Vision Sensing based Filament Clogging & Exhaustion Detection and Machine Interruption System using Serial Interruption Model in Fused Deposition Modelling 3d Printers

K. Chandrakumar
Graduate Research Student
Bannari Amman Institute of Technology
Coimbatore, Tamilnadu, India 638401
Email: chandrakumar3108@gmail.com

A. Naveensankar
Graduate Research Student
Bannari Amman Institute of Technology
Coimbatore, Tamilnadu, India 638401
Email: chandrakumar3108@gmail.com

This is the abstract. This article illustrates preparation of ASME paper using LaTeX2ε. An abstract for an ASME paper should be less than 150 words and is normally in italics. Please use this template to test how your figures will look on the printed journal page of the Journal of Mechanical Design. The Journal will no longer publish papers that contain errors in figure resolution. These usually consist of unreadable or fuzzy text, and pixilation or rasterization of lines. This template identifies the specifications used by JMD some of which may not be easily duplicated; for example, ASME actually uses Helvetica Condensed Bold, but this is not generally available so for the purpose of this exercise Helvetica is adequate. However, reproduction of the journal page is not the goal, instead this exercise is to verify the quality of your figures. Notice that this abstract is to be set in 9pt Times Italic, single spaced and right justified.

Nomenclature

A You may include nomenclature here.

α There are two arguments for each entry of the nomemclature environment, the symbol and the definition.

The primary text heading is boldface and flushed left with the left margin. The spacing between the text and the heading is two line spaces.

1 Introduction

This article illustrates preparation of ASME paper using LaTeX2ε. The LaTeX macro `asme2ej.cls`, the BibTeX style file `asmems4.bst`, and the template `asme2ej.tex` that create this article are available on the WWW at the URL address `http://iel.ucdavis.edu/code/`. To ensure compliance with the 2003 ASME MS4 style guidelines [**?**], you should modify neither the LaTeX macro `asme2ej.cls` nor the BibTeX style file `asmems4.bst`. By comparing the output generated by typesetting this file and the LaTeX2ε source file, you should find everything you need to help you through the preparation of ASME paper using LaTeX2ε. Details on using LaTeX can be found in [**?**].

In order to get started in generating a two-column version of your paper, please format the document with 0.75in top margin, 1.5in bottom margin and 0.825in left and right margins. Break the text into two sections one for the title heading, and another for the body of the paper.

The format of the heading is not critical, on the other hand formatting of the body of the text is the primary goal of this exercise. This will allow you to see that the figures are matched to the column width and font size of the paper. The double column of the heading section is set to 1.85in for the first column, a 0.5in spacing, and 4.5in for the second column. For the body of the paper, set it to 3.34in for both columns with 0.17in spacing, both are right justified.

The information that is the focus of this exercise is found in section **??**. Please use this template to format your paper in a way that is similar to the printed form of the Journal of Mechanical Design. This will allow you to verify that the size and resolution of your figures match the page layout of the journal. The ASME Journal of Mechanical Design will no longer publish papers that have the errors demonstrated here.

ASME simply requires that the font should be the appropriate size and not be blurred or pixilated, and that lines should be the appropriate weight and have minimal, preferably no, pixilation or rasterization.

The journal uses 10pt Times Roman Bold for headings, but Times Bold is good enough for this effort. The text is set at 9pt Times Roman, and again Times will be fine. Insert a new line after the heading, and two lines after each section. This is not exactly right but it is close enough.

2 Very Very Very Very Very Very Very Very Very Very Very Long Heading

The heading is boldface with upper and lower case letters. If the heading should run into more than one line, the run-over is not left-flushed.

2.1 Second-Level Heading

The next level of heading is also boldface with upper and lower case letters. The heading is flushed left with the left margin. The spacing to the next heading is two line spaces.

2.1.1 Third-Level Heading.

The third-level of heading follows the style of the second-level heading.

3 Use of SI Units

An ASME paper should use SI units. When preference is given to SI units, the U.S. customary units may be given in parentheses or omitted. When U.S. customary units are given preference, the SI equivalent *shall* be provided in parentheses or in a supplementary table.

4 Vision Sensing Detection

With the intention of detecting filament clogging or exhaustion in the immediate printing layer defined in [2.1 Errors] this work utlizes the adaptive template matching algorithm to locate the Region of Interest (ROI). In our case, ROI is the extruder nozzle that has to be located in the image frame segmented from the live feed of the webcamera adhered to the extruder. In this work we use Microsoft LifeCam HD3000 Web Camera since it is considerably low in cost and has focus-free lens with High Definition video streaming quality. The cost effective camera module with low installation time and cost can facilitate the users of such mediocre printers to implement this system effectively. The adaptive Framerate system is availed using the imutils library in python which provides series of convenience functions to make translation, rotation, resizing, skeletonization and much more. This adaptive framerate system can adjust the frames per second capturing according to the relative speed of the extruder.

