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Development of a Targeted Welding Point System for Robotic Trainers to Increase Automated Welding Precision

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Abstract

This study presents the development of a Targeted Welding Point System (TWPS) to aid in precision and efficiency. The TWPS investigates how to reduce processing time while improving operational efficiency by addressing three challenges: robotic kinematic limits, environmental unpredictability, and inefficient path selection. Despite advancements in robotic automation, many educational settings still lack affordable and practical tools to train students effectively. Trajectory optimization training and understanding robotic movement in angle-oriented environments limit student readiness for industrial automation deployment. In today's era, in the industrial field, whether an engineer or a machinist, both theoretical knowledge and practical skills are required. The objective of this study addresses key challenges in robotic automation, such as inefficient trajectory planning and limited practical training tools in TVET environments. The proposed method involves testing motions at various angular arrangements using a programmable robotic arm, which mimics industrial welding processes. By examining time efficiency across angles (0°, 30°, 60°, and 90°), the study shows how trajectory complexity affects system performance. Participants in the training displayed significant increases in control of accuracy. Students took longer to complete the sequence of welding points at the beginning. By the final point, the average time decreased, indicating improved understanding and control of the robotic system. Angles demand more joint reorientation and time, leading to reduced efficiency. Collaborating with industries helps us validate the TWPS in real manufacturing conditions, ensuring it works effectively in practical use.

1. Introduction

The use of robotic welding has made it a fundamental aspect of modern manufacturing due to its ability to produce high accuracy and efficiency in repetitive and intricate tasks. Integrating data-driven automation, modular robotics, and smart systems has redefined operational criteria as sectors move into the industry 4.0 age, thereby highlighting the increasing need for trained operators and sophisticated robotic control solutions [1][2]. One of the most important elements of robotic welding, trajectory planning, affects weld quality, energy consumption, and execution time directly. Recent developments in optimization algorithms such as Lévy flightenhanced Whale Optimization (LF-IWOA) and the Chaos Sparrow Search Algorithm (CSSA) have shown notable gains in weld path efficiency.

These techniques have shown up to 25% reductions in cycle time while improving joint smoothness and motion fluidity [3][4][5]. Particularly useful in low-mix production settings and lean manufacturing, where speed and flexibility are crucial, such inventions are especially beneficial. Many Technical and Vocational Education and Training (TVET) institutions still lack access to inexpensive, practical systems for instruction in trajectory planning and robotic control, even in light of these technical advancements. This distance between theoretical instruction and actual use prevents students from being prepared for the changing requirements of smart manufacturing [6][7].

To solve this difficulty, this study presents the Targeted Welding Point System (TWPS), an organized training platform employing programmable robotic arms to replicate industrial welding situations. By examining robot paths over four angular arrangements (0°, 30°, 60°, and 90°), TWPS lets students investigate angular complexity, kinematic constraints, and time-based performance criteria. This method helps students engage in significant experiential learning in a regulated setting.

Additionally, consistent with Malaysia's national efforts to improve TVET through robotics and artificial intelligence integration, is TWPS. Moreover, reflecting worldwide trends in modular robotics, wherein flexible and reconfigurable systems facilitate quick adaptation and skill development in Industry 4. 0 environments [8][9] are TWPS. Equipping future technicians and engineers with skills in trajectory optimization, human-robot cooperation, and intelligent robotic control all of which are critical in contemporary manufacturing settings [10][11] TWPS ultimately acts as a workable link between theoretical knowledge and industrial application.

2. Methodology

The primary aim of this technique is to verify that the Targeted Welding Point System (TWPS) can be utilized as an educational and learning tool for robotic trajectory control. The study was intended to let students engage directly with a robotic system while mimicking industrial welding procedures. The need for actual experiments utilizing quantitative data analysis was identified to evaluate learning growth and system response under various circumstances. To assess the efficacy of the TWPS in a controlled educational environment, this organized approach combines experimental setup, student interaction, and data analysis. The approach combines quantitative evaluation of student performance and robotic efficiency with technical system implementation. Fig. 1 shows the flow chart of this project.

