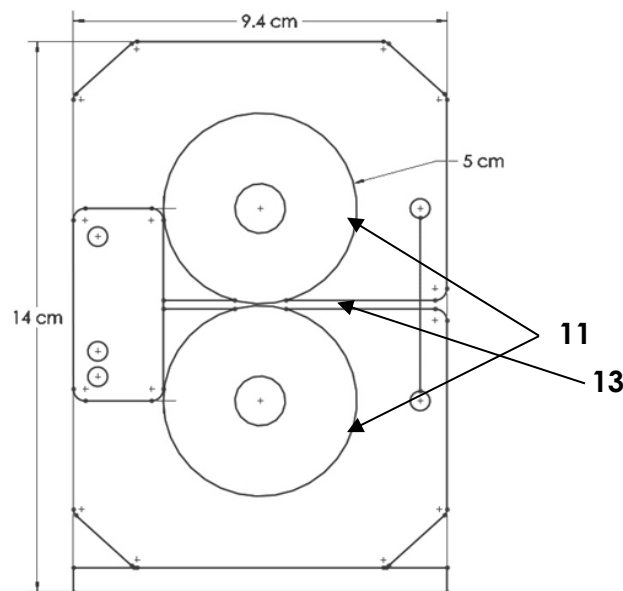


Fig. 15 Front view of the colonoscope tracking device

Fig. 16 depicts the back view of the tracking device. The two wheels 21' get rotated when the colonoscope cord passes through the middle section of the tracking device. This motion is measured by electromechanical sensors 22' and wirelessly displayed to the user in real time by additional electronic components within a case attached to the device.

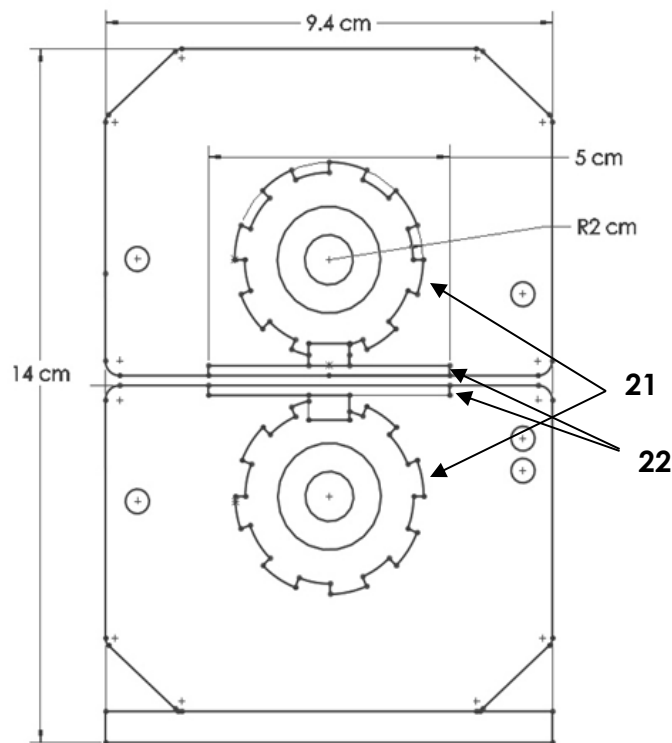


Fig. 16 Back view of the colonoscope tracking device

Fig. 17 shows the lateral view of the electromechanical tracking device, where it is perceived the space 33' in between the two wheels 31' for the positioning of the colonoscope. Overall dimensions of the device are shown as well.

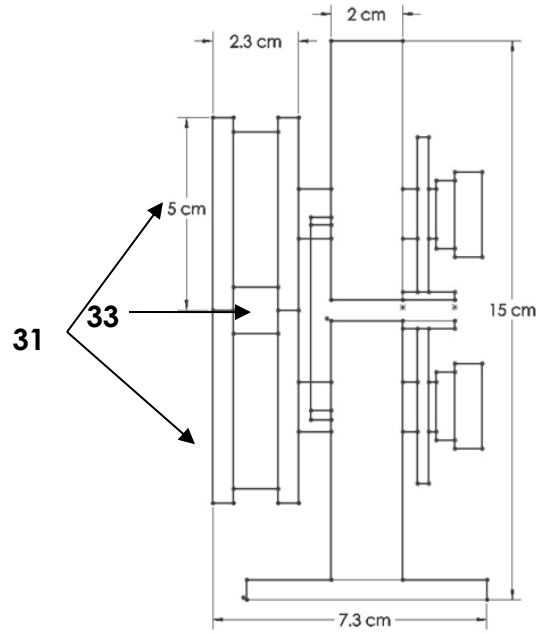


Fig. 17 Lateral view of the colonoscope tracking device

Fig. 18 depicts the electromechanical tracking device in an opened fashion indicating how the colonoscope 44' is intended to be placed in the middle section of the device.

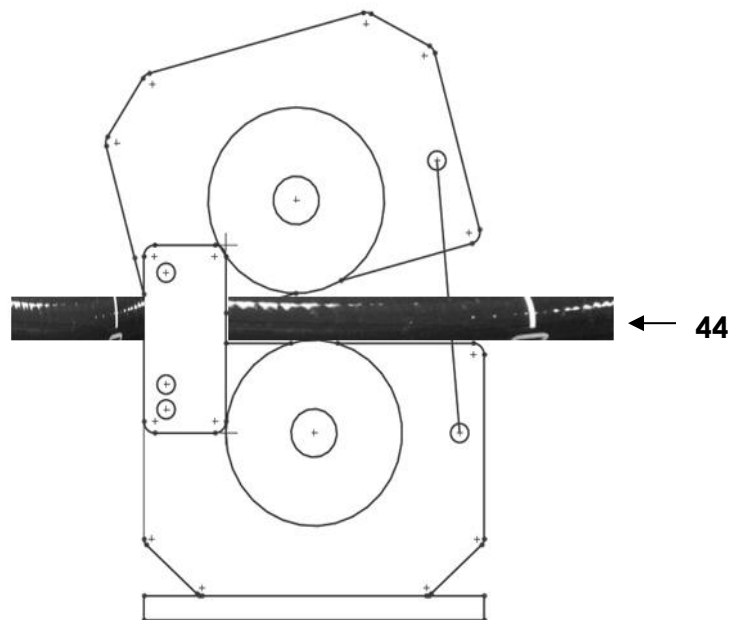


Fig. 18 Opening of the electromechanical tracking device for the positioning of the colonoscope in the middle section

Fig. 19 depicts the support of the electromechanical tracking device that is affixed to a hospital bed using a clamp 55'. The support consists of a metallic arm that relies on the joints 56' to fully turn around and place the colonoscope at the most convenient site for the doctor. In addition, dimensions of the entire device are shown in Fig. 19.

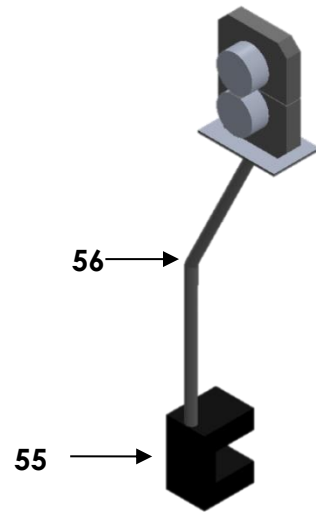


Fig. 19 Support of the electromechanical tracking device to be affixed to the surgical bed

For practicability, different sites for the electromechanical device positioning in the surgical room are proposed. It is proposed that the electromechanical device should be in front of the operating (right) hand of the endoscopist to assess the torque and forward/backward movement of the colonoscope 67' as shown in Fig. 20.

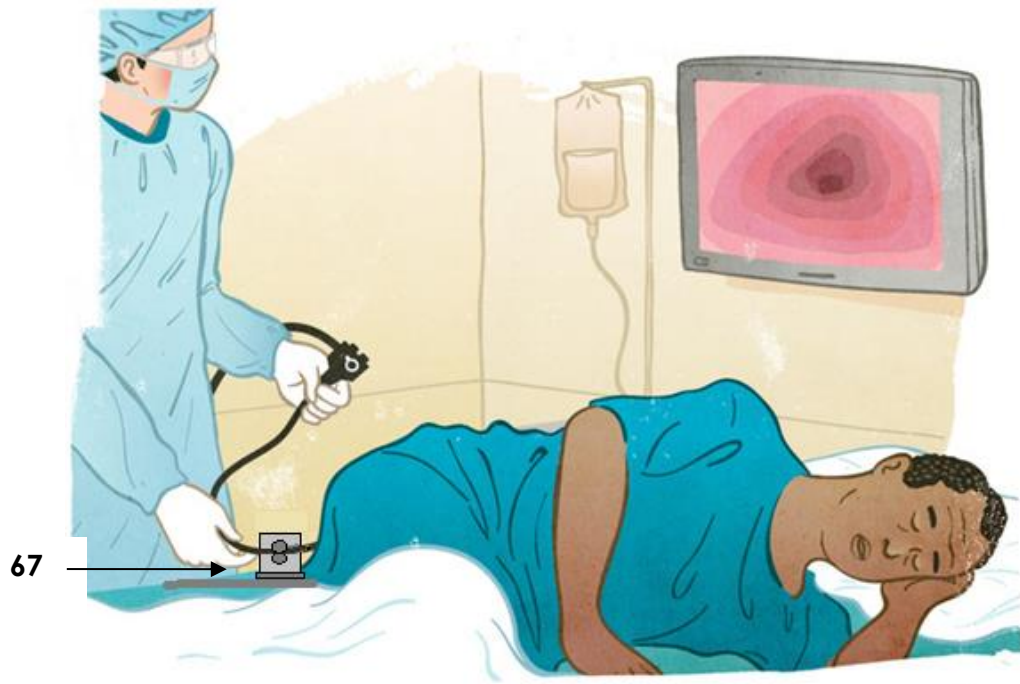


Fig. 20 Colonoscopy procedure set up including the electromechanical tracking device affixed to the bed. The electromechanical device is placed in front of the handset, i.e. the torque of the colonoscope [85]

On the other hand, it was thought that the electromechanical tracking device could also be positioned behind the torque of the colonoscope 77', as shown in Fig. 21. However, results from clinical testing showed that the colonoscope manipulation occurs in front of the endoscopist's hands, and the back part of the colonoscope cord doesn't reflect the direction and travelling distance of the colonoscope.

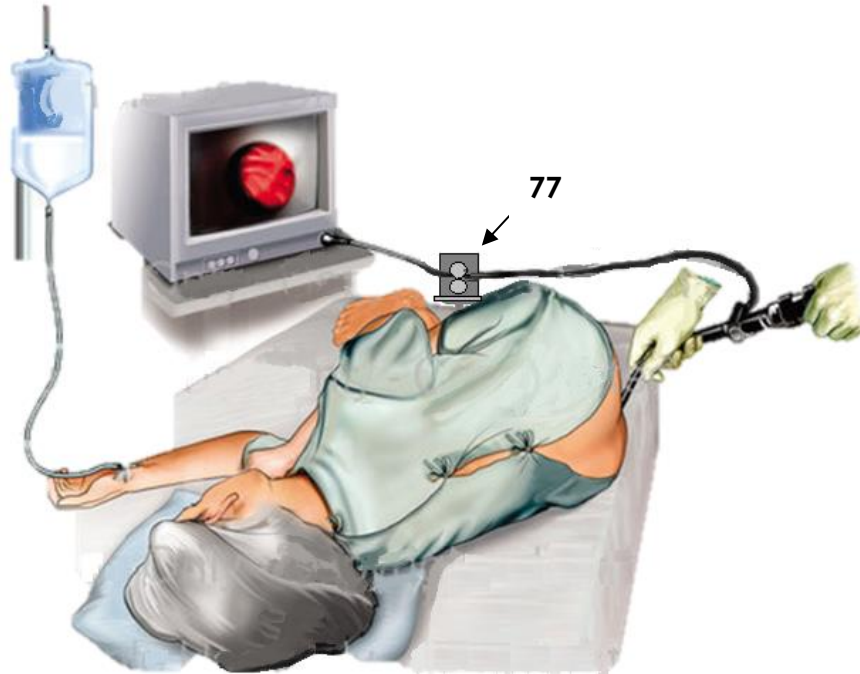


Fig. 21 Colonoscopy procedure set up with the electromechanical tracking device affixed to the bed. The electromechanical device is positioned behind the handset of the colonoscope [86]

The tight channel of the electromechanical tracking device where the colonoscope is positioned, perhaps, could hinder the movement of the colonoscope. Therefore, a soft and smooth contact between the tracking device and the colonoscope is sought, so the tracking device doesn't impede the colonoscope maneuvering by the doctor. A similar approach to track distance and direction can be implemented in a miniaturized design of a ring-like, bearing-based device to be mounted at the anus. In Fig. 22, such a device is shown. The device has one or more trackballs 81' that detect the forward-backward motion when the colonoscope passes across the ring and makes the trackball roll. Overall dimensions of the ring device are presented in Fig. 22 as well.

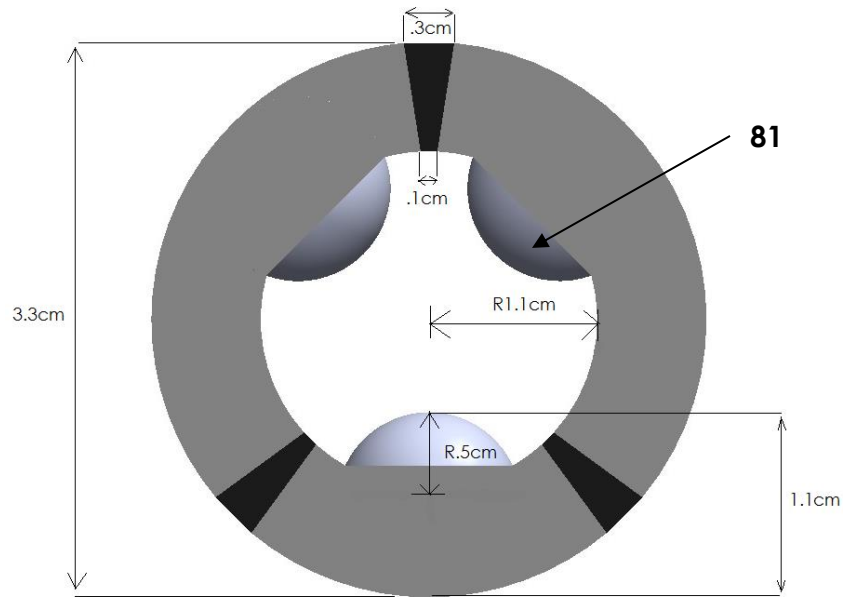


Fig. 22 Ring-like design intended to be placed at the anus

Fig. 23 depicts the transversal section of the ring device mounted at the anus. The device contains one or several protruding balls 91'; each one of them is held by a socket surrounded by the ring. The socket contains the electronic components that record motion when the trackball rolls as a result of the colonoscope movement.

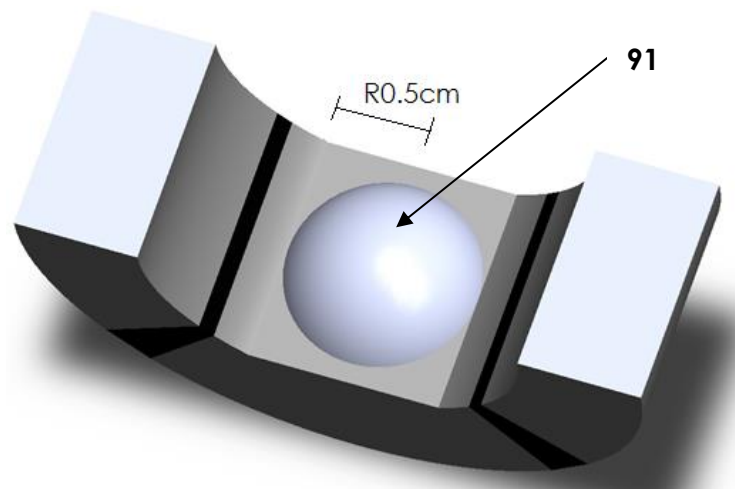


Fig. 23 Cross-section of the ring attached to the anus

Fig. 24 depicts a 3D general view of the ring device to be held at the anus. The ring device slightly embraces the colonoscope, which is positioned in the middle section 103' of the device. The ring diameter can be automatically adjusted in order to assure surface-to-surface contact between the trackball and the colonoscope. This is possible thanks to some portions of extensible material 108' in the ring. This material gets stretched when positioning the colonoscope, and shrinks once the colonoscope is placed in. However, the free movement of the colonoscope is still guaranteed since the ball 101' offers no resistance to movement when being in contact with the colonoscope surface.

