MAKER: Setup and Evaluation of Remotely Accessible 3D Printer Infrastructure for CAD/CAM, CNC, and STEM Courses

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Abstract

Advances in additive manufacturing (AM) have enabled designers and engineers to demonstrate their ideas and build prototypes efficiently and conveniently. Schools, colleges, and universities have welcomed this technology into their classrooms. Richland College (RLC) of the Dallas County Community College District is a two-year college located in Dallas, Texas. It serves approximately 20,000 credit students. RLC worked in collaboration with Texas A&M University, located in College Station, Texas to develop and evaluate a remotely accessible 3D printing infrastructure. This paper describes a remotely accessible system consisting of a commercial 3D printer, work-flow processing, and remote viewing. Students can submit a job after a credential check. The STL file is sliced and uploaded to the 3D printer. Students can view the part being made via webcam and streaming via internet video-sharing providers. Results from a survey of two-year college students who used the system suggest they believe that the system is very relevant to their education and would like to see more tool and system like this made available. Students also commented positively on the system setup including the instructions on how to connect to the 3D printer, the ease-of-use of the remote access application software for connectivity to the 3D printer, and the real-time video of the part being made.

Motivation

Additive manufacturing (AM), known as 3D printing outside of manufacturing circles, has evolved rapidly over the past decade. AM has firmly establish a place in organizations, moving from simple prototype development, to actual production run components, to installed parts and devices with hundreds of thousands of hours of operations. As support for an increasing number of materials including plastics (e.g. ABS, PC, ASA, Nylon, etc.) and composites (metal powders, carbon fiber, etc.), AM is finding applications in numerous industries like aerospace and biomedical. Advances in additive manufacturing have enabled designers, engineers, educators, and students the ability to demonstrate their ideas and build prototypes more efficiently and effectively than before. As a result, many schools and universities have adopted and welcomed 3D printing technologies into their classrooms.

The number of companies producing 3D printers and the yearly market for 3D printers has steadily increased over the past decade, and it's expected to exceed $12 billion dollars annually by the year 2025. The Wohler Report provides clear guidance on the expansion of AM. The number of manufactures selling industrial-grade AM systems has doubled since 2011.[1] Last year, 278,000 3D printers were purchased. However, this represents only a fraction (0.03%) of the total worldwide manufacturing of ~$15 trillion dollars. In the next 3-5 years, more manufacturers (52%) expect AM to be used for high-volume production, up from (38%) two years ago.[2] The expectation is that additive manufacturing revenue will increase at 27% compound annual growth rate worldwide. Therefore, spending in the additive manufacturing market will likely increase from its $11 billion dollar level in 2015 to $26.7 billion by 2019.[3] To meet the growing demand generated by the growth of additive manufacturing, a workforce is needed that can execute all steps in the application of 3D printing. These include product design, part tolerances, CAD modeling, file conversion, and printer operation.

There is a consensus that increasing access to higher education opportunities is necessary to decrease income disparity over the next decade. Contained within this objective is a desire to expanded access to educational pathways and careers in the areas of Science, Technology, Engineering and Mathematics (STEM).[4] In addition, the strength and vibrancy of the US economy relies on knowledge-intensive jobs staffed by well-trained individuals who drive discovery and development of new technologies. Without these career avenues, individuals will face a lower standard of living as income disparity increases.[5] To provide this workforce training service, many educational institutions would benefit from access to 3D printing technology.

While prices for desktop 3D printers have dropped over the past few years, commercial units are still very expensive. Smaller educational institutions, underserved student populations, and many schools in underfunded, disadvantaged, or sparsely populated rural areas often lack the necessary funding to support quality access to 3D printing applications and infrastructure. Therefore, a flexible, remote-access 3D infrastructure is desirable to allow these institutions and students the ability to gain the skills necessary to become part of the emerging additive manufacturing workforce at an affordable cost.

System Design

In conjunction with Texas A&M University, the School of Engineering and Technology at Richland College of the Dallas County Community College District began researching in an effort to meet this objective. At the beginning of the project, RLC operated a single Stratasys Dimensions SST 1200es printer, which is a high quality commercial unit with a proprietary file preparation system.[6] (In any 3D printing file preparation system, the process of converting a file from a 3D surface model to machine code is known as “slicing”.) Initial research showed that remote access solutions for lower-cost desktop printers existed in the marketplace, typically based on their utilization of open source software for the slicing process. However, the proprietary file format of the SST 1200es printer precludes the use of such applications.

