



From 3-D Printing
to

3-D Sprinting

A unique algorithm
enables 3-D printing
at twice the speed

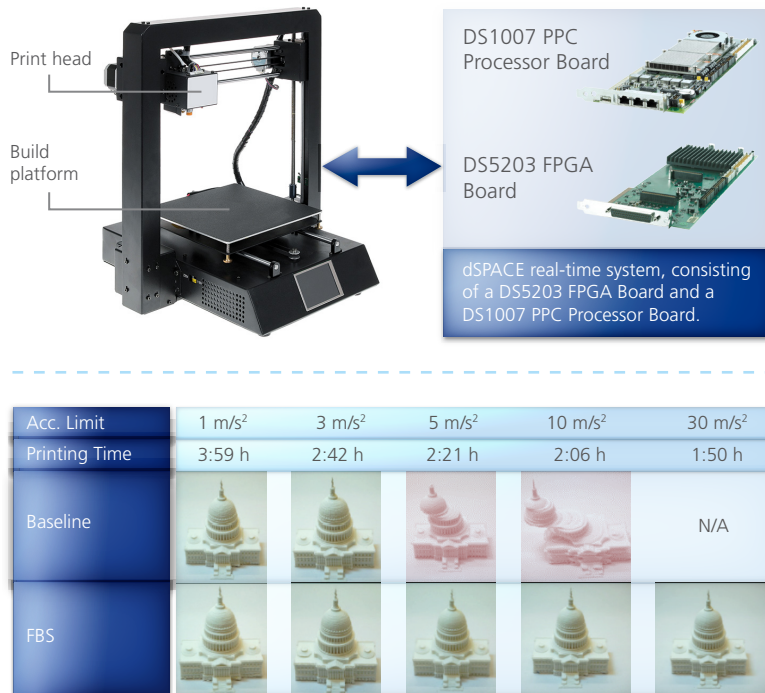
Researchers at the Smart and Sustainable Automation (S2A) Lab at the University of Michigan have developed a method that lets them print twice as fast on a 3-D printer without sacrificing print quality. The method is based on a software algorithm that reduces the disturbing vibrations of the printer. To achieve their goal, the researchers used a dSPACE DS1007 PPC Processor Board and a DS5203 FPGA Board.



These days, desktop 3-D printers are everywhere. They are attractive because of their ability to create three-dimensional objects. However, it can take hours to print a simple object. To keep purchase costs low, these printers are designed to be light and flexible, which makes them susceptible to vibrations from stepper motors. These excessive vibrations result in surface waviness of the printed products and incorrect vertical stacking (figure 1b). Industrial-grade 3-D printers, and other manufacturing machines, have similar limitations due to vibrations. A common remedy is to reduce the motion speed or add damping. However, this leads to reduced productivity, because it takes longer to finish a print. Associate Professor Chinedum Okwudire and his team of student engineers at the Smart and Sustainable Automation (S2A) Lab, University of Michigan, have set out to remedy the vibration-induced error issue. They have completed a research project during which they were able to effectively double the speed of a 3-D printer, in a case study, while maintaining high-quality prints. The basis of the improved printing process is a software algorithm that Okwudire and his team developed. The algorithm generates motion commands to avoid or reduce unwanted vibrations, which is a leading cause of errors and distorted parts in 3-D printers. >>



U-M Mechanical Engineering Associate Professor Chinedum Okwudire examines the results of a new, faster 3-D printing algorithm with research engineering students Molong Duon (left) and Deokkyun Yoon (center).



Acc. Limit	1 m/s ²	3 m/s ²	5 m/s ²	10 m/s ²	30 m/s ²
Printing Time	3:59 h	2:42 h	2:21 h	2:06 h	1:50 h
Baseline					N/A
FBS					

Figure 1a: Commercial 3-D printer controlled by a dSPACE system.

Figure 1b: Thanks to the software algorithm, it is possible to halve the printing time while maintaining the same quality. Photo: Deokkyun Yoon, Michigan Engineering.

Mitigating Unwanted Vibrations

Prior to becoming a professor, Okwudire worked in the machine tool industry. He noticed that machine motors are often operated at lower speeds than they are able to deliver to avoid vibration-induced errors. "I was convinced that with the right algorithm the vibrations could be compensated through software, such that higher speeds and accelerations could be achieved without sacrificing accuracy or increasing hardware costs," Okwudire said. "But a major limitation of machine

tools is that their controllers are typically closed to modifications, which makes it hard to use new control algorithms." This limitation led Professor Okwudire and his research team to test their algorithm on 3-D printers. These also suffer from vibration problems which limit their speed and acceleration. However, their controllers are open. The software algorithm that Professor Okwudire and his research team developed can mitigate vibration-induced errors without sacrificing productivity. The algorithm is based on the

filtered B-splines (FBS) vibration compensation technique. "The FBS algorithm anticipates when the printer may vibrate excessively and adjusts its motions accordingly to minimize vibration-induced tracking errors subject to the kinematics limits of the machine, without introducing time delays," said Professor Okwudire.

