Robotics and Control Systems Master PBL project, 1st semester

Artificial vision:

Introduction:

Screws are probably the most important components of the machines. Due to its design the thread of the screw, which is helical in geometry, could be a complex to measure and inspect.
There are several methods to inspect and measure a screw, such as profile projectors, measuring microscopes, 3-wire units, screw thread micrometres and V-groove micrometres also some of the inspection techniques used in the industries are laser gauging, optical comparators.

In this report we have developed an algorithm for the measurement of screw head and screw thread for a particular metric gauge thread screws for the flat hexagon socket and hexagon screw head. Along with that inspection of screws for the detection of damaged ones or other classes of screw threads such as whitworth threads. In this project we have two stations, the first station is called sorting station which comprise of a MatrixVision Blue Cougar 2MP camera with a opticentric lens and a pair of frontal-lighting as a source of illumination which is mounted to a Kuka Kr3 robot. The second station is called the metrology station which consists of a MatrixVision Blue cougar 5 Mp camera with a telecentric lens and a backlight illumination source placed on opposite sides of the motorised screw holder platform which performs a 360^{o} degree inspection.

The following are the parameters that are considered for the screw measurement and screw inspection during this project which are shown in Fig 1.

1. Screw head diameter
2. Total screw length
3. Thread angle
4. Thread Pitch
5. Pitch diameter

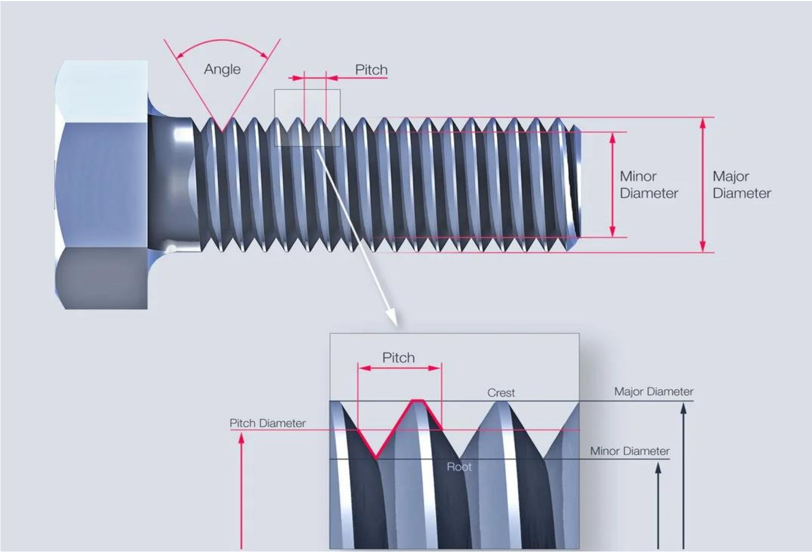


Fig 1: Screw parameters (Source: https://www.volumegraphics.com/)

The following is the procedure for implementing the inspection of the screw thread Fig 2.

