Polyps revealed on a virtual colon voyage

Three-dimensional colonoscopy reduces discomfort

by Bennie Mols

In the western world, colon cancer is the second-largest cause of death from cancer. Since there is a considerable risk that polyps five millimetres and more in diameter may develop into malicious tumours, it is important that they can be detected at an early stage. Until now, this is done by means of an endoscope through the anus. Inserting and manoeuvring an endoscope causes considerable discomfort to the patient, and the endoscope camera may not cover the entire colon wall. Researchers at TU Delft have succeeded in making virtual endoscopy, a process that enables a physician to travel on a virtual voyage through the intestine, suitable for large-scale screening. The process not only provides doctors with a 360° view of the intestine, and allows them to make the diagnosis in less than half the usual time, it may also reduce the amount of radiation to which the patient is exposed. In addition, the researchers have found a method of digitally removing faecal residue from the intestinal images to improve the view of the intestinal wall. Virtual screening not only reduces the discomfort to the patient, it might also dramatically improve the polyp detection rate. In future applications, the process of detecting human polyps will even be supported by automatic pattern recognition software.

Each year in the Netherlands alone, several thousands of new patients come in to be screened for colonic polyps, which may turn into malignant tumours. Current methods involved looking at the inside of the colon centimetre by centimetre through an endoscope inserted through the anus. This causes considerable discomfort to the patient, compounded by the drinking of four litres of laxative to be taken the day before the examination. A local anaesthetic is optional.
A twisting and turning tunnel of a metre and a half in length. Pleats and folds on all sides. Bulges and folds. This is the inner world of our intestine. Any fold can hide an intestinal polyp, a benign tumour of the mucous membrane. Although polyps tend to grow rather slowly, they can develop into malignant tumours. It is generally assumed that polyps over five millimetres in diameter present a large risk of developing into malignant intestinal tumours within a matter of years. In the Netherlands, cancer of the intestine claims some seven thousand new patients every year, mostly people over 55. In the western world, cancer of the intestine is the second cause of death from cancer. Careful screening for polyps is an important method of reducing the incidence of intestinal cancer. Polyp screening currently still takes place using physical methods, involving the insertion of an endoscope through the rectum. The method has many disadvantages, making it unsuitable for large-scale screening schemes like those used to detect breast cancer. In 2002, the Dutch Health Council advised the Minister of Public Health to consider setting up a national intestinal cancer screening plan as soon as a less intrusive method can be found. In spite of the use of local anaesthetics, endoscopy can be a very uncomfortable and often painful process. The physician has to wriggle the endoscope in every different direction to negotiate the twists and folds of the intestine. His control over the position and direction of the camera inside the intestine is minimal. In addition, the intestine is full of irregularities and hidden corners that can cause up to a quarter of the intestinal wall to remain unavailable for inspection. Just the place for polyps to lurk.

Laxative ¶
Preparing for this classic inspection method is another less than exhilarating experience. The patient has to drink four litres of laxative to clear the intestine in order to enable the camera to see as much of the intestinal wall as possible. At the start of the examination, the colon is inflated by blowing CO2-enriched air through the anus. Many patients, in particular older and weaker ones, fail to drink the prescribed amount of laxative, as a result of which traces of faeces will remain inside the intestine. Even if they drank the lot, there would always remain some traces. If these happen to cover a tumour, the camera will fail to spot it. Another drawback of the current medical examination method is that there is a small risk of the endoscope piercing the patient’s intestinal wall, in which case emergency surgery is required.

