Medical Intervention Planning

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Abstract

Throughout time medical doctors have had the need for information to aid them in their course to correctly diagnose illnesses. Usually simple diagnostics are done by asking patients questions about their health to classify or rule out possible illnesses. But the information available without dissecting or conducting examinations inside the human body is sparse. This introduces technology that without harmful intervention, give doctors valuable information and data to be used in diagnostics and treatment. Visualizations derived from data received from these technologies are of key importance in everyday medical planning. Virtual Endoscopy and Multimodal imaging are two hot topics that use existing technology only and takes graphical visualization one step further. Several fields have direct use for such implementations, such as surgery planning, medical research and medical studying.

1 Introduction

The whole process of giving diagnostics (with optional treatment) can be simplified down to 3 different stages. These different stages characterizes the flow of action in medical intervention planning. [Fig1].

Data acquisition is the stage where various medical instruments, screening technologies like CT or X-Ray are used to collect data about the patient. Usually this data is stored and pre-processed by certain criteria, avoiding its semantics, generating different sets of data to be used in the next phase, the planning stage.

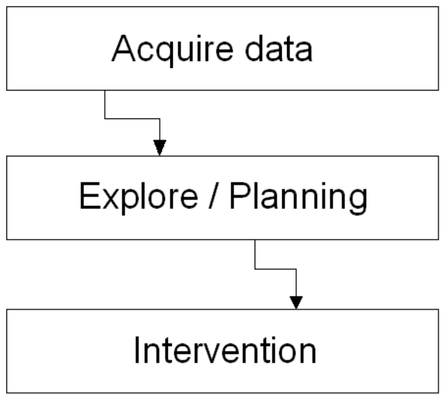

Figure 1: Flow of medical intervention planning

The stage of exploration and planning is when the different sets of data are revealed to the medical doctors. They now have the ability to look at 2d slices taken, 3d volume visualizations, videos generated by sampled pictures etc. This gives doctors good overview of the situation, and is crucial in decision making on which and how intervention should be done. They now deduce a plan on how to

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treat the patient.

The final stage of the model is the intervention. Now a treatment is needed to be taken and the doctors take necessary steps to cure the patient of its illnesses.

It is important to realize that the flow of this model does not allow steps to be taken in reverse order. If data considered in the planning phase is deemed insufficient, a new data acquire-phase has to be done in order to collect what data is missing.

In this paper we will focus on the planning stage of the intervention model [Fig1], and describe several state of the art techniques that will enhance this stage.

1.1 Different kinds of Data Acquisition

These data acquiring technologies can be divided into two different groups; Technology used externally of the human body - screening technologies, and technologies used inside the human body.

1.1.1 Screening technology

The scanning methods outside the body are numerous, different methods include;

- Magnetic Resonance Imaging (MRI)
- Computed Tomography (CT)
- Ultra Sonography (US)

These different techniques to derive information from inside the body are considered safe to use, i.e. there are no or low chance for any harmful impact on the subject being scanned. Each has its own strength and weakness, varying from spatial frequency, size and cost of usage. These techniques have no intervention abilities, i.e. there exists no possibility to do on-the-fly surgery and intervention of any kind while undergoing these examinations, as they belong to the second step in the intervention planning model [Fig1]. They generate data to be viewed after the examination is through.

Ultra Sonography while characterized as a screening technology, allows for real time data to be viewed on monitors. Ultra Sonography merges to two first phases the model [Fig1] enabling users to do data acquisition in parallel with exploration and planning.

Despite the fact that most technologies output data that can be viewed as 2d slices, there is a large difference in difficulty to properly read and understand the slices. CT and MRI slices [Fig2] are much easier to grasp than the ultrasound slices [Fig3].

