

FPGA Implementation of Real Time String Colour Detection

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Abstract

A Machine vision for string detection is useful technologies which benefit to the industries such as food production. It reduces the risk that can harmful to our health and it can do work more accurate and efficient. The algorithm used is a colour detection which determines the colour of string and background subtraction for filter process by using the threshold range values. The target of detection focuses on plastic string with two different colours; pink and yellow strings. The threshold values used in hardware detection are ranged from 158 to 175 and 3 to 35 for pink and yellow string colours, respectively. The result shows that an object tied with strings is able to be detected and captured by using this system. Overall, this project is successfully developed and achieved the goal for real time detecting a string which is implemented on FPGA.

Keywords: FPGA, colour detection, string detection, machine vision

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1. Introduction

Machine vision is the technology of analyzing the image and drawing conclusion purposes by using an image sensor instead of the human eye [1]. It is the simulation of the human cognition. The idea of using it is to replace human work and complete the work by using computer software and programming [2]. In new era of information technologies, an image is the basis of human visual perception of the world. It becomes an important means of accessing, expressing, and transferring information. Image processing refers to the image being processed and modified with a computer image analysis technology to achieve the desired results [3]. According to the number of colour and grayscale images in the computer, it can be divided into four basic types which include binary image, gray image, the index image and true colours Red, Green and Blue (RGB) image. Image processing supports companies to increase the capacity of product and achieve the target of productivity in estimated period. It will make the work done more accurately and effectively. Object detection can be performed with image processing to get the data of the object and analyze the object. Detection automatically can save more time, cost and acquire precise performance.

In manufacturing process, application of machine vision technology is beneficial for variety of industrial activities [4]. Image processing is one of the important roles in recognition process. For instance, in food packaging field, when an unwanted object is detected by the machine, it will be removed from the package and the remaining parts will go into next process. Quality control is the most important process in the manufacturing. Plastic string is one of the common objects used in food processing. There are both advantage and disadvantage when using plastic strings in food processing. The only advantage of using plastic string is to partition, tie off or group foods such as meats and sausages in manufacturing process. On the other hand, the disadvantage of using plastic string is not easy to un-tie and it is not edible. However, it is often attached to the foods when selling to the customers. This will affect the safeness of the food as well as the reputation of the manufacturer that produces the food.

In this work, both software and hardware are developed and implemented for string detection. The concept and design architecture of the project is discussed in section 2 whereas section 3 presents the expected results which are completely achieved. These include the result

for compilation, block diagram, waveform simulation of designed coding and the output images. The overall summary has concluded and recommendation is suggested in section 4.

2. Research Method

The string detection system is implemented on Altera's DE2 board. The VHDL coding has been developed for the conversion of RGB to hue value which is filtered to achieve the detection. Hue value is used because it is similar to the human perception of colour which has a strong perception. Based on the method and proper implementation, the efficiency of the project is increased smoothly.

Figure 1 shows the process of implementation algorithm to achieve the system development. The project is a machine vision used for string detection which use C language programming and VHDL coding to complete the detection system. By using C language programming, a related written program can detect the pattern of string automatically. At the initial stage, C language is used for finding out the range value of colour of the string. Once the range value is identified, it can be tested whether it is capable to detect the string on the image or not. There are software and hardware algorithm used for detection. C language is tested at the beginning. Once acquire the result successfully, the development of VHDL is carried out to implement a system on the Altera's DE2 Board. The C programming language is used because it can easily and usefully to recognize the data information. It is much easier for testing and modifying if compared to VHDL coding.