4.1 Software Requirements

1. We use OpenCV(Open Source Computer Vision Library) in Version 4.3.0 for accelerated Computer Vision functionalities and the opencv-python API for python language support and this provides enormous Core Operations in image processing, Feature Detection, Image Reconstruction and Video Analysis.
2. We use Scikit-Image (skimage) in Version 0.16.1 to utilize versatile set of image processing routines such as image comparison and similarity check using NRMSE, SSIM, etc.

4.2 Workflow Methodology

Our proposed algorithm follows series of steps and methodologies as follows:

1. Preprocessing of Template Image
2. Preprocessing of Source Image
3. Edge Detection of Images
4. Template Matching
5. Localization of Region of Interest (ROI)
6. Differential imaging
7. Similarity Comparison

4.2.1 Preprocessing of Template Image

1. Selection of Template image (T) by capturing nozzle which is a patch to be compared with the source image with the fixed dimension of 432 x 239 x 3 pixels.
2. Resizing the Template image (T) to 15 percent of its original dimension which is 65 x 36 x 3 pixels to make the sliding window smaller for accurate matching.
3. Conversion of Resized RGB template image (3 color channels) to Grayscale/Greyscale image (TG) (1 color channel) to reduce the dimensionality ramification and rapid processing.

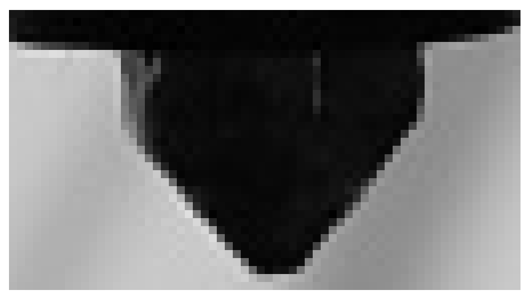

Fig. 1. Template image

4.2.2 Preprocessing of Source Image

1. Every fifth frame of the Video stream is grabbed as Source Image (S) which we expect to find a match to the template image with the fixed dimension of 4032 x 3024 x 3 pixels.
2. Resizing the Source image (S) to 15 percent of its original dimension which is 605 x 454 x 3 pixels to make the processing time agile.
3. Conversion of Resized RGB source image (3 color channels) to Grayscale/Greyscale image (SG) (1 color channel) to reduce the dimensionality ramification and rapid processing.
4. Resizing the SG image according to the scale and will keep track of the ratio of resizing to sustain the shape of TG image to SG image.

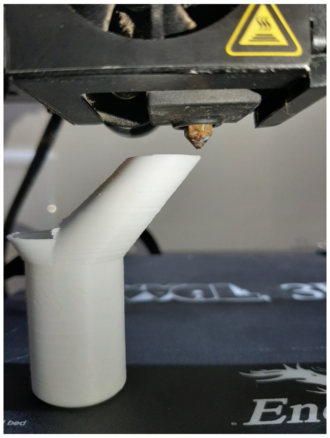

Fig. 2. Source image without Filament flow

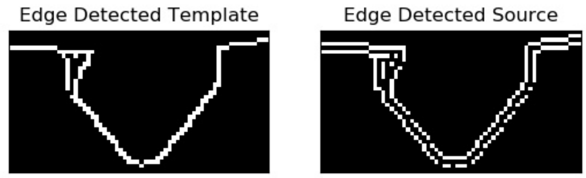

Fig. 3. Edge detected

If the source image at any frame is smaller than the template image, the iteration will stop and the preceding image with edge detection is passed for template matching. The edge detected Source image and Template image is denoted as S_E and T_E

4.2.3 Edge Detection of Images

The resized TG grayscaled and SG grayscaled images are then enforced edge detection. In our work we use Canny edge Detector which is a multi-step algorithm that can detect edges with noise suppression.

