Development of 3D-Virtual Facility Tutorial Implemented in Mobile Environment to Enhance Additive Manufacturing Education

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RYAN WICKER, Ph.D., P.E., is a professor of mechanical engineering and director and founder of the W.M. Keck Center for 3D Innovation at the University of Texas, El Paso, where he also holds the endowed Mr. and Mrs. MacIntosh Murchison Chair I in Engineering. The Keck Center represents a world-class research facility that focuses on the use and development of additive manufacturing technologies for fabricating 3D objects that are plastic, metal, ceramic, of bio-compatible materials, composite materials, or that contain electronics. Major research efforts are underway at the Keck Center in the areas of additive manufacturing technology development; closed-loop process control strategies for additive manufacturing; additive manufacturing of various powder metal alloy systems; and 3D structural electronics in which electronics, and thus intelligence, are fabricated within additive manufacturing-fabricated mechanical structures.

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Zhonghua Hu was born on April 2, 1983 in Shanghai, China. He got his bachelor degree in Mechanical Engineering on the summer of 2005 from Tongji University, Shanghai, China and Master of Science degree in Industrial Manufacturing and System Engineering at University of Texas on the winter of 2012. He started to pursue his Ph.D degree in Electrical Computer Engineering at University of Texas at El Paso from fall 2013. At UTEP, he worked as a research assistant at Industrial Systems Engineering Laboratory.

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Abstract

To date, improving the manufacturing engineering education has become a major mission for universities, particularly when manufacturing industry is currently recovering in the US. There is a need to develop tutorial software implemented in mobile device to allow students to get access of instructional material in 24/7 and enhance student learning in manufacturing engineering courses that will give future workforce engineers the skills that manufacturing companies are searching for. This paper discusses software preparation and development to support undergraduate and graduate Science, Technology, Engineering, and Mathematics (STEM) learning environments through Cyber Based Rapid Manufacturing (CBRM) – preparing students for the needs of industry and promoting advanced manufacturing technologies in higher education. The software currently aims to be used in a mobile device like Microsoft Surface and Microsoft Windows phone. It is also anticipated to be implemented in Android environment eventually. Software features are similar to 3D virtual Rapid Prototyping (RP) simulator based on "U Print" and include RP device fundamentals, virtual calibration, virtual manufacturing and virtual testing. This paper also aims at supporting the development of the multidisciplinary educational activities.

Keywords: Additive Manufacturing; uPrint; FDM; Cyber-based Rapid Manufacturing

Background

Advanced manufacturing technologies and their potential application in industries and research in academia is currently under a lot of attention. Several flexible technologies under the umbrella of advanced manufacturing are currently being modeled with computers, microprocessor, and virtual manufacturing environments[1]. Rapid prototyping is once such advanced manufacturing technology that gained popularity over the last decade to have emerged in facilitating in accelerative product creation[2]. According to JTEC/WTEC Panel Report on Rapid prototyping, Rapid Prototyping can be defined as a process which facilitates in quickly fabricating complex-shaped three dimensional parts/products from Computer Aided Design (CAD) models. Additive manufacturing or 3D printing is once such technology facilitating rapid prototyping by using a set of successive layers of materials laid down in a precise manner.

Additive manufacturing also referred to as 3-D printing is currently under limelight based on President Obama's reference to additive manufacturing at the 2013 State of Union Address. As mentioned by Conner *et al.*, in their paper on 3-D printing, *"General electric CEO, Jeff Immelt, views additive manufacturing as a game changer. By 2020, General Electric (GE) aviation plans to produce over 100,000 additive parts for its LEAP and GE9X engines. It also plans a $3.5 Billion investment in additive manufacturing*" [3]. There are many influential and independent variables in additive manufacturing likely to be the basis for future manufacturing automation along with being reliable and efficient. Increasing trends towards collaborative and customizable manufacturing will lead additive manufacturing towards increased flexibility to keep in pace with global markets.

Accessibility of large value investment banks to industries make it easier for them to reach out and be flexible in acquiring and adapting to emerging technological trends. On the flip side, as pointed out by author John A. Bielec in his article on *Emerging Trends in Technology* currently, colleges and universities in United States are *"challenged to contain and even reduce technology costs while at the same time respond to the expectations of the New Millennial Generation"*. Upgrading educational settings to include emerging technological equipment for training and introducing the future workforce to keep pace and well-trained in new trends is neither simple nor inexpensive. The main implication in academia is that not many schools and colleges can afford in making costly and recurring investments for procuring required infrastructure. Though available in few colleges and universities, boundaries of accessibility and time constrains limit the students to get a full hands-on experience in operating real machines and building models.