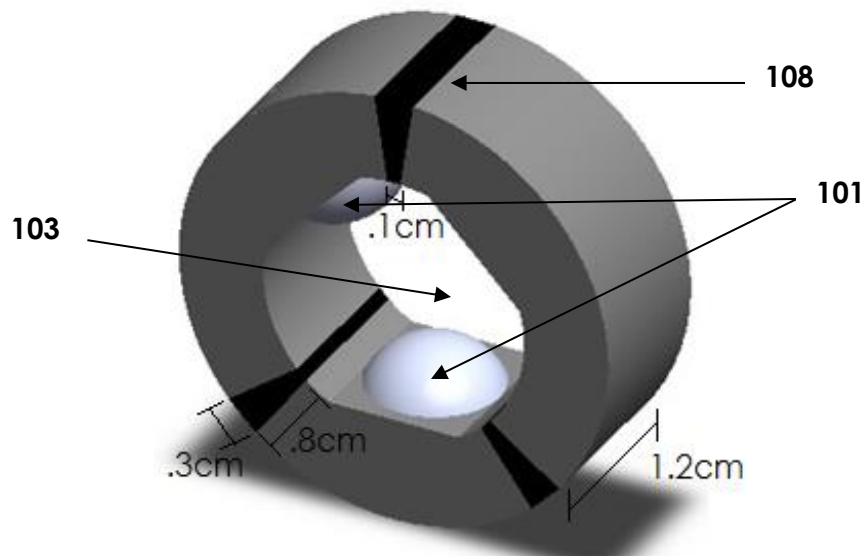


Fig. 24 Complete 3-D view of the ring device affixed to the anus

Fig. 25 depicts a colonoscopy procedure where the ring device 117' is positioned immediately outside the anus, in front of the endoscopist's hands. The miniaturized device doesn't hinder the colonoscope handling by the doctor.

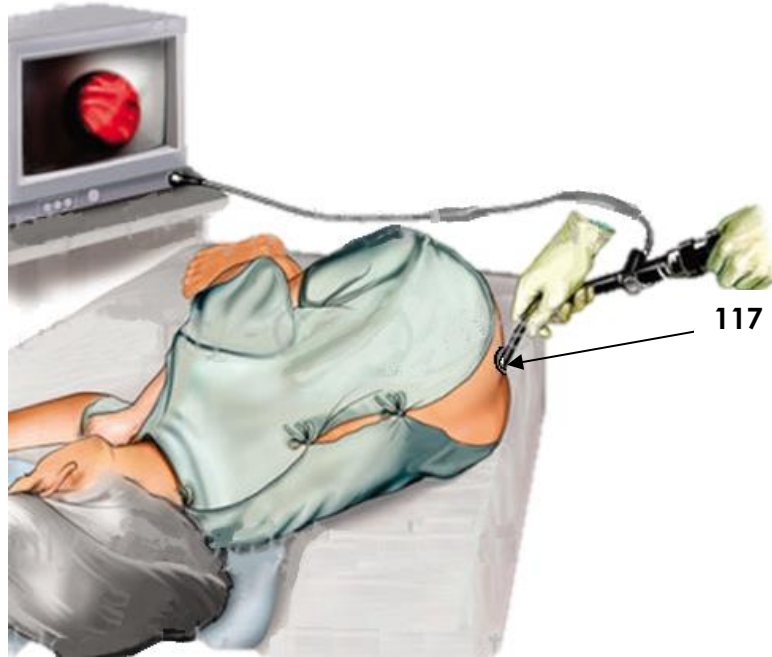


Fig. 25 Colonoscopy procedure set up including the ring-like device positioned at the anus [86]

2.3.1 Calculated Parameters by the colonoscope tracking device

a. Distance and Direction

An encoder is an electromechanical device that provides a signal, from which distance and direction can be read.

In an encoder, two output signals are phase sifted by 90 degrees as seen in Fig. 26, which is referred as quadrature output. The two signals are interpreted as a pulse up and a pulse down. The traveling distance can be calculated from the number of pulses released by either sensor. The direction of movement can be calculated by an encoder when comparing two signals A and B, and detecting which pulse occurs first [87].

The encoders are used to measure distance and direction in the existing colonoscope tracking prototype that is affixed to the bed. When measuring the side to side motion, tracking balls within the ring-device will be used instead.

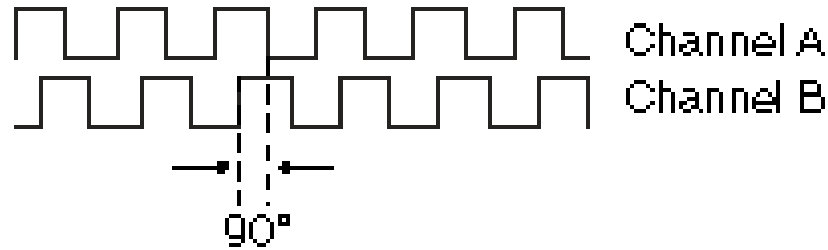


Fig. 26 The 90 degrees time shifting in the encoder signals [87]

b. Velocity

The velocity at which the colonoscope travels is calculated by determining the frequency of the encoder pulses.

In the event it is intended that the colonoscope tracking device provide the velocity parameter outputted already by the Colometer, the processing time to compute it will be significantly reduced. The estimation of velocity will become very straightforward because the necessary input data will be expressed in terms of distance and time. Then, we might proceed to ask skilled endoscopists to conduct colonoscopies and register their average speed, from which threshold ranges for a satisfactory speed will be defined.

c. Forward and backward movements

Based on the calculation of the ratio between forward and backward movements, other movements can be assessed if desired.

Torque and side-to-side movements

Formation of loops and use of torque to assess STS movement will be calculated. STS motion is generally required for a thorough assessment of the colon (i.e. to look behind folds and corners) during withdrawal. Also, looping of the scope upon insertion often leads to difficulty advancing the scope and causes patient discomfort. Looping can also significantly affect withdrawal due to

erratic and unpredictable effects when the loop unfolds. The system can assess these movements through STS movement of the trackballs in the ring device.

Retroflexion

The device could confirm that rectal retroflexion was performed at the end of the screening procedure.

d. Withdrawal time

With the purpose of automatically calculating the time spent during withdrawal time, it is possible to identify the border line between insertion and withdrawal phases. Although, during the insertion phase most movements are forward, the maneuvering of the colonoscope when trying to reach the cecum demands a combination of forward-backward movements. Similarly, during withdrawal phase, there would be a combination of backward-forward movements, as that is when the endoscopist makes an effort to look around folds and corners to find polyps. However, the withdrawal phase is mostly backward. Considering this characteristic, the colonoscopy video can be segmented into 2 parts [69].

It is possible to have a counter for the pulses released by the two encoder signals to determine the length of forward and backward movements. Then, a trajectory can be outlined on the assumption that a forward movement corresponds to a positive pulse (+1), and on the contrary, a backward movement corresponds to a negative pulse (-1). If all pulses are added up, the maximum distance travelled in the lower GI tract will correspond to the maximum accumulated positive value. From this point on, the travelling distance left will correspond to the withdrawal phase. For this reason, the point that divides the two phases i.e. insertion/withdrawal will be the maximum value of the pulse counter.

e. Image blurriness

After detecting the speed the colonoscope travels, it is possible to relate a high speed movement to the formation of non-informative frames, and then omit them from the colonoscopy video.

This method should be source-coded in the future, but flowchart is presented on Fig. 27.

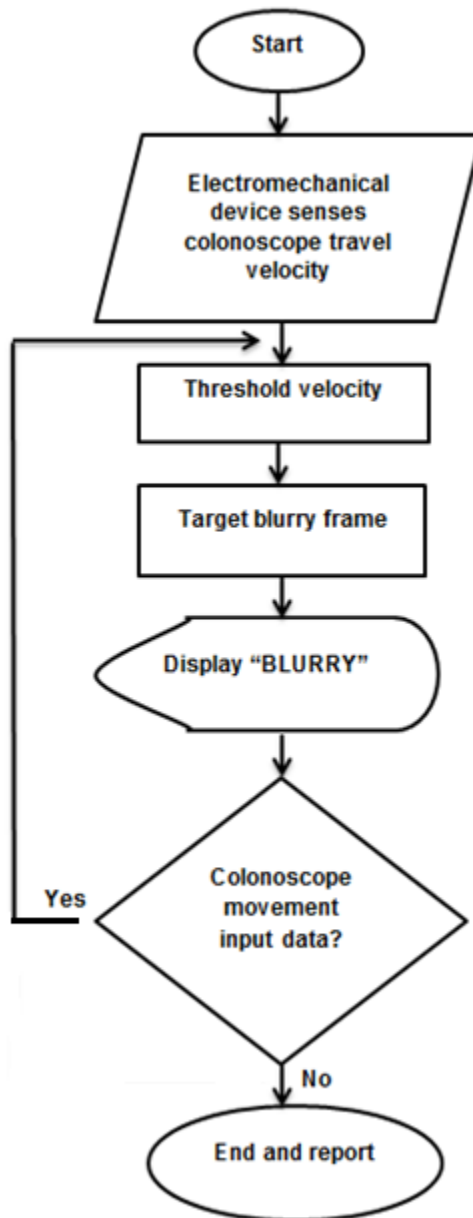


Fig. 27 Flowchart for frame blurriness detection in colonoscopy videos by the electromechanical tracking device

f. Additional features of the colonoscope tracking system

An additional benefit of this technology is that it displays a table of summary metrics and graphics of the ratio between forward and backward movements after the colonoscopy is completed. Fig. 28 shows a theoretical graph that was prepared under the assumption that the ratio of forward/backward movements is greater during the withdrawal phase, and that this phase is around 6 minutes long.

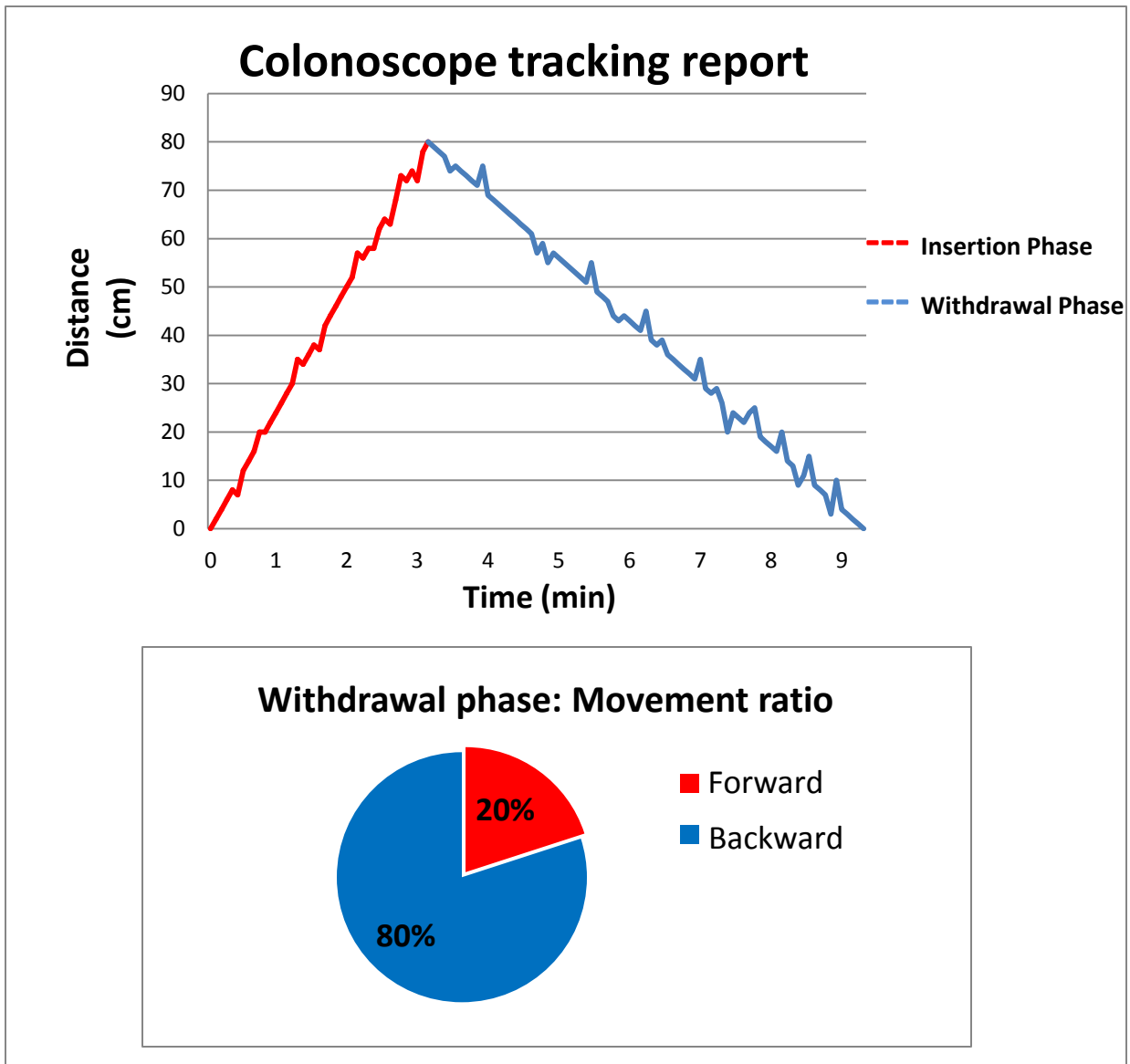


Fig. 28 Summary report sample on the colonoscope movement

2.4 Integration of the Colometer with the Electromechanical Device for Colonoscope

tracking

In order to achieve a comprehensive overall evaluation of colonoscopy procedures, it would be ideal to have a simple-to-use embedded technology that could present precise results about colonoscopy quality and could document them in a database. These metrics include quality of image and withdrawal velocity that the Colometer system already provides, in addition to the bowel preparation estimation and finally the monitoring of the colonoscope direction parameter provided by the electromechanical device proposed here.

Unfortunately, the Colometer can't reliably measure the scope movement from the video, since the colon can move over the scope just as easily as the scope can move through the colon. Consequently, with the integration of an electromechanical tracking device, the scope movement can be recorded. With an electromechanical tracking device as part of a system to quantify the quality of colonoscopy, the processing time to compute output parameters presented by the Colometer will be significantly reduced, since the estimation of velocity and blurriness will become very straightforward, as described in the section 2.3.1.

Table 4 shows compiled information about all the parameters that the Colometer can provide by itself, and together with the electromechanical tracking device. It is concluded that by the integration of both systems, a colonoscopy procedure can be fully evaluated. Moreover, the Colometer integrated with the electromechanical tracking device could definitely compete with patents described in section 1.7, since this new system provides quantification of parameters for colonoscopy quality assessment in a computationally fashion.

Parameter		Colometer (Stand-Alone)		Device for colonoscopy tracking			
Yes/No	Description			Stand-Alone		Integrated with Colometer	
Objective		To offer real-time feedback to clinicians during colonoscopy. To offer a report for both doctor and patient awareness of the procedure quality.		To propose a real-time evaluation system to improve the quality of colonoscopy. To automatically document the procedure in an evaluation report.			
Determination of forward and backward movements		N		Y	When the colonoscopy cord passes through the tight middle section of the device, electromechanical sensors are able to track the distance and travelling direction.	Y	Using the approach described in the device for colonoscopy tracking (Stand-Alone).
Withdrawal time calculation		N		Y	Similarly to De Groen's patent (#US7,894,648), it is possible to have a counter for the positive and negative pulses released by the encoder in the electromechanical device to determine the moment when the withdrawal phase starts.	Y	Using the approach described in the device for colonoscopy tracking (Stand-Alone).
Blurry frame identification/ Non-informative frame filtration		Y	The analysis of blurriness consists of calculating the variance of the frames.	Y *	After detecting the speed the colonoscopy is travelling, it is possible to relate a high speed movement to the formation of non-informative frames, and then omit them from the colonoscopy video.	Y	Using the approach described in the Colometer (Stand-Alone) since it has been already developed and tested.

Scanning Speed Calculation	Y	It uses frame differencing technique based on image contrast. This means that images are compared point-by-point pixel values within the previous frame and the current frame.	Y	Easily calculated by dividing the colonoscope traveling distance by the time that has elapsed.	Y	Both the Colometer and the device for colonoscope tracking provide this parameter separately. However, the easiest calculation is offered by the device for colonoscope tracking.
Stool detection	Y	The algorithm is based on color recognition.	Y * *		Y	Using the approach described in the Colometer (Stand-Alone).
Calculation of additional parameters	Y	Colometer displays a color bar indicating adequate velocity and image blurriness.	Y	The device for colonoscopy tracking can measure and display most important parameters for the colonoscopy assessment. The integration of the stool detection code used in the Colometer will complete the evaluation.	Y	The electromechanical tracking device combined with the Colometer can display all parameters mentioned in this table, including evaluation of the colon cleanliness. All algorithms have been already coded.

