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FPGA Based Area Measurement of Irregular Objects

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ABSTRACT: In this paper, an FPGA based area measurement system for irregular objects using image processing is implemented. The hardware implementation has been done on Papilio one FPGA board using Arduino IDE. We have used MATLAB tool and Arduino code which overcome irregularity problems and measured the area of object. The experimental results and statistics have been shown in this paper. We have measured all images at a distance less than 30 cm for better image acquisition and achieved the experimental results of area measurement with a relative error less 1%.

KEYWORDS: Soft processor, Barrel distortion, Image segmentation, Arduino IDE, Papilio One.

I. INTRODUCTION

There are many applications that need to measure the surface size or area of irregular objects in industries for different purpose. Traditionally, all measurement of irregular objects is carried out by mechanical or electrical methods. In the shipbuilding industry, plate parts with free-from shapes for use in the inner frameworks of ships are cut from rectangular steel plates. In order to achieve a great accuracy in shipbuilding, we need to measure irregular parts with great accuracy and precision.

In agriculture fields, physical attributes such as surface area, size, volume and weight of fresh fruit is used to calculate different parameter such as heat transfer, water loss, quantity of pesticide applications, respiration rates, and so on. In biological research, the length and surface area of fish or sea animals are often used to estimate the age. In leather and shoes industries, traditionally, area measurements of leather sheet are carried out through pinwheel mechanism or laser sensing system. To calculate the area in leather product and shoes industries, different methods are used which include electronics, and mechanical system [1]. Most of these methods offer greater amount of error in the measurement due to its irregular shape. Some area measurement techniques are inaccurate and time consuming compare to proposed algorithms. In addition, some measurement system has a short life and less accuracy [3].

We can calculate the area of objects with the help of Image Processing. There are different methods and algorithms available in Image processing to calculate area of the object. We can also verify the obtained result from image processing method by soft processor along with FPGA.

II. RELATED WORK

In agriculture research field, to determine the plant growth, leaves areas are needed to be calculated. Leaf area plays a vital role in plant growth. There are several methods are used for leaf area measurement. The most of methods are destructive and inaccurate. The available methods for leaf area measurements are regression equitation, grid count method, gravimetric method and planimeter.

Montgomery [11] suggested a formula for leaf area measurement which is, $A=b\times l\times w$. Where b is leaf shape coefficient, l is length of leaf and w is width of leaf. This method is non-destructive, quick and easier. But problem is that formula is not uniform for all plants as coefficient b differs among species.

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In grid counting method [12] first the leaf is removed from plant and placed on a grid paper. Outlines of the leaf are drawn by pencil on grid paper. Finally leaf area is measured by counting grids covered by leaf. This method is accurate but destructive, laborious and time consuming.

Gravimetric method is also used for leaf area measurement [13]. In this method leaf is first removed from plant and placed on white paper. Paper is cut-out according to the shape of leaf. Now weight of this paper is compared to the weight of known area on the same paper. This method is also laborious and time consuming when applied on large number of leaves.

The planimeter offers a less time-consuming technique, but the precision is limited, especially for relatively small leaves [12].

III. ALGORITHM USED FOR AREA MEASUREMENT

1. Distortion Correction

The lens is an axially symmetrical object. The optical distortion may present in camera lens which causes error in the area measurement. We should consider a polar coordinate system while analysing lens distortions. We can consider lens's main axis forming polar coordinates and all distortions to be rotation-symmetric.
There are basically three type of distortion due to camera lens as shown in figure 1: barrel, pillow and moustache distortion.

