International Journal of Multidisciplinary Research and Literature
IJOMRAL
Vol. 5, No. 3, May 2026 pp. 456-469
Journal Page is available at http://ijomral.esc-id.org/index.php/home

IMPLEMENTATION OF NANJING SWANSOFT-BASED CNC LATHE SIMULATION IN THE MANUFACTURING OF PAPER WEIGHT PRODUCTS

Apriyanto[1], Desmarita Leni[2*], Muchlisinalahuddin[3], Yuni Vadila[4], Asroful Abidin[5]
[1,2,3]Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Sumatera Barat, Indonesia
[4]Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
[5]Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jember, Indonesia
Corresponding Email: *desmaritaleni@gmail.com[2]*

Abstract

The development of manufacturing technology demands mastery of precise, efficient CNC lathes, but limited facilities, operational costs, and the risk of programming errors often hamper practical experience. This study aims to implement CNC lathe simulation based on Nanjing Swansoft CNC Simulator (SSCNC) in the manufacture of paper weight products as a medium for program verification and learning. The research methods include product design, calculation of machining parameters, CNC program preparation using G-Code and M-Code based on a FANUC 0i-T control, and testing across two machining stages. The workpiece has an initial diameter of 50 mm and a length of 54 mm, with a chuck exit length of 40 mm at each stage. The cutting parameters used are a spindle speed of 1000 rpm and a feed rate of 0.5 mm/rev with an absolute programming system (G90). The tool configuration consists of a VNMG 350 carbide turning tool, an Ø18 mm drill, and a 2 mm internal grooving tool. The simulation results show that the two-stage program can be run without syntax errors, interpolation alarms, or tool path conflicts. The G02/G03 circular interpolation successfully generated a continuous radius, and all geometric features were formed in accordance with the working drawings. The SSCNC simulation proved effective as a safe technical verification and learning medium before practising on a real CNC machine.

Keywords: CNC lathe, CNC simulation, Nanjing Swansoft, manufacturing, paper weight

INTRODUCTION

Developments in manufacturing technology are driving the implementation of production systems that demand high levels of precision, efficiency and automation.(Hu et al., 2024)Computer Numerical Control (CNC) technology is one of the main solutions in answering these needs, especially in machining processes that require dimensional accuracy and consistent product quality.(Pandu Andariansyah et al., 2025)CNC turning machines are widely used in the manufacturing industry due to their ability to produce cylindrical components with high precision and relatively short processing times. It makes mastery of CNC turning a crucial competency for Mechanical Engineering students.(Prasetya et al., 2023).

Learning CNC lathes in college not only emphasises theoretical understanding but also demands practical skills in programming and operating the machine. (Abougarair & Tabet, 2023). The practical learning process carried out directly on a real CNC machine often faces several limitations, including limited machine availability, high operational costs, and the risk of machine damage from programming errors.(Agrisa, 2020)This situation can affect learning effectiveness, especially in the early stages of students' mastery of CNC programming.

The use of CNC simulation software is a relevant learning alternative in supporting the CNC

https://doi.org/10.53067/ijomral.v5i3.437

lathe learning process. (Fatriyana, 2020)Simulation media allows students to learn programming and machining processes virtually with a high level of security. One widely used simulation software for CNC learning is the Nanjing Swansoft CNC Simulator (SSCNC).(Hermana et al., 2022)This software can visually and interactively display CNC lathe machining process simulations, including tool paths, machine axis movements, and final machining results.(Ntemi et al., 2022).

Learning CNC lathe simulation requires work objects that clearly and systematically represent basic machining operations. (Rahmatullah et al., 2021). Paperweight products were chosen as the object of study because they have simple geometry and involve several basic CNC lathe operations, such as facing, turning, and drilling. ("Network-Controlled CNC Machine Tools," 2024)The use of this object provides a comprehensive overview of the design stages, CNC program preparation, and the implementation of machining simulation, thereby supporting students' understanding of the CNC lathe machining process flow. (Tayier, 2024).

Previous studies have generally focused on the general application of CNC programming and simulation, but have not specifically discussed the validation of G02/G03 radius interpolation in the two-stage workpiece turning process or quantitatively evaluated the suitability of the program path to the actual design. In addition, previous studies emphasise the operational aspects of software use without analysing the verification of path results against the geometric accuracy of the designed product. Therefore, this study provides a specific contribution by providing technical validation of G02/G03 radius interpolation in a two-time workpiece turning scenario, accompanied by a comparative evaluation of the CNC program path, SSCNC simulation results, and product design based on measured geometric parameters. Thus, this study not only demonstrates the practice of software use but also presents an analytical and verification approach that strengthens the accuracy, consistency, and quality of CNC lathe programming learning.