Table 4 Comparative table on the Colometer performance as a stand-alone technology and as an integrated system with the electromechanical tracking device. The second alternative provides the measurement of most valuable parameters to quantify the quality of colonoscopy

*Should be source-coded, but flowchart is presented on Fig 27.

**The stool detection code itself used in the Colometer can be integrated to the electromechanical tracking device.

3. Results

3.1 The Colometer: frame analysis

For a colonoscopy procedure, it is widely known that the visualization quality during withdrawal is higher than the visualization quality during insertion process. Based on this assumption, a comparative study was performed to validate the functionality of the proposed algorithm by comparing the system outputs (% of time of adequate speed in a colonoscopy) between the insertion and withdrawal for 10 colonoscopy procedures. The 10 videos, which were used for validation of the functionality of the proposed algorithm, were different from the videos used to validate the automated scores against an expert endoscopist. The average percentage for the colonoscope withdrawals was $79.3\% \pm 4.96\%$ and it was $50.3\% \pm 13.95\%$ for the insertion procedures. In a total of 10 collected videos, there was a significant difference of $29.1\% \pm 11\%$ ($P < 0.01$) between both procedures. Comparative results are shown in Fig. 29.

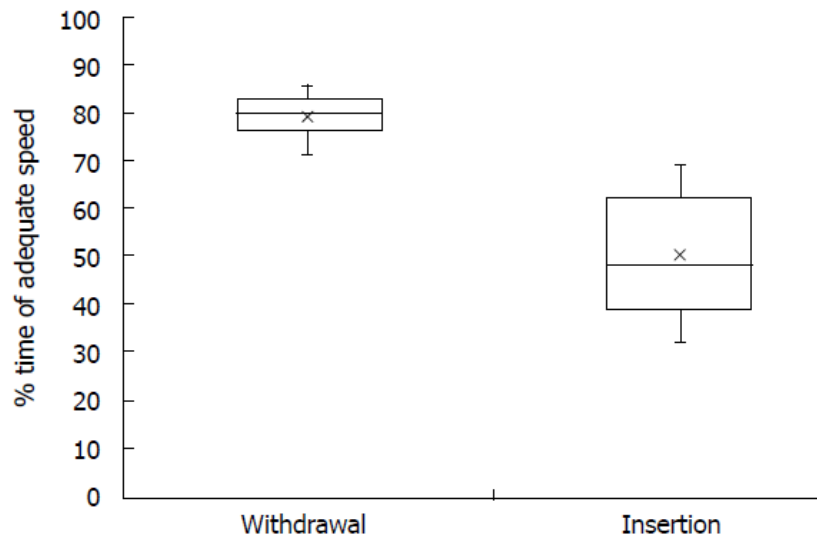


Fig. 29 Comparative results (withdrawal vs. insertion) for 10 colonoscopy procedures.

The output mean values are marked with a cross

a. Correlation between the system output and the subjective endoscopist evaluation

Subsequently, an overall colonoscopy quality rating was computed based on the percentage of the withdrawal time with adequate visualization (scored 1-5; 1, when the percentage was 1%-20%; 2, when the percentage was 21%-40%, etc.). Adenomatous polyps were detected in 4/14 (29%) of the collected colonoscopy video samples. There were large differences in the withdrawal times during which no polyp was removed (range: 4-12 min). The percentage time with adequate visualization in the videos (i.e., not blurry and not over the velocity threshold) ranged from 54% to 81% (mean $68\% \pm 2\%$). The median quality rating from the automated system and the reviewers was 3.45 [interquartile range (IQR), 3.10-3.68] and 2.67 (IQR, 2.33-3.00), respectively, for all colonoscopy video samples. However, there was significant variability in the endoscopist ratings (free-margin kappa statistic = 0.20). The automated overall quality rating revealed a strong correlation with the reviewers overall quality rating (Spearman r coefficient = 0.65, $P = 0.01$) as can be seen in Fig. 30A. Similarly, there was good correlation of the automated overall quality rating and the mean endoscopist withdrawal speed rating (Spearman r coefficient = 0.59, $P = 0.03$) (Fig. 30B). There was no correlation of automated overall quality rating with mean endoscopists image quality rating (Spearman r coefficient = 0.41, $P = 0.15$) (Fig. 30C). There was no correlation of the automated blurriness or excessive velocity metrics and mean endoscopists ratings (data not shown).

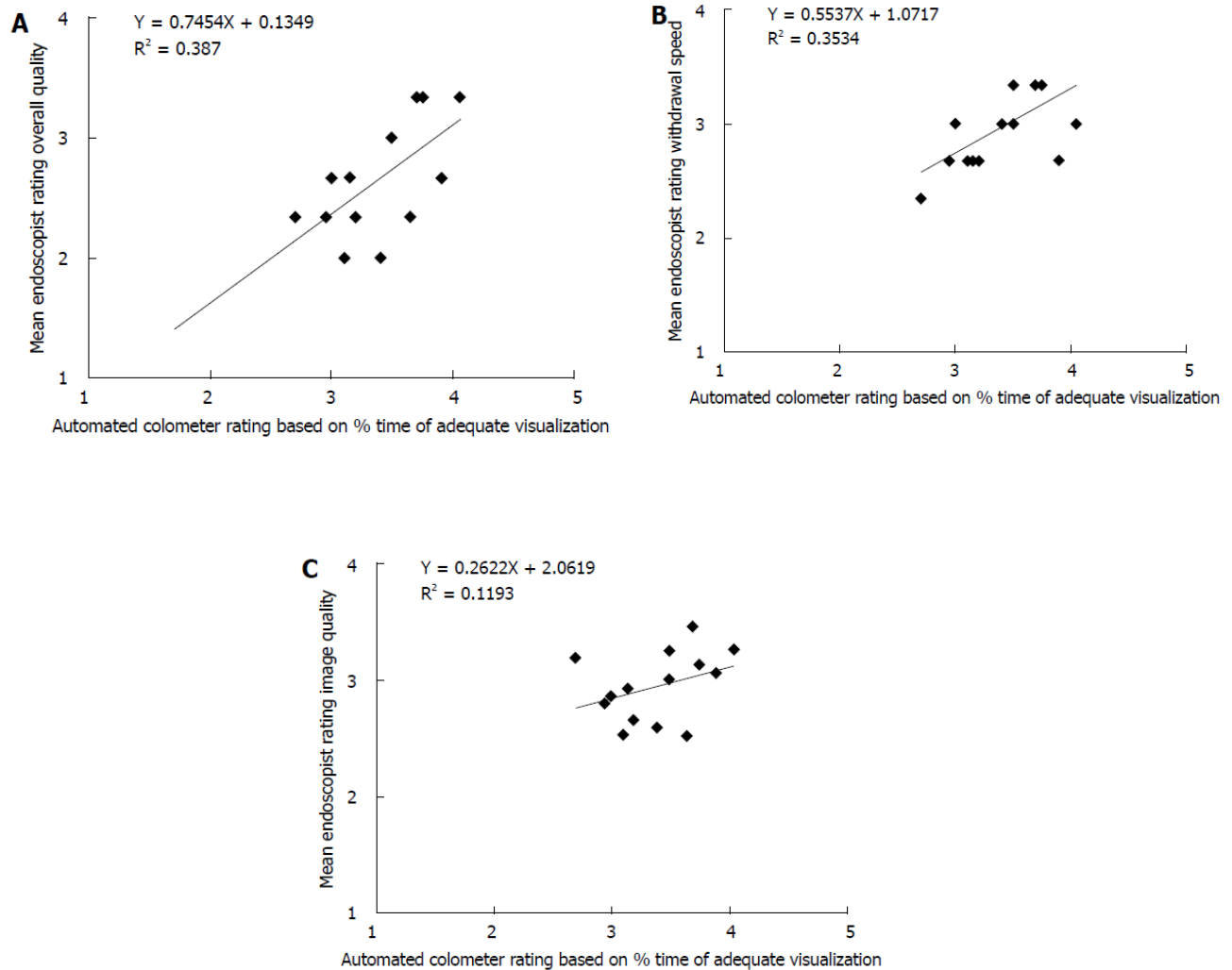


Fig. 30 Correlation between the overall quality ratings from the Colometer system. A: Mean endoscopist overall quality rating ($\rho = 0.65$, $P < 0.01$); B: Mean endoscopist withdrawal speed rating ($\rho = 0.59$, $P < 0.01$); C: Mean endoscopist image quality rating ($\rho = 0.41$, $P = 0.15$).

- b. Comparative analysis between the withdrawal standard and the proposed algorithm

The mean withdrawal time of the videos was 5.8 min (± 0.4 min SE, range 4-10 min). Out of the 14 colonoscopy withdrawal videos, 2 videos with 6 min withdrawal time were rated as poor quality with low diagnostic yield by 3 endoscopists and confirmed with the Colometer. There

was no correlation of automated overall quality rating and withdrawal time (Spearman r coefficient = 0.11, $P = 0.70$).

3.2 Stool detection

Table 5 lists the results utilized to perform the correlation between the Ottawa scores given for each one of the segments in the colon and the mean value of the percentages of pixels identified as stool over the total pixels in the image for each segment in the 13 videos. The values are plotted in Fig. 31, which demonstrates the relationship between the Ottawa scale scores and the percentages retrieved from the proposed system. After performing Pearson correlation analysis [88], the obtained correlation coefficient r was equal to 0.61 which confirmed that there was a statistically significant correlation between the Ottawa scale score given by the endoscopist and the percentage output of the software ($p < 0.01$). Alternatively, the coefficient of determination (r^2) was obtained by squaring Pearson correlation coefficient. It calculates the linear relationship strength between two variables [89]. In this study, the coefficient of determination estimated that 37% of the variances of either variable (Ottawa scale scores and percentages of stool as determined by the proposed algorithm) are shared between one another.

Segment	Right			Mid			Rectosigmoid		
Video #	Ottawa score	% of stool	Standard Deviation	Ottawa Score	% of stool	Standard Deviation	Ottawa score	% of stool	Standard Deviation
1	1	2.879	3.406	2	22.913	34.456	2	13.743	20.200
2	2	3.004	7.279	3	12.434	21.211	3	37.656	36.917
3	3	27.226	32.404	2	22.271	28.398	2	30.891	38.104
4	3	36.028	29.084	3	36.110	32.423	2	37.289	30.765
5	3	39.683	30.648	1	18.530	26.308	2	20.496	33.054
6	1	2.609	8.174	1	4.209	12.638	1	5.449	15.121
7	1	20.761	17.325	2	5.169	11.220	1	1.420	3.878
8	2	38.260	34.029	0	11.344	20.069	1	3.522	13.671
9	1	18.812	30.531	2	17.530	27.703	1	5.267	18.404
10	2	40.112	26.426	2	20.196	27.842	1	2.231	9.393
11	2	35.074	36.736	1	25.571	32.370	2	33.520	32.678
12	1	12.957	12.521	1	24.967	30.424	1	12.057	20.579
13	0	10.950	11.503	1	19.738	29.246	1	10.450	25.965

Table 5 Comparison between the proposed system results and the corresponding Ottawa scores. The percentages represent the per-video average of the ratios of pixels identified as stool over the total number of pixels per frame. The standard deviation of these percentages per video is also listed

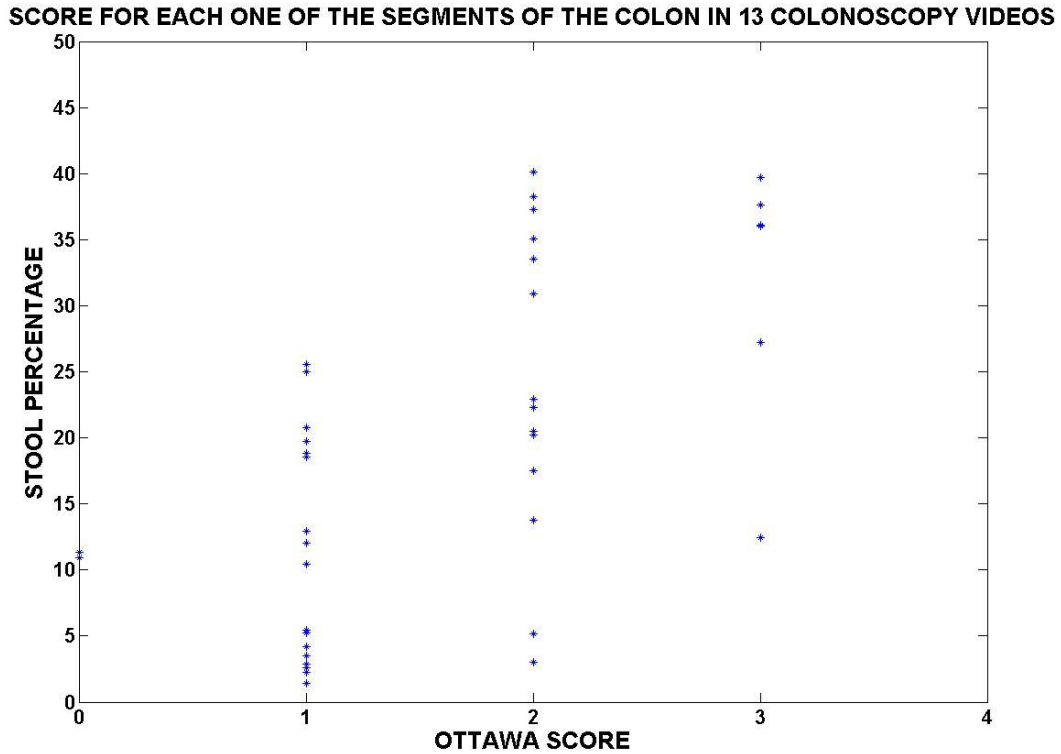


Fig. 31 Graphical representation of the statistically significant correlation ($p < 0.01$) between Ottawa scale scores and the mean of the stool percentages in each segment of the colon retrieved from the proposed system in 13 videos

3.3 The electromechanical tracking device

a. Animal testing

Animal testing was conducted on two hound dogs (2M, 25.1 kg, 26.4 kg). The experiments were approved by the Veterinary Science Animal Welfare Committee at the University of Calgary. The test setup is shown in Fig. 32.