To address this problem, the authors believe in an unrestricted access of learning and training tutorials for students for them to keep updating their skills on new technologies and increase their technology readiness levels. This paper expands on one such tutorial on 3D printing developed based on uPrint® SE Plus 3D printer (manufactured by Stratasys Inc.) for making it available virtually to everyone interested in learning of how to operate 3D printer with no incurred harm or cost. This tutorial is a result of an upgrade to the virtual Cyber-Based Rapid Manufacturing (CBRM) tutorial developed based on Fused Deposition Modeling (FDM) 3000® machine at Industrial, Manufacturing and Systems Engineering (IMSE) Department, University of Texas at El Paso (UTEP) . Furthermore the software developed to facilitate the tutorial will integrate few training courses that use conceptual questions and practical operational tests to check student understanding of the technology. The later sections of this paper explain on how the previously used FDM 3000® machine is different compared to uPrint® SE Plus 3D printer, a detailed analysis on the how the new virtual simulator is developed, perceived future work and conclusions.

Comparing FDM 3000 and uPrint® SE Plus 3D printers

FDM 3000® is a Legacy fused deposition modeling machine for 3-Dimensional prototyping developed by Stratasys Inc. uPrint® SE Plus 3D printer also developed by Stratasys Inc. is the main focus of the simulator developed. Compared to the previously used machine – FDM3000®, the latest uPrint® SE Plus works based on the same technology, but, is more powerful based on its new inherent functions and features [4]:

1) The software CatalystEX used by uPrint® to translate computer aided designs for 3D printing is based on an advanced designed that integrates the functions of Insight software and FDM status. The user interface is *WYSIWYG* (What You See Is What You Get) which is deemed more user-friendly.
2) uPrint® SE Plus 3D printer supports network communication, allowing a 3D printer to be shared in a network. A user can control the 3D printer remotely. This compared to traditional manufacturing is quite an improvement.

3) The main user interface of the uPrint® SE Plus 3D printer is its display panel and keypad making it intuitionistic and clear.
4) Compared to the FDM3000®, uPrint® SE Plus 3D printer processes are mostly automated making it more user friendly and less error prone, thereby making it highly redundant and more efficient.

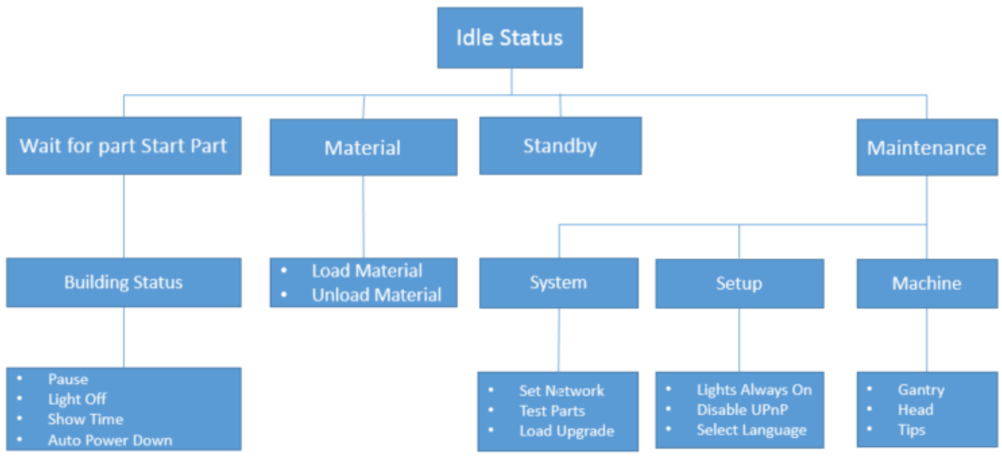

Figure 1: uPrint Display panel hierarchy [4]

5) The calibration process of uPrint® is found to be comparatively easier to that of FMD3000®. For example, in FMD3000® the tip calibration needed a caliper to measure the thickness of a test model manually and then change the metric by the measured value, thereby taking several trials for an optimized result. On the other hand, uPrint®, when in need of calibration runs an embedded program to build a test part. The data displayed on its interface can then be used as a baseline for calibration. The example illustrated in the figure below requires an adjustment by X = +2, Y = -4 units.

