Optimal Colour Filtering for Laparoscopic Surgery

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Laparoscopy was shown to be highly effective in improving patients healthcare outcomes in comparison to traditional open surgery, ensuring faster healing, reduced scarring of the tissue and reduced pain. Laparoscopy has a great technological complexity, causing difficulties which make it of great interest to the engineering community. This research investigated whether colour filtering provides a better contrast during laparoscopic surgery, allowing for easier identification of tissues and vessels. A video of a gall bladder removal surgery was first carefully analysed for key moments when the hepatic vessels, gall duct and gallbladder vessels were visible. Three different reference images were selected from the original video and twelve different RGB (Red, Green, Blue) ratios were used to create new colour enhanced images for each of the selections in Darktable. A compilation of these images along with the original ones were then sent as a survey to eight members of the OR team at Reinier de Graaf hospital. The survey tested whether colour filtering achieves a significant improvement in surgical vision in comparison to the original images using the standard white light technique. The results showed that images with a light blue filter (Red 0.7,Green 1.15,Blue 1.235) and contrast enhancement of 0.25 were rated the highest. Overall, the images with contrast enhancement were rated higher than the images with only a colour adjustment. These findings are promising for improvement of laparoscopic surgery, however further optimisation of the filter and contrast enhancement is required before application in the operating room.

Keywords: Colours, Colour Vision, Laparoscopy, RGB-values, Contrast

I. Introduction

Technology in the area of medicine developed significantly, allowing for complicated procedures to have higher success rates. Surgery, both classic (open) and endoscopic, can be distinguished in this area as well, especially when it comes to the lighting used. This allows for surgery to be performed at any time of the day or night, as opposed to the past where most surgery was conducted in broad daylight only [1]. All of these breakthroughs were possible through the use of technology advancements and clever designs. Although, improvements must also be attributed to the understanding of the human body, its functions and limitations. All these played an equally important role, not only from the point of view of the patient but also the surgeon. Colour vision is one of the aspects that has been intensively studied over the years. It is known that the most common cells in the human eye are rod cells containing rhodopsin. This allows proper visualisation of the blue-green region of the colour spectrum [2]. Moreover, these cells are also considered to be more sensitive to light than cone cells, having however the disadvantage that images obtained with the use of these cells tend to be unsharp. Colour vision can be linked to the current problem when it comes to surgery, consisting of the surgeon's difficulty in distinguishing between different structures under the existing lighting sources. Surgical lighting however is a complex aspect, which involves multiple factors such as light quantity, light beam directionality, shadowing and colour [5]. Each of these factors can be varied independently thus providing multiple individual topics of research. The purpose of this paper is to determine the light colour that could be used in order to optimise the contrast between the tissues and provide better visibility. Different structures and tissues have different absorption spectra[6] meaning using different colours could improve the contrast. The question which is to be answered is ”Can colour and contrast filtering provide better overall contrast between structures in laparoscopic surgery, and if so, what RGB ratio provides an improved image for surgeons?". In order to do so a number of pictures of different colours and contrasts portraying different organs during a gallbladder removal surgery were generated. It must be mentioned that there is a clear difference between using coloured LEDs to obtain an image and editing the RGB (Red, Green, Blue) values in a previously obtained picture consisting of white light. This difference is given by the fact that coloured lights will actually cause a difference in contrast based on the different absorption spectra of the tissues, whereas changing the RGB values alone will not. The RGB approach was considered in this case due to the difficulty in designing a set-up with well controlled variables. Colour is a continuum and it is a difficult element to define due to the large variety of shades present for each base colour. Thus, any discussion or mention of specific colours in this paper will be in terms of the Red, Green and Blue (RGB) values of the specific shade used as to avoid confusion. Based on literature study including the eye anatomy [2] as well as previously conducted research into the "Development and evaluation of a light-emitting diode endoscopic light source" [3] and optimisation of the illumination for texture visibility [10], the expectation (hypothesis) is that the shades generated using higher values of green and blue will be better compared to the ones obtained using higher red values. Moreover, a change in colour alone is expected to be less effective than a combination of colour and contrast.