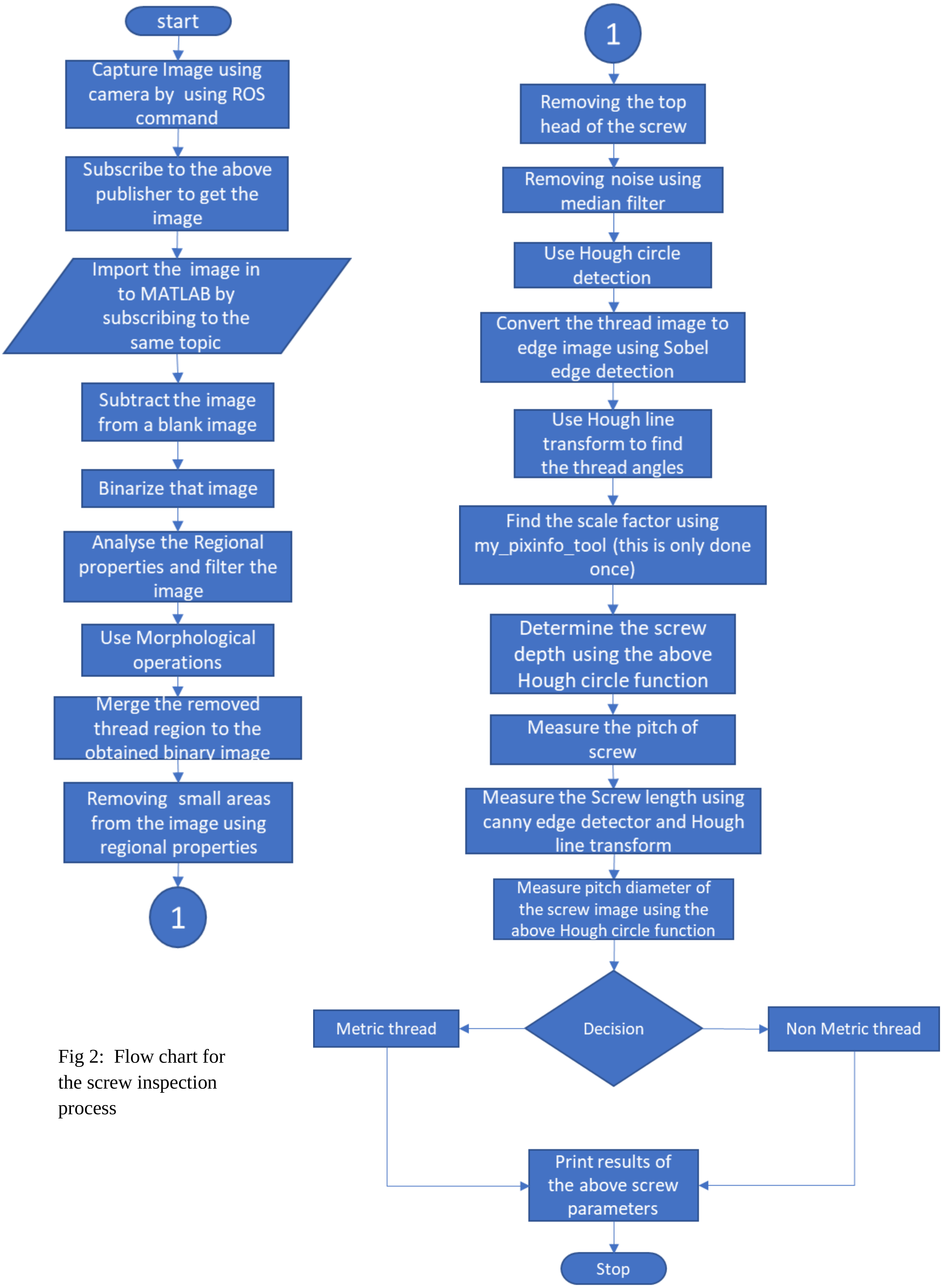


Fig 2: Flow chart for the screw inspection process

The following is the procedure implementation of the measurement of screw head diameter for the case for round head or to measure the width of the hexagon head screw Fig 3.

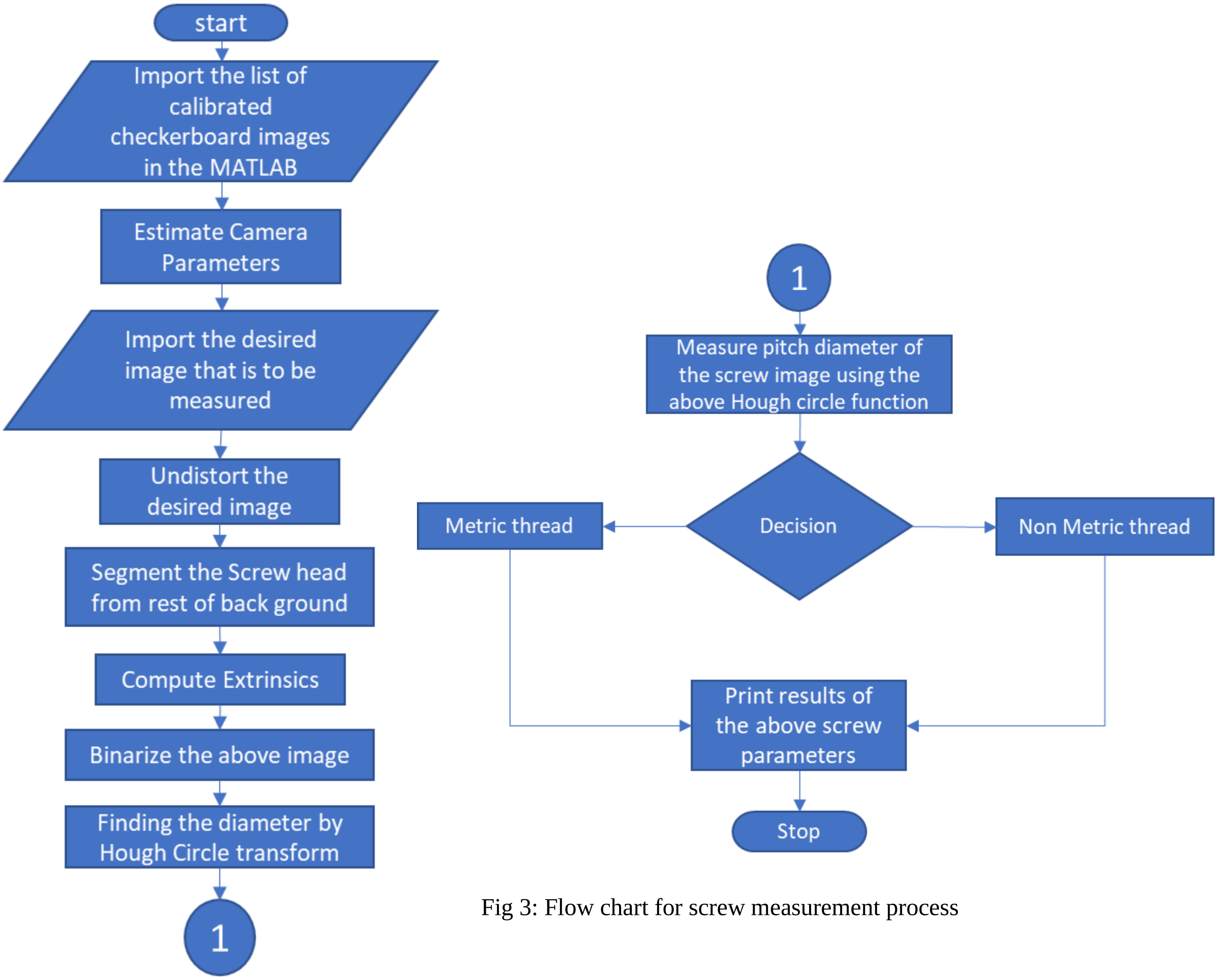


Fig 3: Flow chart for screw measurement process

The steps for the image processing and measurement and inspection of screw thread what done using MATLAB environment the below are the step by step procedure through which the process is performed

Procedure of steps that were implemented for the metrology station.