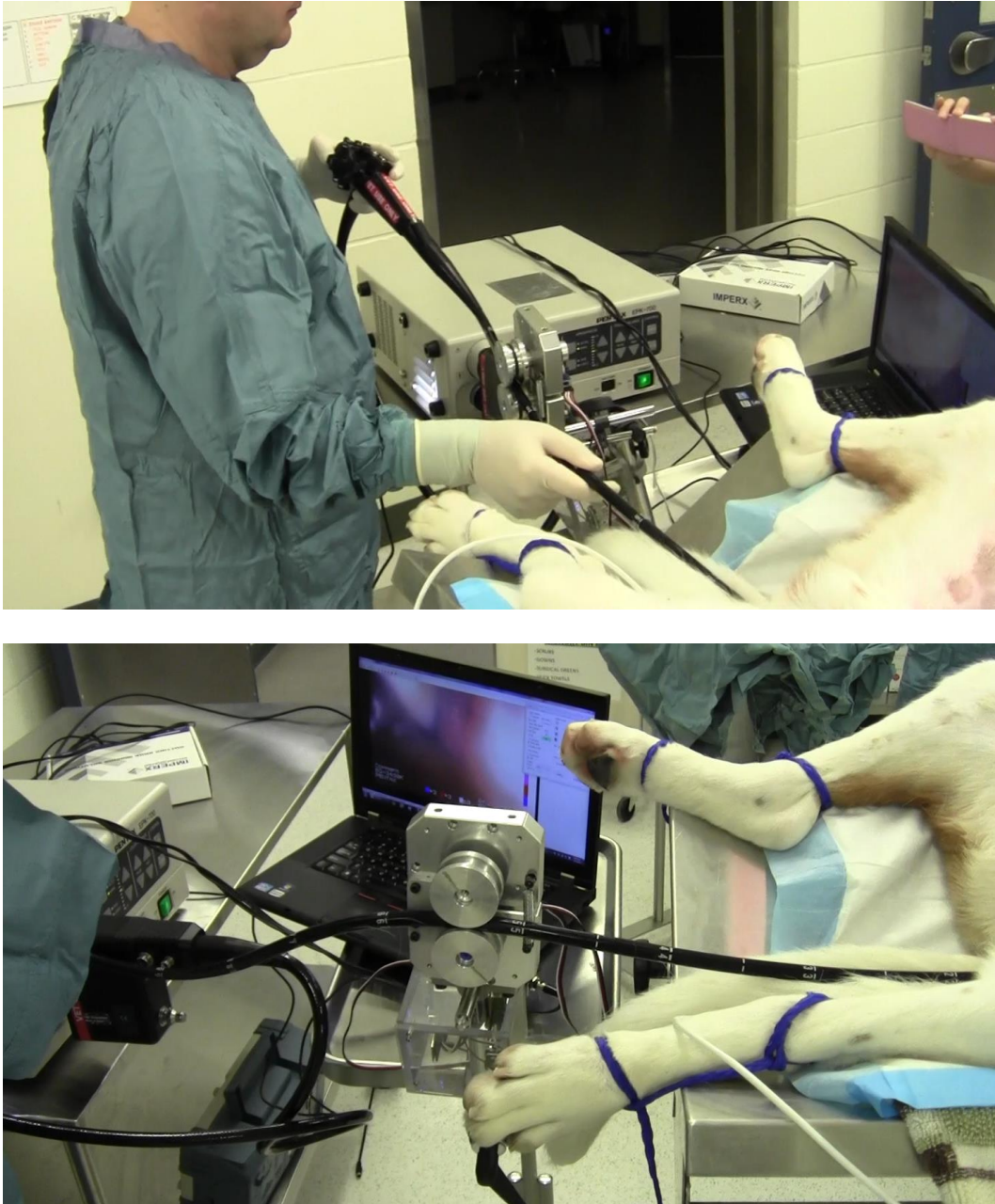


Fig. 32 Animal testing on dogs

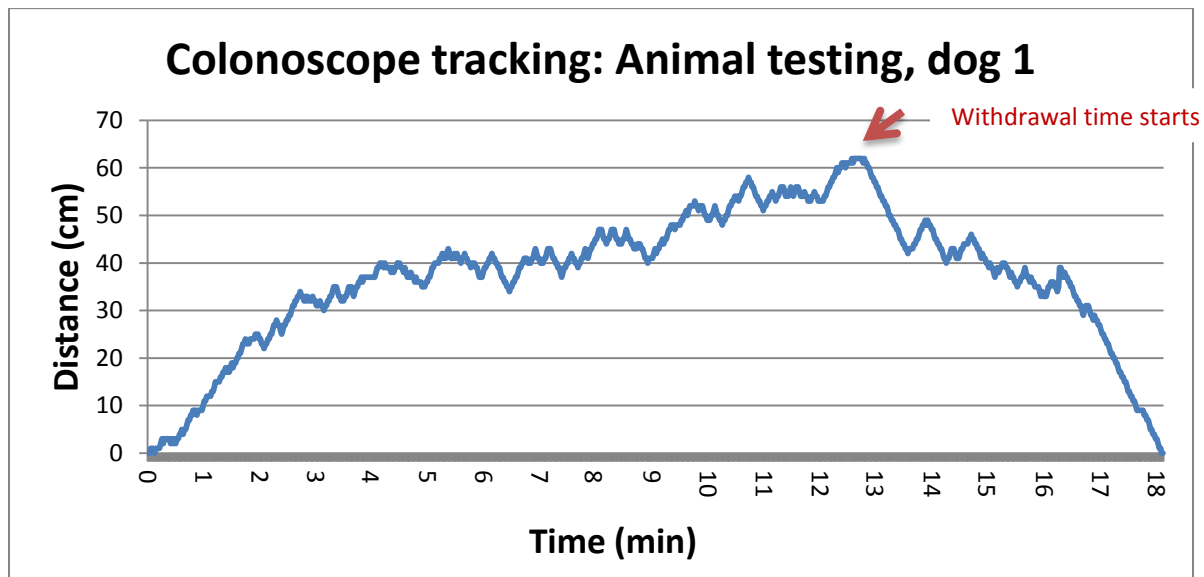
For the colonoscopy test, each animal underwent colon preparation, which consisted of a 48 hour-liquid diet followed by a phosphosoda enema before the colonoscopy procedure. Colonoscopies were performed by Dr. Martin P. Mintchev.

During these set of tests, two objectives were predetermined:

1. To verify the accuracy of the tracking device when measuring the travelling distance within the GI tract.
2. To be able to automatically define the separation between insertion and withdrawal time.

As shown in Fig. 33 the distance measured by the electromechanical tracking device during colonoscopy in dog #1 was 61 cm, and in dog #2 it was 59 cm. The average anus-to-cecum length in a hound canine between 20-28 kg is ~50–60 cm [90]. It can be presumed that our measurement is accurate since the measurements are very close to the upper value of the colon's length range.

For objective #2, we can clearly notice in Fig. 33 the maximum distance point, from where the slopes start to be mostly negative. This indicates the beginning of the withdrawal phase, and it coincides with the time when each dog's cecum was detected during the colonoscopic procedure.



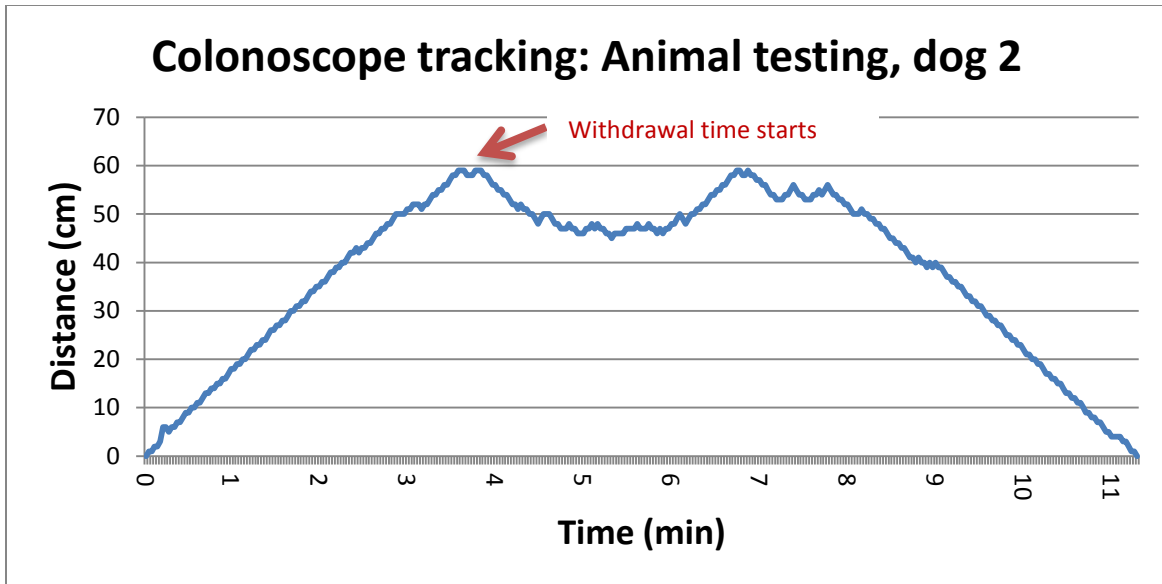


Fig. 33 Results on colonoscopy tracking during animal testing sessions. Above: dog#1, below: dog#2

The detection of the cecum verifies that the colon has been entirely observed, and a picture of a cecum anatomical landmark, such as the appendiceal orifice or the ileocecal valve is generally attached to the colonoscopy final report [20]. Fig. 34 shows both dogs' ceca.

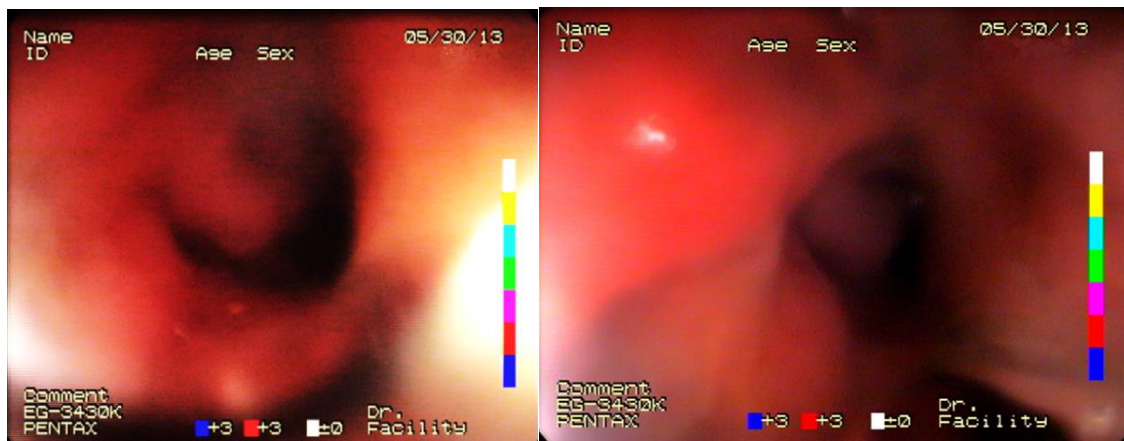


Fig. 34 Endoscopic images of dog cecum, for both dog#1 (left), and dog#2 (right), documenting the maximal distance reached anatomically in each case

Table 6 shows the performance of the colonoscope tracking device to identify the withdrawal phase. Column A shows the time where the cecum was identified in each dog; column B represents the automatic identification of the insertion-withdrawal boundary line by the colonoscope tracking device.

	Automatic boundary detection by the tracking device (min:sec)	Manual cecum identification (min:sec)
Dog 1	12:45	12:51
Dog 2	3:35	3:42

Table 6 Matching values in automatic and manual phase boundary detection

b. Simbionix simulator

The GI Mentor (Simbionix, Ohio, USA) is a simulator that provides training in gastrointestinal endoscopy procedures. This simulator recreates colonoscopy procedures based on real medical cases and images. It also uses an authentic colonoscope to match the tactile sensation in clinical use. The GI simulator provides a realistic tool for training in GI clinical procedures in a safe fashion [91].

The GI Mentor was selected to test the colonoscope tracking device. The simulator belongs to the Forzani & MacPhail Colon Screening Center in Foothills Hospital, Calgary. The test setup using the simulator is shown in Fig. 35.

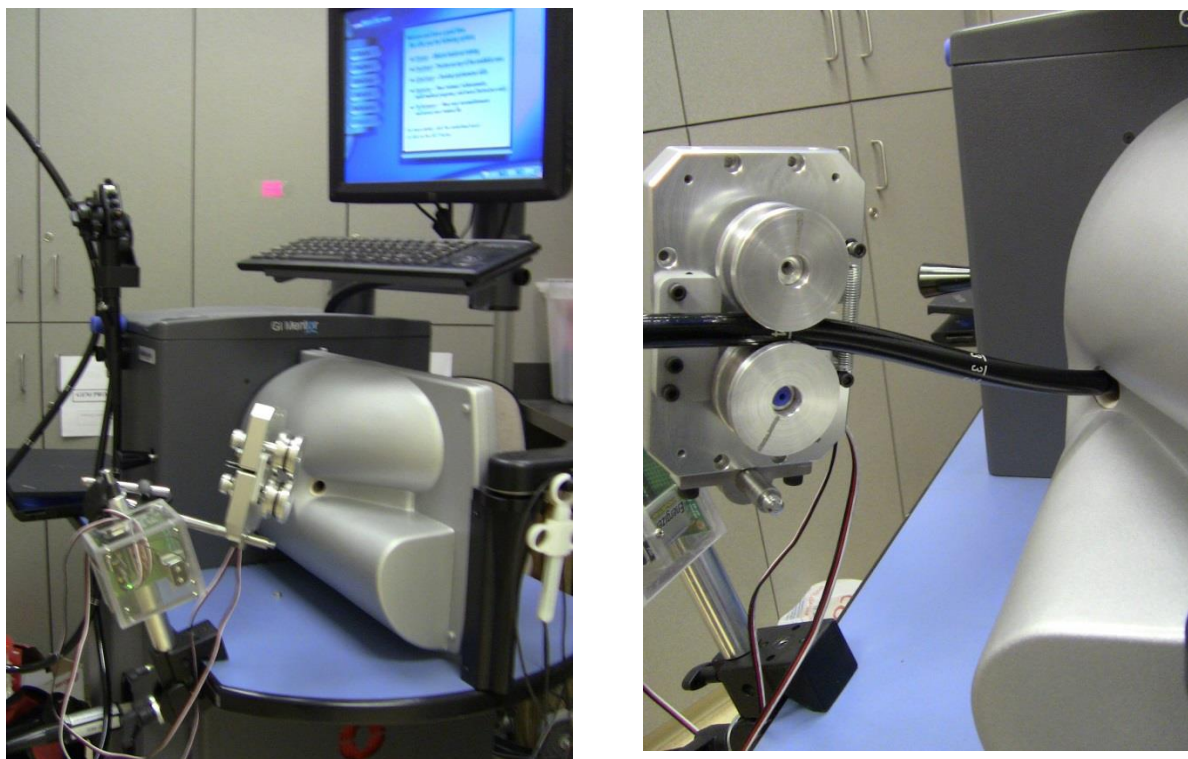


Fig. 35 Tracking device testing using the GI Mentor Simulator from Simbionix TM

The colonoscope tracking device was tested in two different cases, which are described below:

Case 1

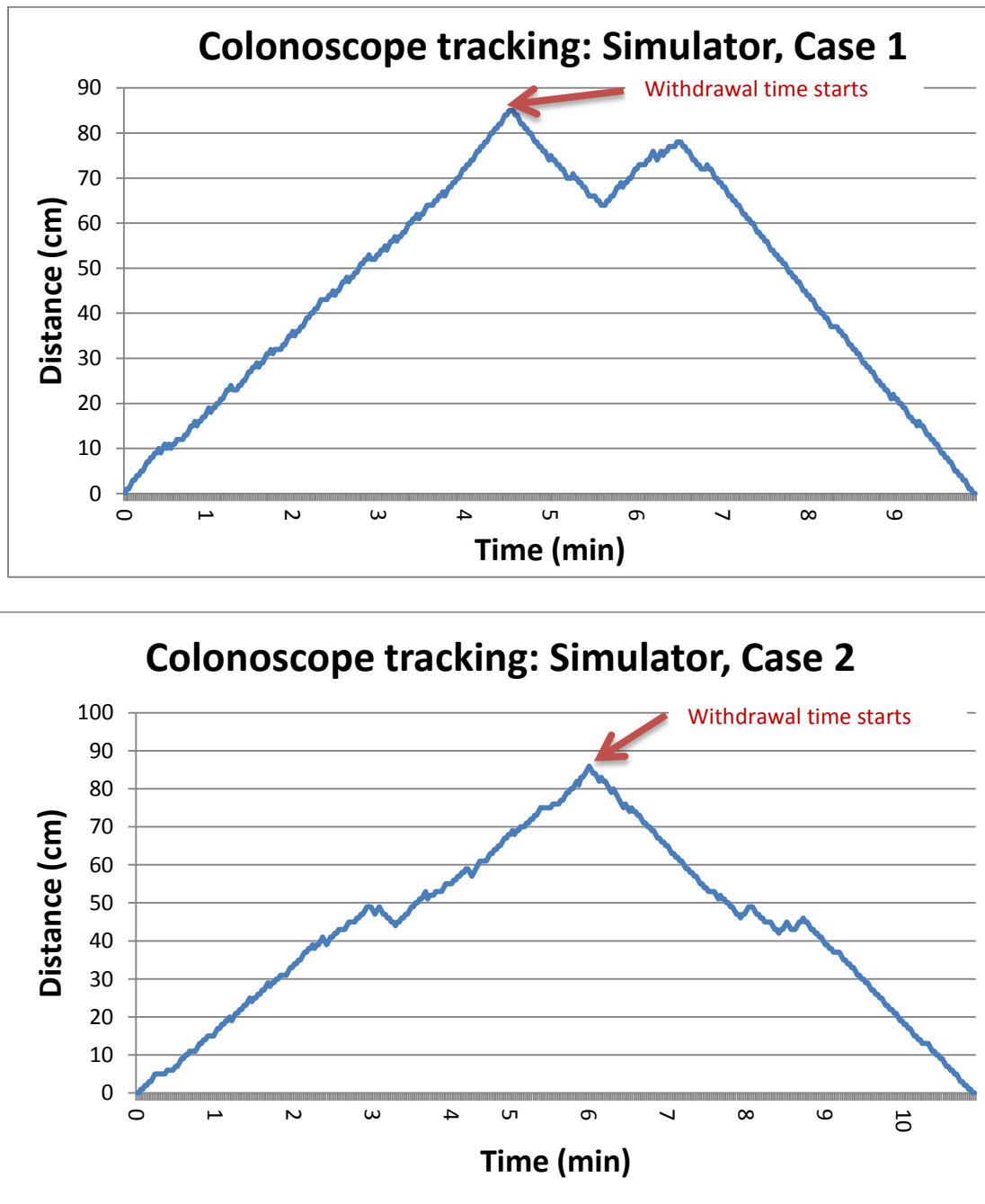
A 30 year old female, with irregular bowel movements, alternates between constipation and diarrhea. Stool is negative for parasites. She was referred to colonoscopy.

Case 2

A 70 year old male with constipation for 40 years. He has been taking laxatives for 30 years. He was referred for colonoscopy.