The system designed at Richland College enables remote control of the 3D printer via remote desktop software, and an in-house security system. Students are added to a list of authorized users by an administrator, and given permission to submit jobs. They can submit print jobs to the Stratasys printer, and log in to the print server remotely to process their files on the Stratasys proprietary slicing software, known as CatalystEX. Once they have processed their files, the jobs are added to the print queue. The jobs are then printed once the machine has been cleared of other parts. Authorized students can watch the process of their jobs via a live video stream.

Description of the Workflow System

To enable this automated system, we used a print server running Microsoft Outlook, CatalystEX, and video streaming software. The authentication system relied on VBA code running in the background of an Outlook session. To add authorized users, the administrator simply pastes email addresses into a dedicated text file on the server, which the code references in real time. To communicate with the system, students send emails to a dedicated email address on the server. If the sender address has been authorized, the automated system begins a conversation with the sender (Figure 3). It provides the user instructions on how to access the printing system and what requirements exist.

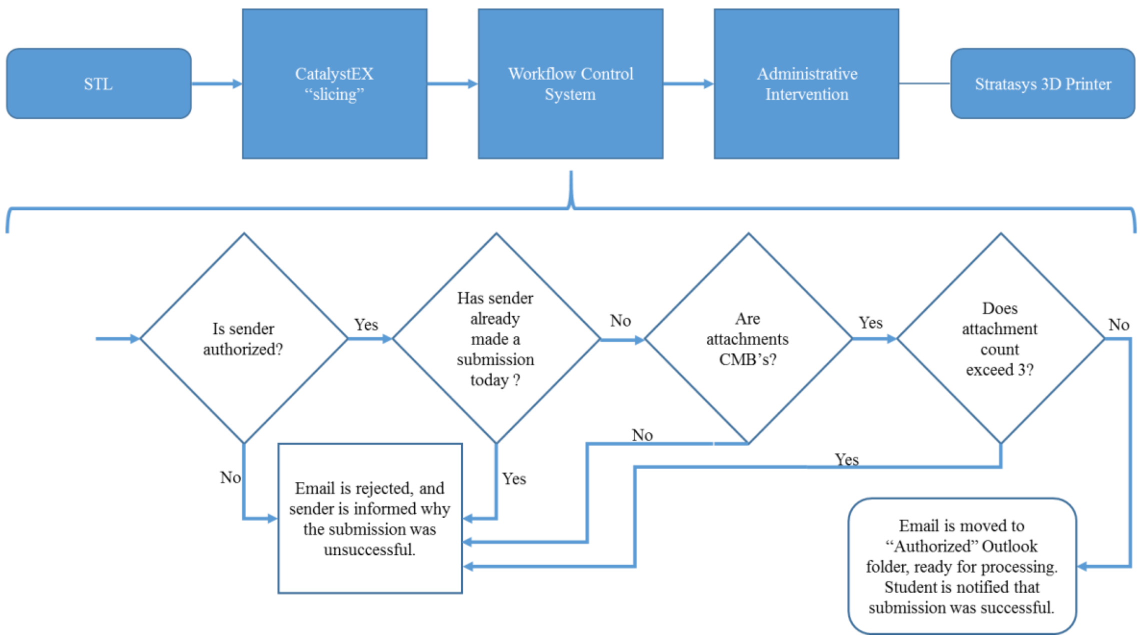

Figure 1. Workflow Control Processing in Remote Accessible 3D Printer Infrastructure System

For example, 3D files must first be converted into the ".STL" (stereo lithography) type, which represents a three dimensional solid as a surface of contiguous triangles. The STL conversion process is completed on the CAD modeling software used to create the part (SolidWorks, AutoCAD, etc). Once the student knows the details of the system, the file is submitted as an attachment to an email, and the system automatically checks the file type and file name to insure they are correct. Upon successful submission of a job, the system sends remote desktop login information to the student, and saves the print job file to a dedicated server location.