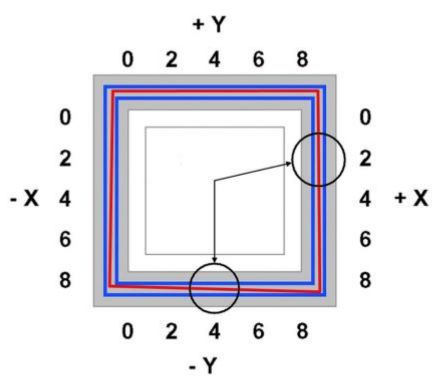

Figure 2: Illustration of XY Tip Offset Part [4]

New Generation Rapid Prototyping Simulator ***(based on uPrint® SE Plus 3D printer)***

Accessibility of the simulator developed based on FDM3000® machine was limited only to Windows personal computers; the students were only able to access the simulator either through their personal computers [5]. To stay viable in this global competitive market, there is a need for the providers to develop learning systems supported by almost all the commercially off the shelf products accessible to students virtually anywhere.

It is of no surprise that there is a rapid increase in demand of mobile device usage when compared to personal computers. According to Forbes contributor Chuck Jones, in their article on "Increasing Mobile Device Usage" worldwide tablet shipments are estimated to grow 70% in 2013 to 197 million units increase by over 300% over a five year time from 2012 to 2107. Also, Mobile phones will show an 80% growth over the same five years [6]. To attract current technologically savvy students, the virtual simulator software developed is based on mobile device accessibility making it swift and convenient. uPrint® simulator developed is accessible 24/7 to students through either a Personal Desktop, a Tablet or a Smartphone. The multi-touch feature embedded in the software will provide a much more user-friendly experience leading to capture student interest and to provide a better quality of education. The network capability feature of the software will constantly check for updates and when available, it will automatically update the software to address any possible errors or bugs present. A possibility of directly connecting to uPrint® 3D printer using virtual simulator is currently being worked on. The virtual simulator application currently runs on Personal computers, Mac-OS and iOS based platforms. In the later stages, it can be installed on smartphones and tablets based on Windows platforms. The simulator can also be translated into various Android-based devices with the help of Mono; Xamarin open source implementation software's making the application to be much easily accessible to students. Table 1 below illustrates the few differences between the developed FDM 3000® and uPrint® simulators.

Table 1: Comparison between FDM3000 Simulator and uPrint Simulator

	FDM3000® Simulator	*uPrint® Simulator*
Support Platform	Windows7	Windows8,Windows phone, Android, IOS
Device	Desktop, Laptop	Mobile Devices(smartphones, tablets)
Interaction	Mouse, Keyboard	Multi-Touch screen
Portable	Weak	Strong
Flexible	Weak	Strong
RP machine network connectivity	Not Available	Supports internet connection

3D Virtual Simulator Development

3D Model of uPrint® 3D printer

To develop the simulator software, two major steps were involved. The first and the most important were extracting a 3D model of the uPrint® 3D printer and then transfer the model file into a format compatible by a programming language. The second step was to develop embedded code that would be able to grad the 3D model and translate the required operations of the uPrint® 3D printer. The authors used SolidWorks®, a computer aided modelling tool that uses a parametric feature based approach enabling a user to create and design 3 Dimensional models, parts, assemblies and drawings; software to build uPrint® 3D model. Illustrated in figure 3 is the 3D model developed.