This research focuses on the working principles of CNC lathes and the stages of creating and simulating CNC programs using the Nanjing Swansoft CNC Simulator during the production of paperweight products.(Soori et al., 2024). The results of this research are expected to contribute to the development of effective, safe, and applicable simulation-based CNC lathe learning for undergraduate Mechanical Engineering students.(Hendra et al., 2023).

METHOD

This research is a simulation-based design verification study that aims to develop and validate a CNC lathe program in a virtual environment before implementation on a real CNC machine. This approach focuses on testing the code structure, coordinate consistency, and tool path continuity digitally without conducting physical comparisons in the field. The research methods include designing a paperweight product, calculating machining parameters (spindle speed, feed rate, depth of cut, and machining time estimation), compiling a CNC program using G-Code and M-Code, and verifying the process through simulation using Nanjing Swansoft CNC Simulator (SSCNC) software.(Faisal & Leni, n.d.).

The selection of Nanjing Swansoft as a simulation platform is based on its ability to interactively model industrial control systems such as FANUC 0i-T, including real-time tool-path visualisation, syntax error detection, and simulation of potential tool and workpiece collisions. Compared to simple graphical simulators, SSCNC provides a control environment closer to industrial practice, making it more relevant for the technical verification of CNC lathe programs. The research was conducted at the Computer Laboratory of the Mechanical Engineering Study Program at Muhammadiyah University of West Sumatra from November 2025 to February 2026. The research's systematic stages are shown in Figure 1.

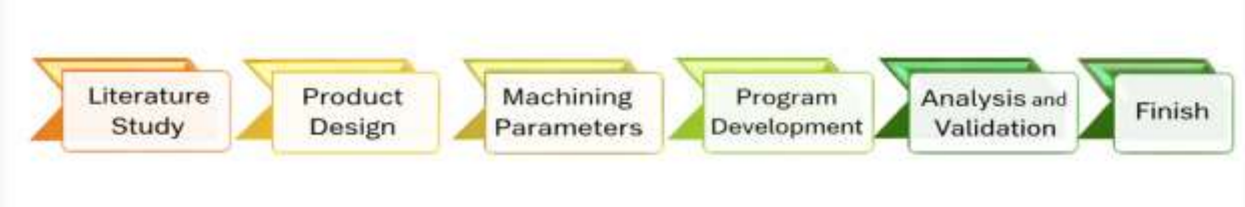


Figure 1. Research flowchart

The following flowchart illustrates the main stages in this research, namely:

1. Problem Identification
   Identifying problems in CNC lathe learning and programming, particularly limitations in direct practice and the risk of programming errors.
2. Literature Study
   Reviewing references related to CNC lathe, G-Code and M-Code programming, CNC simulation, machining parameters, and paper weight product manufacturing.
3. Paper Weight Product Design
   Designing the shape and dimensions of paper weight products in the form of technical drawings as a machining reference.
4. Machining Parameter Calculation
   Determine the machining parameters, namely cutting speed, feed rate, depth of cut, and machining time.
5. CNC Programming
   Compiling CNC lathe programs using G-Code and M-Code based on product design and calculated machining parameters.
6. Simulation Using NSSCNC
   Run the CNC program in the Nanjing Swansoft CNC Simulator (NSSCNC) to display the tool path, machining process, and estimated machining time.
7. Analysis and Validation of Results
   Analyse the suitability of the tool path, product shape, and machining time of the simulation results against the design and theoretical calculation results.

RESULTS AND DISCUSSION.

The CNC lathe machining simulation in this study was conducted using the Nanjing Swansoft CNC Simulator (SSCNC) with the FANUC 0i-T control system, which virtually represents an industrial CNC machine. The simulated product is a paperweight with symmetrical geometric characteristics, which requires high tool-path accuracy and consistent cutting parameters.