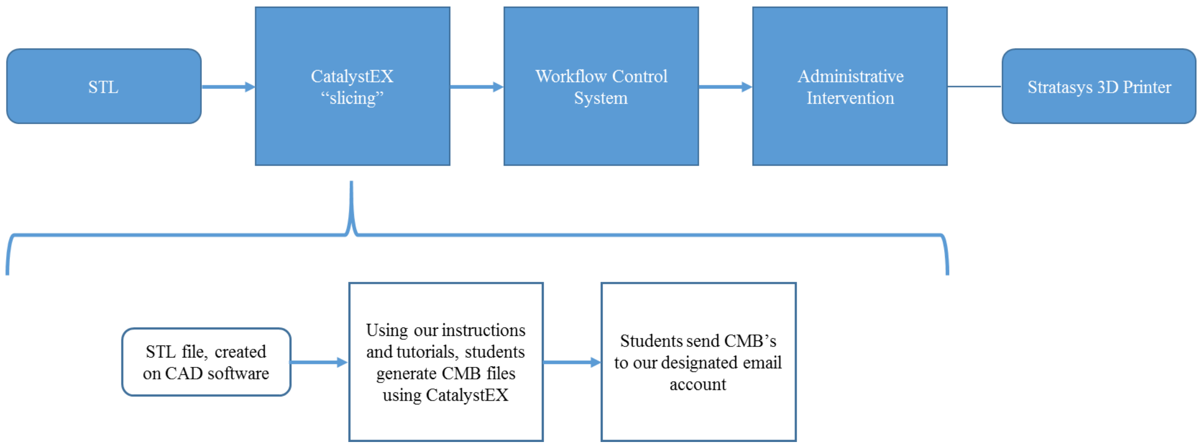

Figure 2. File Slicing in Remote Accessible 3D Printer Infrastructure System

The student next logs in to remotely operate the print server. The student opens CatalystEX and imports the recently submitted file. Within CatalystEX, the job is arranged on the printer palate by the student, as per the instructions in the preliminary email, and submitted to the print queue. There it remains until the printer is ready and cleared by the printer administrator. Once this process is complete, the student logs out and can watch both the real-time queue stream and the live printer video for status updates.

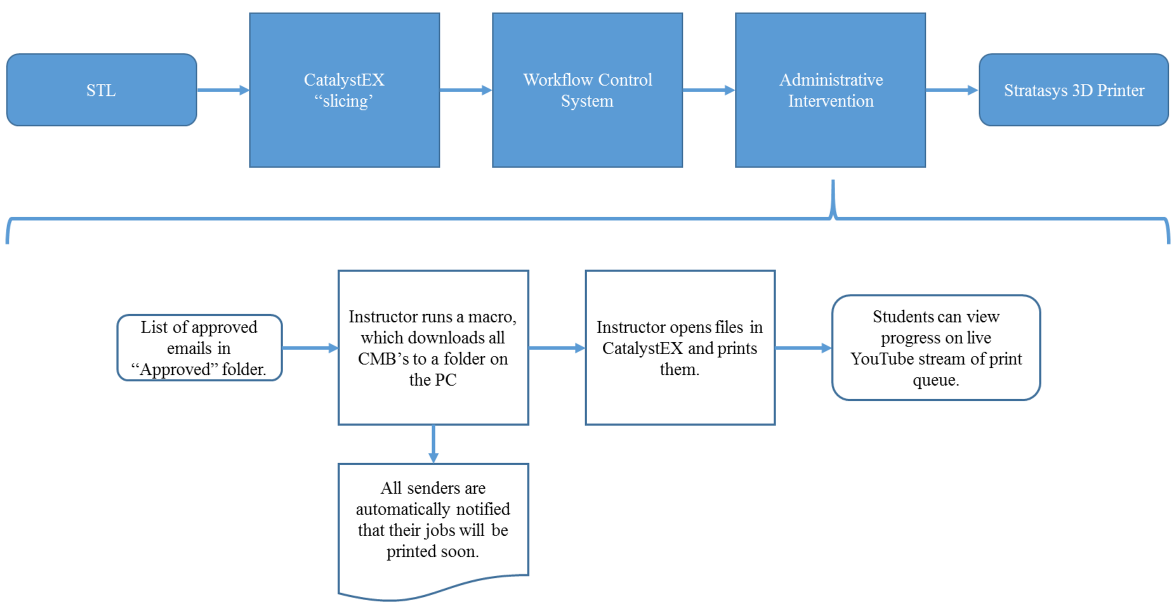

Figure 3. Administrative Intervention & Processing in Remote Accessible 3D Printer System

Student Evaluation and Comments

About twenty students completed a survey to gauge the utility and effectiveness of the remote 3D printing experience and infrastructure system. The survey was implemented on a 7-point Likert scale (1=strongly disagree; 7=strongly agree). Additionally, students gave open-ended responses for plus/delta evaluations. [7] Tables 1 and 2 summarize results from the survey and the open response evaluations.