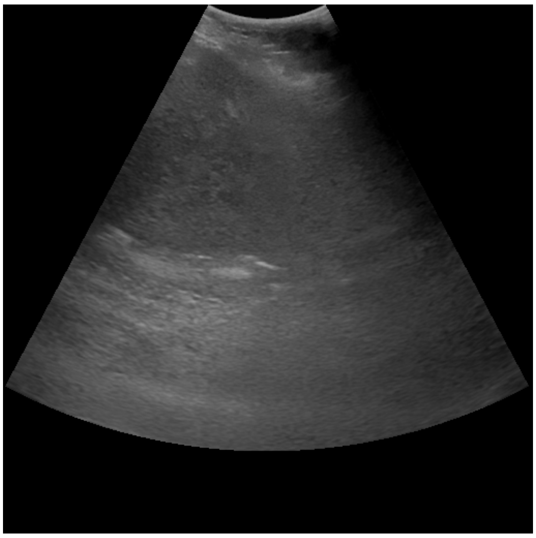

Figure 3: Ultrasound picture. Despite the fact that ultrasound pictures have very high resolution, they suffer from their unreadable (for non-professionals) character.

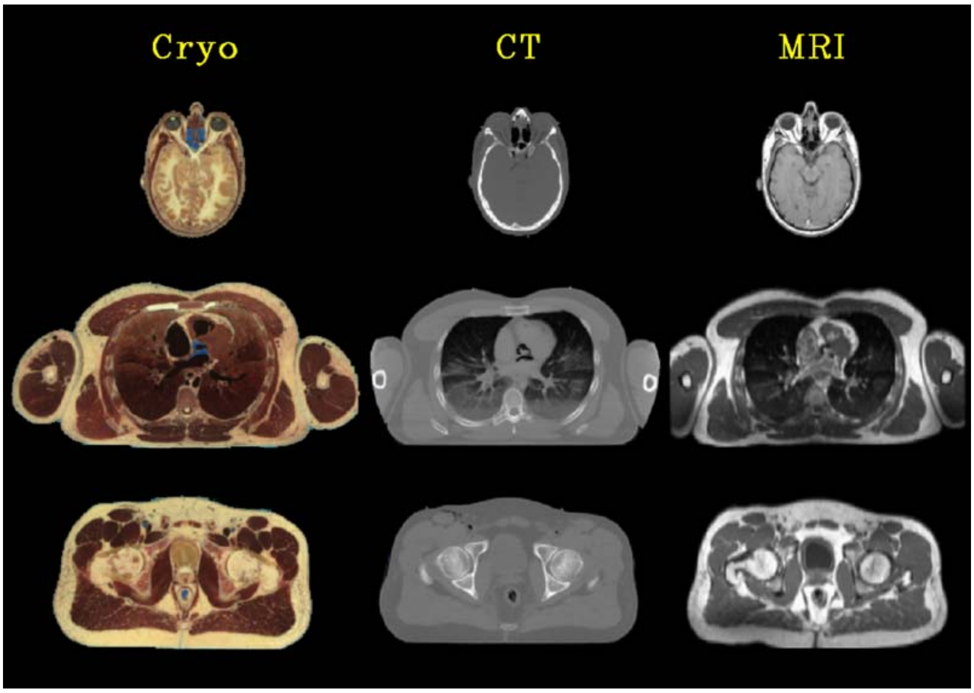

Figure 2: Slices from various screening technologies.

The results given from screening are indeed very different. As seen in [Fig2], slices contain different information. CT is for instance, very good at capturing regions composed of elements of different relative atomic number than its surroundings, such as bones. MRI is on the other hand best suited for non-calcified tissues. The table [Table1] gives a short overview of the difference in equipment cost, time to complete an examination and the corresponding hazards using such technology.

Table 1: Differences between different technologies

	CT	MRI	US
Cost	Medium	High	VLow
Time	Medium	Long	VQuick
Danger	Small Rad	None	None

1.1.2 Endoscopy examinations

Any medical examination inside the human body is usually done by the use of an endoscope. This procedure, known as endoscopy, uses a flexible tube of optical fiber, with an optic lens attached to the end. The light source is normally outside the body, supplying light through the optical fiber. Endoscopy gives medical personnel the ability to look inside the body, inserting the endoscope in the body through the gastrointestial tract, or through the large intestine. The camera feed can be viewed on a large monitor to allow doctors better overview. Endoscopy, unlike the external scanning like MRI, CT etc. allows the users to intervene during examination by tilting or moving the lens. This gives the ability to review and scrutinize interesting areas in realtime. It is also possible to introduce needles and other tools through a parallel accessory channel that may take samples and inject medicine in target areas. Endoscopy as such is a procedure where the phases of data acquirement and exploration / planning merges together. [Fig1]

1.2 Interpretation of data from screening devices

Nowadays screening devices output thousands of slices to be reviewed. Iterating through these are cumbersome, impractical, and time consuming.