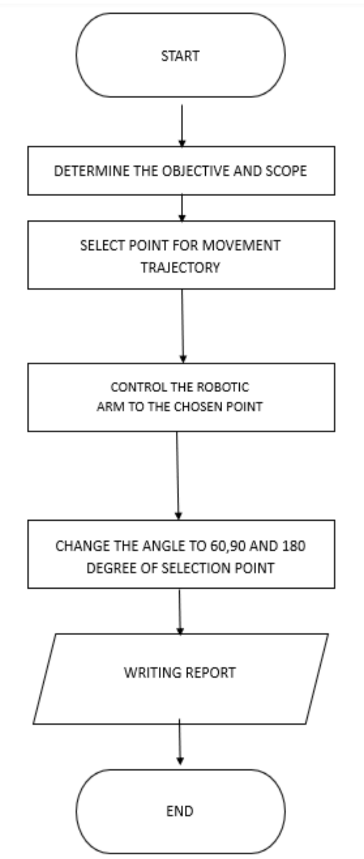

Fig. 1 *Flow Chart Methodology*

2.1 Experimental Setup

The creation of the Targeted Welding Point System (TWPS) was executed with a Mitsubishi RV-2F-D 6-axis robotic arm. Programming relied on a teach pendant; therefore, it enabled exact point-to-point motion control. To recreate real welding conditions, button-type contact switches were installed as designated welding targets in a specially constructed specimen box. Every switch is designed to give immediate feedback after the robotic device contacts it, so students can verify the accuracy and completeness of their trajectory in real time.

Alongside a teach pendant, a programmable robotic arm trainer allows users to manually guide and record robotic motions using particular coordinate settings. The purpose of this project was to replicate real welding situations by placing sixteen button switches in a specially constructed specimen, which had been designed to depict actual welding points. When appropriately touched by the robotic end-effector, these switches serve as feedback sensors that activate an indicator lamp. This lighting reproduced a perfect spot weld.

Under four different angular settings 0°, 30°, 60°, and 90° students engaged in the experiment were instructed to program and control the robotic arm to sequentially touch four predetermined welding points. These angles were chosen to match different industrial welding situations by portraying growing degrees of trajectory complexity and joint articulation. To guarantee data consistency and track growth over time, every angular test was performed three times. This real-world experience helps to build technical skills via the fusion of motion planning and performance validation. The program also simplifies data collection, such as time measurements and trial results, in order to monitor development and assess learning.

2.2 Data Collection Process

To gather quantitative data, the time taken by each pupil was recorded on a stopwatch under each angular setup to complete the robotic welding point sequence. This time period provided a precise means of measuring task efficiency and was essentially proving the performance of robotics and the progress of students. For the purpose of tracking student development, every motion session was recorded individually.

The analysis was backed by the inclusion of qualitative observations and numerical results. These included student behavioral markers such as hesitance to program, the frequency of error correction, and confidence in handling the pendant. These insights into the student learning process added further background to the performance data. Each student was given a performance log sheet recording the following so as to uniformly evaluate them:

- Completion time per angle arrangement: 0°, 30°, 60°, and 90°
- Observed learning patterns over successive trials include enhanced fluency, less programming mistakes, or better decision-making.

Combining qualitative timing data with thorough observational notes, this dual-method data gathering strategy offered a more comprehensive and in-depth knowledge of how the Targeted Welding Point System (TWPS) affected robotic task performance and student skill growth. The qualitative observations captured behavioral indicators like hesitation, correction patterns, and increasing confidence, whereas the numerical data gathered from repeated time trials permitted accurate measurement of student efficiency. Together, these complementary data sets let researchers evaluate not only how fast student finished tasks but also how their engagement with the robotic system changed over time. This thorough analysis guaranteed that the research also covered cognitive learning, adaptability, and the capacity of the pupils to use robotic control concepts in a organized and realistic setting instead of only concentrating on task speed.

2.3 Experimental Procedure

2.3.1 Phase 1: Student Learning Performance

The student was tasked with using the robotic arm to reach 16 predetermined welding locations within the TWPS configuration in order to evaluate skill, student achievement, and proficiency in robotic handling. These locations were strategically arranged around the sample box to mimic actual route changes and complexity; therefore, they replicated traditional welding trajectories seen in the industry. Assessing consistency, repeatability, and user adaptability, each welding point was attempted three times. The teach pendant guided and manually programmed the movement of the robotic arm, thereby demanding that students use both operational precision and spatial reasoning. Making precise contact with each button switch, the robot's tool offered instant feedback when correct alignment was achieved.

