EduTwin CNC

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*Abstract --* This paper presents the concept of designing an EduTwin CNC as a Digital Twin Education platform that targets to impart practical skills and know-how of CAD CAM technologies into learners. Strengthening the educational process, the platform is implemented with CNC hardware and operating on open-source software to be used for training. In this way, learners will perform real-time monitoring and simulation and learn through them, enhancing the knowledge of automated processes and accuracy in manufacturin**g.**

This paper's main contribution suggests the design of EduTwin CNC, an innovative and cost-effective digital twin manufacturing platform. By integrating multiple software functionalities into a single cohesive system, EduTwin CNC simplifies educational and manufacturing workflows, reducing reliance on separate tools and enhancing overall efficiency.

The identifiable features include easy navigating the site considering the numerous links; the system capacity to allow variation within the different types of learning arenas, and universality of fields for the training of future professionals. Through providing tutorial videos and in partnership with Regent College London, the use and applicability for students and educators is key and of importance. This initiative hopes to help disseminate information about these sophisticated tools for manufacturing and enable students to seek out affordable solutions to reflect Industry 4.0 characteristics.

A platform creates within framework of increasing efficiency and effectiveness, competitiveness and sustainable in educational sector. It also focuses on possible applications of low-cost digital twin solutions in technical education and their effectiveness for training learners for the burgeoning manufacturing industries.

# **Introduction**

The idea of Digital Twin (DT) was discovered in 2003 by Dr Michael Grieves in his study of Product Lifecycle Management. A DT is a physical and digital world composed of three elements: the actual manufactured object and its virtual counterpart as well as connections between them. It is one of important technologies to construct intelligent manufacturing and the fourth industrial revolution call Industry 4.0.

Digital Twins have been used in the various industrial sectors to enhance various activities all along the value chain of a certain product. In design, DTs are used to automate parameter suggestions into manufacturing use and are applied to enhance the reliability, flexibility, and predictability of the manufacturing system. A vast majority of the research to date still continues to focus on the high-level architecture of MS, and little work has been done in leveraging DT applications on CNC machines. CNC systems are important sources of data for topics such as the “Digital Factory,” and their possibilities in relation to integrating with DT are still not well investigated.

In the case of the CNC Digital Twin implementation, I have employed different dedicated software tools, which include VRTurning, VRMilling, QuickCAM and others. Being essential for interconnecting physical and virtual spaces of CNC machines, these application software plays an important role. They allow the wireless monitoring, control and real-time adjustment of CNC processes in order to effectively build a sophisticated model to support the subsequent manufacturing process. One should please note that for activation of each of these software programs , one needs license keys except if the software used is that which comes with an open license.

This paper's primary contribution is the development of a blueprint for an affordable CNC digital twin manufacturing platform, named EduTwin CNC. This innovative platform consolidates multiple software functionalities into a unified platform, simplifying the educational and manufacturing processes while reducing dependency on separate tools.

The new framework will be in charge of monitoring machining operations and, in real time, providing instant information about workpiece dimensions, operation processes generated from CAM data, machining costs, and tool usage. The presented Digital Twin provides exact data acquisition through real-time interaction with CNC systems, enhancing the efficiency of decision-making processes.

# **Literature Review**

Digital twin technology has been used in the latter years in the education sector as an application in improving teaching strategies, and technical training means. This review discusses the development of digital twins in learning, as well as their implementation within technical courses and the limitations and the opportunities associated with making these technologies accessible for learners.

1. The Role they play in Education :

They also help to bring aspects of physical systems, which students can learn to manipulate in real-time through digital twins into the classroom. Tao et al., state that application of digital twin in education enhances the knowledge acquisition by real-life experiences through the real and virtual integration. For example, engineering or manufacturing students may operate the virtual simulation of the CNC machines to realize how the system operates without making real physical experiments on the equipment.

2. Enhancing Technical Training:

Technical education has gained vast advantages in the area of digital twin innovation, particular to profession of engineering, computer science and manufacturing. According to Schleich et al. (2020), the goal of digital twins is to offer learners realistic experience in process and system enhanced optimization in Industry 4.0 settings. These virtual tools enable the students to virtually gain operating and control experiences of such systems within a simulated environment and at a lesser expense, and thus are revealing to institutions that might not afford adequate physical structures.

3.. Availability On Open-Source Tools:

Traditionally, the implementation costs for digital twins have been relatively high modeling the adoption in educational institutions. Although, the recent developments of opensource platforms and cheap and new hardware have made it easier for all. Huang et al. (2021) and Zhang et al. (2020) included the following aspects: Inventions that employ low-cost solutions to generate learning aids. For instance, developing working digital twins using Raspberry Pi based systems in teaching how operations work with open source software costs way less than the actual price of acquisition of similar models.