Information derived from medical instruments such as MRI and CT can be post processed and viewed as 3d models. This is due to the fact that the 2d slices scanned by such instruments can be aligned in the order they were scanned and understood as a 3d volumetric data set. Using these 3d models in conjunction with 2d slices gives a very rich and powerful analyzation tool, which enable doctors to do quick examinations on the 3d models, and then scrutinize the 2d slices from regions of interest found at the 3d models afterwards, thus saving time and getting the same results as the iterate through all slices procedure. 3d volume renderings gives unquestionable more oversight than 2d slices, but looking at 2d slices can be in many cases easier than looking at 3d data where certain details may be omitted. Having both available at the same time, gives users the best of the two worlds. [Fig4]

The sets of data can then be used in conjunction with different software to convey its information. There are several techniques to properly visualize its data. Examples of such are by color coding or grey scaling the data, allowing various angles of the data to be viewed. Color coding and alpha values allow for more advanced features like highlighting of important areas to emphasize its importance and cutouts of the 3d data set, allowing views on the inside of otherwise unavailable places. 3d viewing is very easy to understand for both patients and doctors, making explanation of procedures easier for both.

2 Virtual Endoscopy

Virtual Endoscopy is a visualization technique that allows doctors to view inside cavities of the human body without the normal use of an endoscope [6]. By not using any intervening instruments such as the endoscope, virtual endoscopy is able to visualize and display regions that is too small for an endoscope to come by or normally occluded by tissue. An example are examinations done inside small blood vessels where there normally is too small space available for an endoscope to pass through. Another example where virtual endoscopy enables users to view otherwise occluded areas, are examinations done in the colon and the colon folds. In such a case a specialized technique derived directly from virtual endoscopy called colon unfolding [3] may be performed, enabling users to view the whole colon as a rectangular patch.

Intervention done with a regular endoscope is costly by comparison to the virtual one since no sedation is required for CT screening and patients usually dont need to stay overnight at the hospital. Virtual Endoscopy is, in contrast to its counterpart, also much more comfortable for the patient. It can be classified as a non-invasive procedure, it poses no risk of perforation, irritation or hemorrhage that

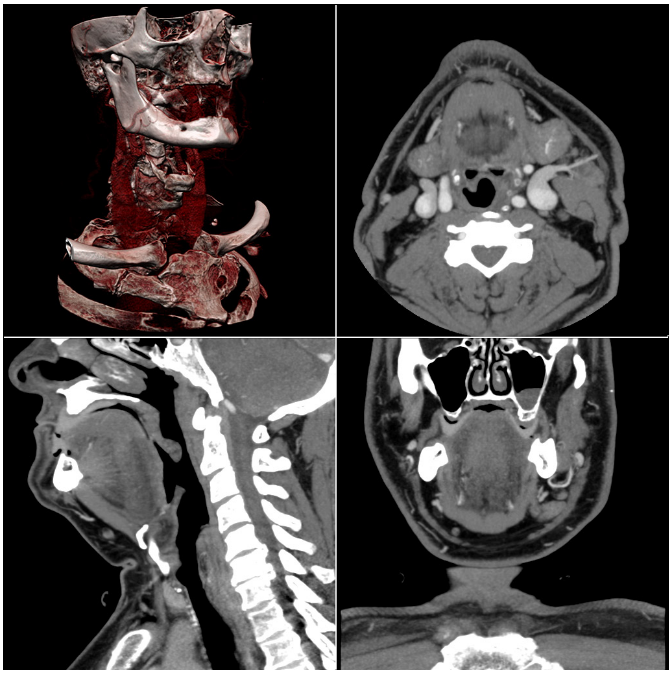

Figure 4: A typical medical workstation interface, displaying three two-dimensional slices, one along each axis, and a three dimensional volume rendering[12]

otherwise may be caused or inflicted during the examination. Regular endoscopy is bound by the set position of the viewing lens, the lens viewing angle, and the stiffness of the instrument the lens is attached to. On an endoscope the lens is positioned at the end of the tube, which means that its ability to twist and turn is very limited. The regular endoscope is unable to look behind itself, i.e. it cannot turn around and look backward. The wide angle lens (fish eye lens) used in these instruments also distorts the viewing projection. Measuring distances on objects viewed through such lens is not trivial. A virtual camera however does not have these restraints. You could change the angle of view at any time, rotate the camera in all three directions and change the position and strength of the light source.