1. Workpiece Specifications and Machining Setup

   Workpiece specifications and machine setup in the CNC lathe simulation are in Table 1

Table 1. Workpiece Specifications and Simulation Setup

Parameter	Mark
Initial diameter of the workpiece	50 mm
Initial length of the workpiece	54 mm
Program 1 out of the box length	40 mm
Length out of check Program 2	40 mm
Number of machining stages	2 stages
Process type	CNC Turning (simulation)

Dividing the machining process into two stages helps maintain clamping stability and prevent workpiece deflection during internal and external contouring. This strategy is commonly used in CNC-based precision machining.

2. Tool Configuration and Machining Strategy

   In this study, a tool configuration was designed to handle all geometric features of the paperweight, both external and internal, without compromising cutting stability. This strategy aims to simulate industrial practices that emphasise tool change efficiency and path optimisation.

   a. Chisel Configuration

      Tool selection is based on the workpiece's geometry requirements, including external turning, drilling, and internal turning. The tool combinations used are summarised in Table 2.

Table 2.CNC Chisel Configuration and Function

Tool	Types of Chisels	Technical Specifications	Machining Function
T0101	Carbide turning tools	VNMG 350, 90° angle	External turning & facing
T0202	Drill	Ø18 mm	Initial drilling
T0303	Internal grooving tool	Insert width 2 mm	Inside diameter turning

1) T0101 (Turning Tool Carbide – VNMG 350)

   This tool is used for external turning and facing. The VNMG insert features a 35° angle with a 90° effective chisel angle, enabling sharp corners and precise multi-stage turning. Carbide was chosen for its:

a) high violence,
b) better wear resistance than HSS,
c) thermal stability at medium cutting speeds.

2) T0202 (Drill Ø18 mm)

This tool is used to create an initial hole before the internal diameter enlargement process. An 18 mm diameter was chosen as the initial size to allow for stable internal grooving. Technically, pre-drilling reduces cutting loads on the internal tool and minimises vibration risk.

3) T0303 (Internal Grooving Tool)

This tool is used to turn inside diameters and form internal contours. The 2 mm insert width provides precise control over the cut depth and width. The use of this internal-specific tool is essential to maintain radial stability and avoid excessive deflection during internal turning.

b. Machining Parameters

In addition to the tool configuration, cutting parameters play a crucial role in determining simulation stability and result quality. The parameters used are summarised in Table 3.

Table 3. CNC Lathe Cutting Parameters

Parameter	**Mark**
Spindle speed	1000 rpm
Feed rate	0.5 mm/rev
Programming methods	Absolute (G90)
Coordinate system	Engine reference (N92)
Machining axis	X and Z

1) Spindle Speed (1000 rpm)

This value was chosen to balance rotational stability and surface quality. At an initial diameter of 50 mm, this speed remains within the safe range for carbide tools.

2) Feed Rate (0.5 mm/rev)

The feed rate determines the rate at which the tool feeds into the workpiece. A value of 0.5 mm/rev provides a compromise between machining time and surface quality. A feed rate that is too high can increase surface roughness, while one that is too low can increase processing time without significantly improving quality.

3) Absolute Programming Method (G90)

The use of an absolute system ensures that each tool position is referenced to a fixed zero point. It improves coordinate accuracy and reduces the risk of accumulating numerical errors common with incremental systems.

4) Engine Reference (N92)

https://doi.org/10.53067/ijomral.v5i3.437

Setting reference points ensures a consistent coordinate system throughout the machining process. It is essential to ensure continuity of tool paths between Program 1 and Program 2.

c. X and Z axes

Since the simulated machine is a 2-axis CNC turning machine, all cutting movements are limited to the X (radial) and Z (axial) axes. This limitation corresponds to the TU-2A CNC lathe's characteristics.

Based on the applied two-stage machining strategy, the paper weight geometry formation process begins with the execution of Program 1 as the basic formation stage. This stage aims to form the main contour on the first side of the workpiece, prepare internal features that will be refined in the next stage, and maintain clamping stability, dimensional accuracy, and tool path continuity. Program 1 is preceded by the preparation of a working drawing, as shown in Figure 2, which includes geometric specifications such as stepped diameters, segment lengths, transition radii, and internal hole details. The working drawing becomes the basis for determining the numerical coordinates on the X and Z axes in the absolute programming system (G90). Accuracy in transforming dimensions from the working drawing to G-code format is a crucial factor in ensuring path precision and machining quality before the cutting stage is executed, in accordance with the designed strategy.

