High Precision Analog Gauge Reader Using Optical Flow and Computer Vision

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***Abstract*— This paper aims at developing algorithms to automate the process of reading analog gauges at different operational industries, healthcare sector and automobiles using Artificial Intelligence (AI) techniques. Proposed algorithms start with video stabilization using optical flow followed by image processing which performs segmentation using HSV color space and morphological operations. Next, Hough transform is applied to determine the dial region and pointer. Using the coordinates locating the pointer in the frame, angle made with minimum valued scale mark is calculated using trigonometry and evaluated reading is displayed in the form of text and a progress bar. The proposed algorithms for Analog Gauge Reader (AGR) is executed using open-source libraries such as OpenCV, NumPy, PIL with Python programming and it is developed in the PyCharm environment. The experimental results show significant decrease in the error with the introduction of image preprocessing and the generalizability of the algorithm to different types of analog gauges captured in different conditions of illuminance. The accuracy and precision of the algorithms is 99% to 100% in the experimental studies.**

Keywords—deep learning, object recognition, optical flow analog gauge reader

I. INTRODUCTION

Instrumentation is a critical area in the science and engineering industries or workstations. It includes gathering of regular and accurate readings for different parameters to generate alerts in case of emergencies. Many utility industries still make use of analog gauges and they do not prefer reinstallation of new digital gauges due to the higher cost. Professional race cars drivers also prefer using analog speedometers due to the ease of monitoring and perception of their real time speeds. Analog gauges are scientific instruments used to measure physical quantities such as speed, pressure, tension, etc. Analog gauges have a pointer or a needle that rotates over the dial pointing at scale marks corresponding to the measured parameter. Though the analog gauges are older; those are still widely found in many industries.

Collecting data from analog gauges needs manual inspection which is tedious, prone to human errors and may also involve risk at workstations. Thus, engineers have been putting significant efforts to automate this process of reading analog gauges. Building such a system would have multiple advantages as the cost of labor, risk of accidents, possibility of errors is reduced. One way to tackle this problem is to apply Artificial Intelligence techniques. Computer Vision is a field of Artificial Intelligence that makes machines capable of understanding and interpreting visual inputs. Installation of still video cameras at workstations is definitely a cost effective alternative and using captured visuals can be fed to a central system to translate reading into digital streams and monitor the environment to avoid any emergency situations.

The study aims at utilizing Computer Vision algorithms to analyze the video feed of an analog gauge and translate the readings into a digital data form which could be further utilized for monitoring and predicting different outputs. This involves separating the region of interest from the entire frames and then apply image processing algorithms to discard any noise or blur present in the frames. Video stabilization is also carried out to adjust the small camera movements that could take place at the actual workstation because of vibrations or other possible forces. Hough Transform is applied in order to determine the circular dial region followed by pointer detection. Segmentation, thresholding and edge detection are some of the intermediate steps taken in the data pre-processing. Using the coordinates of the detected pointer and user input for minimum and maximum scale marks on the dial, final readings are calculated. As the system handles dynamic user input, the same algorithm can be applied to different sets of gauges without many changes for calibration.

II. RELATED WORKS

A. Dial and Pointer Detection Using Traditional Computer Vision

Tradition Computer Vision techniques refer to the video and image processing algorithms used for filtering, transforms, optimization, etc. Majority of the researchers have focused on Hough Transform for finding dial region in the images. With the further developments in OpenCV function, Hough Transform is also made available for different shapes present in the image. Jiannah Chi et al. [1] used Hough Transform to find the direction of pointer along with pointer contour fitting. The location of the pointer is compared with the scale marks on the dial to output the final reading. Scale marks are also detected using the Hough Transform and no user input is required. The paper shows a great demonstration of an automated system with minimum calibration and good performance for the even or uneven scale marks.

Jakob S. Lauridsen et al. [2] have discussed the failure cases of Hough Transform for detecting the bezel, outer ring of the dial. They used analog gauges with chromed bezel for their experiments and as the chromium-plated materials are highly reflective, circle fitting showed poor performance. Least square circle fitting approach was used; it is a more error tolerant method.