The process is solely based on data from screening of the patient at an earlier stage. Such data is commonly in form of 2d slices from screening devices such as CT or MRI. There are different methods to pre process such data, to enable it to be used in Virtual Endoscopy. Two well known ways to process such data is volume rendering through raycasting [2] and iso-surfacing (generation of a geometric model) through usage of the marching cubes algorithm [8].

When the dataset is fully processed, i.e. by means of raycasting or iso surface extraction, the generation of a flightpath is done. This is a path the camera will move along when traversing the dataset. This will often be experienced as a vcr-like playback, with the opportunity to forward, stop and rewind the playback.

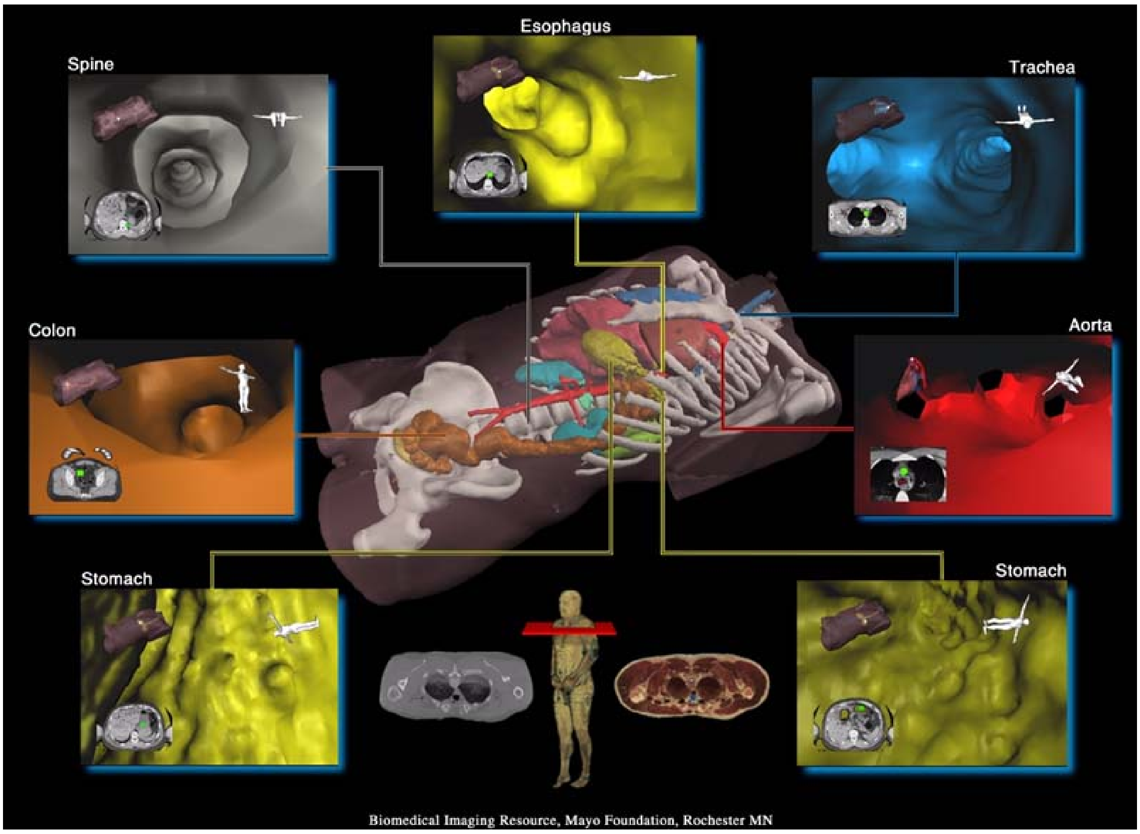

Figure 5: Overview of several different areas of usage for virtual endoscopy. Each of these pictures are taken from a virtual endoscopy visualization environment [1]. Having an overview of the current spatial positioning when using virtual endoscopy is crucial.