The simulator's colonoscope tube is 160 cm long. If during the colonoscopy simulation, the user inspects the colon linearly, approximately half of the tube will be used to examine from anus to cecum. The total distance measured in both simulation tests was around 85 cm, which matches the insertion length of the colonoscope tube into the simulator's model body. In a same

manner to graphs retrieved from the animal testing, in Fig. 36 there is a trajectory in the graph that represents the withdrawal time, and this is from the greatest distance reached to the end of the recording.



**Fig. 36 Results on colonoscope tracking using a colonoscopy simulator. Above: case 1,
below: case 2**

Finally, since the simulator doesn't provide any resistance to the scope, it is straightforward to reach the maximum distance in the simulator body model. In order to assess the reproducibility of our test, each of the two simulator cases must be repeated 15 times in the future.

4. Discussion

Colonoscopy is widely used for CRC screening [92, 92-94] but its miss rate for significant lesions remains a concern [95, 96]. Quality assurance initiatives have been adopted by most national gastroenterology societies, with the mean withdrawal time for colonoscopy strongly correlating with adenoma detection rate; however, there are some other parameters that can serve as indicators for the assessment of colonoscopy quality as well.

In our study, widely recommended criteria for colonoscopy procedures were analyzed, including quality of the bowel preparation, withdrawal time, the video quality, and determination of the colonoscope traveling distance and direction. An embedded system was developed to get these parameters, and remarkable results were achieved when testing the software and hardware parts of the system. However, this was a pilot study; therefore, there are still some limitations and areas of opportunity, which should be considered for future work on this project. The most remarkable aspects of this project are discussed below.

a. Stool detection

The present study describes the development of a system that measures the amount of stool matter in the colon as an approach to quantify the quality of colonoscopy. The main part of the algorithm is color-based detection by hue color space.

In order to set the percentage range that would determine whether the quality of bowel preparation is “Excellent”, “Good”, “Fair”, “Poor” or “Inadequate”, the software should be improved in order to get more consistent results and have less variability in the group of points that correspond to each value in the Ottawa scale. Therefore, the reliability of the software cannot be presently evaluated, and it will be necessary to include some improvements to the code in order to get a greater determination coefficient and confidently conclude that the results are close to those in the Ottawa scale.

There are some potential factors that have an impact on the number of target pixels detected. Among them is the type of consumed laxative, since this might determine the color of the stool, ranging from yellow shade color to a green shade color. Furthermore, in order to agree with the Ottawa scale, the amount of fluid within the colon should be detected separately and automatically displayed by the system as a percentage output. Finally, an additional factor that affects the measurement is the quantity of blurry frames that can be identified in the video. These frames hamper the correct detection of stool matter in the colon. Future work should consist of automatically removing unclear image frames, especially when cleaning maneuvers are being conducted. So far, it is believed that when the stool detection code gets integrated to the Colometer in real time, blurry images will be automatically discarded. In the event the stool detection code is used as a stand-alone, edge analysis could be an appropriate method to discard blurry frames, based on the assumption that the latter would not contain edges.

In summary, our approach for evaluating the quality of bowel preparation accounts for 3 factors:

1. Color of stool
2. Amount of fluid

3. Quantity of blurry images

Since these factors are uncontrollable, it is important to implement a calibration system that can distinguish between different color tonalities of fluid, stool matter and colon walls and can automatically adjust the HSV threshold values accordingly.

Overall future clinical testing of the developed system should include comparing polyp detection rate in colonoscopy utilizing colon cleanliness evaluation.

b. The Colometer: frame analysis

The Colometer is a software-based system created by the Low Frequency Instrumentation Laboratory at the University of Calgary. It is a real-time feedback tool for colonoscopic procedures. The Colometer basically offers an indicator for image velocity and blurriness that is displayed on the endoscopist's monitor in real-time [65].

The Colometer system is a user-friendly method for evaluating the quality of individual screening colonoscopies. This is in contrast to many endoscopist-based quality indicators, such as mean withdrawal time [97]. It has been accepted that endoscopists who use withdrawal times longer than 6 min detected significantly more adenomas. However, many endoscopist's colonoscopies will presumably have a withdrawal time below 6 min [23] and may have lower adenoma detection rates. The individuals with the more rapid withdrawals will not likely be aware of this fact. Further, calculation of mean withdrawal rates is labor-intensive, and even if published, will not likely affect patient choice of endoscopist. Quality indicators for colonoscopy have been selected to establish competence in performing colonoscopy procedures and to help define areas for continuous quality improvement [98, 99]. The Colometer quality measurements appear to correlate well with these outcomes in this small study.

This computer-based method is based on image processing analysis of the live video feed from the colonoscopy processor, and just as easily can be run on digitized video files for retrospective review. The method uses widely available video processing technology and can be retrofitted onto any endoscope processor with digital video output. No remote video processing is required, which will prevent any privacy breach risks. Output of summative metrics is immediate, and could be added to individual endoscopy reports, as well as to a database for simple collection of quality control data in the practice setting on a large scale.

This study was designed to show the proof of the Colometer concept and compare it to subjective quality assessments based on retrospective video recordings of colonoscopy. The software however is designed to provide real-time visual feedback to the endoscopist during the withdrawal itself. We did not evaluate the actual feedback to endoscopists during the colonoscopy to determine whether this type of output (like a speedometer for the scope driver) affects withdrawal speed or other quality measures, but studies in this regard may be conducted in the future. Further uses could be realized in the education and (re)credentialing fields.

Limitations

This study has some limitations. First, it was a small pilot-study looking at mostly good quality colonoscopies. The performance characteristics of Colometer may change with a broader spectrum of colonoscopy withdrawals. Second, overall quality of a screening colonoscopy is a multi-dimensional concept, which may not be completely captured by a small number of quality metrics. The established metrics are certainly not perfect (as shown by the fact that 2 of the videos with a 6 min withdrawal time were in fact of poor quality), but the advantage of an automated system removes the variability and subjectivity of current quality metrics.

Third, the small numbers in this study may have led to underpowering of the correlations. Additionally, the inter-rater variability was high. This is due to a number of factors, including the fact that the rating scale used was invalidated, despite its simplicity and face validity. Moreover, the raters were not trained prior to the study to “anchor” their responses, which we admit is a limitation of this study. Interestingly, the rater with the most experience in colonoscopy quality assessments had significant correlation with Colometer (data not shown), and thus inter-rater correlation will likely be tighter in future anticipated studies.

c. The electromechanical tracking device

This invention is a one-piece miniature device that tracks the colonoscope movement. Its placement is simple, since the clinician has to attach the device to a steady surface, so that the colonoscope shaft can pass through the middle section of the device triggering the operation of the embedded position sensors. Its fabrication process has been simplified compared to other approaches, since it basically consists of an apparatus with one or several electromechanical tracking sensors. It doesn't require any modifications from the colonoscope manufacturers as the electromechanical tracking device is placed externally to the colonoscope. The system delivers and analyses information about the forward and backward distance travelled in real time.

Once forward and backward movements of the colonoscope have been recorded throughout the colonoscopic procedure, a further application of the invention described herein is the automatic documenting of the withdrawal time.

The withdrawal time can be easily calculated after detecting a boundary between the insertion and withdrawal phases as described in patent #US7,894,648 B2, but considerably facilitating the algorithm described therein. Instead of using the affine motion model for DCM

value calculation [64], the electromechanical tracking system can simply count the positive and negative pulses generated by the device encoder.

Moreover, the speed calculation just requires a simple division of the colonoscope traveling distance by the time. The speed assessment can be used as a real-time feedback for the doctor for the achievement of good colonoscopy tests, as proposed on the description of the Colometer system. Also with the speed it is possible to infer the quality of the video frames, as blurry images can result from rough movements of the colonoscope, thus allowing their automatic omission from the colonoscopy video. The above-mentioned applications can help to create a colonoscopy video database where the video storage space and, respectively, the necessary time for video assessment, will be significantly reduced.

Limitations

Even though it was proved that the electromechanical tracking device could accurately detect forward/backward movements and the insertion/withdrawal boundary during colonoscopy in clinical testing sessions, this study has some limitations. First, it was a small pilot-study (2 dogs and 2 simulations). It was planned to do a correlation study between the image blurriness output provided by the Colometer software and the velocity parameter calculated by the electromechanical tracking device. Unfortunately, we didn't have adequate technology to conduct the colonoscopy since the colonoscope we used in the veterinary facility, the PENTAX EPK 700, is an obsolete model, thus, we experienced limitations in the image quality. The image quality affected the blurriness detection, constantly outputting a blurry image, therefore, restricting the creation of a correlation. Ultimately further studies with a large number of colonoscopies in real patients will be required to validate the usefulness of the colonoscope tracking device, both on its own and in conjunction with the Colometer software.

Finally, in order to have an overall assessment of colonoscopy quality, the stool detection code used in the Colometer can be added to the electromechanical device embedded system. For an overall evaluation of a colonoscopy, summative statistics, including withdrawal time, percentage time with adequate visualization and a novel graph of forward and backward movements over time could be presented for clinician and patient awareness after colonoscopy.

5. Future work

The present study describes the development of a system to quantify the quality of CSPY. It measures the amount of stool matter in the colon and monitors the traveling distance and direction of the colonoscope device during the procedure. Future work will consist of generating a calibration algorithm for the stool detection tool, and also defining an interval for the ratio of forward/backward movements that could be a metric for quantifying the quality of colonoscopy.

Finally, in order to have a general evaluation of colonoscopy procedures, in a future stage all tools described in this thesis should be integrated in a system programmed in LabVIEW, thus, the proposed software could provide complete quantitative results about colonoscopy quality and would be able to document them in a database.

a. Stool detection calibration tool

The main part of the stool detection algorithm is color-based recognition by hue color space. In order to set the percentage range that would determine whether the quality of bowel preparation is “Excellent”, “Good”, “Fair”, “Poor” or “Inadequate”, the initial development of the software should be improved in order to get more consistent results and have less variability in the group of points that correspond to each value in the Ottawa Scale. Therefore, it will be necessary to include some improvements to the code in order to get a greater determination coefficient and

confidently conclude that the results are close to those in the Ottawa Scale. There are some potential factors that have an impact on the number of target pixels detected. Among them is the type of consumed laxative, since this might determine the color of the stool, ranging from yellow shade color to a green shade color. Hence, it is important to implement a calibration system that can distinguish between different color tonalities of fluid, stool matter and colon walls and can automatically adjust the HSV threshold values accordingly.

b. Defining an interval for the ratio of forward/backward movements

It would be ideal to fabricate the electromechanical ring device described in this paper, then, torque measurements of the colonoscope movement inside the body could be documented. This would provide an extra parameter for the evaluation of the quality of colonoscopy

At present, to determine a suitable range of forward/backward movements during colonoscopy, it is necessary to contact a specialized ambulatory colon cancer screening center, e.g. the Forzani & MacPhail Center in Foothills Hospital. The validation procedure would consist of recording the movement of the colonoscope using our tracking device while simultaneously recording endoscopic image video of screening colonoscopies. Comparison of the ratio of forward and backward movements and STS movements (the latest is possible once we have a prototype of the ring device) during the insertion and withdrawal phases would be performed to assess a tendency of the analyzed data, and subsequently compared to the visual appearance of movement in the video. In conjunction with the Colometer software, the calculation of a number of quality parameters (forward/backward and STS ratios; image quality; colon preparation; withdrawal time; withdrawal velocity) will be effected. These parameters can be compared to expert opinion and validation in a large cohort of screening colonoscopy cases.

Further work will be required to optimize the tracking device for sterilization or single-use production, and for integration of the device output with Colometer software and ultimately the colonoscope manufacturer's reporting software.

- Proof of concept

For a colonoscopy procedure, it is presumed that there would be more combination of backwards/forwards movements on the withdrawal phase, as that is when the endoscopist is actively looking for polyps. Based on this assumption, a study has to be completed to validate the functionality of the proposed algorithm by comparing the system output (ratio of forward and backward movements) between the insertion and withdrawal phases for at least 30 colonoscopy procedures.

- c. System integration

Finally, in order to have a general evaluation of CSPY procedures, in a future stage the bowel preparation evaluation system has to be incorporated with other useful tools that measure additional parameters of importance in CSPY, such as colonoscope direction monitoring and the ones already provided by the Colometer system: image quality and velocity determination during withdrawal. Therefore, further studies are required in order to better define optimal quality thresholds of these parameters, and to validate the Colometer approach in a larger clinical trial.

Measuring equipment is usually interfaced to a computer that can register the input data. The acquired data can be from analog or digital-output systems. To achieve a robust data acquisition system, system designs usually consider utilizing software and hardware together [100]. This way, the final user can control the system operation through a PC, and visualize the results acquired by the hardware in a real-time fashion as well. Our system has software and hardware components, and it is necessary to integrate them as a whole system in the future.

The overall system for quantifying the quality of colonoscopy includes:

- The Colometer that provides colonoscope traveling speed during withdrawal, measurement of blurriness, and statistics of these parameters after colonoscopy. All these

features are programmed into a single Matlab code. Separately, there is the stool detection code also in Matlab that hasn't yet been integrated because of its limitations in the real-time processing. Additionally, as part of the system to quantify the quality of colonoscopy, there is a device for colonoscope tracking that utilizes a microcontroller with functions written in PBASIC.

For the integration of the whole system, it's necessary to include the codes in Matlab and PBASIC. LabVIEW would be the ideal platform for the system integration, since it has both an Image Processing toolbox and real-time acquisition tools. All features of the system to quantify the quality of colonoscopy have been already code-sourced in Matlab and PBASIC, so next step is to transcribe these codes to LabVIEW for an optimal system performance in real time.

Some advantages of the existing code in Matlab are:

- After using the Colometer software, a report on the measurement of different parameters is delivered. Here, it is easier to analyze the quality of colonoscopy through the visualization of graphs.
- A user-friendly interface, with which the user can operate in order to start and finish the recording, adjust the blurry and speed thresholds, and report the results.

These features are intended to be kept when rewriting the code into LabVIEW.

Materials for the system integration

To achieve the integration of the system for quantifying the quality of colonoscopy, it is required to have a colonoscope device available, a video image acquisition card (the Matlab code was written using the VCE Express Card), a computer with an input port for the VCE Express Card, and the very important electromechanical tracking device to be tested. In addition, Matlab and LabVIEW software should be accessible, with the Image Processing and IMAQ vision toolbox, respectively.

The electromechanical tracking device uses Bluetooth for wireless communication to the PC. LabVIEW versions from 7.1 to present versions support Bluetooth [101], with which communication from distant devices is possible. This is very convenient for the electromechanical tracking device operation, as it is better for the physician to avoid having devices around that can possibly distract him or her.

In the future, it will be necessary to conduct clinical testing of our system to quantify the quality of colonoscopy to validate its effectiveness. The system might be tested in multiple ways: using the electromechanical tracking device in its prototype stage, or already as a ring device; with the Colometer software, or as stand-alone. In any case, it will be important to know the existing regulations for medical devices by the Health Canada Agency. Furthermore, if commercialization of this device is envisioned in the future, it is essential to revise guidelines stipulated by the same Canadian institution. A brief description is presented below.

d. Health Canada approval for medical devices

In Canada, there are strict regulations for the approval of a medical device. These regulations are necessary to insure patients' health and security. Medical devices are regulated by the Health Canada's Therapeutic Products Directorate, and in order to get approval for commercialization, they have to meet all requirements stated on the Food and Drugs Act [102].

Device licensing

Health Canada classifies medical devices into four categories: from Class I to Class IV, depending on the risk factor for the patient in case of malfunctioning, the invasiveness of the device, the interaction with the patient, and the time it is in contact with the patient [102].

Almost all medical devices need a license to certify that commercialization approval in Canada has been granted; however, Class I is exempt [102]. Class I-medical devices are

considered to have a minimal potential risk for the patient. On the other hand, approval for Class II-medical devices is relatively straightforward. Regardless of representing certain risk for the patient, to get approval it is sufficient for a Class II-medical device manufacturer to submit a declaration to Health Canada [102]. This declaration must state that patient safety measures can be guaranteed by the device, as well as describing the advantages of utilizing the device.

Class III and IV medical devices must pass a thorough revision by Health Canada, since their use could be highly risky for the patient in the case of failure [102]. Table 7 summarizes the information mentioned above and provides some examples of medical equipment that fit in each category.

Health Canada Medical device classification based on risk			
Device Class	Risk	Examples	Licensing requirements
I	Lowest	Surgical instrument, laboratory culture media	This equipment doesn't require a device license, but the company that fabricates/commercializes the device should be authorized.
II	Low	Contact lenses, pregnancy test kits, endoscopes, ultrasound scanners	Manufacturers should apply for license from Health Canada, and renew it every year.
III	Moderate	Orthopedic implants, glucose monitors, dental implants, hemodialysis machines	
IV	High	Cardiac pacemakers, angiography catheters, cranial shunts	

Table 7 Medical Device classification by Health Canada. The classification is based on potential hazards associated with their use [102]

Investigational testing in human clinical trials

Permission should be obtained from Health Canada in case the manufacturer wants to conduct clinical testing to validate a medical device of Class II, III, or IV. In the case of Class I there is no need to have permission to conduct clinical trials, though it is mandatory to have a detailed record of the clinical tests [102].