1. To reduce noise and undesireable textures, both images are smoothened with Gaussian Filter where

$$g(m,n) = G_\sigma(m,n) * f(m,n) \tag{1}$$

   where Gaussian filter G_σ is,

$$G_\sigma = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left(-\frac{m^2+n^2}{2\sigma^2}\right)$$

2. This step detects the edge intensity and direction by calculating the gradient of the images using Sobel operator. The magnitude G and the slope θ are calculated as follows:

$$|G| = \sqrt{g_m^2(m,n) + g_n^2(m,n)} \tag{2}$$
$$\theta(m,n) = tan^{-1}[g_n(m,n)/g_m(m,n)]$$

3. Threshold M_T is calculated for both the source and template image as follows:

$$M_T(m,n) = \begin{cases} M(m,n) & \text{if M(m,n) > T} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

4. The output of previous step is again Thresholded by two different thresholds τ_1 and τ_2 (where $\tau_1 < \tau_2$) to obtain two binary images T_1 and T_2.
5. Continuous edges are formed using Link edge segments in T_2. To do so, trace each segment in T_2 to its end and then search its neighbors in T_1 to find any edge segment in T_1 to bridge the gap untill reaching another edge segment in T_2.

4.2.4 Template Matching

The edge detected source and template images from the previous step encounters template matching algorithm. We have to compare the template image against the source image by sliding it through specific window size to determine the matching area i.e. extruder nozzle in our case. Sliding the patch one pixel at a time (left to right, up to down). At each location, a metric is calculated to represent how similar the patch is to that particular area of the source image. For each location of T over I, we store the metric in the result matrix (R). Each location (x,y) in R contains the match metric. We used Template Matching Correlation Coefficient (TM_CCOEFF) method. This method is used to a) make the template and image zero mean and b) make the dark parts of the image negative values and the bright parts of the image positive values.

This means that when bright parts of the template and image overlap we'll get a positive value in the dot product, as well as when dark parts overlap with dark parts (-ve value * -ve value gives +ve value). That means you get a +ve score for both bright parts matching and dark parts matching.

When you have dark on template (-ve) and bright on image (+ve) you get a -ve value. And when you have bright on template (+ve) and dark on image (-ve) you also get a -ve value. This means you get a negative score on mismatches.

$$R(x,y) = \sum_{x',y'} (T'(x',y') \cdot I(x+x',y+y')) \tag{4}$$

where

$$T'(x',y') = T(x',y') - 1/(w \cdot h) \cdot \textstyle\sum_{x'',y''} T(x'',y'') \tag{5}$$

$$I'(x+x',y+y') = I(x+x',y+y') - 1/(w \cdot h) \cdot \sum_{x'',y''} I(x+x'',y+y'') \tag{6}$$

Normalize the output of the TM_CCOEFF and localize the location with higher matching probability from the matrix R usually retrieved by minMaxLoc method in OpenCV class.

4.2.5 Localization of Region Of Interest (ROI)

To localize the coordinates of our region of interest we use the highest matching probability coordinates (x_p, y_p) from the previous step and the resizing ratio (r) to bound the ROI. The bounding box is formed by,

$$
\begin{aligned}
(X_s, Y_s) &= (x_p * r, y_p * r) \\
(X_e, Y_e) &= ((x_p + t_w) * r, (y_p + t_h) * r)
\end{aligned}
$$

where

$X_s \Rightarrow$ starting value for x-coordinate
$Y_s \Rightarrow$ starting value for y-coordinate
$X_e \Rightarrow$ ending value for x-coordinate
$Y_e \Rightarrow$ ending value for y-coordinate
$t_w \Rightarrow$ width of the edge detected template image
$t_h \Rightarrow$ height of the edge detected template image

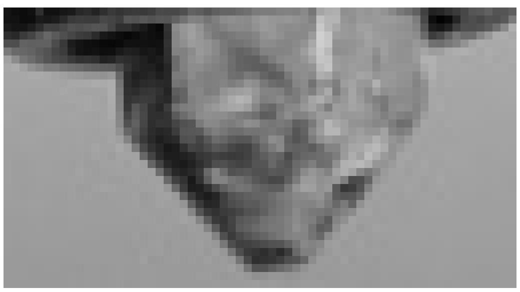

Fig. 4. ROI image

Using the starting and ending coordinates derived, ROI is constructed in single channel of dimension 64 x 35 pixels in addition to the template image of similar dimension.

4.2.6 Differential imaging

Absolute Difference of template image T_i and ROI image R_i generates a differential image. It yields the temporal difference between source and the template.

$$D_i = saturate(|T_i - S_i|) \tag{7}$$

This value of D_i will be considerably low when the filament flow is in the appropriate level. When the filament flow is clogged or exhausted the D_i value will increase abruptly to peak value. This helps in distinguishing whether the filament flow is "good" or "bad" to a meagre level.