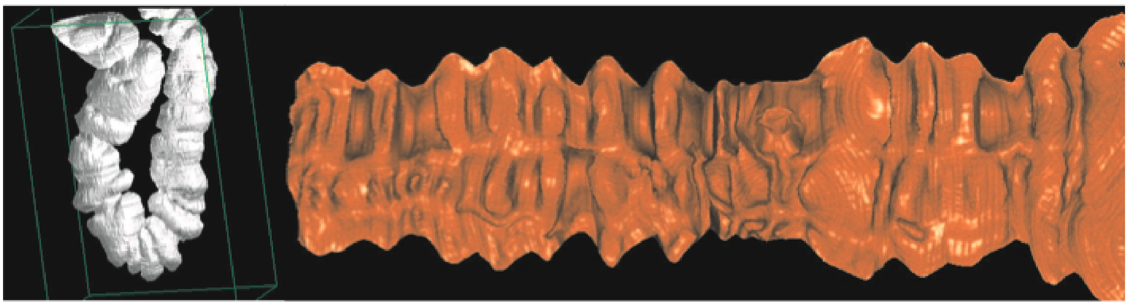

Figure 6: Left side is 3d volume of colon. Right side visualizes the colon in stretched or unfolded state.[3]

More powerful hardware will enable user to interact with the dataset by moving the camera, changing the view angle and soforth. Vivendi is such a working environment for virtual endoscopy by Bartz et al. [7]

[Fig5] displays several different areas of usage for virtual endoscopy.

Currently, the best usage for virtual endoscopy, is early cancer detection in the colon. Virtual endoscopy is not a visualization technique bound to usage on data from the human body, and can be employed on anything that can be successfully screened in a scanner and contains tubes or objects of similar geometry.

3 Multimodal Imaging

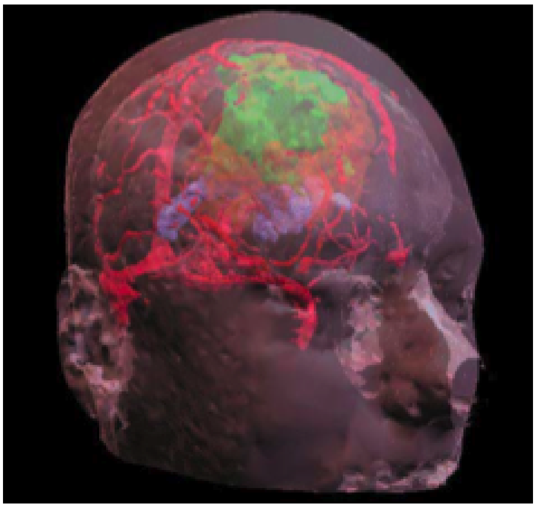

Figure 7: A rendering of the 3d models constructed from several different registered MR modal images.[9]

Datasets from CT or MRI scanners can be used to create fantastic 3d volume renderings. MRI scanners, for instance, have a wide range of different attributes that can be tweaked to get different results from the screening process. Multimodal imaging is all about combining data from different modalities to gain enriched datasets [5]. Screenings with different modalities done in a MRI scanner, will have the property that the samples taken, assuming the object being screened stays still, have the same spatial positions. This enables combination of data from different modalities, generating volumetric results like [Fig7].

As mentioned earlier, screening technology like CT, MRI and Ultrasound all have different characteristics, emphasizing some property better than others [Fig2] at page 3. The key property with multimodal imaging is having data that is co-registered. Co-registered data is data where samples are spatially aligned (they represent the same positions), like [Fig7] where all datasets are taken from the same technology (i.e. all samples are correctly spatially aligned by the fact that they are sampled at the same position).