A stopwatch was used to note the time taken to go from one location to the next for every try. The three repeats per point were averaged to guarantee an accurate measurement of execution effectiveness. Based on comments, students were urged to correct their trajectories between tries; this incorporated a cycle of trial, assessment, and enhancement.

Three important features of robotic training performance were meant to be evaluated during this experimental phase:

- Learning Progression: The rate at which students' task completion and control improved over several trials.
- Control Fluency: The consistency, accuracy, and smoothness of movements throughout the task.
- The capacity to reduce deviation and time while maintaining constant contact with the designated targets.

Furthermore, made possible a comparative analysis across individuals and offered information about the general success of the TWPS as a hands-on robotic training tool were the gathered data.

2.3.2 Phase 2: Angular Configuration Performance

The attention in the second stage of the experiment turned toward assessing the impact of angular orientation on robot trajectory performance. The specimen box was regularly set to four angular positions 0°, 30°, 60°, and 90° to mimic a variety of actual welding circumstances. These preferences were selected to represent typical postural difficulties found in industrial welding projects, including inclined, vertical, and overhead surfaces.

The robotic arm was set at every angular position to grab four pre-defined welding points attached to the modified surface. To make sure angular variance was the only factor influencing performance results, these target positions stayed consistent throughout all angle trials. Three attempts were made on each point to guarantee data consistency and allow repeatability analysis, this produced twelve movements per angular arrangement. The robotic arm's movements were directed using the same teach pendant interface, which asked students to modify their approach, planning, and control depending on the alterations in orientation.

A stopwatch was used to measure the execution time for each trial. For each point, these times were averaged across the three iterations; a general average was calculated for each angle. This helped to detect trends in performance and assess how angular complexity affected time efficiency and control fluency.
This phase's aim was to:

- Investigate how different surface angles affect student trajectory performance.
- Evaluate the rise in difficulty caused by steeper gradients.
- Determine adaptive control abilities in light of angled hurdles.

This angular evaluation offered a thorough understanding of the capacity of the system to simulate multi-orientation welding operations and assessed how well students could apply learned skills across non-horizontal working surfaces.

2.4 Data Analysis Method

This study employs a quantitative approach, which uses numerical data to assess performance. Mean, minimum, maximum, and standard deviation statistics were among the descriptive statistics used to create tables from time data and analyze it. Graphs were created to show how performance changed across trials and how angular variance affected robotic efficiency. Comparative study was carried out to note variations in robotic path time at various angles and to evaluate how angular complexity affects robotic movement.

Moreover, student trials' trends in improvement were investigated to assess the efficacy of the TWPS as a training instrument. This methodical numerical approach helped the study to fairly evaluate both the educational effects of TWPS and its possible usage in industrial training settings.

3. Results

The findings of the project are shown in this chapter together with ideas for the expected results. The observed results are confirmed by the examination of gathered data, together with comparisons to results from prior studies. This chapter also emphasizes how the present results might inform future testing and studies intended either to confirm or enhance efficiency. This study aims to improve students' abilities in operating robotic devices while also investigating how various specimen angles 0°, 30°, 60°, and 90° influence the robotic arm's movement time. The project encourages performance improvement in robotic systems as well as learning by providing pupils practical experience and studying how angle modifications affect them. Future uses of robots could be enhanced by these results.

3.1 Student Learning Performance

Table 1 Learning performance

Point	Time (s)			Average Time (s)	Std. Deviation
	1	2	3		
1	53	48	44	48.33	5.73
2	48	40	35	41	4.69
3	46	42	38	42	4.47
4	40	36	30	35.33	3.96
5	44	38	30	37.33	4.08
6	45	40	33	39.33	4.04
7	39	35	33	35.67	3.58
8	38	37	34	36.33	3.51
9	36	35	32	34.33	3.23
10	35	33	32	33.33	3.16
11	36	34	32	34	3.18
12	36	35	30	33.67	2.71
13	30	31	29	30	1.45
14	29	28	25	27.33	0.84
15	30	26	24	26.67	1.18
16	32	28	25	28.33	0

The gathered data in Table 1 showed a constant and noticeable increase in student competence and project efficiency when using the Targeted Welding Point System (TWPS). Students shown obvious uncertainty with the robotic interface at the beginning of the training, particularly in using the teach pendant for accurate programming. This was shown in their first attempts' rather high mean completion time of 48. 33 seconds for the whole welding point sequence. Errors in joint configuration, poor route planning between points, and lack of self-assurance in carrying out motions frequently caused the delays.