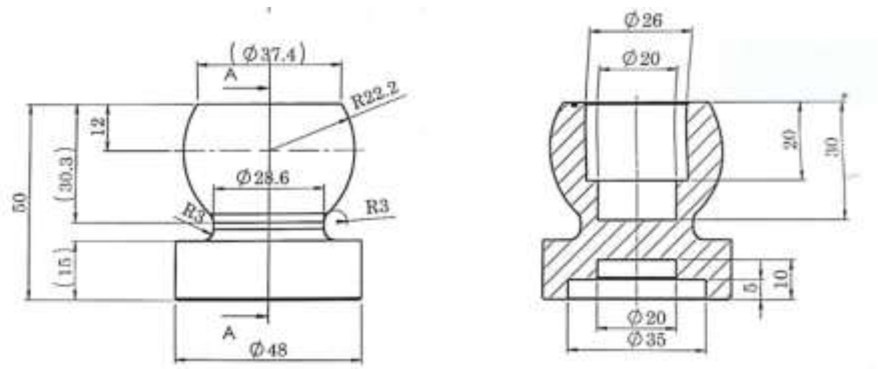


Figure 2. Paper Weight Working Drawing

The working drawing in Figure 2 serves as the primary geometric reference for developing the CNC program. All X- and Z-axis coordinates in the program are derived from the dimensions contained in this engineering drawing. In the context of absolute programming (G90), each cutting point is referenced to a fixed zero point, so dimensional accuracy depends heavily on the interpretation of the working drawing. Therefore, accuracy in translating dimensions into numerical coordinates is a key factor in the success of the simulation.

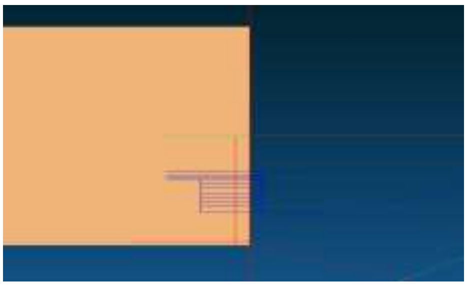


Figure 3. Tool-path Simulation Program 1 on SSCNC

Figure 3: Tool path on the X and Z axes during the facing and multi-stage turning process using the T0101 tool.

The tool path in Program 1 shows a systematic machining sequence, starting from:

1. Facing (Initial Surface Levelling)
   This process aims to ensure the end surface of the workpiece is flat and perpendicular to the axis of rotation. Facing is an important initial step to ensure the length reference (Z0) is accurate and consistent.
2. Step Turning
   The T0101 tool performs a gradual diameter reduction in accordance with the design profile. X-axis movement controls the diameter, while Z-axis movement controls the length of each segment. The path pattern demonstrates a gradual approach that avoids extreme cuts in a single step, thus improving process stability.
3. Initial Drilling
   After forming the outer contour, a T0202 tool is used to create a preliminary hole. This process serves as a preparatory step before turning the inner diameter and reduces radial loads on the internal tool.

From the trajectory analysis perspective, no discontinuities or potential interference between movements were found. It indicates that the program structure was designed with safety and continuity of tool paths in mind.

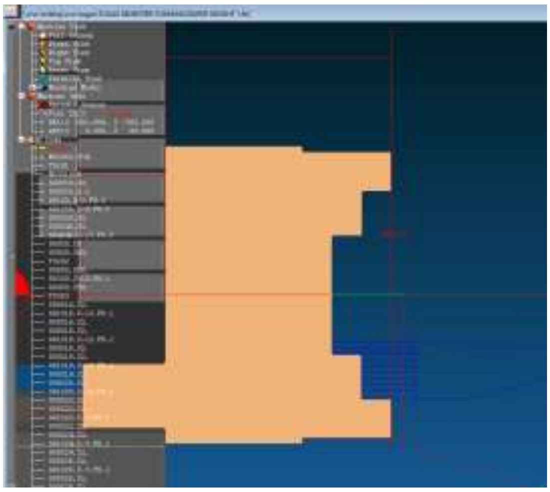


Figure 4. Simulation Results of Program 1

The initial shape of the paper weight, Figure 4, after machining the first side, with the length of the workpiece coming out of the chuck of 40 mm. The results of the Program 1 simulation indicate that the basic contour has been formed as planned. The graduated diameter appears symmetrical, with smooth transitions between segments, and the initial hole has been cut to the specified cutting depth in the program.

https://doi.org/10.53067/ijomral.v5i3.437

After all operations on the first side are completed, the machining process continues to Program 2 through the workpiece turnaround stage, with the coordinate reference system adjusted. At this stage, the length of the workpiece exiting the chuck is maintained at 40 mm to keep the length-to-diameter ratio within stable limits, thereby minimising the potential for deflection and non-concentricity.