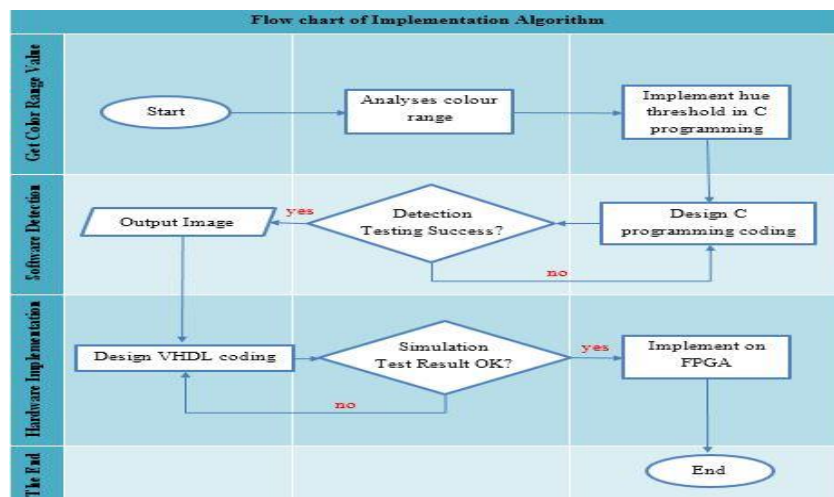


Figure 1. Flowchart of implementation algorithm

2.1. Method used for Image Detection

Many methods or techniques are available for image detection. In this project, colour detection and background subtraction are used to detect the string. Firstly, the colour of image is compared with hue (H) value to differentiate the colour and carried out an analysis to acquire the range value of colour. Image can be then converted into black and white by using grayscale transformation technique. Background subtraction technique is used to eliminate all images others than pink and yellow colours string on the image.

2.1.1. RGB Converted to HSL

RGB represent the colours which are RGB in a cube on different axis whereas HSL [6] colour mode is a colour that through between the hue (H), saturation (S), lightness (L) changes the three colour channels and their mutual superposition to obtain a wide range of colours [7]. HSL is a tool that always used in machine vision and image segmentation or feature detection. HSL is mathematically defined as RGB colour space of Red, Green and Blue of the coordinate's transformation. Figures 2(a) and 2(b) are the example of RGB and HSL respectively.



(a) Red, Green, and Blue (RGB) (b) Hue, Saturation, Luminance (HSL) [10]
 Figure 2. example of RGB and HSL respectively.

2.1.2. Conversion Formulae for RGB to Hue Value

HSL is another approach to describe colour. In this project, only hue value is used which represent the angle on colour wheel. The Equation (1) is used to convert RGB value into hue [8].

$$\text{Hue, } H = 60 * \begin{cases} \frac{G-B}{\max(R,G,B)-\min(R,G,B)}, & R = \max(R, G, B) \\ 2.0 + \frac{B-R}{\max(R,G,B)-\min(R,G,B)}, & G = \max(R, G, B) \\ 4.0 + \frac{R-G}{\max(R,G,B)-\min(R,G,B)}, & B = \max(R, G, B) \end{cases} \quad (1)$$

2.1.3. Background Subtraction

The techniques used is background subtraction [9]. It uses the current frame and background images corresponding to the pixel gray level difference to detect the image. If there is a different between the current image pixel point and background image pixel gray value, it is considered the pixel of moving object. On the contrary, smaller difference between the pixel regions is considered to be the background area.

2.2. Hardware Implementation

Figures 3(a) and 3(b) are the block diagrams of comparator and multiplexer. Figure 3(a) is a comparator which consists of two inputs and compare whether input 1 is greater than, equal to or lesser than input 2. Based on conversion formulae of RGB to hue value, a concept of comparator is required to modify to acquire the minimum and maximum values within RGB value. Besides, the comparator is also used in part of filter for hue value. Hue value is compared with the range value that has been analyzed earlier. Output will be '0' when the hue value is out of range and '1' when hue value is within the range. Figure 3(b) is a multiplexer which consists of several inputs, and a selector used to choose either one of the inputs and sent to the output. In filtering part, it is used for select the output value to display on monitor. If the input is '1', the RGB value is displayed whereas if the input is '0', '0' value is displayed on monitor.



Figure 3. Block diagram

Previous designed part can only be tested in simulation waveform. Once the result is acquired correctly, the two main block diagrams are added in DE2_TV module which can be extracted from the DE2 System CD-ROM. A DE2_TV module is a system that can be used to play video, connected with speaker, DVD player, display image on VGA monitor and so on [11]. In this project, it used to connect with camera and displays the output result on VGA monitor.

The VGA controller module which in DE2_TV module is modified to connect with camera for capturing an image and save it in SD card [12].