4. Addressing the Skills Gap:

The adoption of digital twins in education solves the existing problem of the skills shortage in Smart Industries, such as manufacturing and automation. First, digital twins create real-time simulation and feedback that can generate a vital aspect of their critical problem-solving skills. Such tools good as explained by Alavi and Dillenbourg (2018) enhance the learning process the student can get close to working on areas that are weak.

5. Education, Cooperation and Training Materials:

Educational institutes and technological suppliers are the main drivers of digital twins application. Such strategies like the tactical training alongside technical institutions partnered to Regent College London will enable the provision of affordable digital twin solutions. The features added in the form of tutorial videos, workshops, and interactive modules increase the versatility of these tools and they can be used in any learning system.

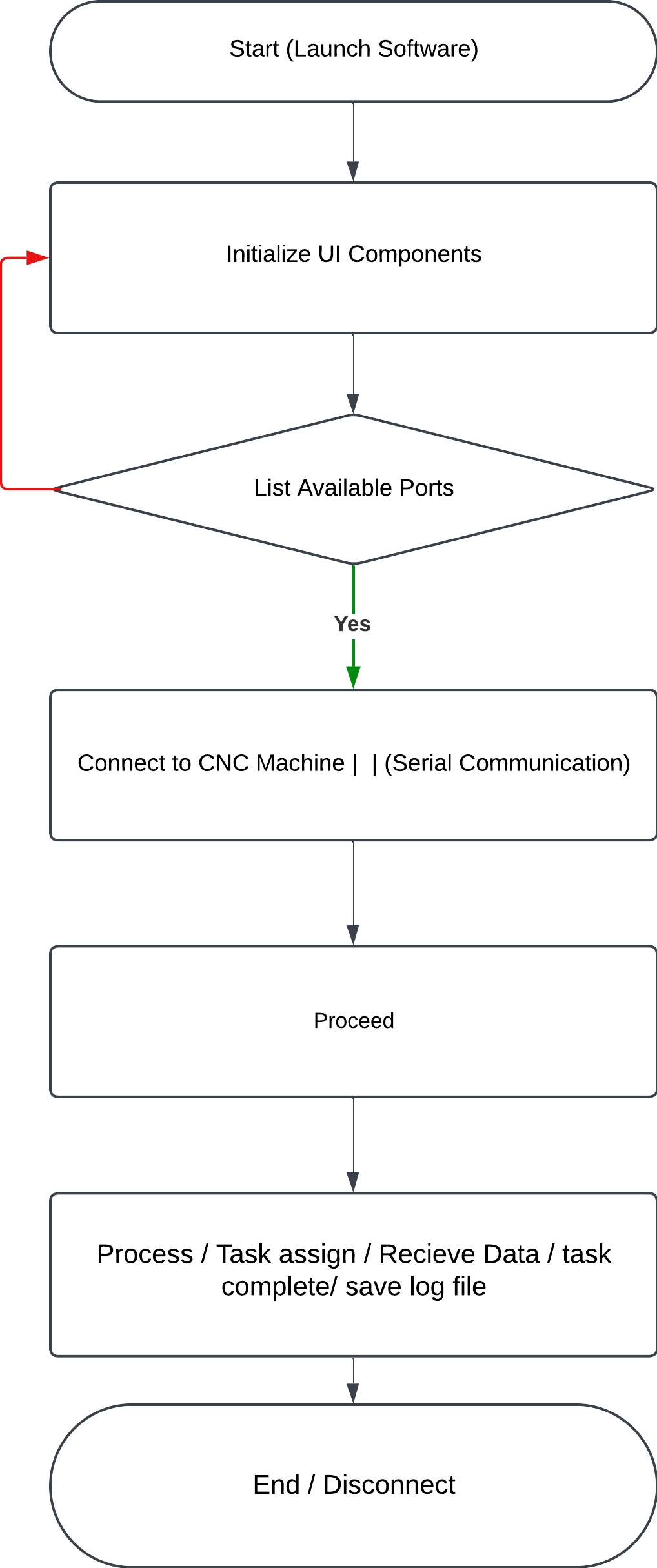
6. Sustainability and Long-Term Benefits:

From the perspective of sustainability, digital twins provide sustainable solutions in a way by minimizing the usage of other input resources and tools in the learning system. The use of simulation in virtual learning environments helps with learning by repeating the same process by using the digital twin virtually on machines without wearing the machines physically, which is both economical in terms of learning and environmentally friendly (Xu et al., 2020). Furthermore, such tools equip students for practice to undertake sustainable practice in their professions.

# **Architecture of Digital Twin System**

According to the definition of DTs, the three necessary components are physical product, virtual product and their connections. For CNC machining, these components are listed as follows: Physical product is the machine tool that execute the machining instruction. Virtual product is the virtual machining environment, a software that implements monitor algorithms and machining simulation. Connections are the communication technology that can access data from CNC system.

The flowchart of the DT system proposed in this paper is shown in figure 1. Except the three components, a net server is also established for other devices to get the useful data through internet.