II. Method

In order to determine the RGB combination that provides an improved contrast, three different images were sampled from a gallbladder removal surgery video. Using a photo editing software called Darktable [4], the RGB levels were adjusted 12 times for each of the sampled images, using the white balance tab of the program. The different RGB levels used are shown in Table 1. Here, it is noticeable that there are multiple combinations that are perceived as a shade of the same colour. This is the reason why it was previously mentioned that talking in terms of RGB combination will prevent any confusion. The combinations were chosen by first taking the base ratio for colours such as for example yellow (1:1:0.5) and gradually adding more of the lacking colour as to achieve shades found in between two different 'base colours'. The next step was to modify the ratios further by adding or removing each of the RGB components as to cover a greater number of shades from the RGB spectrum. As previously mentioned, the change of the RGB values alone should be insufficient for generating enough contrast in the image as to significantly improve the original. Thus in order to simulate to some extent the effect of actual coloured light and test which RGB value enhances the image and is preferred by the surgeon, a contrast enhancement value of 0.25 was added to each of the images using Darktable. This was done using the contrast, brightness and saturation tab of the program.

Table 1. RGB ratios

Option (common shade name)	Red (R)	Green (G)	Blue (B)
Red	0.96	0.52	0.64
Light green	0.75	1.25	1.075
Light Blue	0.7	1.15	1.235
Red	0.96	0.64	0.64
Green	0.64	0.96	0.64
Blue	0.64	0.64	0.96
Orange	0.99	0.78	0.42
Green	0.32	0.96	0.64
Magenta	1.08	0.4	0.84
Yellow	1	1	0.5
Turquoise	0.6	1	1
Magenta	1	0.6	1

Once the images were prepared, an online survey consisting of 36 questions was generated. These were divided into 3 different sections, one for each image and its set of 12 colour combinations. Each question represented one combination of RGB values for a given image. The questions were set up so that the original image, the colour adjusted image and the colour adjustment combined with a contrast enhancement were placed side by side. This way the images could be compared easily as seen in Figure 1. The purpose of the method was to not directly compare the different RGB combinations between each other but each individual one to the original image in order to make it possible to determine based on ratings which option is preferred (if any).

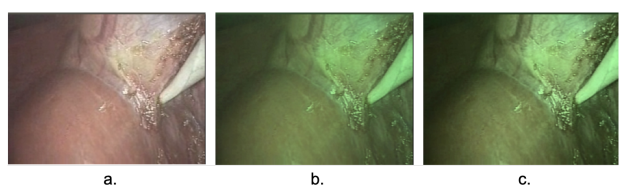

Figure 1: Survey image line-up. Image a - original, image b - RGB adjustment, image c - RGB adjustment and contrast enhancement.

Using a scale from 1 to 4, eight research participants from the Reinier de Graaf operating room (OR) team rated the visibility of the structures in the two enhanced images as follows:

1. Cannot properly distinguish the structures
2. Structures can be distinguished but the image is not better than the original
3. Structures are slightly easier to distinguish than in the original

4. Structures are definitely easier to distinguish than in the original

These ratings ensured that all possibilities were covered: an image that is worse than the original (rating of 1), an image that brings no significant improvement (rating of 2) or an improved image (ratings of 3 and 4).

For analysing the data, the averages of the ratings per image were taken. To analyse these averages, the following conditions were used:

Average lower than 2

For an average lower than 2.0, the image is mainly rated with 1 and 2, meaning that this colour adjustment with/without contrast enhancement is providing an image that is worse than the original image.

Average between 2 and 2.5

For an average between 2 and 2.5, the image had some ratings above 2 and some ratings of 2 or lower, indicating the colour adjustment with/without contrast enhancement is not bringing a significant improvement to the original.

Average above 2.5

For an average higher than 2.5, the image was mainly rated with 2, 3 and 4, indicating that the image is better than the original.