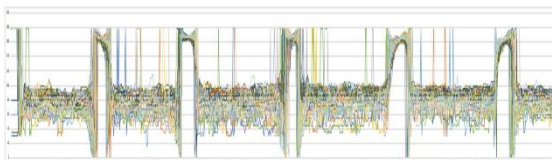
3. Results and Analysis

There are many ways to detect various types of images in image processing. String detection is one of the techniques which can be used to detect a string in the image. The characteristics of string are curly and flexible in shape. In this work, colour differentiate method is used to implement on FPGA chip by using VHDL to identify strings in the image. At the same time, software with C programming is also used to test in order to get the range of colour value and filter the image of string. The result of the software and hardware are slightly different. In real time, it is not perfect ideal case in software. This section will focus on analyzing the data of image and filtering the image to get the detection of string from the image.

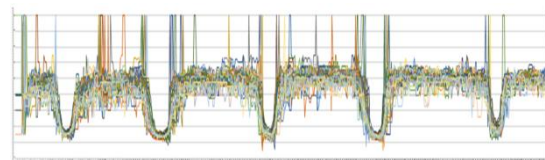
3.1. Analysis for Colour Range Value

The range value is very important value in this project. It is a threshold value used to determine the range value for the colour of string. With the range, system designed can filter the image to get string pattern for output image. In this project, it only focuses on the testing of the pink and yellow colours of the plastic string. So, the analysis is to find out the value range of pink and yellow colours. Firstly, C code is developed to get the range value of pink and yellow colours of plastic string which used to test the detection of string. A captured image is converted into hue value image for both colours of string. C code is developed to open the image file and create a text file to read the data of image and write all data into the text file with .txt extension. There are 9 pieces of hue images for each colour and a program is designed to read out any 6 rows of pixel data of one hue image and do the same step for 9 pieces of hue images. All data images are collected in the text file which has 54 rows of pixels data in total. After that, all data are saved in Microsoft Excel document. Figures 4(a) and 4(b) show all data were analyzed by plotted a graph to get the range value. By using this coding, it can be easily do the analysis and get the value of range.

From the Figure 4(a), there are 5 specific shapes like convex shape which gather all hue values of the pink colour string at that area and others is the background pixels value. Based on the graph, the range value can be determined by looking at the most concentrate area. The range value for pink colour string is between 158 and 175.



(a) Graph of Pink colour string



(b) Graph of yellow colour string

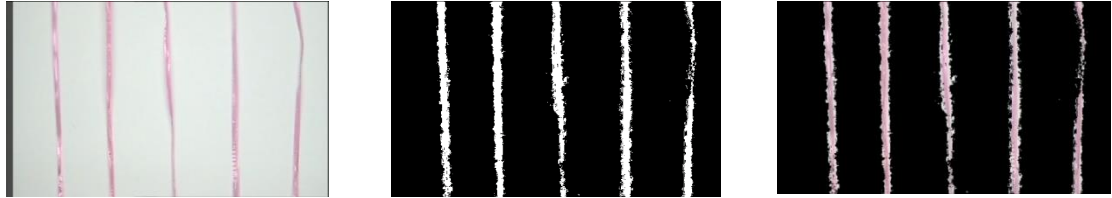
Figure 4. Graph for analysis colour range

Besides that, there is another graph from Figure 4(b) for yellow colour string image which has 5 specific shapes like concave shape. It gathers those hue values of the string colour. From the analysis, the range value can be determined by looking at the most concentrate area as the yellow colour value. The identified range from the graph is between 25 and 33 for yellow colour string.

3.2. Original Image and Filtered Image

Figure 5 shows the red string image which is captured by a camera. After that, the captured image is saved into computer. Then, filter process can be started to detect the position of string by using c code. Figure 5(a) is the original image whereas Figure 5(b) shows the mask of the image which is in black background and white string image. Figure 5(c) shows the merged image which is the output of the red string image. In Figure 5(c), the method of

background subtraction is used to filter the background of red string image and merge the colour of string. The string is detected successfully. Figure 6 shows the image with yellow string. Figure 6(a) is the original image with yellow string whereas Figures 6(b) and 6(c) are the output images which are using a same method. Similarly, the output image is also the ideal image to prove that the pattern of string is detected successfully.