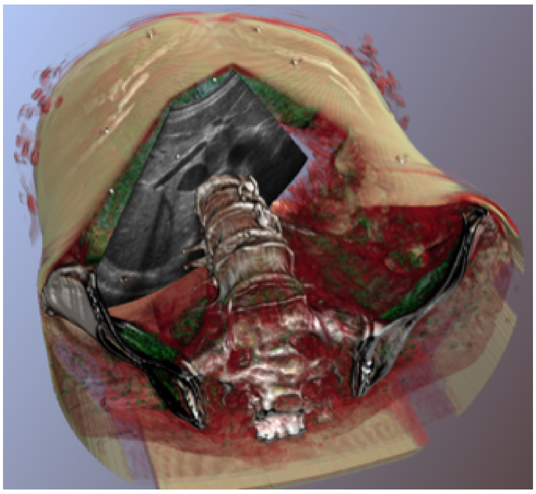

Figure 8: A traversal ultrasound image of a patients liver is shown aligned in the context of a (non-contrasted) CT scan. Bone is allowed to obscure the ultrasound plane and as such helps facilitate spatial perception of the plane.[11]

Recently developments done by Ascension Technology, significantly helps the co-registering of datasets. They made a product called microBIRD [10], an extremely small sensor for intrabody localization. This enables the creation of multimodal datasets, by supplying the spatial information needed for correctly co-registering the datasets from different screening technologies. The microBIRDs sensor is so small, that it easily fits into small catheters.

Combining data from CT, MRI and Ultrasonography technologies, with the property that is co-registered creates very large and rich datasets. The data can be used alongside of each other, for instance a two sided view, with CT slices on one side, and corresponding ultrasound pictures of the other side. The data can also be used in context with each other, displaying for instance ultrasound slices inside 3d volumetric renderings [Fig8]. There are numerous combinations that can be done.

Burns et al. [11] describes a profound usage for a CT and ultrasound multimodal dataset for image guided needle procedures, where the already captured data can display a optimal path for the needle. The microBIRD sensor will play a crucial role is such a case, since we are relying on knowing the spatial position of the needle.

4 Interactive Ultrasound Plugin

VolumeShop is an interactive application for the generation of graphics directly from volume data made by Stefan Bruckner et al.[4]. We have made a plugin for this working environment called Interactive Ultrasound Plugin [Fig9]. The plugin is written in C++ and uses OpenGL to achieve hardware accelerated graphics.

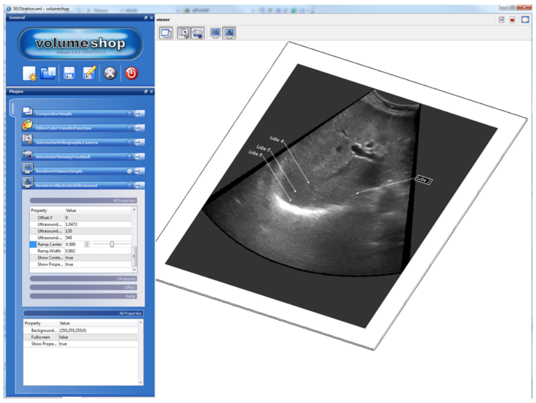

Figure 9: Interactice ultrasound plugin used in the volumeshop working environment. Displays a tilted ultrasound picture with labels attached to corresponding CT slice segmentation.

Figure 10: Ultrasound picture shown in combination with MIP processed CT volumedata

The Interactive Ultrasound Plugin enables viewing of CT volumetric data and slices in conjunction with ultrasound pictures. The CT dataset is co-registered (spatially aligned) with the ultrasound pictures resulting in an enrichened multimodal dataset, which have the best properties of the integrated systems. The dataset still retains the possibility to view the data seperate from each other, i.e. CT slices at one side, and ultrasound pictures at the other. CT slices are Ultrasound pictures are generally difficult to read for non-profesionals. The plugin enables segmentation of the CT data, labeling and annotating the segmentations, and then viewing the same spatial positions labeled in the ultrasound pictures [Fig9]. This has the advantage that one can easily identify regions or characteristics in the ultrasound pictures, and if viewed together with the CT 3d volume, have a complete spatial overview of where the ultrasound picture is captured at. See [Fig10].