In all cases, before clinically testing a new medical device, sponsors should have authorization from a Research Ethics Board, in which the clinical test protocol is approved and most importantly patients should give their consent to participate in the test.

We conclude that our technology belongs to the Class I group, then, which has the simplest authorization process, and just requires ethics approval to conduct clinical trials, without needing a device license to operate.

6. Contributions

The proposed system can lead to future quality control in daily medical practice and can be used to create best practice standards, since CSPY quality metrics would be automatically obtained. In addition, the system could also be part of training programs for endoscopists that would allow for easier continuing professional development and competence maintenance, as well as for becoming a tool for evaluation of medical skills. Finally, it could be pivotal for extracting information from already documented CSPY studies to conduct requirement analyses for future improvements of the procedure.

This work has already resulted in two journal papers in international journals, and in a patent application submitted to Innovate Calgary, the intellectual property company of the University of Calgary. Further information on these achievements is described below.

- i. L. Angulo-Rodriguez, M. P. Mintchev, C. N. Andrews, C. A. Simon. Electromechanical device for Colonoscope Tracking. Submitted to Innovate Calgary on June, 2013. Calgary, AB, Canada.
- ii. L. Angulo-Rodriguez, X. Gao, D. Filip, C. N. Andrews and M. P. Mintchev, "Automated system for quantifying the level of preparation in colonoscopy", ITHEA Journal, vol. 1, pp. 226-235, 2012.
- iii. D. Filip, X. Gao, L. Angulo-Rodriguez, M. P. Mintchev, S. M. Devlin, A. Rostom, W. Rosen and C. N. Andrews, "Colometer: A real-time quality feedback system for screening colonoscopy", World J. Gastroenterol., vol. 18, pp. 4270-4277, Aug, 2012.

7. Conclusions

Quality is a very important issue in medical practice. Having guidelines that can help in the establishment of quality standards can significantly improve health care delivery service. CSPY has become the gold standard for the diagnosis, monitoring and therapeutic treatment of CRC. Yet, its continuous improvement is hampered by the lack of quantitative standards for best practices. In this research study, a new real-time feedback system for screening colonoscopy procedures is proposed. It consists of an objective quantification of bowel preparation stage and colonoscope direction monitoring, and their potential integration with the Colometer, which is a system that measures image quality and withdrawal velocity.

In the course of developing a system to objectively quantify the bowel preparation a detailed revision of the three scales currently available was performed for the purpose of establishing quantitative threshold levels for bowel cleanliness. Stool detection algorithm using

thresholding in the hue component of HSV space and additional imaging processing procedures was proposed.

Based on the performance of the proposed evaluation system in processing 13 colonoscopic videos, correlation was established between the system and the Ottawa Bowel Preparation Scale.

Fourteen screening colonoscopies were assessed using the Colometer software. The results from this system based on the withdrawal dynamics and image quality strongly agreed with the endoscopists' quality ratings. The Colometer system could facilitate a real-time colonoscopy quality feedback for clinical practice, with easily accessible, in depth colonoscopy quality assessment for individual patients.

In addition, the application of an electromechanical device for colonoscope tracking has been proposed as part of this thesis as well. Different metrics for colonoscopy quality evaluation can be extracted from this device. For instance, accurate distance and direction measurements of the colonoscope movement within the body yield to the automatic identification of the insertion/withdrawal bordering line. This is especially convenient when the cecum can't be seen by the doctor, and the algorithm can offer documentation of the maximum distance scoped in the GI tract.

Promising results on the clinical validation of the electromechanical tracking device have been reported in this thesis. However, future goals consist of testing this device in a large set of real colonoscopic procedures in order to validate our algorithm. Certainly, the stool detection algorithm, the Colometer system and the electromechanical tracking device require further study in order to better define the optimal quality thresholds and to validate these approaches in a larger clinical trial. However, it is also anticipated that an integrated system that gathers all these

tools together can be a suitable approach to quantify the quality of colonoscopy and most importantly it has the potential to contribute to the well-being of patients.

Unfortunately, some endoscopists may resist the concept of real-time constant scrutiny of their screening colonoscopies. However, it is clear that high-quality screening colonoscopy requires skill and attention. We therefore should strive for continuous quality improvement of this procedure, and if heightened, non-punitive, scrutiny improves it, this is likely a positive direction for patients.

In conclusion, the proposed integrated system could significantly aid in fulfilling high quality CSPY procedures for both new and experienced clinicians, as this tool will provide feedback for the individual performance in a real-time fashion. This system could also be part of training programs that can be easily implemented in medical centers, thus becoming a globally accessible technology.

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APPENDIX I

a. Electromechanical tracking device materials

All electronic components needed to build the electromechanical tracking device were purchased from Parallax Inc. (Rocklin, CA, USA), since their products are very easy to handle, and examples on how to interface different components are provided in its Website: <http://www.parallax.com>. Therefore, the integration of all electronic components to create a functional device is facilitated.

Next, it is described how each of the components is used to build the electromechanical tracking device.

1. BASIC Stamp 2e Microcontroller Module: a microcontroller based on the PBASIC programming language. Table 8 summarizes its technical features:

BASIC Stamp 2e Microcontroller Module technical characteristics	
Processor Speed	20 MHz
Program Execution Speed	~4,000 PBASIC instructions/sec
RAM Size	32 Bytes (6 I/O, 26 Variable)
Number of I/O Pins	16 + 2 dedicated serial
Current Draw @ 5 VDC	25mA Run, 200 μ A Sleep
Power Requirements	5.5 to 12 VDC (Vin), or 5 VDC (Vdd)
Communication	Serial (9600 baud for programming)
Dimensions	1.20 x 0.63 x 0.15 in (30.0 x 16.0 x 3.81 mm)
Operating Temperature	-40 to +185 °F (-40 to +85 °C)

Table 8 Technical summary of BASIC Stamp 2e Microcontroller Module

2. 36-position Quadrature Encoder

In the electromechanical tracking device, the act of the colonoscope passing by the middle section of the device induces the rotation of a wheel. The wheel movement results in two signals with a 90-degrees shift between one another. These signals are released by a quadrature encoder, and are inputted into a PC through the operation of the Basic Stamp 2e microcontroller. The direction of movement is calculated based on which of the two signals goes up first, as shown in

Fig. 37. In addition, it is also possible to determine the traveling distance and velocity with the encoders. For instance, since the movement of the colonoscope causes a wheel to rotate, and the number of pulses released per rotation is known, then by counting the pulses we can calculate the distance as well. Consequently, to calculate the velocity it is only necessary to know the time elapsed per rotation.

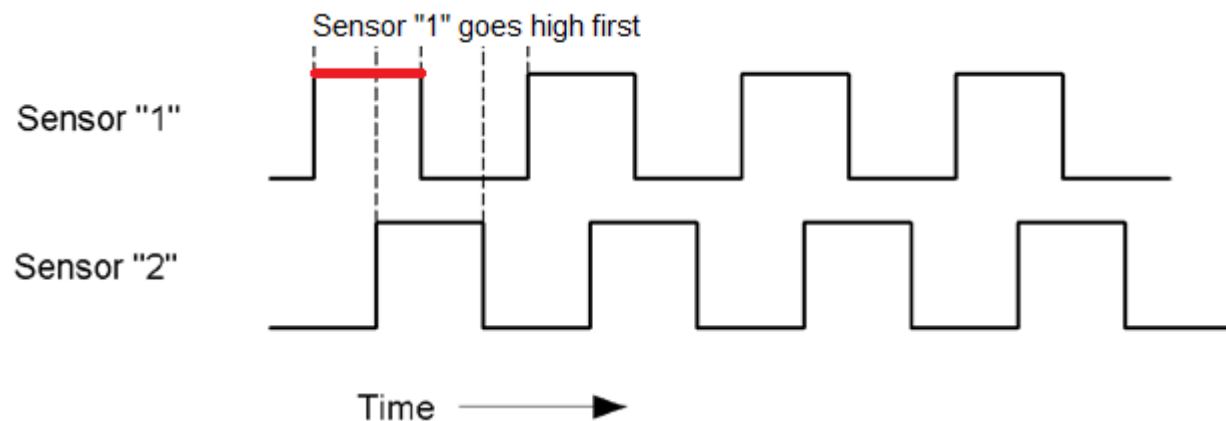


Fig. 37 Quadrature encoder phase shifted-signals. When comparing the two signals, the direction can be determined

To build the electromechanical tracking device, an encoder embedded in a single card was purchased from Parallax Inc. This specific quadrature encoder was selected because of its small size (5.1 x 2.7 x 0.6 cm), and simple shape that can easily be placed in the electromechanical tracking device structure. Further characteristics of the selected quadrature encoder are presented below in Table 9.

Technical characteristics of the 36-position Quadrature Encoder	
Power requirements	2.5 VDC @ 3.5 mA, 3.0 VDC @ 5.0 mA, 11.6 mA @ 5.5 VDC max
Communication	Two-channel high/low pulse output
Dimensions	2.0 x 1.1 x .25 in (5.1 x 2.7 x 0.6 cm)
Operating temperature	32 - 158 °F (0 - 70°C)
Microcontroller interfacing	Dual 3-wire interface

Table 9 Technical summary of the 36-position Quadrature Encoder

3. Bluetooth

A Bluetooth device was selected for the communication between the microcontroller and the PC. The addition of a Bluetooth device to our tracking system was to assure minimum discomfort to the doctor when using the electromechanical tracking device, removing the need for cables. The selected Bluetooth device is the RN-42 model from Parallax. Table 10 presents its technical characteristics:

RN-42 Bluetooth Module Technical Characteristics	
General features	Auto-discovery/pairing Compatible with 5 V and 3.3 V microcontrollers 9600 default baud rate
Power Requirements	5.0 VCD or 3.3 VCD @~ 50 mA max
Communication Interface	5 V / 3.3 V asynchronous serial interface with RTS/CTS flow control, from 1200 bps to 921K bps
Operating temperature	-40 to 185 °F (-40 to 85 °C)
Dimensions	2.33'' x 1.16'' x 0.45'' (59.18 x 29.46 x 11.43 mm)

Table 10 Technical characteristics of the RN-42 Bluetooth Module

4. Circuit diagram

The electromechanical tracking device is integrated by a quadrature encoder, a microprocessor and a Bluetooth device, as shown in Fig. 38.

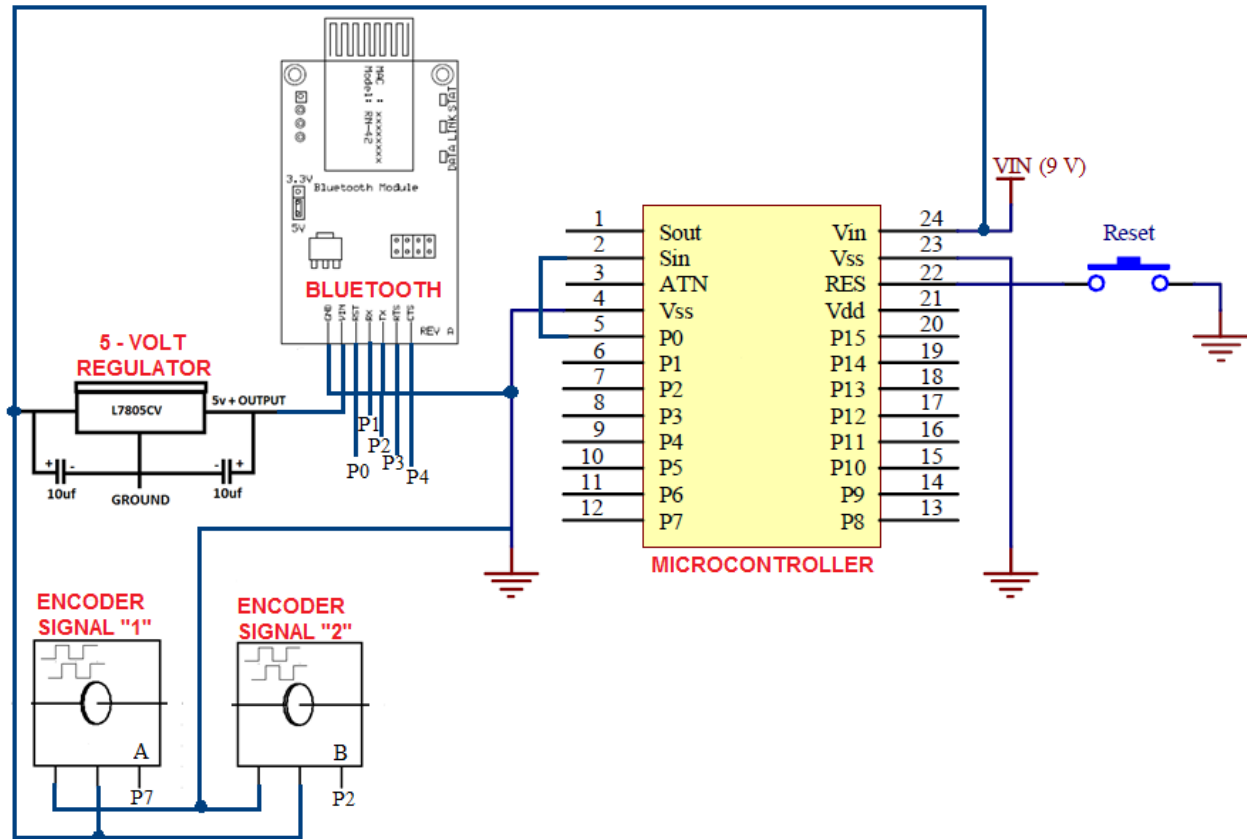


Fig. 38 Circuit diagram of the electromechanical tracking device

5. Pricing Table

Table 11 shows the total price for the electronic components within the electromechanical tracking device. This price is based on the cost found on the manufacturer's website at: www.parallax.com

Electronic Component Pricing Table	
Basic Stamp 2e Microcontroller	\$54.00 CAD
36-position quadrature encoder	\$29.99 CAD
RN-42 Bluetooth module	\$49.99 CAD
Basic Stamp 2 Carrier Board	\$9.99 CAD
Total	\$143.97 CAD

Table 11 Cost for electronic components of the electromechanical tracking device

6. PLX-DAQ software

Parallax also has software to record measurements in real time. This software is called PLX-DAQ and it's designed to place values into Microsoft Excel columns as soon as they're being picked up by the microcontroller of the measuring device. With this software it is possible to plot the data in graph form in real time. Multiple parameters values are dropped into different columns in Excel, in order to assist data analysis by means of Excel functions.

This software offers an intuitive user interface that permits the user to start and stop the monitoring at any time. In addition, current time (hh:mm:ss) registration and recording duration is marked in each data cell on a worksheet. The software is supported by Excel 2000 and newer versions. Fig. 39 shows examples of the functioning PLX-DAQ interface.