4.2.7 Similarity Comparison

To gain more precise results, in addition to differential imaging we calculate Normalized Root Mean Squared Error (NRMSE) and Structural Similarity Index Measure (SSIM) available in skimage module.

1. **NRMSE:** NRMSE is exact deviation between the original and observed images. If the NRMSE value tends to be less compared to the fixed threshold of 0.558 then the template and ROI images are relatively same which concludes that the flow in the nozzle is filament less.

$$I_{NRMSE} = \frac{\sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}}{X_{obs,max} - X_{obs,min}} \tag{8}$$

$$Extruder_{status} = \begin{cases} 1 \text{ if } I_{NRMSE} \leq 0.558 \\ 0 \text{ otherwise} \end{cases}$$

where,
$1 \Rightarrow$ No Filament
$0 \Rightarrow$ Filament

2. **SSIM:** SSIM is a perceptual metric that quantifies image quality degradation caused by processing and finds the similarity of provided images. SSIM will look for similarities within pixels i.e. similar pixel density values. SSIM addresses the main drawback of NRMSE which is difficulty in standardizing arbitarily high NRMSE values. In other hand SSIM ranges between -1 and +1. A score of 1 meant very similar and vice versa.

$$I_{SSIM}(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c1)(\sigma_x^2 + \sigma_y^2 + c2)} \tag{9}$$

$$Extruder_{status} = \begin{cases} 0 \text{ if } I_{SSIM} \leq 0 \\ 1 \text{ if } I_{SSIM} > 0 \end{cases}$$

where,
$0 \Rightarrow$ Filament
$1 \Rightarrow$ No Filament

5 Figures

All figures should be positioned at the top of the page where possible. All figures should be numbered consecutively and centered under the figure as shown in Fig. **??**. All text within the figure should be no smaller than 7 pt. There should be a minimum two line spaces between figures and text. The number of a referenced figure or table in the text should be preceded by Fig. or Tab. respectively unless the reference starts a sentence in which case Fig. or Tab. should be expanded to Figure or Table.

In the following subsections, I have inserted figures that have been provided by authors in order to demonstrate what to avoid. In each case the authors provided figures that are 3.25in wide and 600dpi in the .tif graphics format. The papers containing these figures have been held from production due to their poor quality.

Fig. 5. Another example of a figure with unreadable text. Even when the paper was expanded to double column width the text as shown in Fig. **??** was of such low quality that the paper was held from production.

In order to place the figure in this template using MSWord, select Insert Picture from File, and use wrapping that is top and bottom. Make sure the figure is 3.25in wide.

Figure '**??** was taken from a recent paper that was held from publication, because the text is fuzzy and unreadable. It was probably obtained by taking a screen shot of the computer output of the authors software. This means the original figure was 72dpi (dots per inch) on a computer screen. There is no way to improve the quality such a low resolution figure.

In order to understand how poor the quality of this figure is, please zoom in slightly, say to 200%. Notice that while the font of the paper is clear at this size, the font in the figures is fuzzy and blurred. It is impossible to make out the small symbol beside the numbers along the abscissa of the graph. Now consider the labels Time and Cost. They are clearly in fonts larger that the text of the article, yet the pixilation or rasterization, associated with low resolution is obvious. This figure must be regenerated at higher resolution to ensure quality presentation.

The poor quality of this figure is immediately obvious on the printed page, and reduces the impact of the research contribution of the paper, and in fact detracts from the perceived quality of the journal itself.

5.1 The 2nd Example of Bad Figure

Figure **??** demonstrates a common problem that arises when a figure is scaled down fit a single column width of 3.25in. The original figure had labels that were readable at full size, but become unreadable when scaled to half size. This figure also suffers from poor resolution as is seen in the jagged lines the ovals that form the chain.

This problem can be addressed by increasing the size of the figure to a double column width of 6.5in, so the text is readable. But this will not improve the line pixilation, and a large low resolution figure is less desirable than a small one. This also significantly expands the length of the paper, and may cause it to exceed the JMD nine page limit. Additional pages require page charges of $200 per page. It is best to regenerate the figure at the resolution that ensures a quality presentation.

5.2 The 3rd Example of Bad Figure

An author provided the high resolution image in Fig. **??** that was sized to a single column width of 3.25in. Upon seeing the poor quality of the text, the publisher scaled the image to double column width as shown in Fig. **??** at which point it took half of a page. The publisher went on to do this for all eight figures generating four pages of figures that the author did not expect. ASME stopped production of the paper even with the larger figures due to the pixilation of the font.