The end results was analysed and interpreted based on these averages as well as with the aid of box and whisker plots for visual representation of the data. During the research, the RGB combinations on the whole video were also examined using video processing techniques, working towards the possibility of implementing the research in healthcare practice. The purpose of this was to determine whether videos can be efficiently enhanced automatically as well, rather than only adjusting one specific frame at a time by hand. By creating a graphical user interface (GUI) using MATLAB [7] as shown in subsection D of the Appendices, unintended side effects such as reflections of the enhancements were monitored.

III. Results

On average the images that presented a combination of colour adjustment and contrast enhancement were rated better than the images containing only a colour adjustment, this being in line with the expectations. Images containing only the colour adjustment were rated as being either worse than the original (rating of 1) or bringing no significant improvement (rating of 2) for each of the options. The images containing the colour and contrast enhancement had on average a combination of ratings of 2 and above as seen in subsection A of the Appendices.

Following through with the method presented in section II, the images that had an average rating above 2.5 are: image 1.3 with contrast enhancement (Figure 2), image 2.3 with contrast enhancement (Figure 3) and image 3.3 with contrast enhancement (Figure 4). These images have the same colour enhancement and the same contrast setting of 0.25. The colour adjustment used on these images is a light blue filter, with RGB values of Red 0.7, Green 1.15 and Blue 1.235.

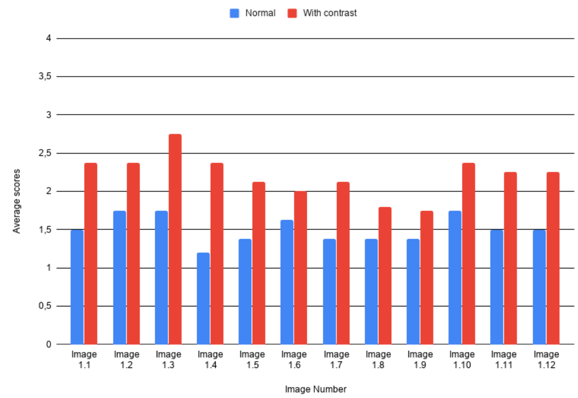

Figure 2: Average results of section 1.

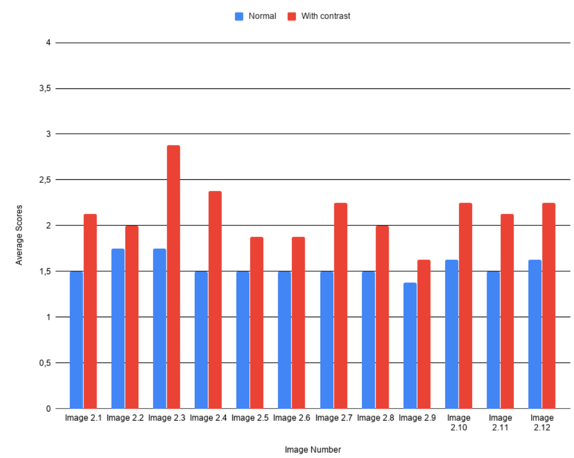

Figure 3: Average results of section 2.

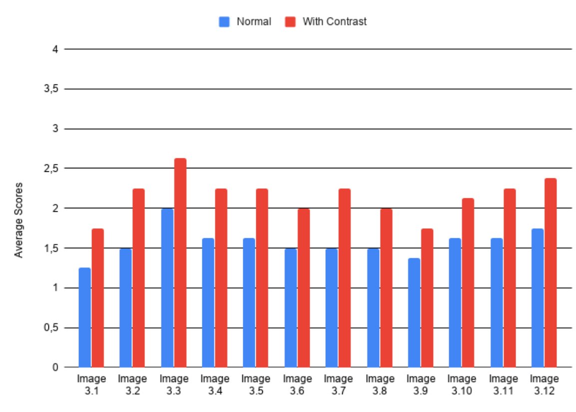

Figure 4: Average results of section 3.

In terms of their common names, the highest rated images were the light-blue ones(images 1.3, 2.3 and 3.3), followed by yellow (image 1.10), various shades of green (images 1.2 and 1.5) and shades of red (1.1 and 2.4).