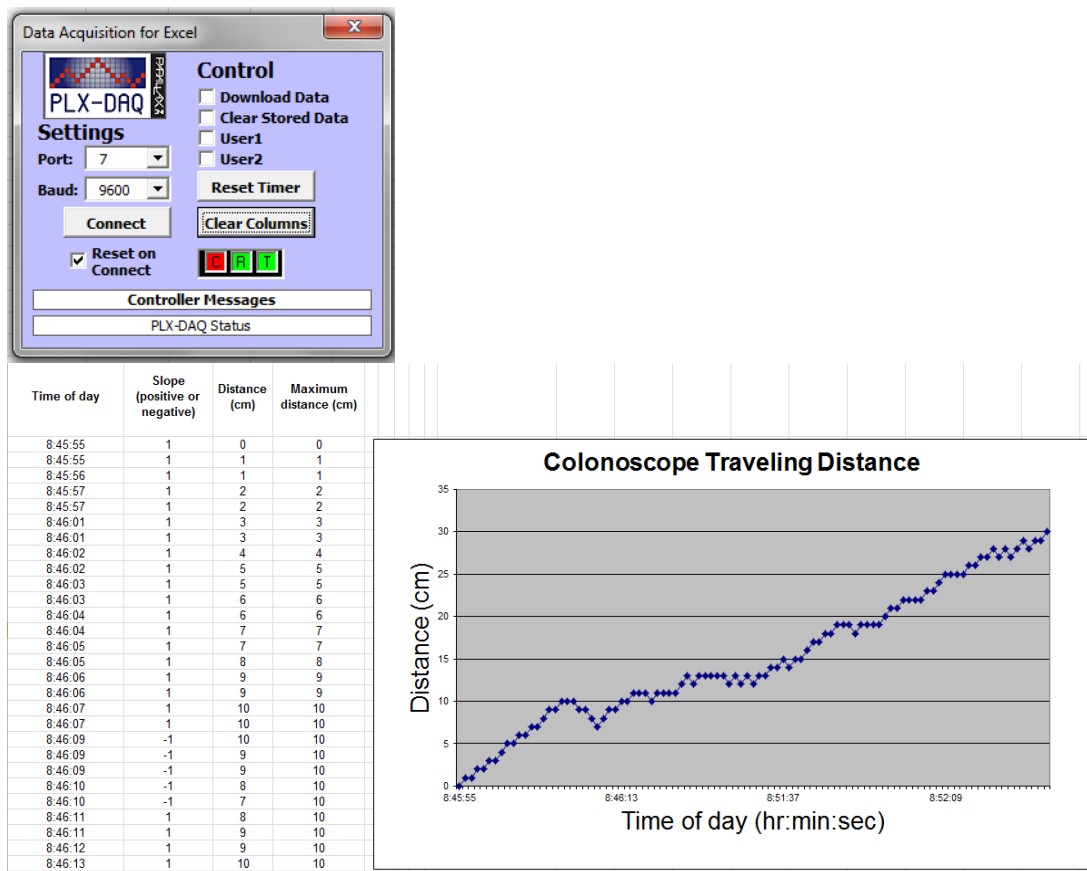


Fig. 39 PLX-DAQ software operation

7. Electromechanical tracking device arm support

In order to fix the electromechanical tracking device to the hospital bed, an arm support was designed. For this propose, different parts of magnetic bases (Fig. 40) were utilized to create a single full rotation arm support, SolidWorks design is shown in Fig. 41. The arm support flexibility allows the doctor to place the tracking device at the most convenient position for handling the colonoscope.



Fig. 40 Magnetic Base with adjustable arm parts. The arm parts of magnetic bases were taken to fabricate a support for the attachment of the electromechanical tracking device to the bed [103]



Fig. 41 Design of an arm support to be affixed to the hospital bed. This support ensures the electromechanical tracking device stability when maneuvering the colonoscope

APPENDIX II

a. Matlab code

Colometer

```
%FEB12 2012 E: for storage of video and results  
%March 30 2012 Proper comments  
%Real-time Indication
```

```
function COLOMETER()
```

```
% Reset all threads
```

```
clear all;
```

```
close all;
```

```
clc;
```

```
delete(timerfindall);
```

```
imaqreset
```

```
% Hardware requirement Imperx VCE express Card : 32 bit matlab system or 64  
% bit system
```

```
% imaqregister('c:\Program Files\Imperx\VCE  
Express\Drivers\Matlab\Win32\yceexpressimaq.dll');  
imaqregister('c:\Program Files\Imperx\VCE Express\Drivers\Matlab\x64\yceexpressimaq.dll');
```

```
% Create a video input object for Imperx VCE express card device  
vid = videoinput('yceexpressimaq', 1, 'RS170');
```

```
% Functionality test with integrated webcam  
% vid = videoinput('winvideo',1,'YUY2_640x480');
```

```
% Record program start timestamp  
time_char_start = datestr(now,'mmddHHMMSS');
```

```
% Prepare the storage folder.
```

```
if (isdir('C:\archive video\') ~= 1)  
    mkdir('C:\archive video\');  
end
```

```
addr_str = 'C:\archive video\Sample_video.avi';  
recObj = VideoWriter(addr_str);
```

```
% Create a GUI window.  
p = get(0,'ScreenSize');
```

```

hFig = figure('Toolbar','none',...
    'Menubar', 'none',...
    'NumberTitle','Off',...
    'Name','Colometer Preview',...
    'OuterPosition', [p(1) p(2) p(3) p(4)],...
    'Color', [0 0 0]);

% Toggle button for control colometer
Colo_btn = uicontrol('Style', 'togglebutton',...
    'String', 'Colometer : OFF',...
    'Value', 0,...
    'Enable', 'off',...
    'Callback', @indicator_fcn,...
    'Units','normalized',...
    'Position',[0.83 0.6 0.16 .14],...
    'BackgroundColor', [1 0 0],...
    'FontSize', 12);

% Toggle button for control Recording
Rec_btn = uicontrol('Style', 'togglebutton',...
    'String', 'Record : OFF',...
    'Value', 0,...
    'Enable', 'off',...
    'Callback', @recorder_fcn,...
    'Units','normalized',...
    'Position',[0.83 0.5 .16 .07],...
    'BackgroundColor', [1 0 0],...
    'FontSize', 12);

% Toggle button for Stop and Start
Stop_btn = uicontrol('Style', 'togglebutton',...
    'String', 'New',...
    'Value', 0,...
    'Callback', @stop_fcn,...
    'Units','normalized',...
    'Position',[0.83 0.76 .16 .08],...
    'BackgroundColor', [0 1 1],...
    'FontSize', 12);

% Toggle button for reporting statistics
Rpt_btn = uicontrol('String', 'Report',...
    'Callback', @Report_fcn,...
    'Enable', 'off',...
    'Units','normalized',...
    'Position',[0.83 0.4 .16 .07],...
    'BackgroundColor', [0.3 0.3 1],...

```

```

    'FontSize', 12);

% Toggle button for closing GUI
Cls_btn = uicontrol('String', 'Close',...
    'Callback', @Close_fcn,...
    'Units','normalized',...
    'Position',[0.83 0.24 .16 .14],...
    'FontSize', 12);

% Toggle button for control colometer
Cfg_btn = uicontrol('String', 'Hide sliders',...
    'Callback', @CfgDisplay_fcn,...
    'Units','normalized',...
    'Position',[0.83 0.15 .16 .07],...
    'FontSize', 12);

% Threshold controlable status labels
Active_label = uicontrol('style','text',...
    'String','Active', ...
    'Units','normalized',...
    'Position',[0.02 0.7 .08 .04],...
    'FontSize', 12,...
    'BackgroundColor', [0 1 1]);
Inactive_label = uicontrol('style','text',...
    'String','Inactive', ...
    'Units','normalized',...
    'Position',[0.10 0.7 .08 .04],...
    'FontSize', 12,...
    'BackgroundColor', [1 0 0]);

% Threshold slider for refreshing or updating rate
Rfh_sld = uicontrol('Style', 'slider',...
    'Min',3,'Max',20,'Value',5,...
    'sliderstep', [0.1 0.05],...
    'Callback', @Refresh_fcn,...
    'Units','normalized',...
    'Position',[0.02 0.26 .16 .04],...
    'FontSize', 12,...
    'BackgroundColor', [0 1 1]);
Rfhsld_label = uicontrol('style','text',...
    'String','processing interval (3 ~ 20)', ...
    'Units','normalized',...
    'Position',[0.02 0.30 .16 .08],...
    'BackgroundColor', [0.5 0.5 0.5],...
    'FontSize', 12);
Rfhsld_value = uicontrol('style','text',...

```

```

    'String','5', ...
    'Units','normalized',...
    'Position',[0.02 0.23 .16 .04],...
    'BackgroundColor', [0.5 0.5 0.5],...
    'FontSize', 12);

% Threshold slider for overspeed indication
Sthd_sld = uicontrol('Style', 'slider',...
    'Min',70,'Max',150,'Value',125,...
    'sliderstep', [0.1 0.05],...
    'Callback', @Sthd_fcn,...
    'Units','normalized',...
    'Position',[0.02 0.42 .16 .04],...
    'FontSize', 12,...
    'BackgroundColor', [0 1 1]);
Sthdsld_label = uicontrol('style','text',...
    'String','speed threshold (70 ~ 150)', ...
    'Units','normalized',...
    'Position',[0.02 0.46 .16 .08],...
    'BackgroundColor', [0.5 0.5 0.5],...
    'FontSize', 12);
Sthdsld_value = uicontrol('style','text',...
    'String','125', ...
    'Units','normalized',...
    'Position',[0.02 0.39 .16 .04],...
    'BackgroundColor', [0.5 0.5 0.5],...
    'FontSize', 12);

% Threshold for blurriness indication
Bthd_sld = uicontrol('Style', 'slider',...
    'Min',20,'Max',50,'Value',27,...
    'sliderstep', [0.1 0.05],...
    'Callback', @Bthd_fcn,...
    'Units','normalized',...
    'Position',[0.02 0.58 .16 .04],...
    'FontSize', 12,...
    'BackgroundColor', [0 1 1]);
Bthdsld_label = uicontrol('style','text',...
    'String','blurry threshold (20 ~ 50)', ...
    'Units','normalized',...
    'BackgroundColor', [0.5 0.5 0.5],...
    'Position',[0.02 0.62 .16 .08],...
    'FontSize', 12);
Bthdsld_value = uicontrol('style','text',...
    'String','27', ...
    'Units','normalized',...

```

```

'BackgroundColor', [0.5 0.5 0.5],...
'Position',[0.02 0.55 .16 .04],...
'FontSize', 12);

% Create the text label for the timestamp
hTextLabel1 = uicontrol('style','text','String','Total WT:', ...
    'Units','normalized',...
    'Position',[0.18 0.07 .10 .04],...
    'FontSize', 12);

TimerLabel1 = uicontrol('style','text','String'," ...
    'Units','normalized',...
    'Position',[0.30 0.07 .10 .04],...
    'FontSize', 12);

hTextLabel2 = uicontrol('style','text','String','Net WT:', ...
    'Units','normalized',...
    'Position',[0.62 0.07 .10 .04],...
    'FontSize', 12);

TimerLabel2 = uicontrol('style','text','String'," ...
    'Units','normalized',...
    'Position',[0.74 0.07 .10 .04],...
    'FontSize', 12);

% Get vid object's resolution
vidRes = get(vid, 'VideoResolution');
imWidth = vidRes(1);
imHeight = vidRes(2);
nBands = get(vid, 'NumberOfBands');

% Specify the size of the axes that contains the image object
% so that it displays the image at the right resolution and
% centers it in the GUI window.
set(gca,'Units','normalized',...
    'Position',[0.17 0.12 0.67 0.67*p(3)/640*480/p(4)]);
sizeinfo = get(gca,'Position');
scale = sizeinfo(3)*p(3)/640;
hImage = image( 0.3*ones(floor(imHeight*scale), floor(imWidth*scale), nBands) );

%%%%%%%%%%%%%%
% default parameters for uicontrol
indicator_on = 0;
recorder_on = 0;
total_timer = 0;

```



```

net_timer = 0;
bk_speeding_indicator = 0;
bk_blurry_indicator = 0;
countdown = 0;
frm_idx = 1 ;
temp_frm_idx = 2;
speed_recording = zeros(36000,1);
accel_recording = zeros(36000,1);
blur_recording = zeros(36000,1);
bkp_speed_rec = 0;
bkp_accel_rec = 0;
bkp_blur_rec = 0;
flag_refreshslider = 0;
flag_hidecfg = 0;
ShowImage = 0;
%%%%%%
update_rate = 0.1;

t_timer = timer('executionmode', 'fixedrate', 'period', 0.1, 'TimerFcn', @t_timer_fcn);
n_timer = timer('executionmode', 'fixedrate', 'period', update_rate, 'TimerFcn', @n_timer_fcn);

% t_timer
% n_timer
function t_timer_fcn(hObject,event)
    set(TimerLabel1, 'String', num2str(ceil(total_timer)));
    total_timer = total_timer + 0.1;
end

function n_timer_fcn(hObject,event)
    set(TimerLabel2, 'String', num2str(ceil(net_timer)));
    net_timer = net_timer + update_rate;
    speed_recording(frm_idx)= bk_speeding_indicator;
    accel_recording(frm_idx)= temp_result(1,1)/200;
    blur_recording(frm_idx)= bk_blurry_indicator;
    frm_idx = frm_idx + 1;
end
function stop_fcn(hObject,event)
    flag_refreshslider = flag_refreshslider + 1;
    if mod(flag_refreshslider,2) == 1
        set(Rfh_sld, 'Enable', 'off');
        set(Rfh_sld, 'BackgroundColor', [1 0 0]);
        set(Cls_btn, 'Enable', 'off');
        set(Colo_btn, 'Enable', 'on');
        set(Rec_btn, 'Enable', 'on');
        set(Rpt_btn, 'Enable', 'off');
    else

```

```

set(Rfh_sld, 'Enable', 'on');
set(Rfh_sld, 'BackgroundColor', [0 1 1]);
set(Cls_btn, 'Enable', 'on');
set(Colo_btn, 'Enable', 'off');
set(Rec_btn, 'Enable', 'off');
set(Rpt_btn, 'Enable', 'off');
end
if strcmp(t_timer.running, 'on')
    stop(t_timer);
end
if strcmp(n_timer.running, 'on')
    stop(n_timer);
end

button_state = get(hObject, 'Value');
bkp_speed_rec = speed_recording(1: frm_idx);
bkp_accel_rec = accel_recording(1: frm_idx);
bkp_blur_rec = blur_recording(1: frm_idx);

if button_state == get(hObject, 'Max')
    % Toggle button is pressed-take appropriate action
    set(hObject, 'String', 'Stop', 'BackgroundColor', [1 1 0]);
elseif button_state == get(hObject, 'Min')
    % Toggle button is not pressed-take appropriate action
    set(hObject, 'String', 'New', 'BackgroundColor', [0 1 1]);
    indicator_on = 0;
    set(Colo_btn, 'Value', 0, 'String', 'Colometer : OFF', 'BackgroundColor', [1 0 0]);
    if recorder_on == 1
        recorder_on = 0;
        close(recObj);
    end
    set(Rec_btn, 'Value', 0, 'String', 'Record : OFF', 'BackgroundColor', [1 0 0]);
    try
        time_char_start = datestr(now, 'mmddHHMMSS');
        wndwSize = 100;
        h = ones(1, wndwSize)/wndwSize;    % equiv to a moving average window
        speeding_filtered = filtfilt(h, 1, bkp_accel_rec);
        len = length(speeding_filtered);

        frm_per_min = 600 * 0.1/ update_rate;
        X = 1/frm_per_min:1/frm_per_min:len/frm_per_min;
        figure('Name', 'Record Display', 'OuterPosition', [24 68 600 400]), subplot(2,2,1);
        plot(X, speeding_filtered); xlim([0.1 len/frm_per_min-0.1]); grid on; title('Time
Chart');
        xlabel('Time (Min)'); ylabel('Normalized Velocity');

```

```

wndwSize = 100;
h = ones(1,wndwSize)/wndwSize;    % equiv to a moving average window
accel_filtered = filtfilt(h, 1, diff(speeding_filtered));
len = length(accel_filtered);

X = 1/frm_per_min:1/frm_per_min:len/frm_per_min;
subplot(2,2,3);
plot(X, accel_filtered); xlim([0.1 len/frm_per_min-0.1]); ylim([-0.005 0.005]);grid on;
title('Time Chart');
xlabel('Time (Min)'); ylabel('Normalized Acceleration');

subplot(2,2,[2 4]);
h = pie([length(bkp_blur_rec)- sum(bkp_blur_rec)-sum(bkp_speed_rec)-2
sum(bkp_blur_rec)+1 sum(bkp_speed_rec)+1],[1 0 0]);
title('Video Quality Ratio')
textObjs = findobj(h,'Type','text');
oldStr = get(textObjs,{'String'});
val = get(textObjs,{'Extent'});
oldExt = cat(1,val{:});
Names = {'Adequate: '; 'Blurry: '; 'Fast Withdrawal: '};
newStr = strcat(Names,oldStr);
set(textObjs,{'String'},newStr);
val1 = get(textObjs, {'Extent'});
newExt = cat(1, val1{:});
offset = sign(oldExt(:,1)).*(newExt(:,3)-oldExt(:,3))/2;
pos = get(textObjs, {'Position'});
textPos = cat(1, pos{:});
textPos(:,1) = textPos(:,1)+offset;
set(textObjs,{'Position'},num2cell(textPos,[3,2]));
figure_addr = ['C:\archive video\' time_char_start '_metrics.fig'];
jpeg_addr = ['C:\archive video\' time_char_start '_metrics.jpg'];
saveas(gcf,jpeg_addr)
saveas(gcf,figure_addr);

results_file = ['C:\archive video\' time_char_start '_Measurement_results.xls'];
d = {'Velocity Recording','Acceleration Recording', 'Blurry Indicator','Average
Velocity', 'Standard Deviation'};
xlswrite(results_file, d, 1, 'A1')
xlswrite(results_file, bkp_accel_rec, 1, 'A2');
xlswrite(results_file, diff(bkp_accel_rec), 1, 'B2');
xlswrite(results_file, bkp_blur_rec, 1, 'C2');
xlswrite(results_file, mean(bkp_accel_rec), 1, 'D2');
xlswrite(results_file, std(bkp_accel_rec), 1, 'E2');
catch
set(Rpt_btn, 'Enable', 'off');
msgbox(sprintf('No report.\nWithdrawal time should be longer than 1 minute.'));