4.1 Label placement algorithm

When placing labels the first thing that should be taken into account is the spatial characteristics of the segmentation being labeled. We want to find the position nearest the edge of the ultrasound image to avoid as much occlusion presented by the label anchor lines as possible. There are three borders to be taken into account here, see example in [Fig11].

For each label, an optimal placement is calculated, which is most cases will result in overlapping or occluding labels [Fig12]. The occluding labels will then be identified by using box intersection tests and solved iteratively. The first step in solving the occluding labels, is to displace one of the occluding labels some small distance delta along the corresponding border chosen earlier. This will continue until a valid placement for the label is found [Fig13].

The final step for calculating label positioning is to untangle the anchor lines.

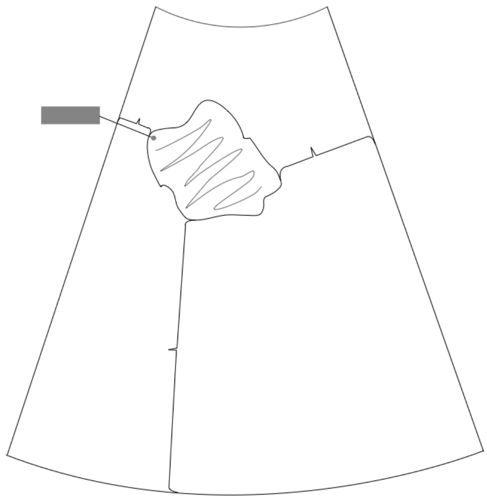

Figure 11: The three distances to be taken into account when calculating the optimal label placement.

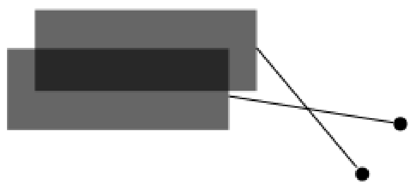

Figure 12: Occluding labels and anchor lines are crossing each other

After solving the previous problem, anchor lines were still in a tangled state [Fig13]. By switching spatial positions on the labels, the lines successfully untangle. Every point is interchanged, but the point the label were constructed to point to. This completes the algorithm for avoid occluding labels and untangling anchor lines [Fig14].

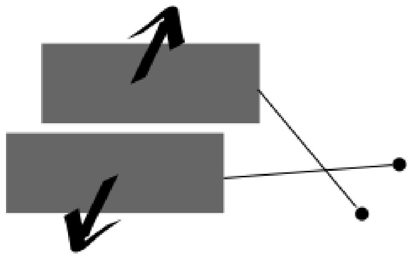

Figure 13: Displace one label away from the other to avoid occluding labels. Anchor lines still crossing each other.

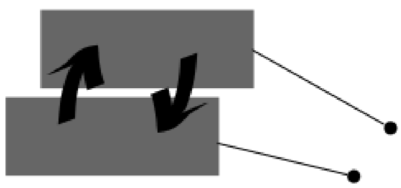

Figure 14: Switch spatial position of labels to solve problem of occluding labels completely. Only the original points the labels were constructed to point to, is kept.

5 Conclusions

Virtual Endoscopy is a fantastic visualization which enable users to do endoscopies with the possibility to examine almost everywhere, and doing so interactively while avoiding the negative effects of regular endoscopy discussed in section 2. At the given time, it is clear that virtual endoscopy has its limitations and that the optical endoscopy will never fully be replaced. The camera resolution of the virtual procedure can never fully give the same results as the optical counterpart. Most regular endoscopes used today, also contain one or more accessory channels, enabling them to do biopsies and inject medicine during the actual examination, a thing that can never be realized in virtual endoscopy.

The interactive ultrasound plugin presented in section 4 eases the learning curve for spotting interesting regions in ultrasound pictures by allowing classification on the corresponding (co-registered) CT slices transfered to the ultrasound pictures. Labels and annotations eases the transfer of knowledge between individuals and combined with slice interaction significantly increases the spatial understanding. An improvement proposal is to take into account several ultrasound pictures instead of just one when calculating the label placement. This can reduce the repositioning of the labels to generate more static label positions.

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