<u>**Step 1:** Importing the image into MATLAB environment.</u>

The respective images are read into MATLAB using imread function and it assigned to a specific variable here as shown from the figure 4.

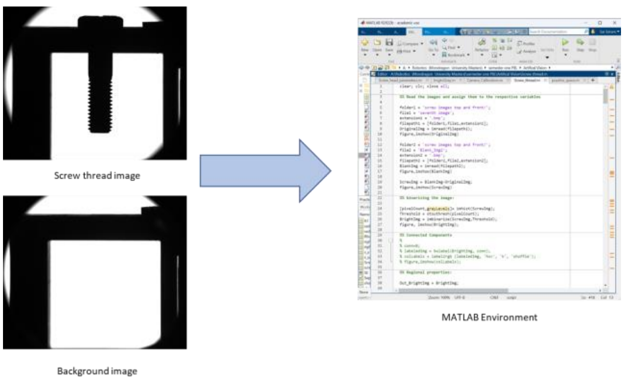


Fig 4: Importing the images into MATLAB

Step 2: Obtaining only the Screw image.

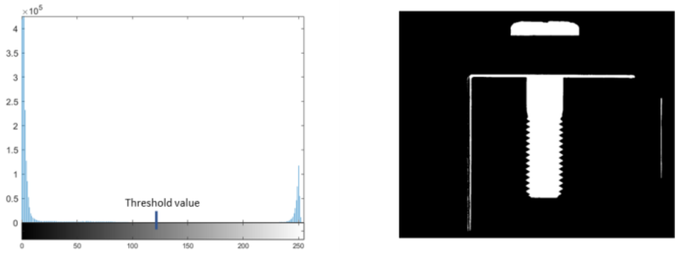
From the above imported images contain the screw as well as the background so to remove the that and having only a screw image we are performing a subtraction operation to remove the pixels that are similar this is shown from the figure 5.

Background image Screw thread image Subtracted thread image

Fig 5 : Subtracted image of the screw thread

Step 3: Binarizing the image

Since the above image in the format of unsigned integer 8-bit format to apply the image processing operation we need to convert the image into a binary format. For this we are using Otsu global thresholding using imhist function. Then the pixel count is obtained and is passed to otsuthresh function to obtain the global threshold value. Using this value, we could binarize the image using imbinarize function. So the output image will be in a logical format that is either zero or one the results are shown in figure 6.

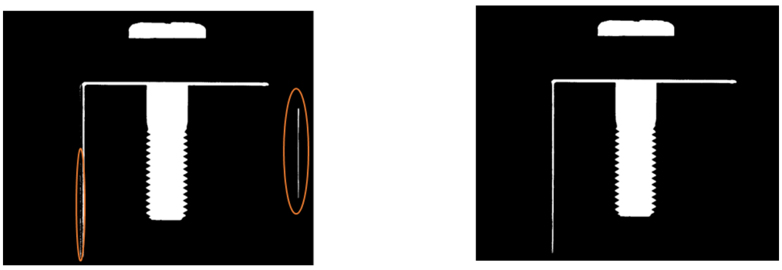


Histogram of the grayscale image Binary image

Fig 6: The threshold level as well as binary image of the screw thread

Step 4: Obtaining the Regional properties.

Since, there are still small regions that were remained due to misalignment those portions could be removed using a matlab function called bw propfilt function which filters the image based on the image parameters such as area, perimeter soon. In this we have choose area as the determining factor by which the region with least area gets removed as shown in figure 7.



Binary image Removed small areas

Fig 7: Removal of small area

Step 5: Performing Morphological Operations

Although we had obtained the screw image separately still there are few areas that relate to the screw image which could be removed using the above process, for this we perform morphological opening operation (imopen) and considering the structural element (strel) as diamond to get rid of the connected areas the results is viewed in figure 8.

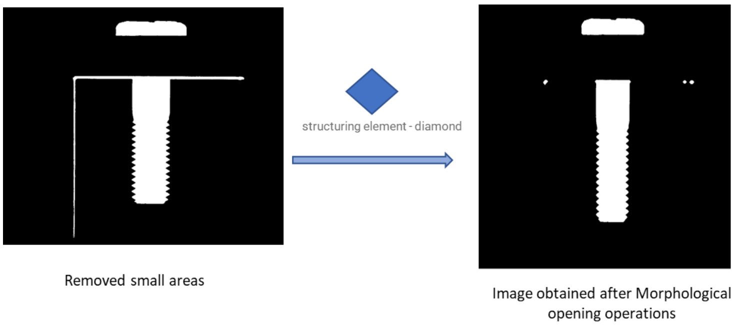


Fig 8: Opened screw image.

Step 6: Obtaining the tiny, removed thread areas.

The morphological operations will affect the whole image including our region of interest, because of this we had removed some tiny outer screw edges during this operation. We are going to recover them by subtracting the image before morphological operation to the image after the morphological operation by performing this function we could obtain an image that was removed during the above process as viewed from the figure 9.