(a) Original pink colour string (b) Mask image for pink colour string (c) Merge image with original and the mask image

Figure 5. Original image for pink colour string



(a) Original yellow colour string (b) Mask image for yellow colour string (c) Merge image with original and the mask image

Figure 6. Original image for yellow colour string

3.3. Hardware Implemented on FPGA using VHDL

By using VHDL coding, part for RGB convert to hue value is designed and shown in RTL viewer. Figure 7 shows the block diagram that makes RGB value converted into hue value. RGB value from the data pixels is sent in parallel into the block diagram and acquire the hue value as output.

Table 1 show the functionality of each block diagram that consisted in the RGB conversion block diagram. Firstly, it parallel sends each pixel with RGB value into comparator to do the comparison for maximum and minimum values.

Table 1. Function of Block Diagram in RGB to Hue Value Conversion

Block diagram	Function
Compare	To get the maximum value within RGB
Hue	To get the hue value
reg10bit	To store the data temporarily

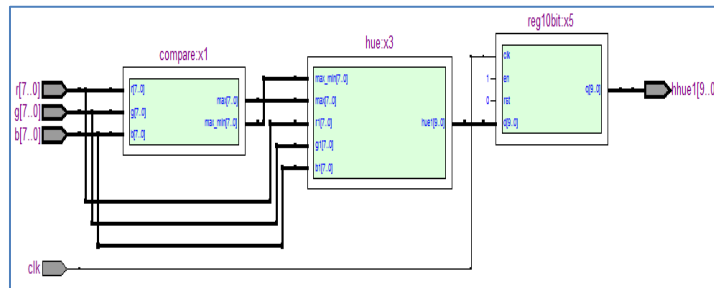


Figure 7. RGB to hue value conversion

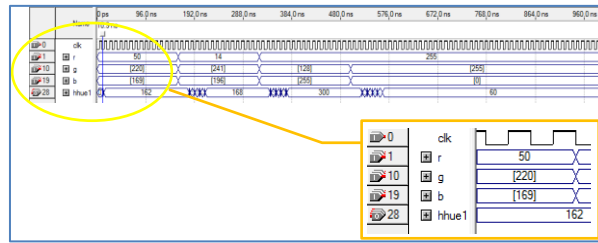


Figure 8. Waveform simulations RGB value converts to hue value

The output is the maximum value, minimum value and the difference between maximum and minimum value. After that, both of the outputs are sent into “hue” block diagram to get the hue value. At the end, the data will be kept in a register. Thus, the output will get the hue value that is converted from the RGB value. Figure 8 shows the waveform simulation for hue value. There are 3 inputs which are RGB values that are used for test whether the output will get correct result. When the input is set as R=50, G=220 and B=168, the hue value is 162. By using manually calculation, the answer is same as the output of waveform simulation. This is proved that the block diagram to convert RGB value into hue value is function correctly.

3.4. Filter String Image

Figure 9 is the filter part which is combination of comparator and multiplexer to detect the string image. Those images are not string will be filtered out and background becomes black in colour while the string pattern will remain the colour of string in the image.