Program 2 focuses on refining the final geometry of the paper weight as an integrated continuation of the basic structure established in Program 1. The operations performed include shaping the back contour, creating a transition radius using G02/G03 circular interpolation, chamfering, and refining the external and internal dimensions to meet design specifications. Unlike Program 1, which focuses on shaping the basic geometry, Program 2 is more complex because it involves circular interpolation and precise control over the geometric transition. This stage demands stricter coordinate accuracy and path consistency, especially in ensuring profile continuity between sides after the workpiece turning process.

Program 2 serves as a finalisation stage that ensures geometric consistency, symmetry, and the overall accuracy of the product, as specified in the planned working drawings.

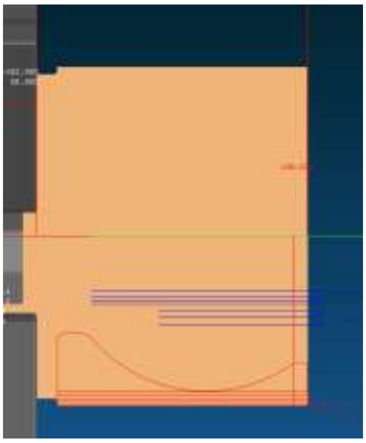


Figure 5. Workpiece Turning Process in SSCNC

Workpiece repositioning, Figure 5, before second-stage machining. The workpiece repositioning process is a critical step in the two-stage machining strategy. Technically, this stage has several important implications:

1. Coordinate System Reorientation

   After the reversal, the Z-axis reference changes direction relative to the work surface. Therefore, consistent use of the absolute system (G90) is crucial to avoid positioning errors.

2. Reclamping Stability

   Reclamping must maintain the workpiece's concentricity to the spindle axis. In SSCNC simulations, this condition is ideally represented, but in real-world practice, it can affect runout and dimensional accuracy.

3. Geometric Continuity Between Stages

The resulting surface of Program 1 becomes the machining reference in Program 2. It requires coordinate continuity to prevent dimensional mismatch at the meeting of the two sides.

Turning of workpieces is not simply a mechanical procedure, but rather part of an accuracy control strategy.

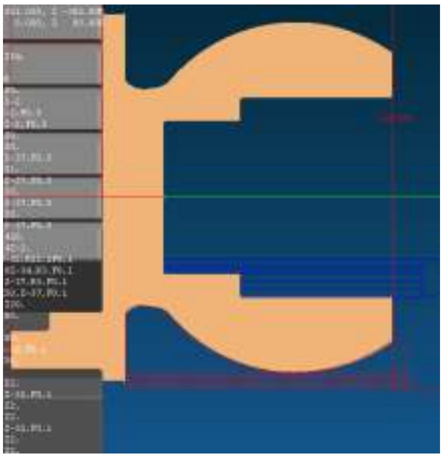


Figure 6. Sculpting Track Program 2

The tool-path of Figure 6 uses circular interpolation G02 and G03. The tool-path in Program 2 demonstrates the use of circular interpolation commands G02 (clockwise) and G03 (counterclockwise) to form the transition radius. Theoretically, circular interpolation allows simultaneous movement of the X and Z axes in one continuous pass, resulting in curved profiles with high numerical precision.

Some technical aspects that can be analysed from this track:

1. Continuity of Curve

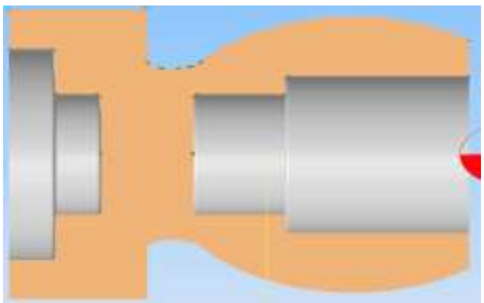
   No discontinuities or sharp corners are visible at the intersection of the line segment and the circular arc. It indicates that the radius parameter (R) has been determined correctly and is consistent with the trajectory's start and end coordinates.