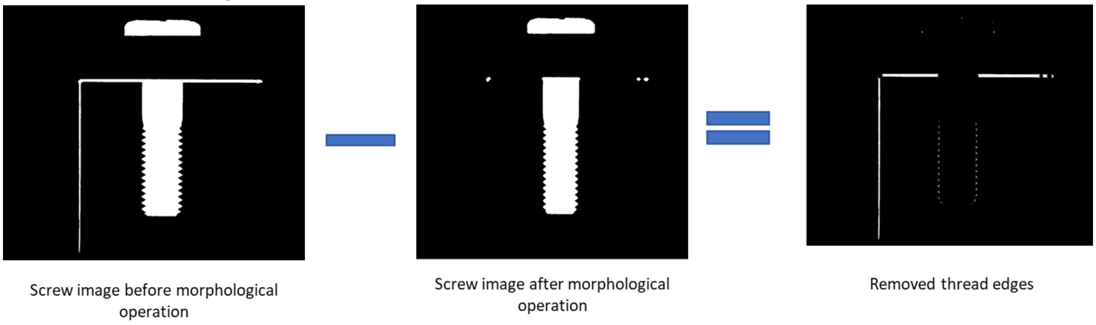
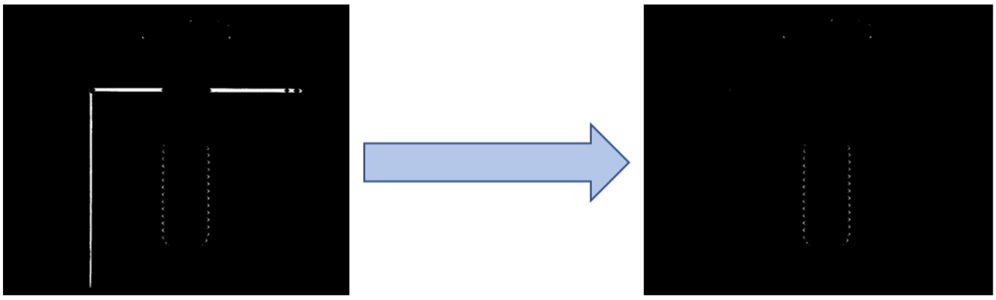


Fig 9: Removed portion of the screw thread.

Step 7: Removing the larger areas using regional properties.

Next, we had removed the regions that are unnecessary for our analysis using image filter based on image properties that is bwpropfilt and removed the higher areas in the image as shown below in figure 10 so that we could obtain only the thread areas.



Removed thread edges

Small thread edges

Fig 10: Small thread areas

Step 8: Merge the image of the screw thread.

Using a merging operation, we are merging the small thread profile areas with the image obtained after the morphological operations thus restoring to its true size the above modification is seen in the figure 11.

Screw image after morphological operation

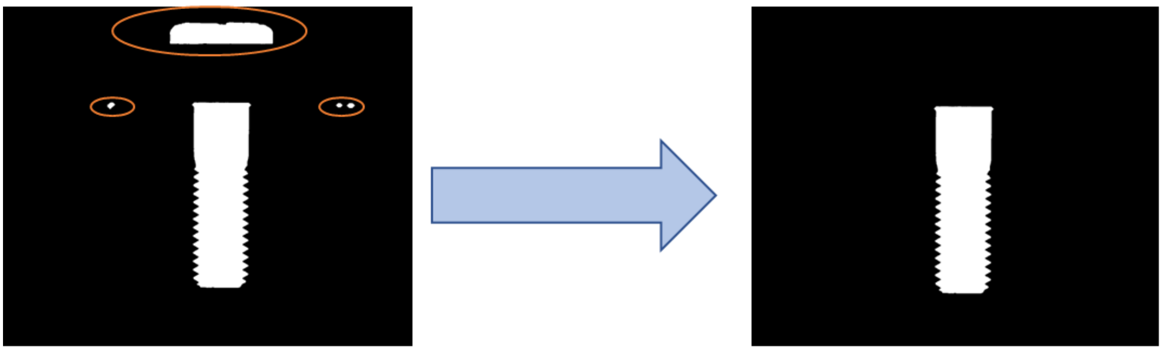
Small thread edges

Merged screw of image

Fig11: Merged screw image

Step 9: Removing the Top head of the Screw.

Since to measure the following parameters such as thread angle and pitch diameter and screw pitch we had removed the screw head by implementing the properties function from the above and used area as the deciding factor and the final obtained image is as shown in figure 12.



Merged screw of image

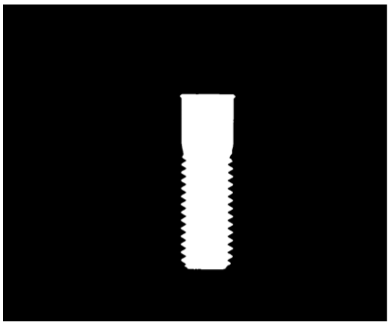
Only the screw thread

Fig 12: Screw thread Image

Step 10: Removing small noise in the image.

From the above operations now we had obtained only the screw thread image but we could not obtain the desired measurements because there is still some image noise is present because of the image obtained from the camera or from the external sources such as vibration or dust particles on the screw threads could also be the reasonable factor.so there may be some spikes at the edges of the image so to smooth the image edges we use Median filter [1]. By using a function called medfilt2 filter we could achieve a smooth transition. Here we had used a built in MATLAB application called smoothing filter area and verify the respective results as shown in the figure 13.