Significant changes were seen as the training went on and students got more used to the system interface and the robotic arm's movement behavior. The average completion time had dropped dramatically to 28. 33 seconds (Fig. 2) by the conclusion of the trial sessions a more than 40% reduction. This decline in execution time points clearly to a learning curve distinguished by improved hand-eye coordination, greater command of pendant controls, and a deepening knowledge of how angular designs impact robotic trajectories.

This progress showed greater control over joint motions, more knowledge of trajectory planning, and less reliance on trial-and-error. Observations also observed that more independently students started perfecting their sequences and correcting mistakes.

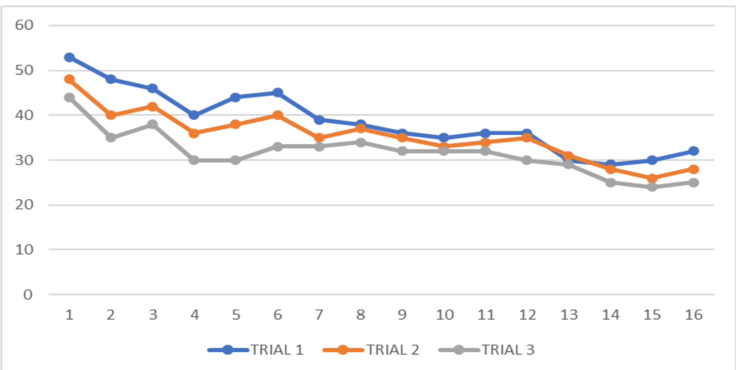

Fig. 2 *Time taken each point*

3.2 Angular Configuration Performance

Every angular design presented different levels of difficulty affecting the robotic arm's movement efficiency and necessitating control approaches.

Table 2 0º angle

Welding Point	Angle (º)	Time (s)			Average Time (s)
		1	2	3	
1	0	6.53	6.55	6.42	6.50
2	0	5.73	5.90	6.12	5.92
3	0	5.10	5.05	5.15	5.10
4	0	6.45	6.63	6.55	6.54

Table 3 30º angle

Welding Point	Angle (º)	Time (s)			Average Time (s)
		1	2	3	
1	30	7.20	7.10	7.35	7.22
2	30	6.32	6.35	6.24	6.30
3	30	6.37	6.20	6.28	6.28
4	30	7.00	7.20	7.25	7.13

Table 4 60º angle

Welding Point	Angle (º)	Time (s)			Average Time (s)
		1	2	3	
1	60	7.50	7.44	7.55	7.50
2	60	6.98	7.04	7.12	7.05
3	60	6.88	6.94	7.06	6.96
4	60	7.68	7.70	7.74	7.71

Table 5 90º angle

Welding Point	Angle (º)	Time (s)			Average Time (s)
		1	2	3	
1	90	8.28	8.00	8.25	8.18
2	90	7.30	7.36	7.32	7.33
3	90	7.06	7.10	7.12	7.09
4	90	8.40	8.48	8.38	8.42

The recorded average completion times for every setup were:

- 0 degrees: 5. 9 seconds
- 30 degrees: 6. 7 seconds
- 60 degrees: 7. 3 seconds
- 90 degrees: 7. 8 seconds

Base on the data analyzed in Table 2 till Table 5, high angular settings resulted in slower task performance and delayed learning increases, therefore confirming a regular pattern. Students at 0° attained quicker and more consistent control, with average times of 6. 59 seconds. The 90° setup, however, had the highest average time 7.8 seconds reflecting greater complexity due to joint reorientation and spatial complexity.