2. Interpolation Stability

   Execution of G02 and G03 proceeded without any error alarms, indicating that the control system consistently calculated the interpolation centre.

3. Smooth Geometric Transitions

   The formed radius shows a smooth transition between graduated diameters, which theoretically can reduce stress concentration and improve product aesthetics.



https://doi.org/10.53067/ijomral.v5i3.437

Figure 7. Final Results of Paper Weight Simulation

Final product of paper weight resulting from the CNC lathe simulation based on Nanjing Swansoft, Figure 7. The final simulation results show that all geometric features have been formed as designed. The external diameter, internal hole, radius, and chamfer appear symmetrical and consistent.

Analytically, several indicators of success can be identified:

1. Geometric Symmetry

   There is no visual eccentricity, indicating that the coordinate system and clamping remain consistent between stages.

2. Dimensional Precision

   The transition between diameters shows no overcut or undercut, indicating that the feed rate and spindle speed are within a stable range.

3. Theoretical Surface Quality

   With a feed rate of 0.5 mm/rev and carbide chisels, the resulting surface quality is theoretically in the medium-to-good range for non-structural products such as paper weight.

Program Performance Evaluation and Validation of CNC Lathe Simulation

The simulation results show that the compiled CNC program can be accurately translated by the FANUC 0i-T control system implemented in the Nanjing Swansoft CNC Simulator (SSCNC) software. The absence of syntax error alarms, interpolation errors, or indications of potential tool collisions during all machining stages marks this success. From a numerical control perspective, this condition indicates that the program structure meets three fundamental requirements: coordinate system consistency, tool path continuity, and the logical accuracy of the operation sequence.

Coordinate consistency is achieved through the use of an absolute programming system (G90), which ensures all tool movements are referenced to a fixed zero point. This approach minimises the accumulation of numerical errors common to incremental systems, particularly in complex paths with many motion segments and radius interpolation. Alarm-free program execution indicates that the start and end coordinates of each path are precisely defined and compatible with the designed radius, depth of cut, and machining strategy parameters.

In terms of path continuity, the transition between commands G00 (rapid traverse) and G01/G02/G03 (linear cutting motion and circular interpolation) occurs without geometric conflicts or path overlaps. It indicates that the program is not only syntactically correct but also strategically structured, with safety, efficiency, and process stability in mind. Thus, the resulting tool path reflects a structured and geometrically verified machining process plan.

The two-stage programming strategy with workpiece flipping also significantly contributed to the overall success of geometry shaping. This approach allows each side of the workpiece to be machined under stable clamping conditions, with a safe length-to-diameter ratio, thereby minimising the risk of deflection and vibration. In precision manufacturing, the two-sided method is a common procedure for maintaining concentricity and surface quality on cylindrical components. Therefore, the implementation of this strategy in the simulation is not only technical but also represents realistic industrial practice.

SSCNC's ability to detect program errors, visualise trajectories in real time, and simulate tool-workpiece interactions demonstrates that the software is highly representative of the behaviour of industrial control systems. From a safety and production efficiency perspective, the simulation-based verification phase plays a crucial role in reducing the risk of tool damage, cutting errors, and material waste before implementation on a real machine.

Quantitative Analysis of Simulation Results and Theoretical Comparison

In addition to visual analysis of the tool path and final product shape in SSCNC, a comparison was made between theoretical calculations of machining parameters and simulation results. The parameters compared included estimated cutting time and tool path length for three main operations: facing, turning, and drilling. The theoretical estimation of cutting time was calculated using equation 1.

$$t = \frac{L}{f \times n}$$

with:

t = cutting time (minutes),

L = feed length (mm),

f = feed rate (mm/rev), and

n = spindle rotation (rpm).

Based on the program parameters used in this study, a comparison of Table 4 was obtained.