Image Smoothing Filter App- MATLAB

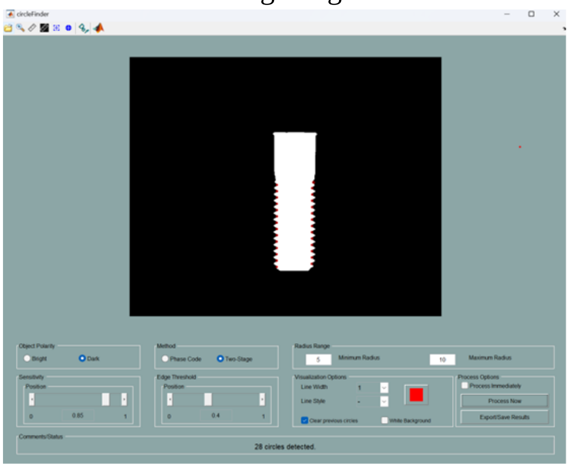


Filtered image without noise

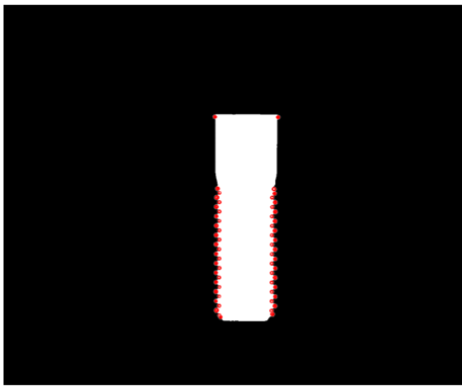
Fig 13: Smooth filtered thread image.

Step 11: Apply Hough Circle detection.

Then applying Hough Circle detection function called imfindcircles function in matlab to find the circles near the screw thread edges. The particular parameters that we obtained with a number of iterations that were performed in the Circular finder application and obtained the respective values of maximum and minimum radius and the sensitivity and edge threshold values. Later the circles are created using viscircles the obtained results are shown is figure 14. Here we found the circles both in the dark as well as bright regions.



Circle Finder (MATLAB App)



Detection of circles around the screw edges

Fig 14: Generated circles in dark and bright regions.

Step 12: Edge detection and apply Hough Line transform to find the Thread angles.

To measure the Thread angles we had applied Hough line transform. But before that we need to convert the above solid image into a edge image this could be done using a edge detection function and we used Sobel edge operator because is could detect edges and their orientation after this we had performed

Hough line function and detect the peaks using houghpeaks and generated lines using houghlines function. From this we found the theta values that is in turn the thread angle the blow is the figure 15 which shows the lines formed on the screw thread edges.

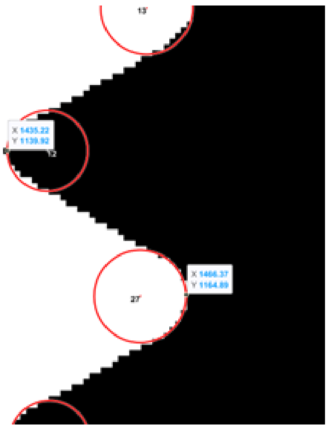
Segment Image App - MATLAB

Thread angle between the lines

Fig 15 Generating lines on the screw thread edges.

Step 13: Detection of Screw thread depth parameters

The thread depth of the screw is determined by using the previously obtained circle centre values from the hough circle detection. Here we had divided the screw thread into left thread part and the right thread part for which the screw thread depths are obtained separately. Initially we found the circles that were closer to each other than after that we had obtained the outermost x coordinate points using the radius that was obtained during hough circle transformation by this we had found the thread depth this process is similar to the left side of the thread the following snippet of image coordinates points are shown in the figure 16.

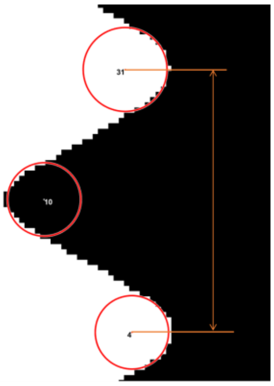


Detection of outer and inner most points

Fig 16: Out most points of the circles.

Step 14: Determine the Screw Thread Pitch

The Screw thread pitch is determined by measuring the shortest distance between the consecutive circles in either of the region that is dark or bright and the resultant value provides the screw thread dimensions as shown in figure 17.

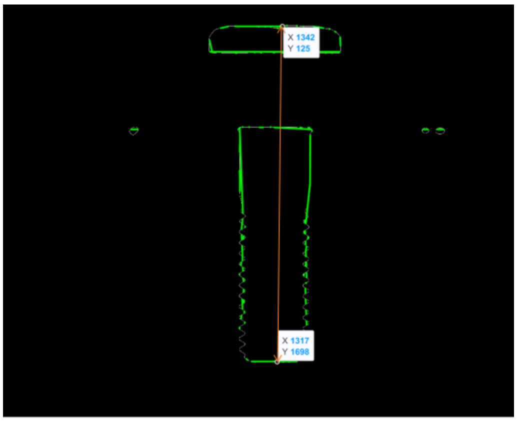


Screw pitch length

Fig 17: finding the distance from the centres.