For some images, such as 2.8, 2.9 3.8 and 3.9, the variation in the ratings was high as seen in subsection B of the Appendices. These images achieved both positive scores (rating of 3 and 4) and negative (rating of 1) simultaneously. It is also noticeable that some images were rated differently in the three sections presented, despite having the same colour enhancement setting. One example where the variation is more evident is with images 1.1, 2.1 and 3.1. For these images, the average ratings for the contrast enhanced option are at 2.375, 2.125 and 1.750 respectively. Despite these few examples however, the overall trends appear to be constant while looking at the shape of the graphs from the three different sections. For a visual representation of the data, a set of box and whisker plots have been generated as seen in subsection B of the Appendices.

Also important to note is the answer to the question asking for comments. Here, a surgeon commented: ”I'm not familiar with the different colour filters, so it is difficult to tell if the filter provides a clearer image than the original”.

The MATLAB GUI proved to be working as well, thus indicating that colour and contrast adjustments can also be applied to the whole video, and not just specific selections from it. However, some difficulties were encountered in terms of applicability in real time, since the enhancement took a significant amount of time to be applied, thus making it difficult to use for a live video.

IV. Discussion

The light blue filter, applied with a contrast enhancement, gave the highest and consistent average rating. The rating showed that this overall enhancement provided an improved contrast between different tissues in the image. Thereby, the adjustment with the RGB value of R 0.7, G 1.15 and B 1.235, combined with a contrast enhancement of 0.25 could potentially provide a better contrast for the surgeon during a gallbladder removal surgery.

Due to the field and topic of the study, a challenge that occurred was finding a large number of participants. This small sample made it more difficult for a conclusive result to be established due to the large variation for some of the colour combinations. An example of this was image 3.8 with contrast enhancement, where half of the answers deemed the combination neutral, while the other half were equally distributed between a rating of 1 and a rating of 3 or 4. Moreover, the idea of finding an optimal colour combination is difficult in itself due to the great differences between individuals and the highly subjective perception of colour. This is also a way of explaining the variation in the results for some of the questions.

Some colour combinations were rated consistently across the different sections of the survey. As illustrated by analysing images 1.1 and 2.1 it can be seen that they have the same colour combinations yet different ratings, meaning that the image itself (the composition) is also an important factor in determining the colour combination needed. This was consistent with the literature, numerous articles mentioning that different tissues will have different absorption spectra and thus different colour combinations might be required depending on the purpose[8][6]. Another reason why the answers were spread out could be the experience and personal preference of each surgeon. Years of training using standard white light could have caused each of them to be comfortable with the natural colour of tissue. Therefore changes in colour, although useful in terms of contrast between tissues, would introduce some issues in distinguishing the type of tissue one is looking at. One of the surgeons confirmed this by commenting ”I'm not familiar with the different colour filters, so it is difficult to tell if the filter provides a clearer image than the original”. This could be a reason why some of the images with a red filter and contrast enhancement were also rated highly, due to the surgeon's familiarity with the colour of the tissues.

The images with contrast enhancement were rated at all times higher than the images without the contrast enhancement. This indicates that the contrast enhancement itself can improve the image quality as well. There is a chance that applying just the contrast enhancement on the original image will provide a better visibility for the surgeons, but further research should be conducted in the area.

The outcome of this research can be a start of optimisation process to find the best suited values for the light blue filter and the contrast enhancement for laparoscopic surgeries. Testing which filter improves the vision of different tissues could help surgeons perform their job more efficiently and safer.

Acknowledgements

We would like to express our gratitude to Prof.Dr. Maarten van der Elst for the valuable advice and support throughout the project. We would also like to thank Reinier de Graaf and the OR Team for the opportunity of observing the procedures as well as for participating in our research experiment. Last but not least, we would like to thank Associate Professor John van den Dobbelsteen for helping with the overall organisation as well as preparation of the final posters.