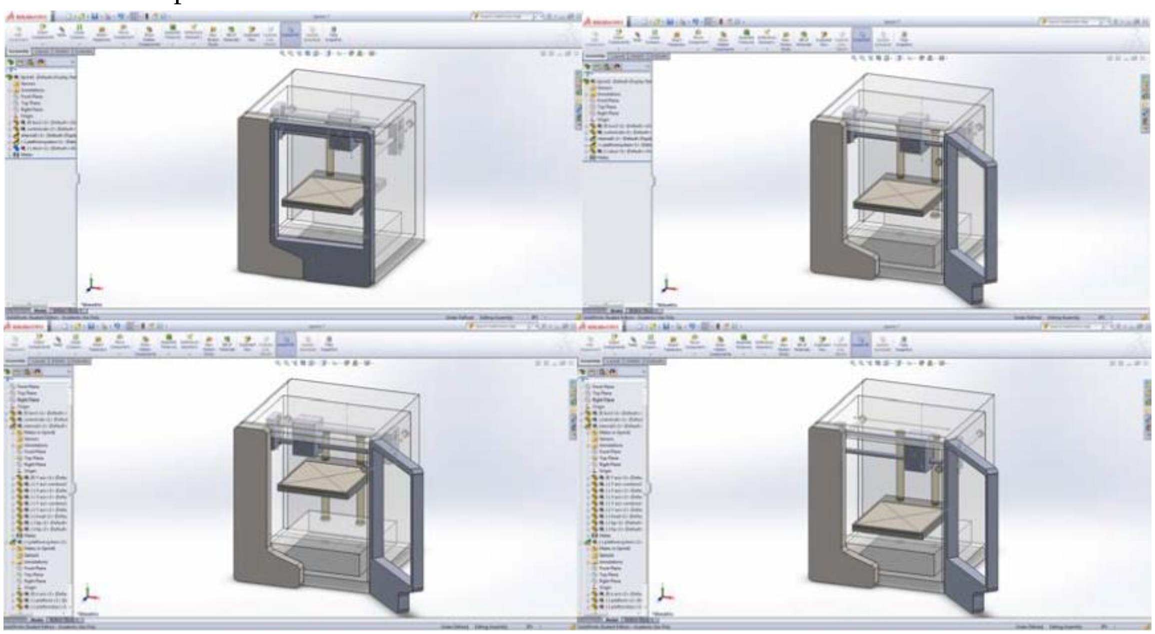

Figure3: uPrint® model designed in SolidWorks®

After the model was generated using SolidWorks®, it was saved to a standard 3D model format *"vrml97"* and converted to an *".X"* file that could be identified and used in a programming language *("C-Sharp")*.

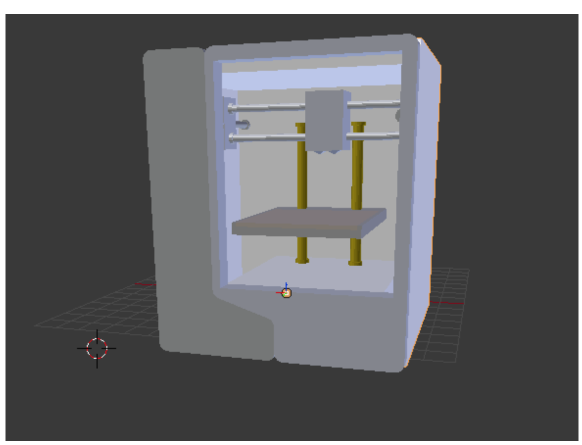

Figure 5: '.X' model file after converting from vrml97

uPrint® simulator using Visual Studio

uPrint® SE Plus 3-D printer manufactured by Stratasys technologies is highly integrated user friendly. Most of all the pre-preparation tasks of the printer are coded modules that are automatically executed. A simple interface is used by uPrint®, where in which, by a simple press of a button located on the interface panel helps the user to setup the machine to be ready to print. The software developed mimics this mechanism of the printer. This implies that, by using the touch interface, user can setup the machine to be ready for print along with seeing the software animation of how the uPrint® printer reacts. The main modules of the printer (Head, Tip and Plate) that facilitate in printing 3D models move portraying the 3D printing process. The software Application is designed to simulate or clone each and every function of the control panel associated to uPrint® SE Plus 3-D printer.