Step 15: Finding Total Screw length.

For determining the total screw length, we need to obtain the entire screw image and perform a edged detection such as canny to obtain the edges of the screw image and then perform the hough line transform to find the thresholds as well as peaks in the image and the lines are generated along those peaks as shown in the figure 18. After this the maximum point of y coordinate and the minimum point of the y coordinate is taken and measured the distance which is equal to the screw length.



Total Screw length

Fig 18 finding the minimum and maximum points.

Step 16: Finding the pitch diameter of the Screw.

To determine the pitch diameter of the screw is done using the theoretical way because the pitch diameter will is in between the maximum diameter and the minimum diameter of the screw thread so from the figure 19 shown we have to obtain the necessary values to find the pitch diameter thee below is the calculation performed to obtain the pitch diameter.

The thread depth of the ISO Metric thread = $5 * \frac{h}{8}$

The length of pitch diameter point to the crest of the screw thread is = $3 * \frac{h}{8}$

By finding the h from the distance of the screw thread that was obtained previously then we could find the pitch diameter point from the right end side of the screw the same above mentioned procedure is repeated to find the pitch diameter point from the left side of the screw.

To obtain the Pitch diameter of the screw the distance is measure from the obtained coordinate points. Since, in real time due to some noise the pitch diameter distance could deviate so the mean of the pitch diameter is obtained.

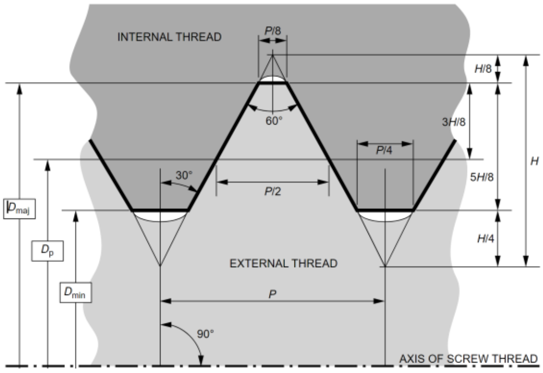
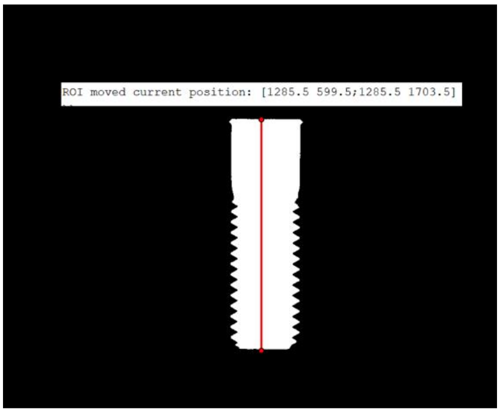


Fig 19: Basic profile of ISO Metric Screw thread (Source: Wikipedia)

Step 17: Determining the Scale Factor (This step is performed only once)

Since, the above measured values are all in term of pixels to get the actual dimensional value that is in millimetres we need to find the scaling factor which is done by taking the distance of the screw thread excluding the head and is measured in terms of pixels then the same screw is measured in actual units using the vernier calliper and that value is divided with the respective pixel value to obtain the scaling factor in terms of mm/pixel. The following is one of the figure 20 generated and is measured using a line function to measure the distance in terms of pixel values and then by taking the average we obtain a scaling factor which is in this case is approximately (0.03 mm/pixel). (Table attached in the appendix)

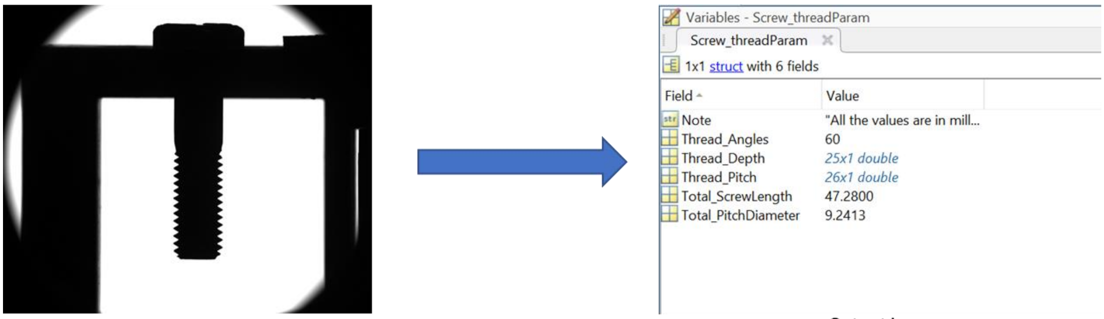
Fig 20: obtaining the pixel coordinates using drawline tool.



Finding the length of the line in pixel values

Step 18: Display the result of the Screw inspection parameters.

Until now the results obtained are in the form of pixel values after multiplying with the scale factor that is 0.03 mm/pixel we will obtain the results in millimetres. All the necessary screw thread parameters are stored in a MATLAB structure file called “Screw_threadParam.m” the below is the figure 21 from which the output is shown.