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Appendices

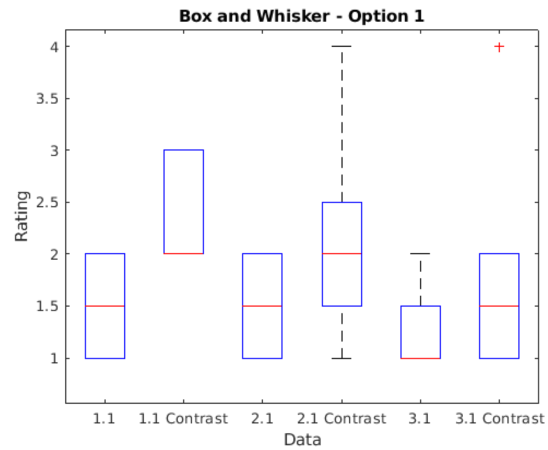
A. Raw Data

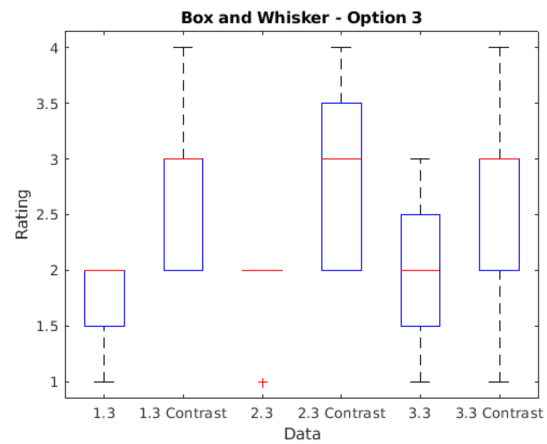
	Enhancement Type															
Image Number	Colour								Colour + Contrast							
	Ratings															
1.1	2	2	2	1	1	1	2	1	3	3	2	2	2	2	3	2
1.2	2	2	2	1	2	2	2	1	3	2	2	2	2	1	4	3
1.3	2	2	2	1	1	2	2	2	3	3	3	2	2	3	4	2
1.4	2	2	2	1	1	1	2	1	2	2	2	2	2	2	4	3
1.5	2	1	2	1	1	1	2	1	3	1	2	2	2	2	4	1
1.6	2	1	2	1	1	1	2	3	2	2	2	1	1	2	4	2
1.7	2	1	2	1	1	1	2	1	3	2	2	1	2	1	4	2
1.8	2	1	2	1	1	1	2	1	3	1	2	1	2	1	4	1
1.9	2	1	2	1	1	1	2	1	2	1	2	1	2	1	4	1
1.10	2	2	2	1	1	2	2	2	4	2	2	1	2	2	4	2
1.11	2	1	2	1	1	1	2	2	2	2	2	2	2	1	4	3
1.12	2	1	2	1	2	1	2	1	3	2	2	2	2	1	4	2

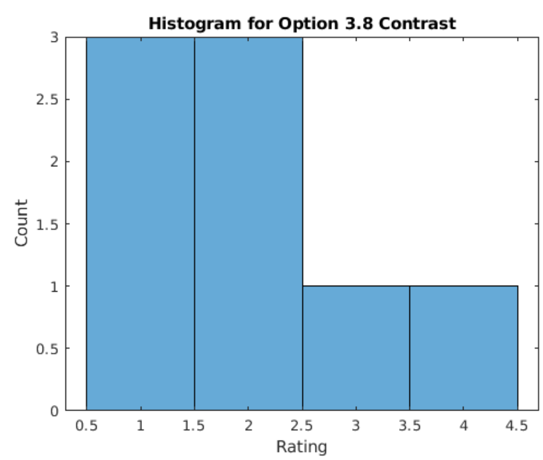
	Enhancement Type															
Image Number	Colour								Colour + Contrast							
	Ratings															
2.1	2	1	2	1	1	1	2	2	2	2	2	1	2	1	4	3
2.2	2	2	2	1	2	2	2	1	3	2	2	1	2	2	4	2
2.3	2	2	2	1	2	2	2	2	4	2	3	2	2	3	4	3
2.4	2	1	2	1	1	1	2	2	2	2	2	1	2	2	4	4
2.5	2	1	2	1	1	1	2	2	3	2	2	1	2	2	4	2
2.6	2	1	2	1	1	1	2	2	3	1	2	1	1	1	4	2
2.7	2	1	2	1	1	1	2	2	3	2	2	1	2	2	4	2
2.8	2	1	2	1	1	1	2	2	3	1	2	1	2	1	4	2
2.9	2	1	2	1	1	1	2	1	1	1	2	1	1	2	4	1
2.10	2	1	2	1	2	2	2	1	2	2	2	2	2	2	4	2
2.11	2	1	2	1	1	1	2	2	2	2	2	1	2	2	4	2
2.12	2	2	2	1	1	2	2	1	3	2	2	2	2	2	4	1