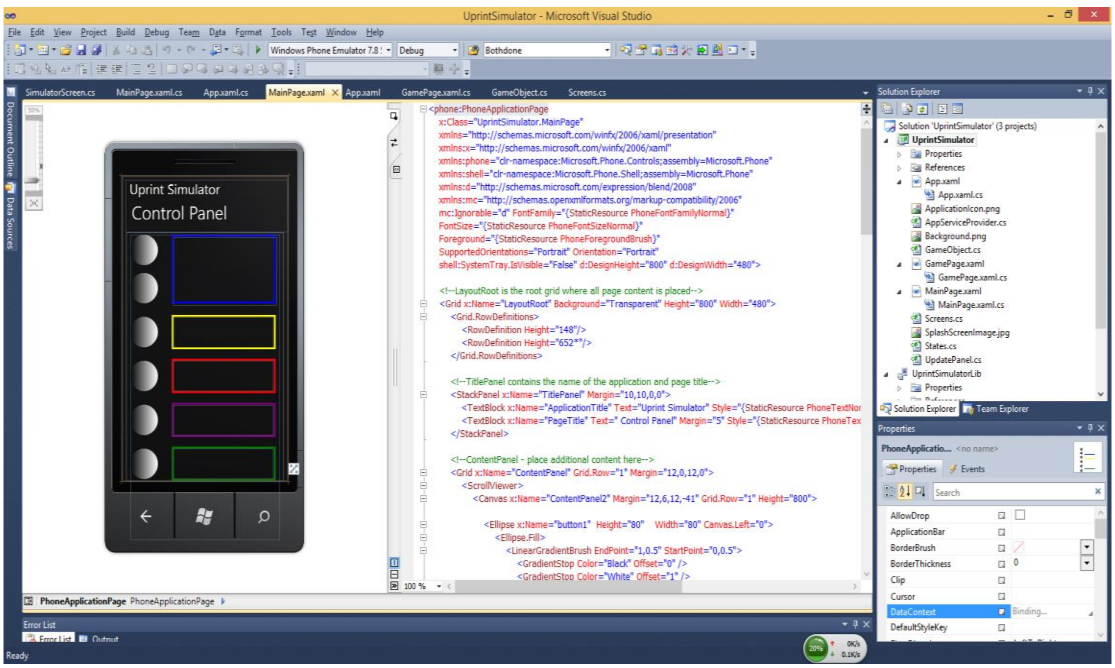

Figure 6: Design and Program with Visual studio to develop Windows platform based Phone Application

The limitation of screen size in smartphones sometimes tends to make the application a-synchronous. This meaning that, when a user while using the virtual simulator selects a specific option in the control panel, the screen changes to replicate the action requested. To improve this experience, and to take advantage of screen size of tablets, the graphical user interface (GUI) developed is more realistic in tablets by showing the changes concurrently on same screen.
The simulator currently developed and ready to be deployed mainly:

- Replicates the basic functions of uPrint® 3D printer enabling the students to learn on how to operate the machine and also to be familiar to its response.

- Simulates testing environment of uPrint® 3D printer, to test and review students familiarity on how to operate the machine correctly before a real hand-on session.