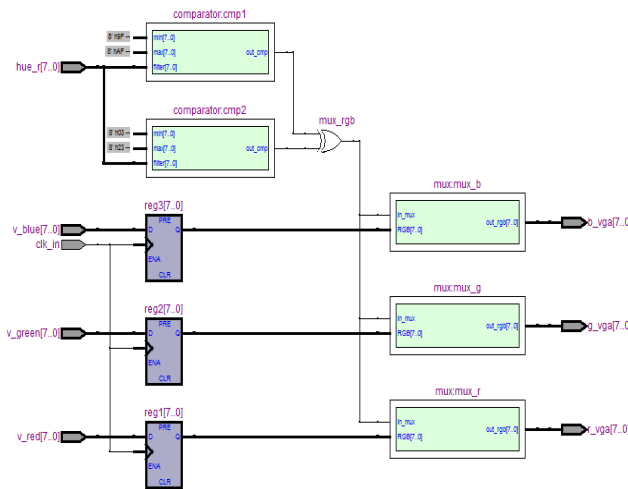


Figure 9. RTL viewer of filtering for hue value

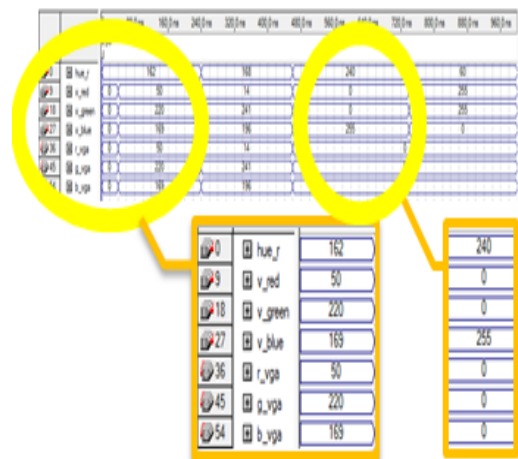


Figure 10. Waveform simulation of filtering for hue value

Figure 10 is the waveform simulation of filtering for hue value. There are 4 inputs for hue value and RGB value. The 3 outputs are the RGB value that display on monitor. When the hue value is out of range of colour value, the output RGB value will get ‘0’ which is black colour. When the hue value in within the range of colour, the output RGB value will same as the input RGB value. The range is either between “159” and “175” or “3” and “35”. For example, the hue value is set as “162” and the output is same as the input RGB value which are R=50, G=220, B=169 whereas the hue value is set to “240” and the output is ‘0’. The waveform is proved that the result is correctly. This means the filter part is working well. Figure 11 is the block diagram to convert an image and filter the image. In this project, the DE2_TV system is used to do string detection. Without DE2_TV system, this project cannot complete successfully.

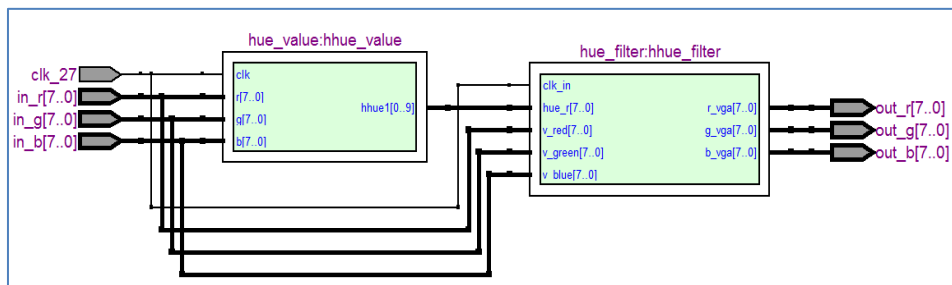
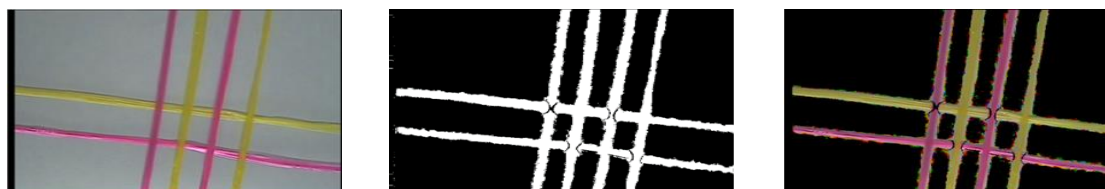


Figure 11. RTL viewer combines with RGB conversion and filter part for hue value

3.5. Result of Image Captured

The image is displayed in real time. When the setup is ready, the compiled program is downloaded into DE2 board by programmer. The system in DE2 board will run the processing and it will directly display the filtered image that sensed by the optical zoom CCTV camera on monitor. In this work, only two colour (pink and yellow) strings can be detected. Thus, the output will display the string with pink or yellow only.