Table 4. Comparison of Theoretical Estimates and SSCNC Simulation Results

Operation	Theoretical Path Length (mm)	Theoretical time (seconds)	SSCNC Simulation Time (seconds)	Difference (%)
Facing	20	12.0	12.4	3.3%
Turning	50	30.0	31.2	4.0%
Drilling	25	18.0	18.7	3.9%

The comparison between theoretical estimates and simulation outputs shows that the machining time in SSCNC differs by only a small amount, namely, below 5%. This deviation is within technically acceptable limits and can be explained by additional time components modelled in the simulation, such as the approach phase, tool retraction, and spindle acceleration and deceleration. These parameters are generally not considered in the theoretical formulation, which is ideal and only considers the effective cutting path. Thus, the closeness of the simulation results to the mathematical

https://doi.org/10.53067/ijomral.v5i3.437

calculations indicates that SSCNC can numerically represent the behaviour of the machining system with sufficient accuracy.

Overall, the results of this study confirm that the Nanjing Swansoft-based CNC lathe simulation (SSCNC) can execute two-stage programs consistently without syntax errors, interpolation alarms, or tool-path conflicts, and produce paperweight geometry that matches the design. This consistency not only reflects the correctness of the G-code structure but also demonstrates the geometric validity of the path, including the G02/G03 circular interpolation, which requires precision in the simultaneous coordinates of the X and Z axes.

These findings align with various studies over the past five years that have positioned CNC simulation as both a technical verification instrument and an effective learning medium. From an educational perspective, Andariansyah et al. reported that the use of Swansoft CNC Simulation significantly improved students' psychomotor skills in operating CNC lathes. (Pandu Andariansyah et al., 2025)These findings support the results of this study, which showed that simulations can validate G-code structures and their relationships to workpiece geometry. Prasetya et al. also stated that the CNC virtual laboratory enables safe program verification before actual practice.(Prasetya et al., 2023), In line with the tool path testing process via SSCNC in this study.

From a manufacturing technical perspective, Fujita developed a digital twin approach to verify programs and minimise production errors.(Fujita et al., 2022), while Guo showed that simulation improves trajectory accuracy and error detection before physical machining.(Guo et al., 2023). Furthermore, Zhang emphasised that CNC virtual simulation contributes to process optimisation and to product geometric precision.(Hu et al., 2024). The consistency of the G02/G03 interpolation trajectory and the precise determination of the radius in this study are in line with these findings, thereby validating the simulation approach as scientifically relevant.

CONCLUSION

Based on the research results, the implementation of Nanjing Swansoft-based CNC lathe simulation (SSCNC) in the manufacture of paper weight products is proven to run two-stage programs systematically and consistently, without syntax errors, interpolation alarms, or tool path conflicts. The use of an absolute coordinate system (G90), a two-stage machining strategy with workpiece inversion, and appropriate cutting parameters produces continuous, stable, and safe tool paths. The simulation successfully generates all geometric features, including stepped diameters, internal holes, interpolation radii (G02/G03), and chamfers, according to the working drawing design, indicating that the CNC program structure is logically and technically well-structured. Specifically, this study confirms the successful validation of the G02/G03 circular interpolation path and the geometric consistency of the two-stage machining strategy with workpiece inversion, thereby making technical contributions to verifying the numerical accuracy and profile continuity in the CNC turning process.

Furthermore, SSCNC-based simulations have proven effective as a program verification tool before being applied to a real CNC machine, as they minimise the risk of programming errors, potential tool collisions, and material waste. From a learning perspective, simulations help students understand the relationships among G-code, machining parameters, and geometric consequences, both visually and analytically. However, simulations still assume ideal conditions and do not fully account for physical factors such as vibration, tool wear, and clamping tolerances, which can affect actual results. Therefore, further research should focus on live testing on a real CNC machine to validate simulation results and evaluate dimensional deviations under actual operational conditions.

REFERENCES

Abougarair, A. J., & Tabet, M. A. (2023). Practical work for exploring the capabilities and benefits of CNC technology. *International Robotics & Automation Journal*, *9*(2), 55–60. https://doi.org/10.15406/iratj.2023.09.00264

Agrisa, H. H. (2020). An Overview of Process CNC Machining. *Journal of Mechanical Science and Engineering*, *6*(2), 029–033. https://doi.org/10.36706/jmse.v6i2.32

Faisal, B. A., & Leni, D. (n.d.). *Optimasi Waktu dan Kapasitas Produksi Desain Pion Menggunakan Mesin CNC Bubut Melalui Simulasi Autodesk Fusion*.