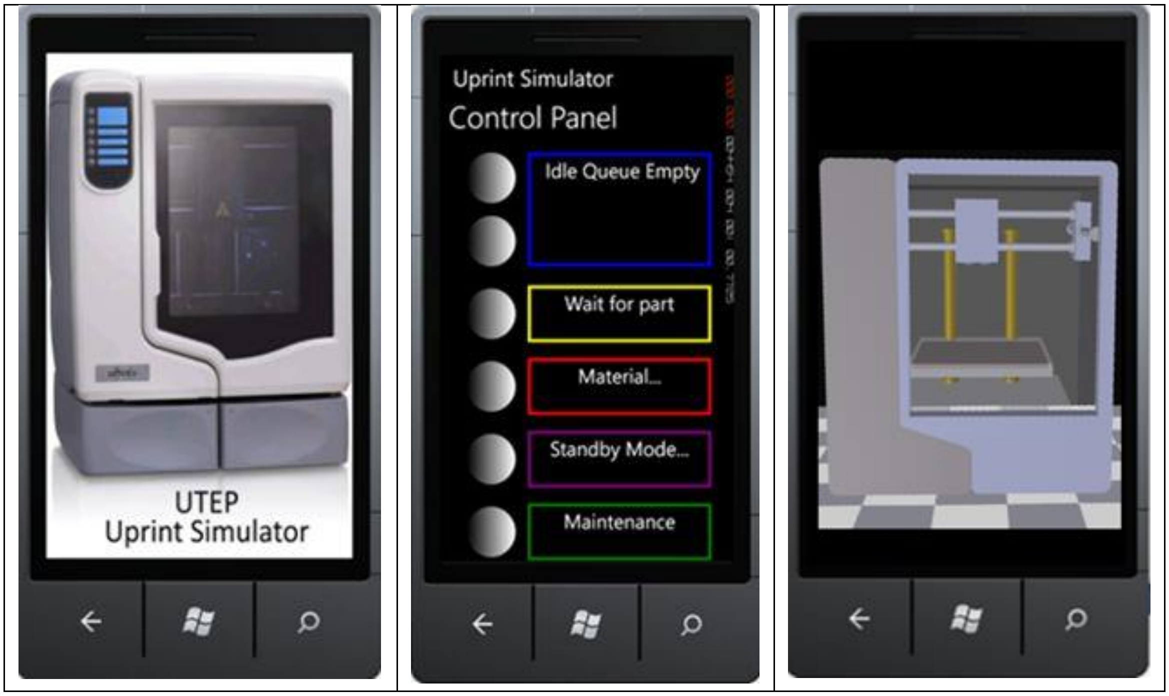

Figure 7: Screenshot of emulator for uPrint® simulator on Windows Phone

Figure 8: Layout of Windows Tablet simulator

Future work

Tutorial Implementation

To provide a better virtual student experience more functions will be integrated in the later versions. The main goal is to realize 3D Virtual Facility Tutorial for enhancing additive manufacturing educational experience in students. The conceptual framework for successful implementation of 3D-Virtual Facility Tutorial **is** illustrated in Figure 9. It consists of three main steps: (a) uPrint® simulator, (b) Application server and (c) Network setup.

a. *uPrint® Simulator*

   The uPrint simulator is the main part of this project. As mentioned previously, the software will be installed on a set of students' devices (including Personal Computers, Laptops, Smartphones and Tablets). The users can access and test the basic functions of the virtual tutoring environment based on the real time functions of uPrint® SE Plus 3D printer.

b. *Application Server*

   The application server contains student information such as their score, operation level and uploaded CAD files. Students will also be given access to a database of course materials and tutorial modules for organizing all the materials and information which can also be accessed and maintained by the teacher/administrator.

c. *Network Setup*

   The uPrint® simulator also connects with the real machine through API. In the future, users may import their own .STL file into the Rapid Prototyping Support Systems (RPSS) and simulate the whole procedure of 3D printing.

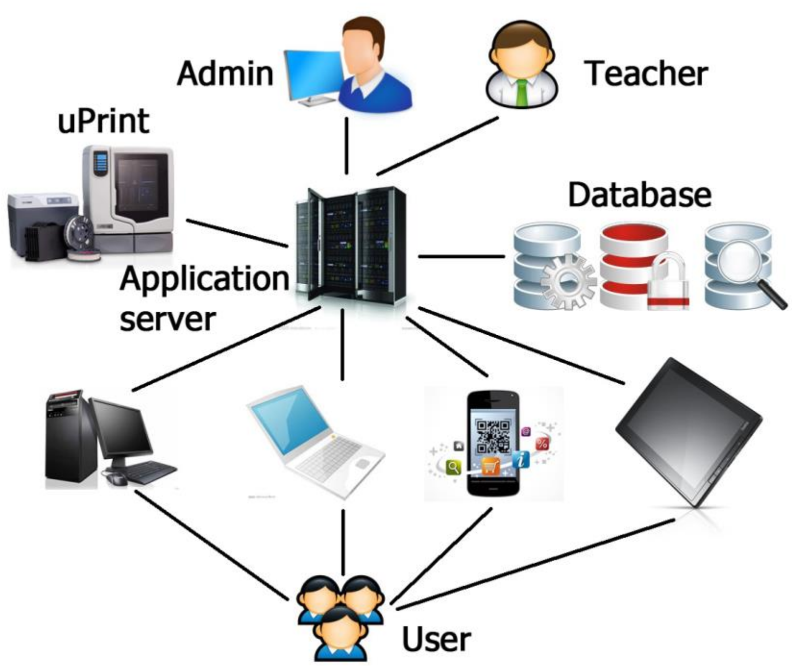

Figure 9: The conceptual framework of the uPrint® Virtual Facility Tutorial

Data Gathering and Analysis

The main aim of developing a technology savvy virtual rapid prototyping simulator based on uPrint® 3D printer is to enhance student learning at Industrial, Manufacturing and Systems Engineering (IMSE) Department, University of Texas at El Paso (UTEP) by integrating the software to the courses related to Additive Manufacturing, Advance Manufacturing, Rapid Prototyping and Green Manufacturing. On contrary to traditional teaching methods, it allows students to virtually get access to and interact with real time based simulators which proved successful in training students. The key aspect of providing such simulators to students would be to (a) Allow 24/7 access virtually from anywhere in the globe (b) Keep students updated with practical experience of frequently used techniques in industries (c) Provide Affordable access. A student centered continual improvement strategy will be put in place to improve student experience along with tackling software accessibility and operational issues if any. Figure 10 illustrates this methodology incorporating the developed software in student training courses along with capturing and reflecting student feedback.