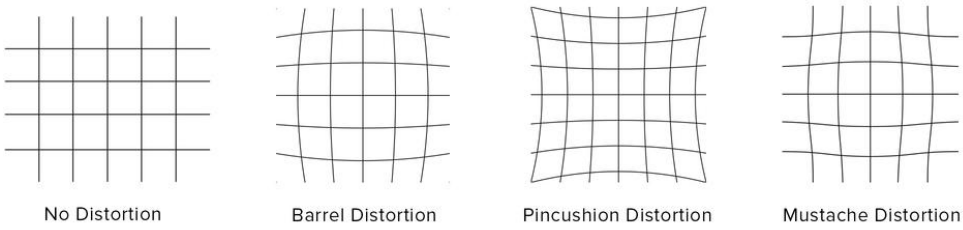

Figure 1: Distortion Types

A. Barrel distortion

Barrel distortion is the most common type of lens distortion. Barrel distortion is mainly associated with wide angle lenses and typically appears in application of zoom lenses, since it tries to squeeze the image in a smaller space. It is mainly during the magnification of lens as shown in figure 1. Barrel distortion has a "bulging" effect at the centre of lens. In barrel distortion, the magnification decreases with axial distance in result each image point to move radically towards the centre of the image. Higher quality lens can solved the problem of barrel distortion, but

This problem can be solved by higher quality lens; but this will greatly raise the cost of image capture system. Instead of cost effective lens system, we can correct the distortion using algorithm based on pixel phenomenon.

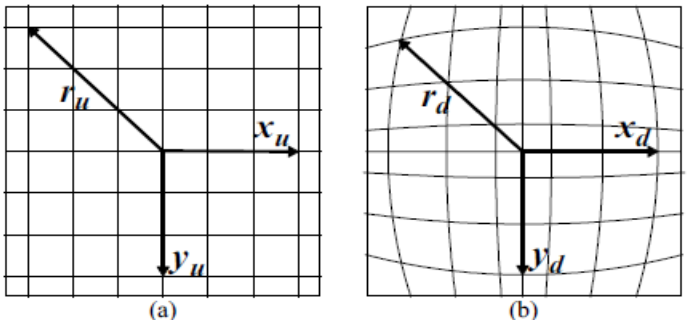

Figure.2. Barrel Distortion Model

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The figure 2 illustrates the Barrel distortion model in which barrel distortion model is defined as $r_u = r_d(1+kr_d^2)$ where r_u is the distance measured from the centre of distortion in the undistorted images, r_d is the distance measured from the centre of distortion in both undistorted and distorted images and *k* is the distortion parameter of lens.

B. Pin-cushion distortion

Pincushion distortion is a type of lens distortion opposite of barrel distortion which causes images to be pinched at their centre. It is mainly associated with telephoto, since it tries to stretch the image to fit the space. Pincushion distortion mainly appears in tele lenses.

C. Moustache distortion

It is a rare type of distortion. It is the combination of both barrel distortion and pincushion distortion. There are different algorithms to correct the lens distortion, where each algorithm approximates the pixel in a different way.
In polar coordinate system implementation, the calculated coordinates may be truncated in order to discard the fractional component. In result, it introduces substantial error in the pixel location. Bilinear interpolation gives better results while providing computational efficiency and image quality.
Bilinear interpolation is a non-adaptive algorithm which includes nearest neighbour concept. It uses pixels of distorted image and considers closest 2x2 neighbourhoods of known pixel values surrounded by the unknown pixel. It takes a weighted average of neighbouring 4 pixels to arrive at its final interpolated value. In case of bilinear interpolation algorithms; it uses the four pixels of the distorted image that are closer to the approximated pixel P.

2. Edge detection

An edge is a set of curved line segment at which image intensity changes rapidly. Edge Detection is an image processing techniques in the areas of feature detection and feature extraction for finding the boundaries of objects within images at which the image brightness changes sharply.
An edge detection method detects the discontinuities in brightness in order to find edge in an image. In image processing, edge detection is basically used for image segmentation and data extraction.

3. Canny Edge Detector

The most powerful edge detection method is canny method. It uses two different threshold values for edge detection. It includes both the strong edges and the weak edges. This method is less affected by noise. The Canny edge detector uses a combination of algorithm to detect edges in an image.

- Apply Gaussian filter to remove the noise and prevent false detection
  During edge detection, images are affected by noise which causes false edge detection in the result. Gaussian filter is applied to remove noise and smooth the image.