Optimizing Motion Commands

The method used takes all movements of the stepper motors of the print head (x-axis) and the build platform (y-axis) into consideration and actively controls them. Particularly, accelerating the motion of the build platform causes inertial loads to exceed the holding torque of the motors, causing them to skip count and lose position tracking. To control the vibration rate, the 3-D printer is connected to an online system that can control the tracking to remain at a preset, constant level (limited preview FBS approach). The algorithm can look ahead and calculate parameters to make adjustments and achieve optimized motion commands.

High-Quality Printed Parts at Faster Speeds

To put their algorithm to the test, Professor Okwudire and his research team conducted a case study. They set out to print a 3-D scale model of the U.S. Capitol. In their first series of prints, they did not use the FBS algorithm method. Conventional acceleration of the printing process led to grave vibration-induced registration errors which rendered all



"dSPACE provided an easy-to-use and reliable platform for prototyping our algorithm within a very short lead time."

Chinedum Okwudire, Associate Professor Mechanical Engineering,
University of Michigan

The Algorithm in Detail

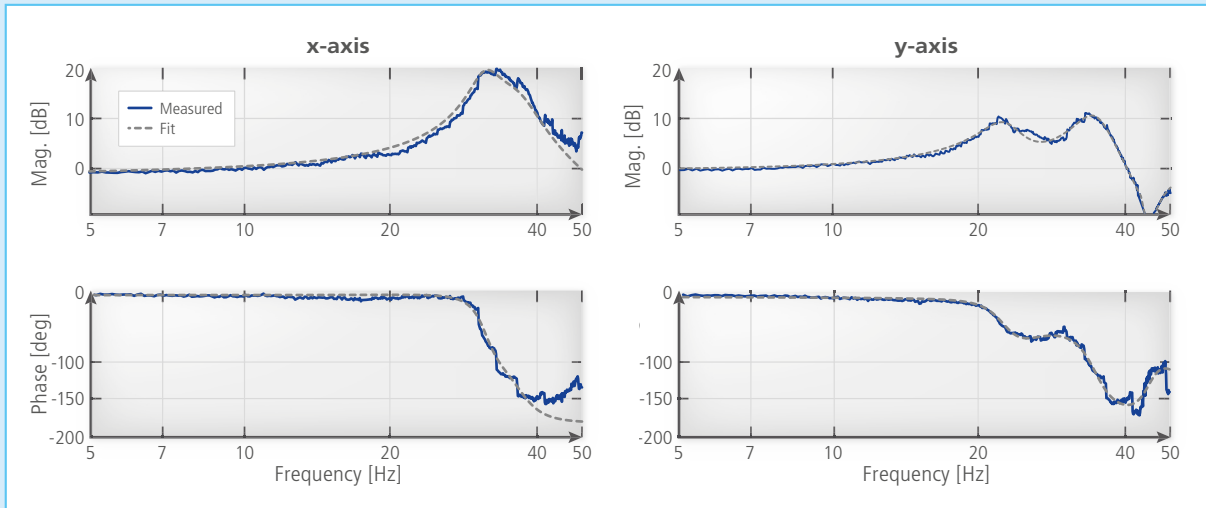


Figure 2: Frequency response functions of the x- and y-axes of the 3-D printer. Least square curve fitting is used to identify the axis level dynamics.

Figure 2 shows the measured and curve fit x- and y-axis frequency response functions (FRFs) of the 3-D printer. The FRFs are measured by applying swept sine acceleration signals to the printer's stepper motors. In addition, the relative acceleration of the build platform and print head is captured using accelerometers. The curve fit model is generated using the MATLAB® `invfreqs` function. To implement the filtered B-splines (FBS) method, the printer's proprietary motion controller is bypassed. Instead, the dSPACE real-time system consisting of a DS1007 PPC Processor Board and a DS5203 FPGA Board sends the axis-level motion commands to

the printer's stepper motors at a sampling rate of 1 kHz via stepper motor drives (Pololu DRV8825).

The dSPACE system loads G-code text files and interprets the data, and then runs the FBS vibration compensation algorithm in real time to optimize the motion trajectories and minimize vibration-induced errors. Additionally, the dSPACE system was used to convert the optimized motion trajectories into stepping and direction pulses, and to send the pulse trains to the stepper drives through digital channels at a pulse width of 0.075 ms.

printed 3-D objects useless. In the second series of prints, the FBS algorithm method was applied. It soon became clear that registration errors could be avoided very reliably. The FBS algorithm method enabled high-quality prints at much shorter printing times compared to the baseline print results. By implementing the FBS algorithm method, the U-M Engi-

neering Team was able to reduce 3-D printing time by 50% (from four hours to two hours, using a 3x factor of safety), without sacrificing printing quality. Their work shows that applying the FBS algorithm method can upgrade a 3-D printer's firmware, enabling faster 3-D printing for existing printers at no additional cost. ■

Courtesy of the University of Michigan



For more information about the algorithm, go to the following video:
www.dspace.com/goldMag_20191_UM