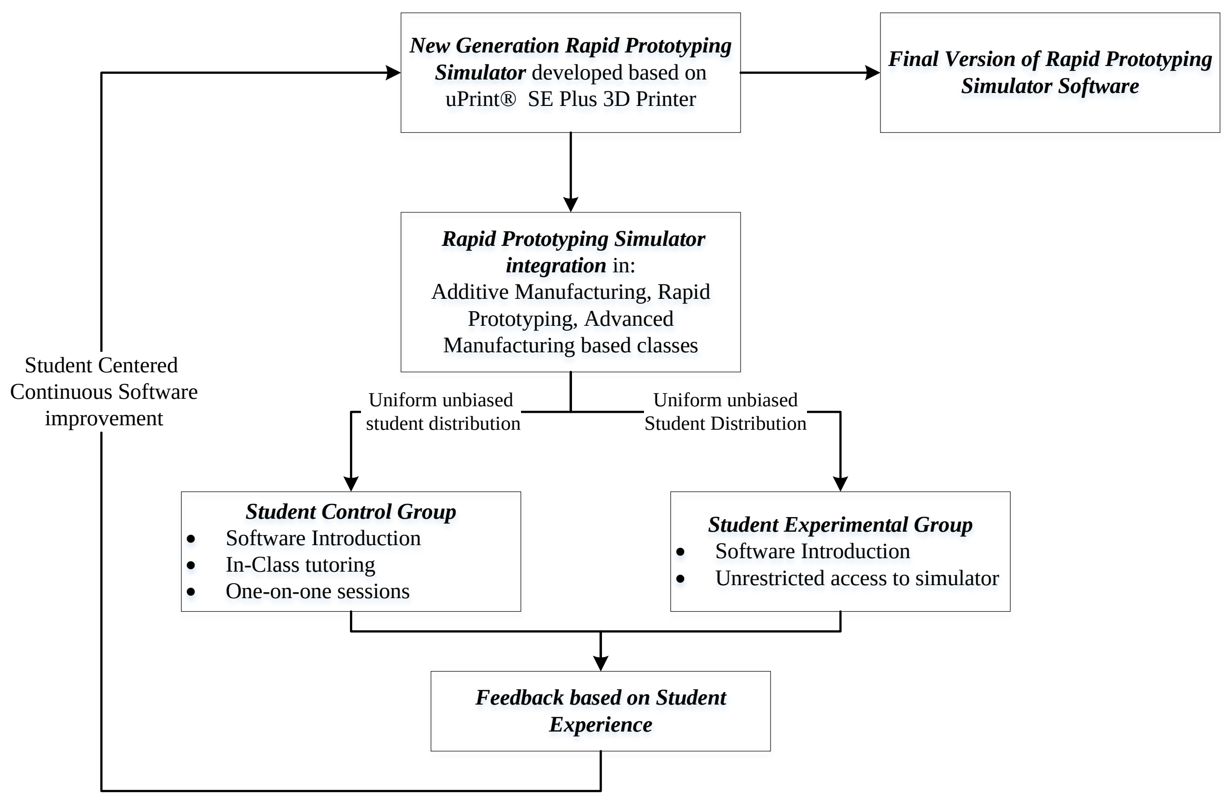

Figure 10: Software Improvement Methodology based on Continual Student Feedback

Conclusions

This paper provides a comprehensive overview of new generation rapid prototyping simulation software developed at Industrial, Manufacturing and Systems Engineering (IMSE) Department, University of Texas at El Paso (UTEP) to increase student technology readiness level in Additive

Manufacturing technologies. This software developed incorporates real time functioning of an uPrint® SE plus 3D printer, contrary to the previously developed software based on FDM 3000® machine. A frame work proposed for effective implementation of similar Cyber-based tutoring software's is also illustrated in this paper. Though developing simulation software's to enhance additive manufacturing technology education will prove effective in student learning, the lack of experience among students in using such cyber based tutoring facilities will result in one on one student centered training until they get familiar with.

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