Fatriyana, M. (2020). CNC Program And Programming Of CNC Machine. *Journal of Mechanical Science and Engineering*, *7*(1), 019–023. https://doi.org/10.36706/jmse.v7i1.37

Fujita, T., Xi, T., Ikeda, R., Kehne, S., Fey, M., Brecher, C., Advanced Technology R&D Centre, M. Electric Corporation 8-1-1 Tsukaguchi-honmachi, Amagasaki, Hyogo 661-8661, Japan, & Machine Tool Laboratory (WZL), RWTH Aachen University, Aachen, Germany. (2022). Identification of a Practical Digital Twin for Simulation of Machine Tools. *International Journal of Automation Technology*, *16*(3), 261–268. https://doi.org/10.20965/ijat.2022.p0261

Guo, M., Fang, X., Hu, Z., & Li, Q. (2023). Design and research of a digital twin machine tool simulation and monitoring system. *The International Journal of Advanced Manufacturing Technology*, *124*(11–12), 4253–4268. https://doi.org/10.1007/s00170-022-09613-2

Hendra, H., Nur, I., Leni, D., Roza, Y., & Mayana, H. C. (2023). Pembuatan Simulasi Kelistrikan Motor Sebagai Media Pembelajaran Interaktif Bagi Siswa SMK Teknik Otomotif Di Smkn 1 Sumbar. *Jurnal Vokasi*, *7*(3), 307. https://doi.org/10.30811/vokasi.v7i3.4187

Hermana, R., Fahrur Aza, M., & Setyoadi, Y. (2022). A Comparative Study: The Precision of CNC Machines Using a Sliding Mode Controller (SMC) and a Wi-Fi ESP32. *Jurnal Teknik Mesin Mechanical Xplore*, *3*(2), 49–57. https://doi.org/10.36805/jtmmx.v3i2.2757

Hu, F., Zou, X., Hao, H., Hou, P., & Huang, Y. (2024). Research and application of simulation and optimisation for the CNC machine tool machining process under data semantic model reconstruction. *The International Journal of Advanced Manufacturing Technology*, *132*(1–2), 801–819. https://doi.org/10.1007/s00170-024-13415-z

Network-Controlled CNC Machine Tools: State-of-the-Art and Future Directions. (2024, May 26). *CONFERENCE PROCEEDING*. International Conference on Cutting-Edge Developments in Engineering Technology and Science. https://doi.org/10.62919/mtgk5653

Ntemi, M., Paraschos, S., Karakostas, A., Gialampoukidis, I., Vrochidis, S., & Kompatsiaris, I. (2022). Infrastructure monitoring and quality diagnosis in CNC machining: A review. *CIRP Journal of Manufacturing Science and Technology*, *38*, 631–649. https://doi.org/10.1016/j.cirpj.2022.06.001

Pandu Andariansyah, C Rudy Prihantoro, & Hari Din Nugraha. (2025). Efektivitas Penerapan Software Swansoft CNC Simulation Terhadap Hasil Belajar Psikomotorik Siswa pada Elemen Teknik Pemesinan Nonkonvensional di SMK: The Effectiveness of The Application of Swansoft CNC Simulation Software to Students' Psychomotor Learning Outcomes on

Nonconventional Machining Engineering Elements at SMK. *Jurnal Pendidikan Teknik Mesin Undiksha*, *13*(1), 75–85. https://doi.org/10.23887/jptm.v13i1.91248

Prasetya, F., Syahri, B., Fajri, B. R., Wulansari, R. E., & Fortuna, A. (2023). Utilising Virtual Laboratory to Improve CNC Distance Learning of Vocational Students at Higher Education. *TEM Journal*, 1506–1518. https://doi.org/10.18421/TEM123-31

Rahmatullah, R., Amiruddin, A., & Lubis, S. (2021). Effectiveness Of Cnc Turning and Cnc Milling in the Machining Process. *International Journal of Economic, Technology and Social Sciences (Injects)*, *2*(2), 575–583. https://doi.org/10.53695/injects.v2i2.610

Soori, M., Ghaleh Jough, F. K., Dastres, R., & Arezoo, B. (2024). Sustainable CNC machining operations: a review. *Sustainable Operations and Computers*, *5*, 73–87. https://doi.org/10.1016/j.susoc.2024.01.001

Tayier, W. (2024). Review Of Structure and Application in Three-Axis Cnc Machining: Errors, Tool Path Strategies, And Efficiency Improvements. *Journal of Engineering & Technological Advances*, *9*(1), 28–41. https://doi.org/10.35934/segi.v9i1.107