(a) original image

(b) mask of image

(c) output image

Figure 12. String images

Otherwise, other object or background with the colour other than pink and yellow will be deleted and become black colour background. Figure 12 shows the image of string with pink and yellow colours. Figure 12(a) is the original image which captured with full RGB value. In this original image, pink and yellow colour strings with white paper used as a background. Figure 12(b) shows the mask for the string image. The data of original image is passed through filtering process to get the mask image with the threshold range. The range of threshold value is fixed to make image data becomes black colour background which are out of the ranges and make the pixels become white colour that are within the ranges. The black colour edge in the image is based on the shadow of the colour. Figure 12(c) shows the merging image with black background and colour string. It merged an image with the original colourful image and the mask of image. If the value of pixels is out of the threshold range, the pixel will be deleted and become black colour background. If it is within the range, the colour of string will be detected and displayed on the image. This result shows that the string is detected successfully.

3.6. String with Green Leaf Image

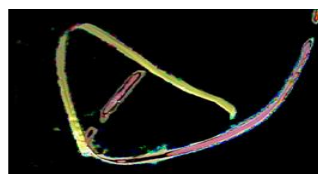
Figure 13 shows the image of string that tied with leaf. Figure 13(a) is an original image of green leaf tied by two colour strings. The original image with full RGB colour is captured and used to compare with the result after filtering process. From Figure 13(b) which is the output image, the position of string is successfully detected with both pink and yellow colours after captured.

3.7. String with plastic bag

Figure 14 shows the image of string with plastic bag. Figure 14(a) is an original image of plastic string which tied with pink and yellow colour string whereas Figure 14(b) shows the output of the image which only displays colour of string. It is proven that the string can also be detected even though the other object is attached, but ensure that the object is not the same colour with the string.

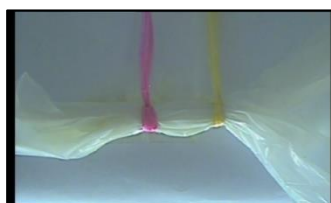


(a) full RGB original image

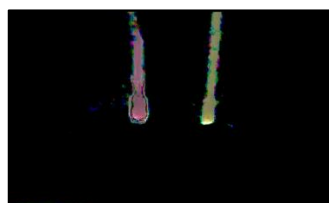


(b) output image with string detected

Figure 13. Image of string with leaf



(a) Original image with full RGB value



(b) Output image with string detected

Figure 14. Image of string with plastic bad

3.8. Comparison between Software and Hardware Implementation for String Detection

In this project, both software and hardware are tested for string detection. By using software, it can easily understand how to read out and create a bitmap file image. The range of colour value can be obtained by using C programming. For C code design, the range value to detect the pink colour string is from 158 to 175 and yellow colour string is from 25 to 33. The range is adjusted accordingly when implemented on hardware Altera DE2 board which is 159 to 175 and 3 to 35 for pink and yellow colour values, respectively.

Based on the result, the output image of software and hardware are slightly different. Software has the ideal image which is clearly image but real time has slightly different result. This is due to the lightness while capture the image in real time. The insufficient light is emitted on the image. While setting-up the workstation, the lightness value should be well adjusted to get better performances. The shadow of the image is also based on the lightness level and it will affect the output result.

When it implemented on DE2 board, the camera is set-up and ready to capture any image which is set to detect only string image. The image must be static when it is captured in real time. The camera used is an analog camera. The signal is always changed and it creates noise while running the camera. If the image is not static during capturing, the output obtained is inaccurate. Hardware can detect pattern of string in real time and capture it properly but software image can only be processed offline.

4. Conclusion

Detection of string pattern within an image using FPGA approach has been successfully presented in this work. The algorithm is developed in a form of architecture by using VHDL and then is implemented on Altera DE2 board as a string detection system. In early phase, C programming language was used to identify the colour range of the string for pink colour string and yellow colour string. With the range of colour, string pattern from an image is identified by the conversion of RGB value to hue value and background subtraction. The architecture is developed based on the conversion and filtering technique. Based on the experimental result, the FPGA based string detection system is capable to perform string detection in real-time. A comparison on image processing between software and hardware was carried out. The hardware-based is able to perform real-time string pattern detection. However, colour range readjustment is required for hardware as compared to software implementation. Lightness level of the captured image is also one of the concerns in image processing. The future works were suggested in order to improve the system performance such as detection of different colour string, using advanced image processing technique and applying high resolution of digital

camera. This application is also recommended for manufacturing industry such as remove unnecessary string during packaging.

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