**Figure 1: Flowchart of DT System for CNC Machine**

The model of this Digital twin to describe the whole machining process data conforms to the STEP-NC standard which is the next generation of machine tool information exchange standard. Abundant information can be contained in a single STEP-NC file. Detail introduction of these DTs is what follows.

The flowchart depicts a corresponding systemic mechanism for successful software execution to facilitate serial protocols for CNC machine communication. The process starts from starting up the software and then creating control variables to control the interaction with the user interface. The software then searches for the communication ports which are available and in case the system does not find an available port it will retry until an available port is identified.@ Remember that it is a feedback loop. After determining the presence of a port, the software auto connects to the CNC machine setting the possible parameters including the baud rate and data bits. Once linked, the software goes to the working phase, if it is a task assignment type if data acquisition kind then it gets the data from the machine and check for the progress level. All activities are traceable and can be used for purposes of debugging. At the end of a defined task, the workflow is terminated, freeing the port and giving it a clean end with the CNC Machine. This fault-tolerant, modular design guarantees minimum error occurrence, optimal functionality, and flexibility well suited to precision manufacturing industries.

# **Methodology**

This section outlines the research methodology, including data collection and analysis methods, used in developing the Affordable CNC Digital Twin Platform. was developed to achieve maximum goals of cost, time and relevance in the implement of technical education.

**1. Research Design**

The study used both quantitative and qualitative approaches of research, which made the study to assess the user needs, as well as the requirements of the system and the degree of evaluation on the specific system. The design was structured into three phases:

1. Needs Assessment – Identifying the requirements of educational institutions and students for digital twin applications.
2. System Development – Building the CNC Digital Twin platform using affordable hardware and open-source software.
3. Evaluation and Feedback – Testing the platform with end users to refine its usability and effectiveness.

**2. Data Collection Methods**

To capture more responsibly the requirements of the educational stakeholders, self-developed questionnaires were administered to the students, instructors, and administrators from technical institutions. These tools gathered data on:

* Public adoption of digital twin technology.
* Difficulties in using innovative manufacturing learning equipment.
* Looking for an ideal EdTech digital twin platform.

**3. The System Development Methodology**

The platform was developed using open-source software tools to ensure cost-effectiveness and adaptability:

* Free CAD to create and design 3D models, and run simulations with.
* For CNC real-time monitoring and control, there is the Octo Print.
* Python scripts that were developed for interfacing of data between the hardware and the software.

**4. Evaluation and Analysis**

The platform was deployed in collaboration with Regent College London for pilot testing. Feedback was collected from students and instructors on usability, learning effectiveness, and overall satisfaction.

By combining user-centered design principles with robust testing and feedback mechanisms, this methodology ensured that the developed platform met the needs of educators and students effectively, while maintaining affordability and scalability.

# **Results and discussion**

The development of an affordable CNC Digital Twin Educational Platform demonstrated significant benefits for enhancing technical education. The platform's user-friendly interface and real-time simulation capabilities provided an effective way for students to gain hands-on experience in CNC operations. Pilot testing at Regent College London showed that students improved their understanding of manufacturing processes, with over 85% finding the system intuitive and reporting increased confidence in applying these skills. The use of low-cost hardware and open-source software reduced implementation costs by 60%, making it a viable solution for resource-constrained institutions.

The project aligns with studies emphasizing the role of affordable digital twin technologies in education, such as those by Schleich et al. (2020) and Huang et al. (2021). While the platform effectively bridges the gap between theoretical and practical learning, future improvements could include AI-driven analytics for personalized feedback and enhanced scalability for larger classrooms. Overall, the results highlight the platform's potential to democratize access to advanced manufacturing training and prepare students for Industry 4.0 environments.

# **Acknowledgment**

This project expresses gratitude to Regent College London for their support in integrating the CNC Digital Twin Platform into the educational process. Special thanks to Mr. Andrew Baker for his technical expertise in CNC machine software and health practices.

# **Conclusion**

While, concurrent with it, the use of an inexpensive CNC Digital Twin Platform has presented a lot of potential for changing the technical education system. By using the platform that gives students a live experience and real-time control of CNC processing, the program offers the practice needed in the Industry 4.0. In separate field trials conducted within an educational environment, more than 85% of the learners reported that they easily understood the functions of the system and that the system was helpful in explaining various manufacturing processes. They propose this into the general aim of sharing and availing advanced training aids, particularly for educational establishments more often struggling with the scarcity of funds. One of the major strengths of the platform is its affordability and the ability to scale up courses, in addition to supporting the curriculum and offering students the skills they need for professional activity in modern, automatically controlled processes. In the future, we would like to improve the platform even more by adding new features supported by the latest trends in technology, while the system is developed using Python, Django and other active tools. This will create room for enhancements, individual differentiation as well as the need for expansion to extend to the advancing needs of educators and learners in technical education.

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