This performance difference is attributed to kinematic limitations; as the angle increases, the robotic arm requires more complex joint motions and precise alignment, necessitating improved cognitive and motor skills. Initially, pupils had trouble internalizing the movement reasoning needed for non-linear courses. The data, however, did not point toward any learning plateauing. Students kept getting better across multiple trials, even at steeper angles, showing that learning stayed dynamic and sensitive to input.

4. Discussion

The results of this research point toward the Targeted Welding Point System (TWPS) as being helpful for pupils to develop robotic movement control skills. Students could finish jobs quicker and more precisely over several trials, which demonstrates that the system is an effective training tool. Furthermore, emphasizing the need of thorough robotic movement planning are the changes in performance at several angles. By means of this method, students not only learned how to use the robot but also improved their problem-solving abilities by modifying their actions to be more effective. TWPS is still open to growth as well. Future iterations of the system might comprise smart elements like AI-based feedback that detects problems and offers users real-time guidance. The data gathered from student activities also helps to track the status of the robot and anticipate part failure dates. This would help predictive maintenance, a core component of smart manufacturing in the industry 4.0 era.

5. Recommendations

Based on the findings of this research, several suggestions may be given to improve the Targeted Welding Point System (TWPS) and promote its use in education and training. First it is advised to include sensors or vision technology among the more complex capabilities of the system. These upgrades could provide improved feedback for students throughout their practice and enable more accurate simulation of actual welding surroundings. Moreover, automated data gathering systems should be put in place to take the place of hand timing. This will help to increase the correctness of performance tracking and simplify time-based results analysis.

Finally, educational institutions should think about setting up industrial visit for companies that employ robotic welding on a daily basis. This exposure will enable student to observe the practical use of robotic systems in real-world manufacturing and so grasp more clearly the relationship between their education and possible future employment. It also presents opportunities for hands-on learning and industry cooperation.

6. Limitations and Future Work

Four angular settings (0°, 30°, 60°, and 90°) were the only focus of this study, which provided insightful results but did not encompass the whole spectrum of movement possibilities in industrial robotic welding. Furthermore, stopwatch-collected timing data was gathered manually, which could have caused little discrepancies or measurement delays.

Future studies should investigate a wider range of welding angles and more sophisticated path conditions to better represent actual industrial work. Using sensor-based technologies or programmed software-timed data gathering would help performance monitoring's reliability and accuracy. Furthermore, improving the system's capacity will be the inclusion of adaptive algorithms enabling real-time path learning and error correction. These elements would help the robot to modify its path depending on past mistakes or shifting target positions, hence improving the system's intelligence and bringing it more closely to industrial standards. These developments would elevate TWPS not only as a training aid but also as a venue for smart robotics and predictive maintenance research in Industry 4. 0.

7. Conclusion

There were two main objectives in this study, to improve the ability of student to operate their robotic equipment and to investigate whether the angle of a sample matter matters on how long invasive with 'anterior' or moving limbs affect the movement time of one robotic arm. The tests' results gave insightful information about both objectives. The results indicate that students' performance got better throughout several trials as they gained more familiarity with controlling the robot's axis and motion. This confirms the hypothesis that creating technical skills and confidence in robotics systems depends on regular, practical experience.

Furthermore, the data clearly showed that longer movement times resulted from greater specimen angles. The robotic arm finished its work the quickest at 0 degrees, 90 degrees produced the longest times. This shows how more sophisticated joint motions and reorientation are needed for larger angles, which affects efficiency. In essence, the research fulfilled its goals. It emphasizes the need of hands-on instruction in robotics education and demonstrates how task setup, particularly angular placement, can greatly affect robotic arm performance. These discoveries help to refine industrial robotic job planning as well as learning techniques.

Reflecting the system's success as a learning tool, students made notable improvement in lowering task completion time and learning to fit various angular setups. By providing visual feedback and task repetition, which are critical for mastering robotic skills, TWPS also showed useful for technical training. Integration of artificial intelligence (AI) capabilities including automated error detection, adaptive guidance, and real-time feedback is advised for next studies. To improve measurement accuracy and automate performance analysis, researchers should also think about integrating sensor-based data collecting systems.

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This guide contains examples of common types of APA Style references. Section numbers indicate where to find the examples in the Publication Manual of the American Psychological Association (7th ed.).

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