Segmented Time Series Visualization Tool for Additive Manufacturing

William Halsey*
Oak Ridge National Laboratory

Chad Steed
Oak Ridge National Laboratory

Ryan Dehoff
Oak Ridge National Laboratory

Vincent Paquit
Oak Ridge National Laboratory

Sean Yoder
Oak Ridge National Laboratory

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1 Introduction

Additive manufacturing promises to deliver the ability to build complex shapes and parts while using raw materials more efficiently than traditional manufacturing approaches. However, material scientists are continually striving to understand how complex build parameters affect the 3D printing process and the quality of the final product. Understanding the intricate relationships between parameters and final product will yield the opportunity for automatic tuning of variables to ensure consistency of quality across build iterations.

A valuable initial step is to explore the log file data that is produced by the 3D printers over the course of a single build. These log files contain sensor information, machine calculations, and other information about the status of the build. A log file contains thousands of variables, some with thousands of values, for a single build. All of the data have timestamps indicating when the readings or calculations took place, so time series visualization techniques are amenable to this application.

While many visualization techniques exist for full time series [1], they do not allow the material scientist to see how the log data signals change as the 3D printing process progresses from one build layer to the next. We have developed a new visualization tool that reads in data from the log files and segments a variable's time series automatically. Combining the segmented time series view with images of each layer in the build allows researchers to quickly understand how differences in the time series segments translate to physical differences, such as porosity and swelling, between layers in an object. Additionally, this tool employs a time series mining technique, fast dynamic time warping [2], to quantitatively calculate a distance metric between build layer segments. This tool gives researchers a fine level of detail for understanding the relationships between build parameters and product quality.

2 Segmented Time Series View

Figure 1 shows the segmented time series visualization tool. The tool gives researchers options for investigating the variables in the log file as well as modifying the visualization. The settings panel, denoted by the Label 1 in Figure 1, is where the user can manipulate the width and height of the time series segments in order to display more segments in the current window for a coarser view or increase granularity for inspection of minute patterns. Also, they have control over what segmented variable they wish to investigate. The user has several different options for automatically segmenting the time series. From this panel the user is able to choose a reference segment which is used for several of the other visual components.

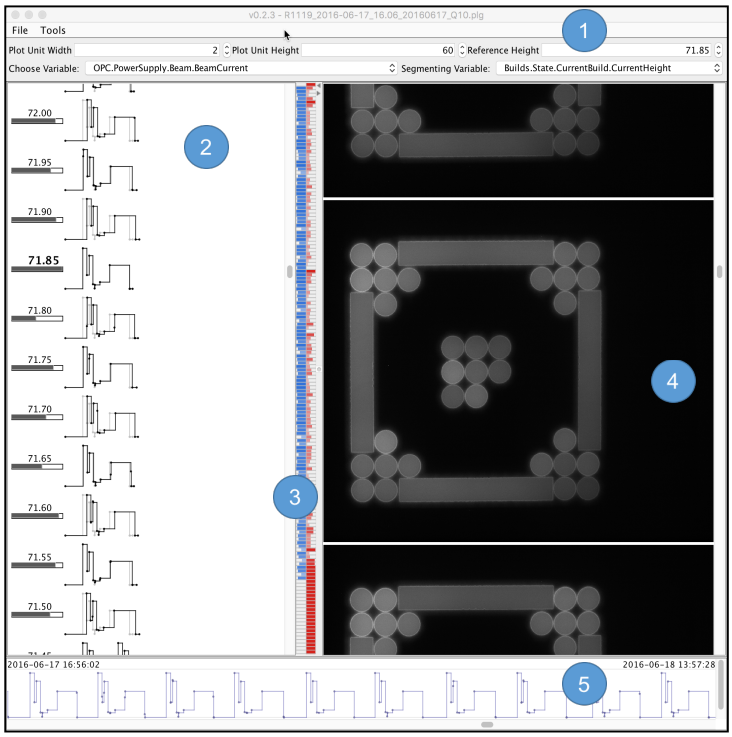

Figure 1: The segmented time series visualization technique provides multiple linked views of a 3D printer build.

2.1 Time Series Segment Visualization

The panel denoted by the Label 2 shows the main visualization. The primary purpose of the main panel is to display the segmented time series. Each individual segment is rendered in a stepwise fasion. The segment is drawn using horizontal spacing between points to denote duration between measurements and vertical spacing to denote differences in value. The segments are then stacked vertically so the user can visually compare the patterns between proximate segments. The full time series is segmented by build height. To the left of the segments are a build height label and similarity indicator bar.