Figure 1 shows a general block diagram of steps involved in traditional Computer Vision based analog gauge reading system.

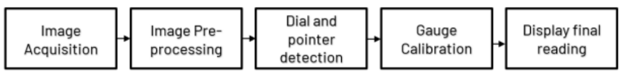

Figure 1. Traditional Computer Vision Based Analog Gauge Reading System

B. *Determining Reading Using Deep Learning*

The drawback of using just the image and video processing algorithms is that the designed system can handle up to a certain number of gauges. There are various parameters which need to be changed for a new gauge. Thus, the other approach followed by researchers is to use Deep Learning to find the features of the gauges and then train the large networks to ultimately find the final readings by image classification. Ben Howells et al. used multitask CNN to develop for transcription of analog gauges on mobile platform [3]. At the start of the pipeline, they have performed gauge detection using a light-weight detector which draws bounding boxes around the circular gauge, which discards any manual settings involved in cropping out regions of interest. Perspective correction is another key step included in the pipeline which considers different alignments between camera face and gauge and correct it to find a flat gauge image. Different features such as center and tip of pointers, minimum and maximum scale points are given to another key-point detector to determine gauge reading.

Xiao Yang [4] has provided a solution to train CNNs on desktop or mobile platforms by utilizing TensorFlow frameworks. A better predictive performance is obtained by training deep neural network along with the ensemble learning. Demerits of having a limited data are also discussed and how it can be overcome by generating more data synthetically is also shown.

C. *Segmentation of Pointers*

M. Q. Tran et al. [5] dealt with the problem of calibrating analog gauges having double edge pointer with the help of geometrical formulization. They also incorporated color segmentation for pointer detection and performed a morphological operation- opening which refers to sequence of erosion and dilation used to discard the small object from the image. D. Hema and Dr. S. Kannan have designed an interactive color image segmentation using HSV color space [6]. Given method can segment more than one object which is the essential foreground in the data. Authors have also concluded that integration of segmentation with other morphological operations enhances the results.

III. PROPOSED METHOD

Figure 2 shows the proposed pipeline to deliver a more effective and generalized automated analog gauge reader system. The main blocks are presented in the pipeline and there are further detailed operations performed in each step.

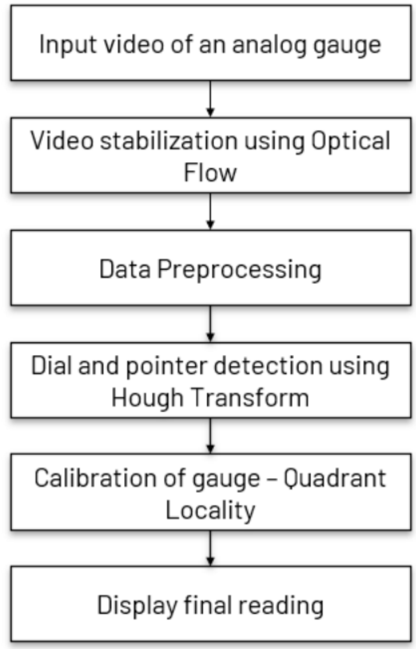

Figure 2. Proposed Pipeline Using Traditional Computer Vision

A. *Input Video of an Analog Gauge*

To gather the gauge data in real time, a camera needs to be mounted at workstation with correct perspective and alignment. The parallel alignment of camera face with the dial face is recommended. But if it not possible, Computer Vision also has some effective techniques to correct these perspectives. With further improvements, a GUI can be made available where the operator can see the live feed from camera and respective readings along with any analysis that is required.