- Find the intensity gradients of the images
  To detect edges in a variety of direction, the canny algorithm uses four filters in horizontal, vertical and diagonal directions of images.

- Apply non-maximum suppression
  To thin the edges, non-maximum suppression is used. The non-maximum suppression is used to suppress all the gradient values to 0 except the local maximal.

- Apply double threshold to determine true edges
  The spurious response and color variation are present still at the edge pixels. To avoid spurious response, we need to apply two threshold value namely high threshold value and low threshold value.

- Track edges by hysteresis
  To track true edge and extract the strong edge in presence of the strong edge with the weak edge.

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4. Morphology

Morphology is the most widely used image processing operations deals with the image size or shapes. A structuring element creates an output image of same size that of input image in Morphological operations. The value of each output pixel in an image is computed by comparing of the corresponding input pixel in an image with its neighbours pixels. We can construct a morphology operation by selecting the size and shape of the input pixels neighbourhood.

Dilation is the most widely used morphological operation. In a proposed design, we use dilation method for detection of edges in an image in order to find object boundaries. Dilation operation adds pixels to the boundaries of objects in an image.

The size and shape of the structuring element determines addition of pixels on boundaries of objects in an image during dilation. In the morphological dilation operations, the value of pixels in the output image is determined by applying a rule based on a structuring element to the corresponding pixels in the input image and its neighbours and its neighbouring pixels. The rule is used to process the pixels by dilation operation.

5. Why Design with the FPGA?

The DSP is the most suitable choice for system with sample rate of a few kilohertz. However, as sample rate increases beyond megahertz, FPGAs become more suitable. The DSP may struggle at high data during processing due to the many shared resources, buses and even the core within the processor. In contrast, the FPGA can dedicate resources to all functions.
DSPs are instruction based while FPGAs are clocking based [9]. In case of DSPs, typically, three to four instructions are required for any mathematical operation on a single sample. The data must first be captured at the input, then forwarded to the processing core, cycled through that core for each operation and then released through the output.
In case of FPGAs, every clock cycle has the potential ability to perform a mathematical operation on the incoming data stream. FPGAs provide IP cores for video processing and image processing, communications, automotive etc. applications.

In image processing applications [10], FPGAs can provide a very high performance at their low operational frequency. FPGAs provide a high level of parallelism for image processing applications, good computing solutions. The FPGA also offers
(1) 8 bit operations, and
(2) Soft core and hard core on FPGAs and a large number of I/O sources and internal memory banks

FPGAs have larger blocks of RAM. These generally have flexible word widths from 1 to over 64 bit wide. The size makes BRAM well suited for row buffers for image processing, for larger size FIFO buffers or distributed data caching.

IV. PROPOSED SYSTEM

The block diagram of the proposed system is as shown in figure.3 which includes camera, MATLAB and Papilio one development board.

In this paper, we propose a low cost and more accurate FPGA based area measurement system. We are using MATLAB for visualization of process and results going on inside FPGA. Camera is interfaced to PC for image acquisition and captured image will be sent to FPGA by serial communication. Soft-processor ported to FPGA will send the image through sequence of processes like binarization, thresholding, pixel area measurement and calibration to get actual area in terms of cm^2. This value will be sent back to PC and will be displayed on MATLAB.

The embedded system is incorporated with a low cost high performance Papilio one board with Spartan 3E XC3S250E processor with ARV8 soft-processor as main core and camera for image acquisition. We are using Papilio one FPGA board for the design and implementation of area measurement system. The processor supports maximum clock

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frequency of 32 MHz and MATLAB processed images will be coded in Arduino. The processed data will be transmitted to PC on MALTAB display in terms of cm^2.