Table 1. Student Survey Results Summary

Question	**Average**
Using the remote access program help me learn more about the 3D printing process.	5.81
I would like to have more tools like this available to help me learn.	5.94
Using 3D printing is relevant to my education.	5.31
The instructional materials were easy to understand.	4.06
The video feed helped me visualize the process.	5.93

Table 2: Student Survey Results Summary

Table 3. Survey Feedback

The most helpful thing about this experience was:	**The experience could be improved by:**
The remote access to the 3D printer.	Improving the help request instructions.
The live video.	The video feed was dark.
The Catalyst software was easy to use.	Ability to see position of print job in queue.
The email received gave needed instructions.	Ability to move jobs up in print queue.
The whole experience was good, especially remote printer control.	Additional training to slicing software.

Bill of Materials

To implement a similar system, an institution would need a commercial printer comparable to the Dimensions model owned by RLC. In addition, a camera for monitoring the printer is needed, and a server for handling the submission process is required. A server capable of running Outlook, CatalystEX, and a browser can be used.

Unit	**Price**
Stratasys Dimensions SST 1200 ES	$9500
Video Camera	$50
Server	$500
Total	$10500

Conclusions and Future Work

Survey results and evaluation feedback indicate the workflow system can meet the need of students without access to AM systems. We are currently investigating possible solutions to address these issues raised by the student survey. First, by implementing live chat through media platforms such as Blackboard, students will have instant access to guide them through the printing process. In regards to the video stream, advanced cameras that are customized to view 3D printing should be considered to replace the current webcam used in the system. Furthermore, code development giving students additional options to request printing instructions are currently in progress and will be added to our server in the near future. Finally, we will consider online tutorials for system operation for students to complement on-site training in our labs.

In addition to the in-house workflow system for a proprietary printing system, future work will entail adoption of a standardized workflow interface for multi-vendor 3D printer platforms. This is due to the fact that RLC has acquired additional 3D printers, and we desire a uniform interface. Where the Stratasys is better for large parts or parts that must meet strict tolerances, our smaller 3D printer is open source, has lower operation cost, and has greater materials versatility. It also has its own interface applications as well. Although the interface is simpler to utilize, there is still a learning curve. This system will allow the administrator to a control access, instructors to view submissions, and printer operators the ability to control materials costs. These interfaces will allow students to securely upload and manage their STL files. They will also have to capability to perform the necessary "slicing', which allows the students to prepare their print jobs in the web portal and submit them to an available printer through a dedicated print server. Once the job starts, students can watch the progress on a live video feed streamed by the server.

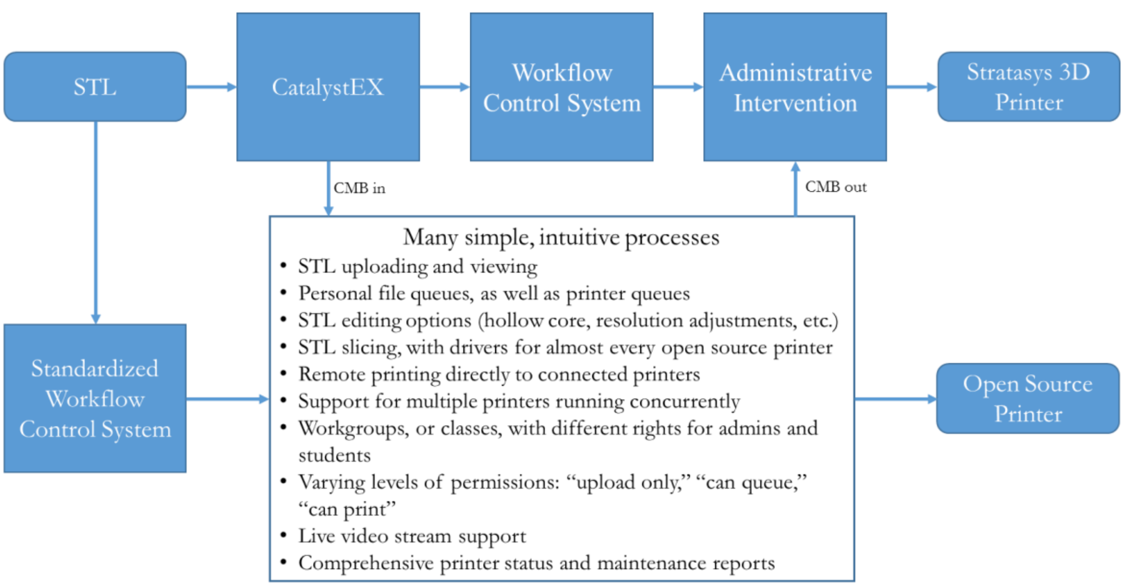

Figure 4. Diagram of part flow through parallel systems

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