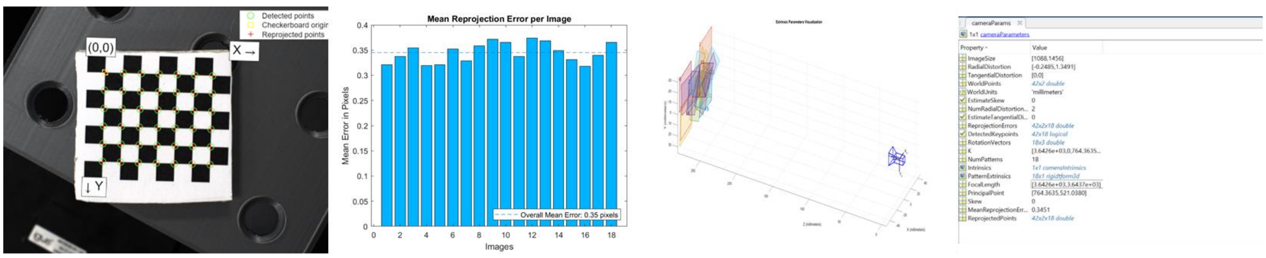
Output image

Input image

Fig 21: The result for the screw thread parameters.

Procedure of steps that were implemented for the Sorting Station

Step 1: <u>Determining the Camera parameters using the Camera Calibration App</u>
The camera calibration is done using a Camera Calibration app in MATLAB. Here we need to import the checkboard images and mention the size to the checker board square size in our case it is 6mm. After that we can obtain the mean reprojection error graph and the camera intrinsic and the extrinsic parameters also. This tool will generate a file called "Camera Params" which contain the both the intrinsic and the extrinsic parameters along with the radial and tangential distortions. The following are the images obtained as shown in the figure 22.



Reprojected points of Checker board image

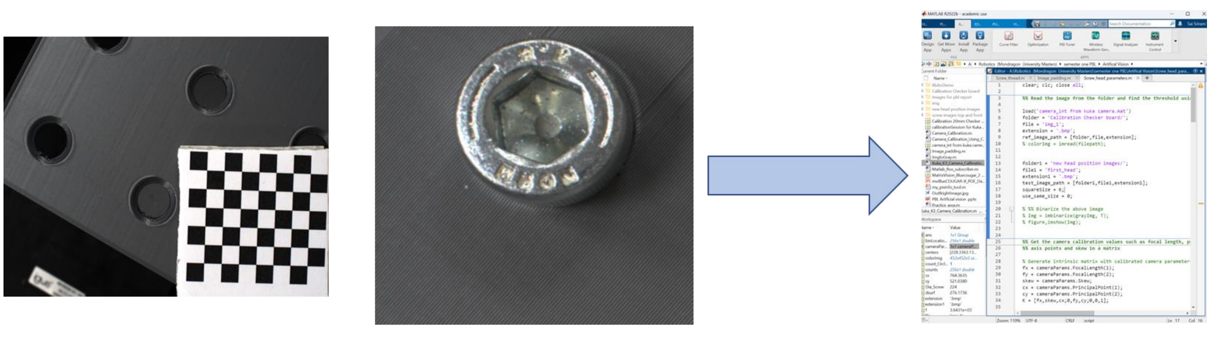
Overall mean projection error for all reference images

Extrinsic parameters

Intrinsic parameters

Fig 22: The results from the Camera Calibration App

Step 2: <u>Importing the reference image, test image and load the camera parameters.</u>
After obtaining the above results we had loaded the respective camera parameters and a checkerboard image as a reference image and a screw head image as a test image as shown in the figure 23.



Checker board as reference image

Screw head image as test image

MATLAB Environment

Fig 23: importing reference image and the test image.

Step 3: Generate Camera Intrinsic and compute Extrinsic.

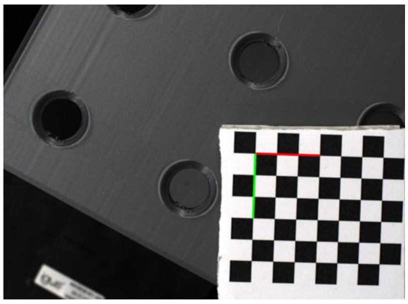
Generate the camera intrinsic matrix and use undistortImage function to remove lens distortions next, find the rotation and translation of world frame with respect to camera frame, then define transformation from measurement place to the image plane that is homography from world to image plane.

Step 4: Generate Intrinsic and Extrinsic for Virtual camera and compute the scaling factor.

Define a transformation from measurement plane to the orthonormal image to define the virtual camera that should be placed such that the principal ray observes the same point as the real camera, and the image plane is parallel to the measurement plane. Then the intrinsic and extrinsic parameters for the virtual camera is computed. Also set the focal length in a isotropic scale.

Step 5: Generate rotation and translation values for virtual camera and compute the scaling factor.

The rotation and translation for virtual camera is obtained by defining a rotation of world place with respect to virtual fronto parallel camera as shown in the figure 24. Then find the point on the measurement plane observed by the principal point and the camera measurement plane distance along the optical axis. Then the virtual camera distance is computed at same distance from the point as physical one. Then compute the homography from world to image of the perpendicular view camera. Then Compute the scale factor of a fronto parallel that is in (pixel/mm)



Axes for reference image

Fig 24: rotation of the world plane with respect to virtual camera

Step 6: Apply Homography to the test image.

The following is performed with a image padding so that it could be equal to the reference image dimensions, here we perform a zero padding around the image where the image is being at the centre. Then undistort the image after this apply prospective correction by projecting the above obtained homography matrix. The below is the resultant image obtained by the above-described procedures as shown in the figure 25.