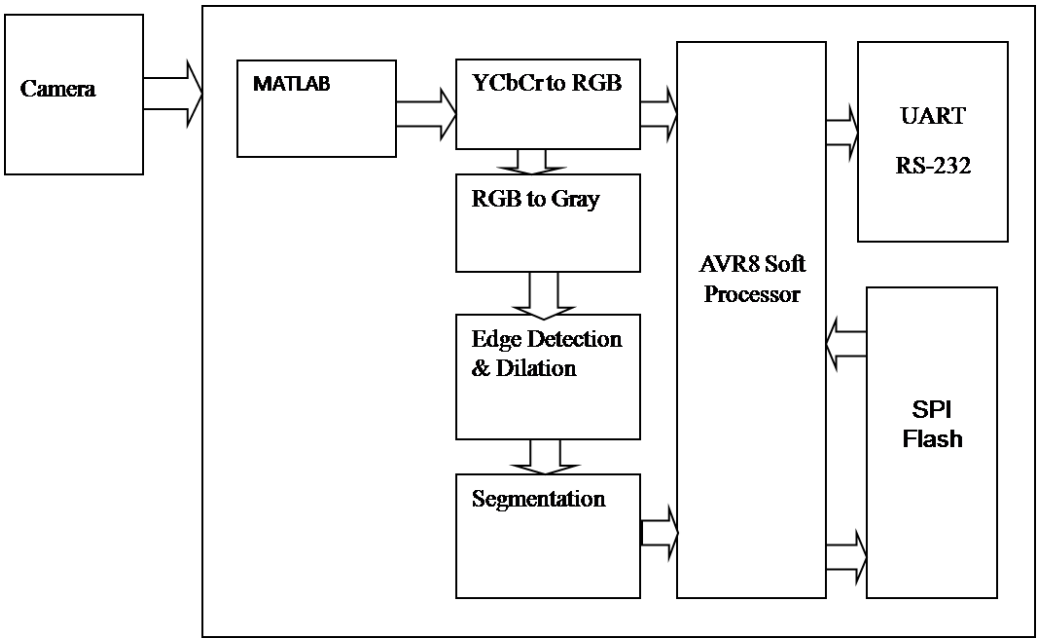

Figure.3. Barrel Distortion Model

A. Image Processing Unit

The image processing involves following algorithm RGB to Grayscale, canny edge detector, thresholding and image segmentation operation. We are taking two objects, one as area known reference object and other one as test object during processing and calculating area of test object by comparison.

$$\text{Area of Test object} = \left(\frac{Area\ of\ refrence\ \ object\ \ in\ cm^2}{Area\ of\ test\ object\ \ pixels}\right) \times \text{area of test Object pixels}$$

B. AVR8 soft Processor

The Papilio one board provides a serial communication to a computer through UART. The AVR8 soft-processor is the main control unit of the FPGA based system, it controls the data transfer and performs the initialization. In addition, it processes the image processing algorithm and calculates the area of selected patterns.

V. RESULT AND DISCUSSION

We used different shaped plant leaves to carry experiment. The areas of different shaped leaves are calculated using proposed algorithm and compared with area calculated by grid count method. In this case grid size is $1mm^2$. We have achieved accuracy of 99% and error less than 1% in the area measurement as shown in Table 1.

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Object	*Al* -leaf area, calculated by proposed algorithm cm^2	*Ag* -leaf area calculated by grid count method cm^2	Error in measurement (%)
1	78.648	78.96	0.39
2	40.714	40.57	0.35
3	9.905	10.12	0.21
4	87.714	87.88	0.18
5	90.214	90.37	0.17
6	32.985	33.11	0.37
7	30.937	30.86	0.24

Table.1: Experiment Result

VI. CONCLUSION

This paper proposed the design of an FPGA based embedded system for area measurement of irregular shapes or objects using image processing. The different image processing algorithms can used for image acquisition and processing in order to achieve good quality image. We can conclude that proposed designed of embedded system based on the FPGA can provides a high accuracy and reliability; therefore it is a very suitable system for area measurement. These would be probably most useful advantages in the field of applications such as leather and shoe industries, agriculture and we are aiming its implementation in a cost effective manner. Future work will be oriented to implement proposed design in hardware in order to achieve real-time monitoring and to reduce the processing time.

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