B. *Video Stabilization Using Optical Flow*

The effect of camera motion significantly affects the preprocessing as it may result into some intermediated blurred frames where obtaining sharp features becomes difficult. Thus, we can pass the video through Optical Flow which reduces or corrects any camera motion present in the video. This is advantageous as we don't have to move the camera apparatus every time at the workstation. Optical Flow carries out motion estimation, motion smoothing and image composition [7-9]. Motion estimation refers to calculation of transformation in the coordinates of pixels in consecutive frames. Motion smoothing applies to cancel out the unwanted motion. All processed individual frames are gathered and final video is generated again.

C. Data Preprocessing

To collect sharp and best features from the data, preprocessing plays an important role. Data quality is improved, and all the noise is suppressed. In our pipeline, a series of preprocessing steps are followed as shown in Figure 3.

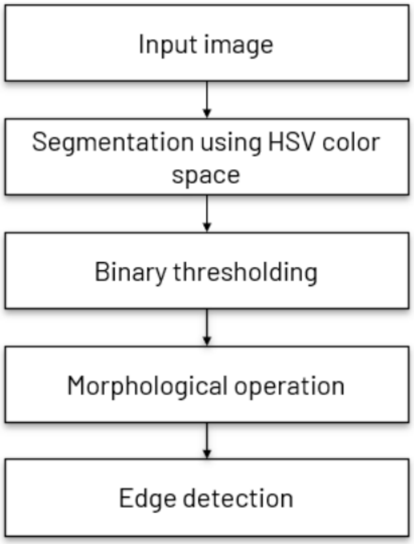

Figure 3. Multistage Image Preprocessing

Segmentation refers to separating out the object of interest from the data. We focus on separating the pointer from the frame. The pointer is red colored in our input test video. Thus, a mask is generated that represents the range for red color in HSV color space. RGB color space is generally used for the experiments, but HSV color space is also widely used. Each pixel is represented in terms of Hue, Saturation and Value ranging from [0,179], [0-255] and [0-255] respectively. The mask used in the experiment is [140,130,0] to [179,255,255]. Once the segmented image is obtained, it is converted into a grayscale image for binary thresholding.

Binary thresholding simply puts pointer area with 1 and the background with 0 which will be a requirement to see the effect of next morphological operations.

Morphological operations are a set of processing techniques applied on binary images and they change the shape of underlying binary objects. A binary structuring element or a filter is convolved with all the pixels and a binary value is selected by setting a threshold value for convolution output [10]. With dilation, maximum values of the pixel in the filter region are chosen which makes the object more visible and fills in small holes in the object. On the other hand, erosion choses minimum value of the pixel to remove small objects and islands. Figure 4 shows a close up of these two operations on images of a clock.

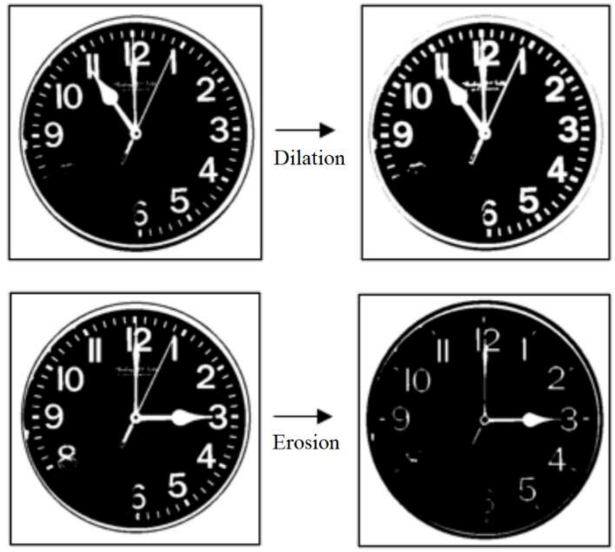

Figure 4. Results of Dilation and Erosion on Clocks

Before we apply the Hough Transform on the images, we find out the edges using Canny edge detection. Its implementation using OpenCV function has advantages as it performs noise reduction, finds intensity gradient and also performs non-maximum suppression and hysteresis thresholding.