Looking behind the folds ¶
A much less intrusive method is to make a body scan of the patient, using computers to create a detailed three-dimensional image of the intestine. The radiologist can then use his computer display to move through the digital reconstruction of the intestines and search for polyps. The process is called virtual colonoscopy. The method was pioneered in 1996 in the United States, and is now being used on a limited scale in Europe.
alongside the physical method. However, even the virtual method has its drawbacks. The current virtual version reduces the invisible area of the intestine to about six percent, which is a considerable improvement over the endoscope method. Nonetheless, things can be improved, according to Ir. Iwo Serlie and his supervisors, Dr Frans Vos of the TU Delft Pattern Recognition Department, who also works at the Amsterdam Academic Medical Centre, Ir. Frits Post of the Information Technology & Systems faculty at Delft University of Technology, and Ir. Roel Truyen of Philips Medical Systems. Together they have developed a virtual colonoscopy method that reveals over 99.5% of the intestinal wall, considerable increasing the chances of detecting the presence of polyps. It is all done using smart image enhancement and visualisation techniques. Serlie, who graduated in computer graphics at the faculty of Information Technology and Systems (its), is currently working on image processing in virtual colonoscopy for his doctorate thesis in Applied Physics.

“What I am doing is fundamental research, but at the same time the benefits to society of my work are considerable. The amc has provided us with intestinal scans from several patients, to which we have applied our image processing software with the purpose of establishing the highest possible detection rate for polyps over five millimetres in diameter. These are clinically relevant since they may develop into cancer after a few years.’

CT Scanning ¶

Virtual colonoscopy, which is already being used on a limited scale as a pilot, still has its limitations, Serlie explains. ‘Patients still have to drink a laxative, and the process involves taking two X-ray images. In addition, the imaging is still limited because the virtual camera model is based on the physical endoscope, so it can look straight ahead and to the rear, but not to the side at the same time. As a result, the on-screen image often does not allow the radiologist to look deep behind a fold that obscures the view. In practice, the radiologist will often stop the movie for a moment to get a better view of the intestinal wall. It currently takes up to twenty minutes to make the virtual voyage through the intestinal tract. We are looking for ways to reduce this time.’ The virtual visualisation of the intestines is made possible thanks to data produced by a CT (Computed Tomography) scanner. The operating principle of this device, which uses X-rays, is based on the differences in X-ray absorption of various types of tissue. The CT scanner rotates in a spiral trajectory around the patient’s abdomen, and in twenty seconds produces a full scan of the intestines, first with the patient in a prone position (laying face down), then in a supine position (laying face up). During the scan, patients have to remain motionless, even holding their breath, which can be difficult for older people. The team at Delft University managed to improve the virtual visualisation process in a matter of a few months. The essential ingredient of the new method is the construction of a virtual cube at the centre of the intestinal mass.

‘From within this cube, you can look all around, in a
full 360° view,’ Serlie explains, ‘with the cube being unfolded flat onto the two-dimensional computer display, so the physician can see every one of the six faces of the cube simultaneously in front of him in a perspective view projected onto a (flat) screen. This enables the radiologist to look in all directions at the same time, and gives a much improved and intuitive view of the twists and turns of the intestinal wall.’

Through the intestines in 7 minutes ¶

The benefits of the unfolded cube method soon became apparent when tests were conducted by AMC radiologists. Where the process used to take up to twenty minutes, the radiologist now takes only seven minutes to view the virtual images. The much improved view of the intestinal wall means that the animation no longer needs to be stopped as often to take a closer look at the surface areas. Serlie: ‘Radiologists can now see the entire surface in a single view. They can also click on any suspect protrusion for a close-up inspection, and even look behind the intestinal wall. In some cases, a bump in the intestinal wall can appear to be a polyp, but a look on the outside of the intestinal wall will reveal the presence of something outside the intestinal tract pushing against the intestinal wall, for example another part of the intestines.’