```



```

wndwSize = 100;
h = ones(1,wndwSize)/wndwSize;    % equiv to a moving average window
speeding_filtered = filtfilt(h, 1, bkp_accel_rec);
len = length(speeding_filtered);

frm_per_min = 600 * 0.1/ update_rate;
X = 1/frm_per_min:1/frm_per_min:len/frm_per_min;
figure('Name','Record Display','OuterPosition', [24 68 600 400]), subplot(2,2,1);
plot(X, speeding_filtered); xlim([0.3 len/frm_per_min-0.3]); grid on; title("Time Chart");
xlabel("Time (Min)"); ylabel("Normalized Velocity");

wndwSize = 100;
h = ones(1,wndwSize)/wndwSize;    % equiv to a moving average window
accel_filtered = filtfilt(h, 1, diff(bkp_accel_rec));
len = length(accel_filtered);

X = 1/frm_per_min:1/frm_per_min:len/frm_per_min;
subplot(2,2,2);
plot(X, accel_filtered); xlim([0.3 len/frm_per_min-0.3]); grid on; title("Time Chart");
xlabel("Time (Min)"); ylabel("Normalized Acceleration");

subplot(2,2,3);
h = pie([length(bkp_blur_rec)- sum(bkp_blur_rec)-sum(bkp_speed_rec)-2
sum(bkp_blur_rec)+1 sum(bkp_speed_rec)+1],[1 0 0]);
title('Video Quality Ratio')
textObjs = findobj(h,'Type','text');
oldStr = get(textObjs,{ 'String' });
val = get(textObjs,{ 'Extent' });
oldExt = cat(1,val{:});
Names = { 'Adequate: '; 'Blurry: '; 'Fast Withdrawal: ' };
newStr = strcat(Names,oldStr);
set(textObjs,{ 'String' },newStr);
val1 = get(textObjs, { 'Extent' });
newExt = cat(1, val1{:});
offset = sign(oldExt(:,1)).*(newExt(:,3)-oldExt(:,3))/2;
pos = get(textObjs, { 'Position' });
textPos = cat(1, pos{:});
textPos(:,1) = textPos(:,1)+offset;
set(textObjs,{ 'Position' },num2cell(textPos,[3,2]));
figure_addr = ['C:\archive video\' time_char_start '_metrics.fig'];
saveas(gcf,figure_addr);

results_file = ['C:\archive video\' time_char_start '_Measurement_results.xls' ];
d = { 'Velocity Recording', 'Acceleration Recording', 'Blurry Indicator', 'Average Velocity',
'Standard Deviation' };
xlswrite(results_file, d, 1, 'A1')

```

```

        xlswrite(results_file, bkp_accel_rec, 1, 'A2');
        xlswrite(results_file, diff(bkp_accel_rec), 1, 'B2');
        xlswrite(results_file, bkp_blur_rec, 1, 'C2');
        xlswrite(results_file, mean(bkp_accel_rec), 1, 'D2');
        xlswrite(results_file, std(bkp_accel_rec), 1, 'E2');
    catch
        set(Rpt_btn, 'Enable', 'off');
        msgbox(sprintf('No report.\nWithdrawal time should be longer than 1 minute.'));
    end
    set(Rpt_btn, 'Enable', 'off');
end

function Close_fcn(hObject,event)
    stop(vid);
    delete vid;
    delete recObj;
    clear all;
    close all;
end

function Refresh_fcn(hObject,event)
    step = floor(get(Rfh_sld, 'Value'));
    set(Rfhsld_value, 'String', num2str(step));
end

function Sthd_fcn(hObject,event)
    sthd = floor(get(Sthd_sld, 'Value'));
    set(Sthdsld_value, 'String', num2str(sthd));
end

function Bthd_fcn(hObject,event)
    bthd = floor(get(Bthd_sld, 'Value'));
    set(Bthdsld_value, 'String', num2str(bthd));
end

function CfgDisplay_fcn(hObject,event)
    flag_hidecfg = flag_hidecfg + 1;
    if mod(flag_hidecfg,2) == 1
        set(hObject, 'String', 'Show sliders');
        set(Rfh_sld, 'Visible', 'off');
        set(Sthd_sld, 'Visible', 'off');
        set(Bthd_sld, 'Visible', 'off');
        set(Rfhsld_value, 'Visible', 'off');
        set(Sthdsld_value, 'Visible', 'off');
        set(Bthdsld_value, 'Visible', 'off');
        set(Rfhsld_label, 'Visible', 'off');
    end
end

```



```

ypos = 320;
% Frames buffer
frame_queue = uint8(zeros(480,640,3,step));
temp_frame = uint8(zeros(480, 640, 3));
% Load necessary file into memory
% I = imread('blury_text.jpg');
% blurry_text = I;
% [row col level]=size(blurry_text);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Set up the update preview window function.
triggerconfig(vid,'manual');
set(vid,'TriggerRepeat',Inf);
set(vid,'FramesAcquiredFcn', @mypreview_fcn);
set(vid,'FramesAcquiredFcnCount', 1);

start(vid);
trigger(vid);

% setappdata(hImage,'UpdatePreviewWindowFcn',@mypreview_fcn);
%
% preview(vid, hImage);

function indicator_fcn(hObject,event)
    button_state = get(hObject,'Value');
    if button_state == get(hObject,'Max')
        % Toggle button is pressed-take appropriate action
        indicator_on = 1;
        set(hObject,'String', 'Colometer : ON', 'BackgroundColor', [0 1 0]);
        if strcmp(t_timer.running,'off')
            start(t_timer);
        end
        start(n_timer);
    elseif button_state == get(hObject,'Min')
        % Toggle button is not pressed-take appropriate action
        indicator_on = 0;
        set(hObject,'String', 'Colometer : OFF', 'BackgroundColor', [1 0 0]);
        stop(n_timer);
    end
end

function recorder_fcn(hObject,event)

```



```

button_state = get(hObject,'Value');
if button_state == get(hObject,'Max')
    % Toggle button is pressed-take appropriate action
    rec_time_start = datestr(now,'mmddHHMMSS');
    %         time_char_start = datestr(now,'HHMMSS');
    % Prepare the new file.
    if (isdir('C:\archive video\') ~= 1)
        mkdir('C:\archive video\') ;
    end
    addr_str = ['C:\archive video\' rec_time_start 'video.avi'];
    recObj = VideoWriter(addr_str);
    recObj.FrameRate = 1/update_rate;
    open(recObj)

    recorder_on = 1;
    set(hObject,'String', 'Record : ON', 'BackgroundColor', [0 1 0]);
    set(Rec_btn, 'Enable', 'off');
elseif button_state == get(hObject,'Min')
    % Toggle button is not pressed-take appropriate action
    recorder_on = 0;
    set(hObject,'String', 'Record : OFF', 'BackgroundColor', [1 0 0]);
    set(Rec_btn, 'Enable', 'on');
end
end

function mypreview_fcn(obj,event,himage)
% Example update preview window function.
%     % Get timestamp for frame.
%     tstampstr = num2str(etime(clock, indicator_timer));
%     % Get handle to text label uicontrol.
%     ht = getappdata(himage,'HandleToTimestampLabel');
%     % Set the value of the text label.
%     set(ht,'String',tstampstr);

% Display image data.
%     temp_frame = uint8(event.Data);
temp_frame = getdata(vid, 1);
frame_queue(:, :, :, num) = temp_frame;

ShowImage = temp_frame;

if indicator_on == 1
    % Add the Indicators
    if blur_flag == 0

```

```

        ShowImage(1:30,1:640,1) = color(1);
        ShowImage(1:30,1:640,2) = color(2);
        ShowImage(1:30,1:640,3) = color(3);
        set(hFig, 'Color', color/256);
    else
        ShowImage(1:30,1:640,1) = 5;
        ShowImage(1:30,1:640,2) = 5;
        ShowImage(1:30,1:640,3) = 230;
        set(hFig, 'Color', [5/256 5/256 230/256]);
    end
    % Count the num of frames will be processed
    num = num + 1;
    if (recorder_on == 1) && (frm_idx >= temp_frm_idx)
        writeVideo(recObj,ShowImage);
        temp_frm_idx = frm_idx + 1;
    end
end

ShowImage = imresize>ShowImage,[floor(imHeight*scale) floor(imWidth*scale)]
,'Method', 'bicubic');% 'bicubic','bilinear'
% Display custom processed image.
set(hImage, 'CData', ShowImage);
flushdata(vid)

% Start processing when buffer is full (buffer size is determined by
% the size of step
if (num == step + 1)
    % Get enough frames for processing once
    update_flag = update_flag + 1;
    num = 1;
    % First Sample for processing
    FirstImage = frame_queue(:, :, 1);

    % Binary transformation for blurry
    BW_First = rgb2gray(FirstImage(50:400,50:600,:));

    % Second Sample for processing
    SecondImage = frame_queue(:, :, step);
    [a b c] = size(SecondImage);

    % Frame differences
    Z=((imabsdiff(FirstImage(:, :, 1),SecondImage(:, :, 1))))*5;

    % Temporary variables
    count=0;
    sumZ=0;

```

```

% Remove the bright blobs
for i = 2:a
    for j = 2:b
        if (SecondImage(i,j,3)>120 || FirstImage(i,j,3)>120)
            Z(i,j)=0;
            % BW_First(i,j) = 0;
            count=count+1;
        end
        sumZ=double(Z(i,j))+sumZ;
    end
end

% Calculate the speeding metric
temp_result(update_flag,1) = sumZ/(a*b-count);
temp_result(update_flag,1) = floor(temp_result(update_flag,1));
init_result = temp_result(update_flag,1);
% disp(init_result);

% blur threshohld
Blur_thresh = max(max(BW_First));
Blur_thresh_std = std2(BW_First);
Blur_thresh_mean = mean2(BW_First);
% disp(Blur_thresh);

% Speeding or blurry or adequate
% for step = 5 update_interval = 1
% choose 130 210

if Blur_thresh <190 || Blur_thresh_std < bthd || Blur_thresh_mean >210
    blurry_indicator = blurry_indicator + 1;
elseif init_result >= sthd
    speeding_indicator = speeding_indicator + 1; %red
end

% Update the indicator color based on the samples in 1 second
if update_flag == update_interval
    update_flag = 0;
    if blurry_indicator >= update_threshold
        blur_flag = 1;
        countdown = 3;
    elseif speeding_indicator >= update_threshold && countdown == 0
        color = [125+(init_result/sthd) abs(125-(init_result-sthd)) 0];
        color = [255 0 0];
        blur_flag = 0;
    elseif countdown == 0

```

```

        color = [abs(125-(sthd-init_result)) 125+(sthd-init_result) 0];
%         color = [0 255 0];
        blur_flag = 0;
    end
    if countdown > 0
        countdown = countdown - 1;
    end

    display_result = floor(mean(temp_result));
    display_result = min(floor(display_result*1.5), ypos-1);
    bk_speeding_indicator = speeding_indicator;
    bk_blurry_indicator = blurry_indicator;
    speeding_indicator = 0;
    blurry_indicator = 0;
end
end
trigger(vid);
end
end

```

Stool detection

%CODE FOR STOOL DETECTION. IT DETECTS YELLOW COLOUR AND
%CALCULATES ITS PERCENTAGE IN THE FRAME.

```

clear all;
clc;
singleFrame = imread('video1_1.png');
figure(1),subplot(2,1,1),imshow(singleFrame);
%use valores para gamma de .35-.4-.5
cont = imadjust(singleFrame, [], [], 0.35);
hsvim = rgb2hsv(cont);
hImage = hsvim(:,:,1);
sat(:,:,3) = hsvim(:,:,2); sat(:,:,2) = hsvim(:,:,2); sat(:,:,1) = hsvim(:,:,2);
sImage = sat(:,:,3);
val(:,:,3) = hsvim(:,:,3); val(:,:,2) = hsvim(:,:,3); val(:,:,1) = hsvim(:,:,3);
vImage = val(:,:,3);
% Assign the low and high thresholds for each color band.
hueThresholdLow = .134;
hueThresholdHigh = .18;
saturationThresholdLow = .5;
saturationThresholdHigh = 1;
valueThresholdLow = .7;
valueThresholdHigh = 1;
hueMask = (hImage >= hueThresholdLow) & (hImage <=
hueThresholdHigh);%figure(1),subplot(2,1,2),imshow(hueMask, []);

```

```

saturationMask = (sImage >= saturationThresholdLow) & (sImage <=
saturationThresholdHigh);%figure(1),subplot(2,1,2),imshow(saturationMask, []);
valueMask = (vImage >= valueThresholdLow) & (vImage <=
valueThresholdHigh);%figure(1),subplot(2,1,2),imshow(valueMask, []);
yellowObjectsMask = uint8(hueMask & saturationMask &
valueMask);%figure(1),subplot(2,1,1),imshow(yellowObjectsMask, []);
%figure(1),subplot(2,1,2),imshow(yellowObjectsMask,[]);
SHoles = bwareaopen(yellowObjectsMask, 50);%Erase little bubbles
%figure(1),subplot(2,1,2),imshow(SHoles);
BW1 = edge(SHoles,'canny');
se = strel('diamond',10);
closeBW = imclose(SHoles,se);
figure(1),subplot(2,1,2),imshow(closeBW);

% YRoutline = bwperim(closeBW);
%Segout = singleFrame;
%Segout(YRoutline) = 255;

nonzero = nnz(closeBW);
pixels = size(closeBW,1) * size(closeBW,2);% Total number of pixels
per = (nonzero/pixels)*100;
s_per(:, :) = per; %save percentage

```

b. PBASIC code

Electromechanical tracking device

```
'{$STAMP BS2e}
```

```
'{$PBASIC 2.5}
```

```
' LETICIA ANGULO - MARCH 16, 2013 -
```

```
'*****
```

X	VAR	Byte	'Variable to represent data
TX	PIN	1	' TX of the Easy Bluetooth
sPin	CON	16	'Serial Pin - P16, Programming port
pulse	PIN	5	
cnt_enc	PIN	2	
RTS	PIN	7	

```

Baud    CON    84      'Baud mode for a rate of 9600, 8-N-1
          'BS2P, BS2SX use 240 for 9600, 8-N-1
Row     VAR    Word    'Variable to hold row data
cnt_dist VAR    Word
dist    VAR    Word
dir     VAR    Word
'dist_cm2 VAR    Word
dist_cm VAR    Word
DataIn  VAR    Byte
enc_frac VAR    Word '.33 cm per pulse
conv    VAR    Word 'convert to cm
maxi    VAR    Word
prevdist VAR    Word
old_max VAR    Word
new_maxi VAR    Word
maxi_cm VAR    Word

cnt_dist = 1
enc_frac = 57
conv = 100
*****

SERIN cnt_enc,Baud, [DataIn]

PAUSE 1000          'Allow data communications to stabilize
SEROUT sPin,Baud,[CR]      'Send a lone CR to ensure PLX-DAQ buffer is ready

'Label 3 columns with TIME, X, and SIN X
SEROUT sPin,Baud,[CR,"LABEL,Time,Timer,Slope,Distance,Withdrawal",CR]
SEROUT sPin,Baud,["CLEARDATA",CR]    'Clear all data columns (A-J) in Excel
SEROUT sPin,Baud,["RESETTIMER",CR]   'Reset Timer to 0

```

DO

SERIN cnt_enc,Baud, [DataIn]

prevdist = dist

old_max = new_maxi

'FOR X = 0 TO 255 'Count from 0 to 255

' Send String with data for Excel

'DEBUG "direc= ", SDEC dir, CR

IF cnt_enc = 0 THEN

IF (RTS > pulse) THEN

dir = 1

dist = dist + cnt_dist

'DEBUG "direc= forward", CR

'DEBUG "cm",SDEC dist_cm, CR

ELSEIF (RTS = pulse) THEN

dir = -1

dist = dist - cnt_dist

'DEBUG "direc= backward", CR

ENDIF

,

IF (dist > prevdist) THEN

maxi = dist

IF (maxi > old_max) THEN

new_maxi = maxi

ENDIF

ENDIF

'dist_cm2 = dist * enc_frac 'dist in cm^-2

dist_cm = (dist * enc_frac) / conv

maxi_cm = (new_maxi * enc_frac) / conv

ENDIF

SEROUT TX,Baud,["DATA,TIME,TIMER,", SDEC dir, ",", SDEC dist_cm,",", SDEC
maxi_cm,CR]

' Request last row of data

SEROUT sPin,Baud,["ROW,GET",CR]

' Accept returning data and store into Row with 200mS timeout

SERIN sPin, Baud,200,TimeOut,[DEC Row]

' If Row is or exceeds 300, set row back to 2

IF row >= 1000 THEN SEROUT sPin,Baud,["ROW,SET,2",CR]

Timeout:

LOOP