	Enhancement Type															
Image Number	Colour								Colour + Contrast							
	Ratings															
3.1	2	1	2	1	1	1	1	1	1	2	2	1	2	1	4	1
3.2	2	2	2	1	1	2	1	1	3	2	2	2	2	2	4	1
3.3	2	3	2	1	2	3	2	1	3	3	3	2	2	3	4	1
3.4	2	1	2	1	1	2	2	2	1	2	2	1	2	2	4	4
3.5	2	2	2	1	1	1	2	2	3	2	2	1	2	2	4	2
3.6	2	1	2	1	1	2	2	1	2	1	2	1	2	2	4	2
3.7	2	1	2	1	1	1	2	2	3	2	2	1	2	2	4	2
3.8	2	1	2	1	1	2	2	1	3	2	2	1	1	1	4	2
3.9	2	1	2	1	1	1	2	1	2	2	2	1	1	1	4	1
3.10	2	1	2	1	2	2	2	1	3	2	2	1	2	2	4	1
3.11	2	1	2	1	1	2	2	2	2	2	2	1	2	2	4	3
3.12	2	1	2	1	1	3	2	2	3	2	2	1	2	3	4	2

B. Summary Statistics







C. Original and Enhanced Images

Figure 5: Original image 1 from the video

Figure 6: Original image 2 from the video

Figure 7: Original image 3 from the video

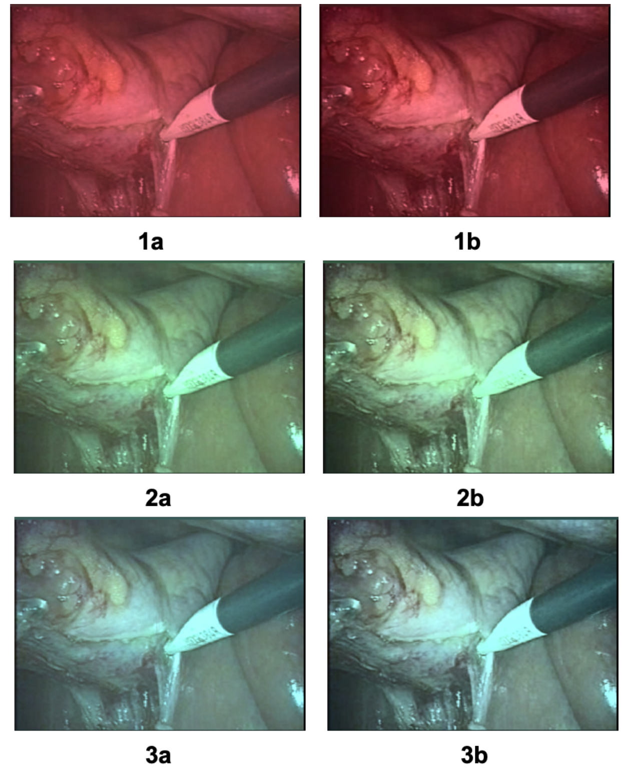


Figure 8: Image 1, Options 1-3. a - colour adjustment, b- colour and contrast adjustment