The researchers even managed to automate the reporting of suspect bulges. A series of unfolded cubes from camera positions near a polyp can be stored as bitmap files, such as the jpg-format, together with annotation details. The full CT scan comprises some 200 to 300 sections of the intestinal mass. The sections are 1.6 millimetres apart, and each has a resolution of approximately 0.6 millimetres in its viewing plane. A full scan requires a total of two hundred megabytes of storage capacity. A computer then converts all these sectional views into a movie of unfolded cubes in a process that take from fifteen to thirty minutes. ‘The unfolded cube method has already been used to detect polyps that had not been spotted using normal virtual colonoscopy’, Serlie says. The method has now been implemented in EasyVision software by Philips Medical Systems, which the customer can order as a module with the CT scanner. The image quality is determined by the data acquisition resolution, the signal to noise ratio, and the contrast level. Nevertheless, there is a drawback to the virtual colonoscopy method when compared with the physical endoscopy method. Virtual colonoscopy can only show the shape of the intestinal wall using levels of grey; it does not contain any colour information. Looking through an endoscope, the examining physician can also judge the blood flow through the tissue by its colour. The virtual technique includes no colour information. On the other hand, virtual colonoscopy can show the areas (shape and thickness) below the surface of the intestinal wall.

Electronic enema ¶

One disadvantage of the first generation virtual methods is that they require a double set of exposures, resulting in twice the amount of radiation for the patient. Serlie: ‘The reason for having to make double exposures is that
some liquid will always remain behind in the intestines. Turning the patient over causes the liquid to sink to the other side of the intestine, where it no longer obstructs the virtual view. We were looking for an entirely digital solution to this problem by using a different method to automatically filter out the faecal residue. The actual method of electronically cleaning up the image is based on image processing techniques that estimate percentages of material. I cannot divulge the exact details of the method at this point, since we still have a patent application running,’ the scientist says, ‘but I can tell you about the results. Researchers elsewhere have developed a virtual cleaning procedure that is limited to smooth liquid levels. These procedures run into problems when a patient fails to drink the full quantity of laxative so faecal remains adhere to the intestinal wall. We have been the first team to successfully remove all such residue using purely electronic means, so the real intestinal wall shows up in the images.’ Serlie displays an image showing a number of small bumps on the intestinal wall. ‘After the electronic cleaning process, only one small bump remained, and that turned out to be a polyp. It had not been detected by the previous method, because the faecal remains obscured the view of the real intestinal wall. It can keep a polyp from being detected, or even result in false positives when faecal remains resemble a polyp.’ The electronic cleaning process now takes from thirty minutes to one hour, depending on the size of the patient’s colon and the processing speed of the computer. The method is currently being evaluated at the Amsterdam Medical Centre, and practical application may soon follow. The advantage of using a good electronic cleaning method is that the CT scan can be run even at lower radiation levels. Although higher levels of radiation result in increased contrast, the aim is to use as little radiation as possible in order to minimize the risk of side-effects. Using an effective electronic cleaning method to remove faecal remains from the scan images, a single scan may suffice (with patients lying either on their back or on their front), reducing exposure to radiation by half.

Trained eyes ¶

Two days a week, Dr. Frans Vos works at the amc, thus maintaining a link between the technical research at Delft and the practical needs of physicians. ‘Three-dimensional colonoscopy is very intuitive in the way it works,’ Vos says, ‘but we still have to provide satisfactory proof that our method helps radiologists to detect polyps quicker and better. Radiologists are nobody’s fool. They can even find a polyp using the two-dimensional images from a CT scan.’ Future developments will probably see the use of Magnetic Resonance Imaging (mri) instead of CT scans, since the desire is to move away from the ionising radiation used by CT scanners. We should not forget that the effects of X-rays on the human body are cumulative, in other words, one dose plus another dose after an interval of ten years still equals two doses. The radiation levels involved in CT scans may already be very low, but it
would be better to avoid the use of X-rays altogether. However, dispensing with X-rays altogether is not possible yet. MRI images contain too much noise, the resolution is too low, and the signal is subject to general fluctuations, so the same type of tissue may come out grey at one end of the picture, and white on the other, making it very difficult for doctors to interpret the results. ‘Looking at a CT scan you can be certain that grey represents soft tissue’, Vos says. ‘Matters aren’t quite as clear-cut in the MRI scanning technology. The 3D imaging technique based on MRI images simply has not yet developed to the point where it can start replacing CT scans. However, I expect matters to change in the future.’