Fig 25: rectified image

Step 7: Binarize the Test image

For calculating the screw head measurements binarize the test image using imbinarize as shown in the figure 26.

Fig 26: Binary screw head

Binarize the screw head

Step 8: Find the Circle or lines using Hough transform.

Find the circle using a hough circle transform for the given binary image this is done for the round screw heads for the hexagon screw heads the hough line transform is performed the width of the hexagon screw head is obtained by finding the distance between the farthest points of the lines that were created using hough line function. The below figure 27 which shows the results obtained after the above process.

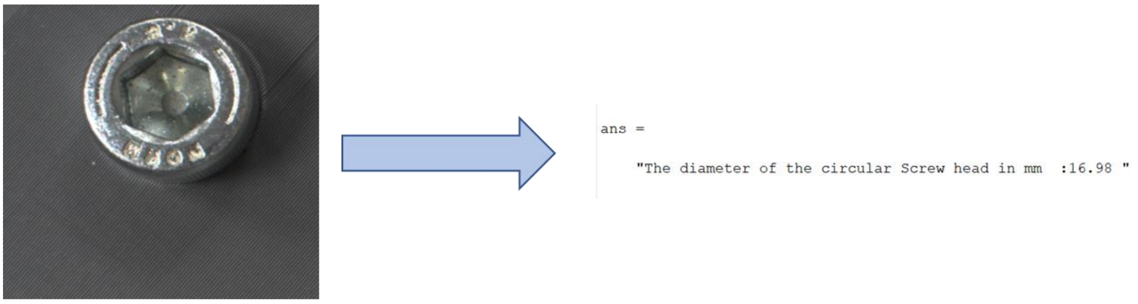
Insert circle using Hough circle transform

Insert lines using Hough line transform

Fig 27: Circles and lines generated on the images.

Step 9: Display the results.

The above pixel values are converted into millimetres by dividing with the scaling factor that is “scale_rect” which is in pixel/mm. The output results are obtained in millimetres as shown in figure 28.



Input image

Output image

Fig 28: Results of the screw head parameters.

Weak points:

1. The foreground and the background texture of the 3d printed screw table and the screw head are very similar, because of that it is very difficult to binarize the image and difficulty faced while finding the lines or circles using hough transform.

Solution: By printing the screw table with the different colour filament will cause a better output result since, we could easily binarize them

2. Having a telecentric lens limits the region of measurement for only a limited range of Screw hights it could not measure larger lengths than its eyepiece diameter.

Solution: we can equip a high-definition zoom lens to the industrial camera with the necessary know camera calibration is done to measure accurately

3. Having difficulty to detect the dark screw head and the shiny screw heads.

Solution: We can have a lighting such as having a front lighting with a darkfield and a diffuse light source.

Future lines:

1. In the future task if there could a robotic arm that which has both the gripper and the camera equipment on the same end effector it could reduce the time of process.
   Such as one shown in the figure 30.

2. Having a motorized focus lens could provide the robot to take a better image of the screw without extending its arms up to its singularity pose, as shown in the figure 31.

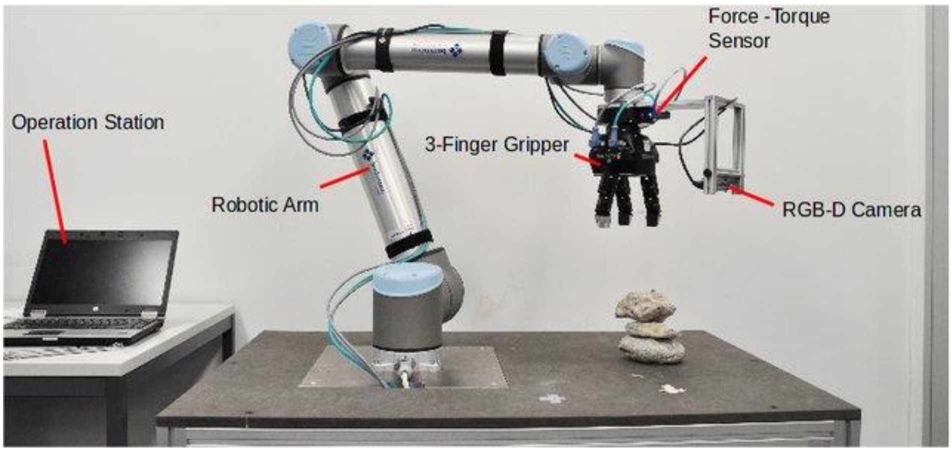


Fig 30: robotic arm with the integrated gripper and camera setup module
(Source: Fadri Furrer)

Fig 31 Motorized camera holder with auto focus (Source: canon)

References:

[1] Development of Computer Vision Algorithms For Measurement And Inspection Of External Screw Threads by E.S. Gadelmawla .

Appendix-I

Table for finding the scaler factor for the metrology station

Original Screw thread length(mm)				length of screw thread that was obtained from the image in pixels								
40	mm					1100.56	pixels				0.036345	mm/pixel
40.2	mm					1100.24	pixels				0.036537	mm/pixel
40.5	mm					1103.64	pixels				0.036697	mm/pixel
40	mm					1104	pixels				0.036232	mm/pixel
									Mean value		0.036453	mm/pixel