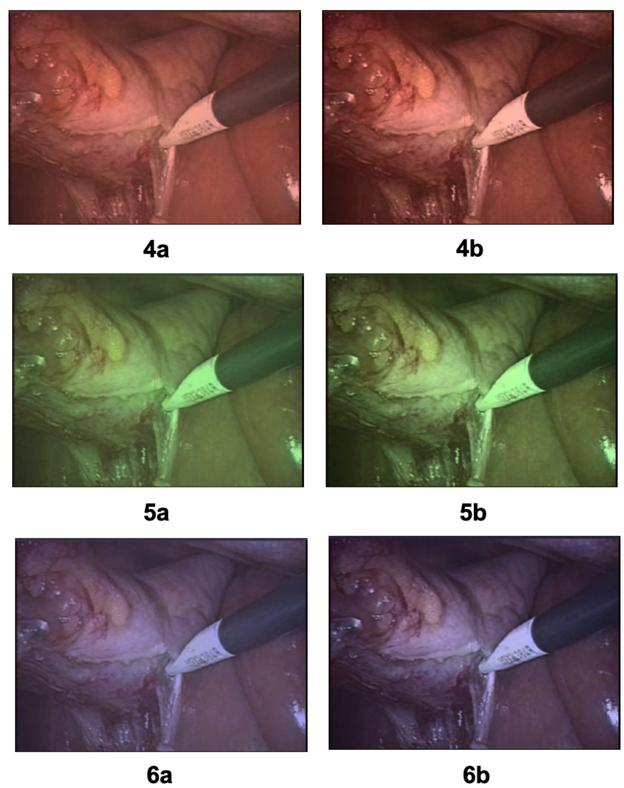


Figure 9: Image 1, Options 4-6. a - colour adjustment, b- colour and contrast adjustment

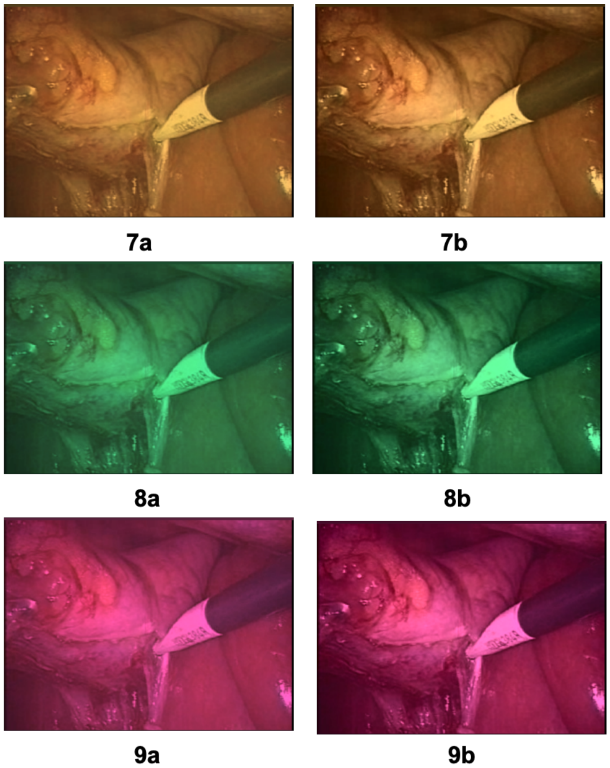


Figure 10: Image 1, Options 7-9. a - colour adjustment, b- colour and contrast adjustment