D. Dial and Pointer Detection Using Hough Transform

Hough Transform is another powerful technique because of its capability of grouping pixels into lines, circles and other shapes even across gaps and occlusions. The lines in the real case scenario can be discontinuous because of the glare or reflection. Thus, Hough Transform is a good solution to find the dial and pointer in the image. For the dial, the circle detection outputs the center and radius of the dial. For the pointer, pixel positions of the endpoints are given out.

E. Calibration of Gauge – Quadrant Locality

In order to calculate final reading, the following parameters are required.

a. Minimum and maximum possible values.

b. Minimum and maximum value pixels on the scale.

c. Center pixel of the dial region.

A user input is asked to enter these values though an interactive window and corresponding instructions. Once the direction of the pointer is obtained, using those coordinates the angle made with the 0-scale value is calculated, followed by calculating corresponding reading for an even scale. This is easy to carry out using the math library with readily available trigonometric functions.

As it can be seen in Figure 5, the dial can be divided into four quadrants and based on the pixel locations of the midpoint and endpoints of pointer, its quadrant locality is determined.

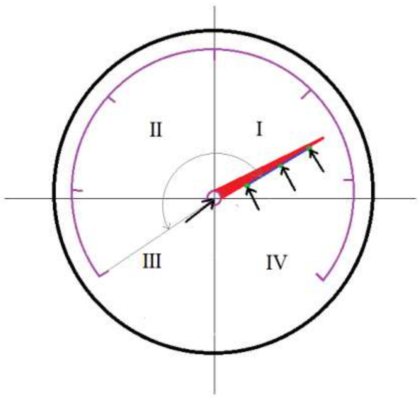

Figure 5. Calibration of Gauge

F. Display Final Output

Final reading is displayed in the form of text and a progress bar as well. A continuous line graph is generated to see the pattern of reading. Also, readings are saved into the excel file for further statistical analysis.

IV. System Description

A. Hardware

As the input to the system is in the form of an image or video, a camera is required to capture the analog gauge. There are no specific requirements regarding the camera. Any good quality and resolution camera can be used to take input. The resolution of the camera can be kept higher to not miss out any details.

B. Software

• OpenCV, PIL - To capture and process the images.

• Math – To calibrate the gauge data and determine the quadrant locality based on output of Hough Transform.

• PyCharm – For development of the entire analog gauge reader system.

V. Results

A. Test Data

The test videos used for the experiments display the readings of a tachometer. Figure 6 shows a frame from a test case video. In the short video, there are total 170 frames in which the pointer spans over most of the scale. The video is captured in the dark time and the dial is also completely dark with sharp boundaries for scale and pointer.

B. Image Preprocessing

We have discussed the different steps performed during image preprocessing in the previous sections. The various outputs obtained at each step are as shown in Figure 6. We see the Hough Transform defined circle in green color that borders the scale in the RGB image. The RGB image is then converted into HSV color space, and we can see how pixels with same Hue, Saturation and Value look in HSV color space. Using the defined mask, segmentation results show a clearly segmented out pointer along with some portion of the scale as it also falls under the red color range.

Segmented image is then translated into grayscale format for the binary thresholding where pointer pixels are presented with '1' and the background with '0'. Now the main task is to make the pointer thinner and discard unwanted scale region. Morphological operation erosion does this job for us. Erosion results are satisfactory and are a good input for Canny edge detection which precisely finds the edges of pointer. In the last pointer detection step, Hough Transform is again applied to find all the lines in the image, and we can see how it lines the pointer and it is shown in white color.

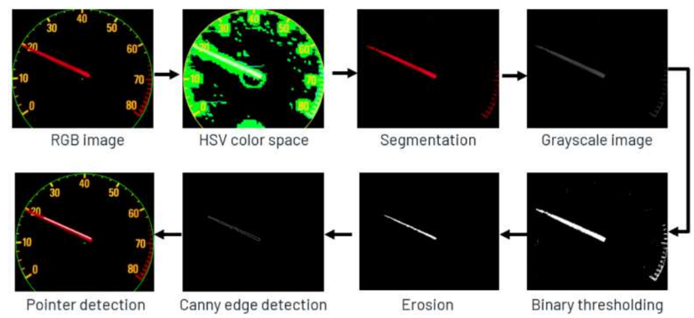

Figure 6. Image Preprocessing Results

Performance of the Hough Transform is compared with and without the introduction of image preprocessing and results are shown in Table I.