Auto polyp ¶

The ultimate step forwards will be to automate polyp recognition using pattern recognition technology. You simply store hundreds of sample images of polyps in a database, and let the computer use these examples to recognise the pattern of a new polyp in an intestinal scan. Research on the subject recently started at the Pattern Recognition department.

In the ideal case, future patients will only have to come into hospital for a short visit, without the discomfort of the current colonic preparation. The scan will take only twenty seconds, followed by automatic analysis producing the virtual animation, and supported by automatic polyp detection. If a polyp is detected, the patient can immediately make a new appointment to have the polyp removed. Usually, a radiologist makes the diagnosis, and another physician removes the polyp. The polyp is removed using a heated metal wire lasso attached to the end of an endoscope. The physician loops the lasso around the polyp, pulls the loop tight, and so cauterises the polyp. The patient feels nothing of the entire process, because the mucous membrane of the intestinal tract contains no nerve endings. ‘We have just finished a prototype of our improved virtual colonoscopy method’, Serlie announces. ‘Clinical evaluation with a large number of patients at the AMC will now have to show whether our prototype manages to live up to the promise of its initial test results. If it does, it will mean a leap forward on the path to easier intestinal screening methods.’

For more information, please contact Ir. Iwo Serlie, phone +31 15 278 1303, e-mail iwo@ph.tn.tudelft.nl, or Dr. Frans Vos, phone +31 15 278 7133, e-mail frans@ph.tn.tudelft.nl.
Composite image of the entire colon wall area. Using a quantitative analysis, researcher Serlie can show which parts of the intestinal wall escaped inspection, shown in black in this illustration. The average is about six percent. Serlie started by creating a model of the entire wall of the large intestine. He then calculated which parts came into vision, subtracting the results from the full view. The resulting differential image reveals where the camera did not look.

Whereas the first-generation virtual colonoscopy systems showed a front and rear view along a central axis through the intestinal tract, Serlie came up with a different type of projection, consisting of an unfolded cube. The advantage of this method is that it enables the user to see, and intuitively understand, a 360° view at a single glance. The unfolded cube can also be easily stored as a 2-D image without any loss of data.
To help the user, the folds of the cube are indicated by white lines. To prevent polyp views being bisected by the unfolding cube, overlap areas have been included.
The 2-D images on the left show the density before and after digital cleansing. The two lighter sections in the upper view turn out to have been caused by faecal remains. The 3-D images show how faecal remains were removed to reveal the clean surface and a polyp.

Using the new method, only one half percent of the surface remains hidden from view. Serlie realised that sections too small to contain a five millimetre polyp would not require inspection, thus further reducing the workload for the radiologist.
Invisible areas can also result if the distance between sampling steps is too great.

In order to arrive at a well-founded choice for the distance between the virtual camera positions, Serlie carried out a number of calculations. The diagram shows how the percentage of visible surface area of each method increases as the distance between the camera positions decreases. The differences become less marked at a distance of 4 millimetres.

The 3-D projection provides no information about material located behind the intestinal surface. The radiologist only has to click the cursor on a suspect spot to be shown sectional views of the area. The images at top and bottom right are composed using the original data. They show the distribution of tissue, air, and materials in order to enable differences in density to be observed. These views do not automatically result in an assessment of polyp or not; this requires the experienced eye of a radiologist. The images show views at right angles to each other.
The display of the prototype used by radiologists at the AMC to evaluate the unfolded cube. The radiologists were very happy with the absence of sub-windows; all the available information is on the same screen. 1. Patient details. 2. List of suspect locations. 3. View of the large intestine with the exact positions of both the virtual camera and the suspect polyps. 4. Cube image controls. 5. 3D window of a specific area. This can be used to view a suspect location from every direction. 6. Sectional views of the specific suspect locations. The superimposed circle is always 1 cm in diameter, so the absolute size can be estimated.