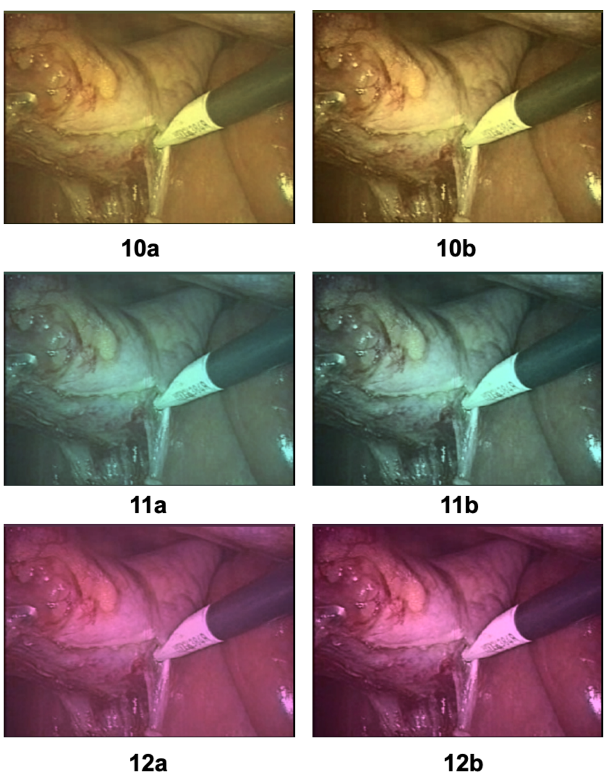


Figure 11: Image 1, Options 10-12. a - colour adjustment, b- colour and contrast adjustment

D. MATLAB Code

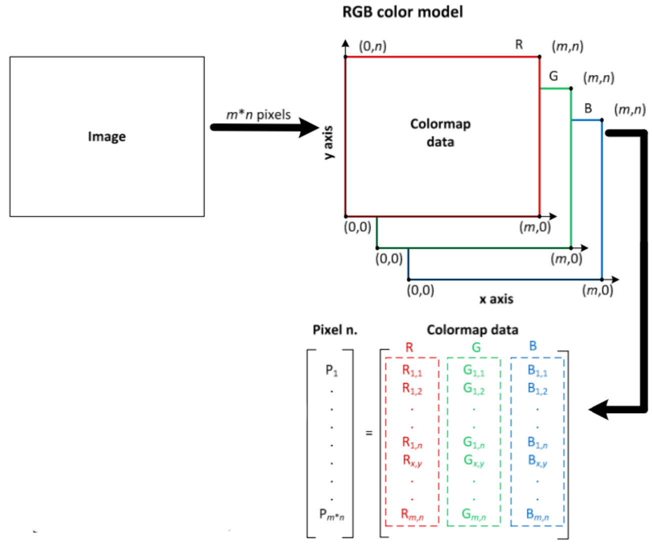


Figure 12: System diagram: Adjusted from Roger M. Groves [9]

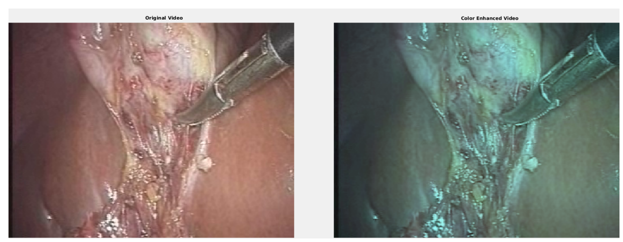


Figure 13: Screenshot of MATLAB GUI.

```
processFrame.m
% Process frame function
function result = processFrame(im)
result = im;

red = result(:,:,1)*0.6;
green = result(:,:,2)*1;
blue = result(:,:,3)*1;
result = cat(3,red,green,blue);

end
```

Figure 14: Matlab code snippet applying RBG combination .

```
properties (Access = private)
    filename % Filename of the video to be played
    videoReader % Video reader
    duration % Duration of the video
    videoIm % Image object used to show the video
    plateIm % Image object used to show the colour video
    frameH % Height of the video
    frameW % Width of the video
    T % Duration of one frame
end

methods (Access = private)
    function displayVideo(app)

        i = 0;
        while hasFrame(app.videoReader) && isvalid(app)
            if (app.Switch.Value == "Pause")
                waitfor(app.Switch, 'Value')
            end

            frame = readFrame(app.videoReader);
            set(app.videoIm, 'CData', frame);

                app.Button.Text = num2str(app.videoReader.CurrentTime);
                segment = processFrame(frame); % Create colour image
                set(app.plateIm, 'CData', segment); % Show it
            pause(app.T);
            i = i + 1;
        end
    end
end
```

Figure 15: Matlab code snippet processing video .