TABLE I. Overall Performance of the Proposed Pipeline

Data	Number of frames	Dial detection (success rate)	Pointer detection (success rate)	
			Without preprocessing	With preprocessing
Test 1	170	100%	80.28%	98.8%
Test 2	71	100%	90.58%	100%

C. Displaying Final Results

The final results are put on all individual frames and are as shown in Figure 7. The progress bar makes it easier to understand the transition of the values as reading the text with the higher speed is not feasible. Also, the pattern behavior can be studied based on the curves generated for given time period as seen in Figure 8.

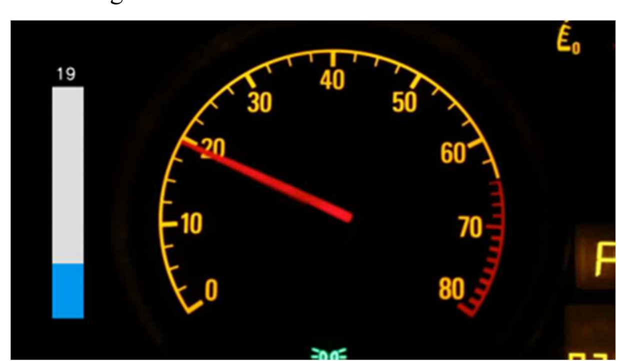

Figure 7. Final Reading Displayed on Frame

Also, the pattern behavior can be studied based on the curves generated for given time period as seen in Figure 8.

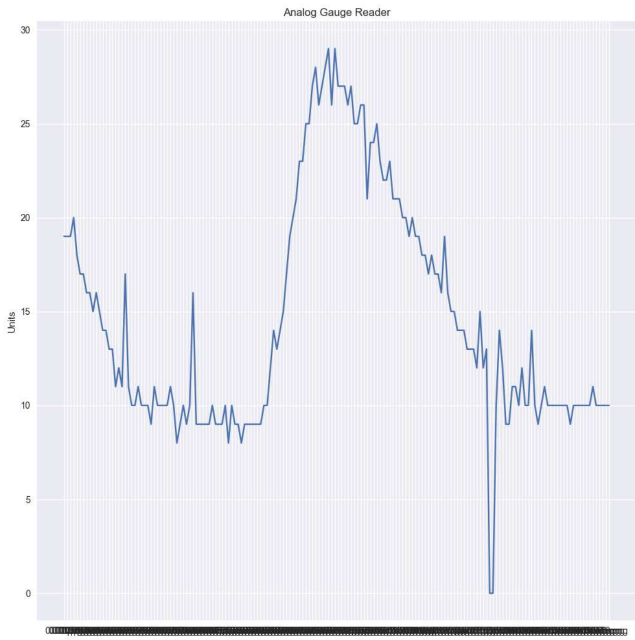

Figure 8. Behavior of Readings Over Time

Based on all collected readings calculated using proposed pipeline, comparison with actual reading is done to check the overall performance of the system and is shown in Table II.

TABLE II. OVERALL PERFORMANCE OF THE PROPOSED PIPELINE

Data	Number of frames	Range of dial	Decimal places	Average error
Test 1	170	0-80	0	6.35%
Test 2	71	0-9	1	4.33%

VI. CONCLUSION

Proposed pipeline requires minimum adjustment of parameters and can handle different cases of analog gauges. Computer Vision techniques are utilized to build the system with the availability of open-source libraries. Image pre-processing significantly affects the pointer detection success rate. To handle all industrial test cases, CV techniques such as perspective correction and optical flow need to be improvised. Designed solution can be incorporated for live monitoring of gauges at work stations.

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