Table 1. Figure and table captions do not end with a period

Example	Time	Cost
1	12.5	$1,000
2	24	$2,000

Clearly the text in this figure is unreadable, and it is doubtful that the author can print the output in a way that it is readable. This is a problem that the author must solve, not the publisher.

As you might expect, I have many more examples, but in the end the author is the best judge of what is needed in each figure. ASME simply requires that the image meet a minimum standard for font and line quality, specifically the font should be the appropriate size and not be blurred or pixilated, and that lines should be the appropriate weight and have minimal, preferably no, pixilation or rasterization.

6 Tables

All tables should be numbered consecutively and centered above the table as shown in Table **??**. The body of the table should be no smaller than 7 pt. There should be a minimum two line spaces between tables and text.

7 Citing References

The ASME reference format is defined in the authors kit provided by the ASME. The format is:

> *Text Citation*. Within the text, references should be cited in numerical order according to their order of appearance. The numbered reference citation should be enclosed in brackets.

The references must appear in the paper in the order that they were cited. In addition, multiple citations (3 or more in the same brackets) must appear as a " [1-3]". A complete definition of the ASME reference format can be found in the ASME manual [?].

The bibliography style required by the ASME is unsorted with entries appearing in the order in which the citations appear. If that were the only specification, the standard BIBTEX unsrt bibliography style could be used. Unfortunately, the bibliography style required by the ASME has additional requirements (last name followed by first name, periodical volume in boldface, periodical number inside parentheses, etc.) that are not part of the unsrt style. Therefore, to get ASME bibliography formatting, you must use the `asmems4.bst` bibliography style file with BIBTEX. This file is not part of the standard BibTeX distribution so you'll need to place the file someplace where LaTeX can find it (one possibility is in the same location as the file being typeset).

With LATEX/BIBTEX, LATEX uses the citation format set by the class file and writes the citation information into the

Fig. 6. A figure expanded to double column width the text from Figure ??

.aux file associated with the LaTeX source. BIBTeX reads the .aux file and matches the citations to the entries in the bibliographic data base file specified in the LaTeX source file by the `\bibliography` command. BIBTeX then writes the bibliography in accordance with the rules in the bibliography .bst style file to a .bbl file which LaTeX merges with the source text. A good description of the use of BIBTeX can be found in [?, **?**] (see how two references are handled?). The following is an example of how three or more references [?, ?, ?] show up using the `asmems4.bst` bibliography style file in conjunction with the `asme2ej.cls` class file. Here are some more [**?**, **?**, **?**, **?**, **?**, **?**, **?**, **?**, **?**, **?**, **?**] which can be used to describe almost any sort of reference.

8 Conclusions

The only way to ensure that your figures are presented in the ASME Journal of Mechanical Design in the way you feel is appropriate and meets the requirement for quality presentation is for you to prepare a double column version of the paper in a form similar to that used by the Journal.

This gives you the opportunity to ensure that the figures are sized appropriately, in particular that the labels are readable and match the size of the text in the journal, and that the line weights and resolutions have no pixilation or rasterization. Poor quality figures are immediately obvious on the printed page, and this detracts from the perceived quality of the journal.

I am pleased to provide advice on how to improve any figure, but this effort must start with a two-column version of the manuscript. Thank you in advance for your patience with this effort, it will ensure quality presentation of your research contributions.

9 Discussions

This template is not yet ASME journal paper format compliant at this point. More specifically, the following features are not ASME format compliant.

1. The format for the title, author, and abstract in the cover page.
2. The font for title should be 24 pt Helvetica bold.

If you can help to fix these problems, please send us an updated template. If you know there is any other non-compliant item, please let us know. We will add it to the above list. With your help, we shall make this template compliant to the ASME journal paper format.

Acknowledgements

ASME Technical Publications provided the format specifications for the Journal of Mechanical Design, though they are not easy to reproduce. It is their commitment to ensuring quality figures in every issue of JMD that motivates this effort to have authors review the presentation of their figures.

Thanks go to D. E. Knuth and L. Lamport for developing the wonderful word processing software packages TeX and LaTeX. We would like to thank Ken Sprott, Kirk van Katwyk, and Matt Campbell for fixing bugs in the ASME style file `asme2ej.cls`, and Geoff Shiflett for creating ASME bibliography stype file `asmems4.bst`.

Appendix A: Head of First Appendix

Avoid Appendices if possible.

Appendix B: Head of Second Appendix

Subsection head in appendix

The equation counter is not reset in an appendix and the numbers will follow one continual sequence from the beginning of the article to the very end as shown in the following example.

$$a = b + c. \tag{10}$$