* Author emails: {halseywh, steedca, dehoffrr, paquitvc, yodersl}@ornl.gov

While using this panel the user can select a single segment to serve as a reference of comparison to all other segments by clicking on the segment's label. In the main panel, the reference segment is rendered beneath every other segment in light gray as seen in Figure 2. This gives the user a visual comparison of the reference segment to all other segments in the build. Also, when a reference segment is chosen the distance from the reference is calculated for all segments. Using the distance from dynamic time warping, the main panel provides a similarity indicator for each individual segment in relation to the reference segment. If the bar is completely filled, the segments are exact matches. Less filled bars denote less similar segments to the reference. If the bar is empty and outlined in red then that segment is statistically significantly different then the reference segment so the corresponding build height may warrant further inspection.

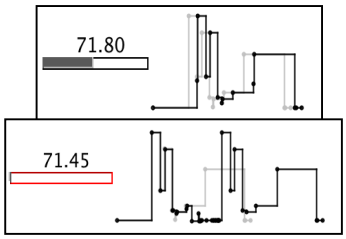

Figure 2: Each segment is rendered in a stepwise fashion with the reference segment overlaid in light gray for visual comparison. The similarity bar gives a quick visual indication of the quantitative distance of the two segments.

2.2 Distance Indicator Overview Visualization

Label 3 in Figure 1 shows the distance indictor panel. This panel also relies on the distance results from dynamic time warping. Its purpose is to give the user a quick view of where interesting segments are in the build so they can focus their investigation. Interesting segments are those that are significantly closer or further away than the median distance of all segments to the reference segment. The tick marks represent the entire build from top to bottom. A single tick mark consists of a red and blue half. In order to be visible the tick marks have a minimum width of five pixels. Since the maximum number of tick marks is constrained by the size of the window, the number of actual segments can outnumber the number of tick marks that can be displayed. As such, multiple consecutive segments may be binned into a single tick mark. Within each bin the segments with the largest and smallest distances to the reference segment are chosen. The smallest distance will be represented by the blue half of the tick mark; the greatest is represented by the red. This encoding gives the user insight about the range of distances in the different regions of the build. Longer, more intense bars denote that the segment is significantly closer or further away than the median distance.

2.3 Build Slice and Overview Panel

The panels denoted by Labels 4 and 5 in Figure 1 indicate the build slice viewer and overview panels respectively. For additive manufacturing, an image of each build layer is useful to see in conjunction with the time series segments. When the user finds anomalies in a signal they can reference the corresponding build height image. This capability helps them understand the relationship between anomalies seen in the signals and properties in the physical build. The scrolling for this panel is synchronized with the main panel to ensure that whenever an image is centred in the panel, its corresponding segment is viewable in the main panel. When the user hovers over an image, a tooltip is displayed showing the corresponding segment label. The overview panel allows the user to maintain awareness and understanding of the context of the segments in the full, unsegmented time series.

3 Example Usage Observations

In Figure 1, we see that the user has chosen layer 71.85 as the reference segment. They might have chosen that particular layer because it appears to demonstrate a pattern that is typical for this particular build. In the top image of Figure 2, we determine that the reference segment and segment 71.80 are visually quite similar, even if they are not the most quantitatively similar.

Now, we proceed to investigate the distance indicator overview panel to see where other interesting segments may be found. In Figure 3, we see a tick mark that is bright red and full denoting that a significantly distant segment from the reference is somewhere towards the upper middle part of the build. The tooltip indicates that the segment label is 71.45 and the scaled distance value is 2.56. Clicking on that half of the tick mark will bring the time series segment into view in the main panel for the user to inspect. The

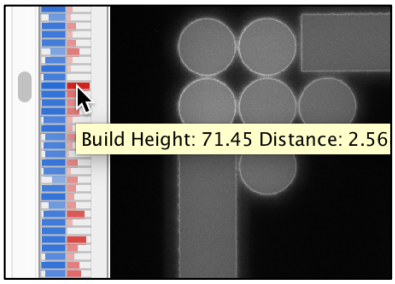

Figure 3: A closer view of the distance indicator overview panel. The bright red tick mark indicates a significantly different time series segment at build height 71.45.

bottom image in Figure 2 shows the anomalous time series segment. Visually, we quickly observe that the segment is significantly different that the reference segment. Also, the similarity indicator bar is completely empty and bright red. This shows that the segment is also quantitatively significantly different than the reference. We can now proceed to visually inspecting the image for height 71.45 to see if any physical anomalies like pores or swelling are occurring.

4 Conclusion

This new visualization tool builds on the wealth of time series visualization techniques in order to facilitate exploratory data analysis for additive manufacturing. It gives material scientists an environment for exploring the correlation between 3D printer log data and the quality of the final product by showing the variations and inconsistencies on a per layer basis.

References

[1] W. Aigner, S. Miksch, H. Schumann, and C. Tominski, *Visualization of Time-Oriented Data*. Springer, 2011.

[2] S. Salvador and P. Chan, "Fastdtw: Toward Accurate Dynamic Time Warping in Linear Time and Space," in Proceedings of the ACM KDD Workshop on Mining Temporal and Sequential Data, 2004, pp. 70 – 80.