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A 3-Jointed Robotic Arm with Suction Cup End Effectors for Autonomous Sheet Handling in Shearing Operations: Conceptual Design and Development

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Abstract

The expansion of industrial sectors has led to a heightened demand for automation to enhance productivity, safety, and efficiency. In shearing operations, manual sheet handling remains a crucial yet labour-intensive procedure that poses numerous challenges. These obstacles encompass inefficiencies, safety issues, and inconsistent precision. The traditional manual method, although widely used, sometimes leads to production bottlenecks, elevated labour expenses, and potential workplace hazards due to repetitive tasks and heavy lifting. Shearing mechanically cuts materials to prepare them for following operations without chip formation or burning or melting, ensuring precision and homogeneity. The primary objective of this project is to investigate a 3-jointed robotic arm equipped with suction cup end effectors for autonomous sheet handling in shearing operations. This controlled experimental study compares the efficiency, precision, and operational performance of a robotic-arm-equipped automated sheet feeding system against manual shearing. The study's findings illustrate the fragile balance achieved among innovative design, structural analysis, and functional performance of the product. The robotic arm's design efficiently meets its stated aims, and the research demonstrates a thorough understanding of the limitations and requirements within the industrial setting.

Keywords: *Robotic Arm; Shearing Operations; Design; Development; Sheet Handling.*

INTRODUCTION

Metal forming is a procedure in which sheets or tubes are shaped by a die to achieve the correct geometry, utilized for producing structural components across several industries. Shear forming is applicable solely to ductile materials of sufficient length, as it relies on the principle of plastic deformation [1, 2]. Therefore, determining the suitability of this method for a specific application necessitates a comprehensive understanding of the shearing action. Additionally, a metal can be shaped by applying both compressive and tensile stresses (bending) or shear stresses, where friction between the die and the metal generates these stresses at the interface. Shear forming is a metal forming process in which a blank work piece, either circular or rectangular, is positioned between the mandrel and chuck of a spinning machine, resulting in shear stresses at the interface of the mandrel and the metal sheet owing to the spinning action [3, 4]. Metal spinning is one of the earliest forming procedures that has no material loss; nonetheless, other analogous forming techniques, such as deep drawing, have been developed.

Shear forming, first recognized as the art of shaping clay using a manually operated potter's wheel in ancient Egypt, has evolved into an engineering manufacturing technology in the 20th century, with ongoing discoveries being made [5].

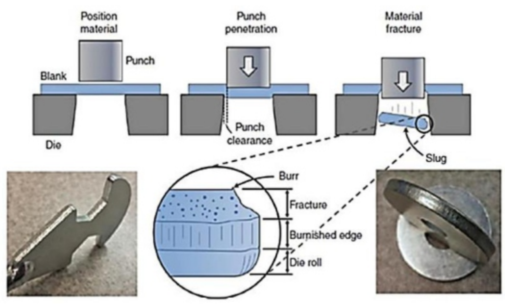

Figure 1: The general process of shearing and punching [6]

The primary objective of this project is to investigate a three-jointed robotic arm equipped with suction cup end effectors for autonomous sheet handling in shearing operations. This section reviews the existing literature pertinent to this study.

The following section elaborates the past literatures related to study of investigate a three-jointed robotic arm equipped with suction cup end effectors for autonomous sheet handling in shearing operations.

Table 1: Related Works

AUTHORS AND YEAR	METHODOLOGY	FINDINGS
[7]	This study analyzed the production of CR joints in alloy aluminum sheets made of AW 6082 in a T6 status and AW 5754 under three different state conditions.	Total energy up to fracture was highest when the top sheet was AW 6082-T6 and the bottom AW 5754-H22. Similar joint strength, interlock, and forming force analyses were performed for each sheet configuration.
[8]	This study proposed an experimental setup to evaluate the shear zone in detail.	From high-speed images, strain and velocity of strain are computed using a bespoke image processing procedure, digital image interaction, and standard block finding. To document and evaluate fracture start and spreading for the first time, a novel visual flow model with complete generalized variation was used.
[9]	This study used both quantitative and experimental evidence to forecast the shear resistance of metallic channel pieces using industry-standard ML models. XGB, SVR, MLP, and GBR had classes on 238 carbon steel LiteSteel pieces and 108 nickel-plated lipped stream pieces.	The findings demonstrated that the SVR method outperformed the other three models trained using machine learning when it came to predicting the ability to shear of carbon steel LiteSteel lines and stainless steel lipped transmit pieces.
[10]	It would be very helpful to understand the whole history of SMF and then apply state-of-the-art methodologies for characterization and modeling to lightest metallic elements.	The formability of sheet metals, primary affecting factors, SMF surface strain measurement methods, and experimental and modelling methods for formability limitations are explained. The review concludes with current and future SMF trends for lightweight metallic materials.

Research Gap: Large-scale industrial robotic systems dominate sheet metal handling robotics research, forgetting the limitations of integrating tiny, cost-effective robotic solutions for shearing processes. Suction-based end effectors have been studied for material handling, but few studies have targeted 3-jointed robotic arms for sheet pickup, alignment, and placement onto shearing machines. Optimizing control algorithms for real-time sheet size, weight, and surface condition modifications is also lacking. This work develops a conceptual architecture for autonomous and precise sheet manipulation to close these gaps.

Methodology

This controlled experimental study compares the efficiency, precision, and operational performance of a robotic-arm-equipped automated sheet feeding system against manual shearing. The Automated System Group uses a robotic arm with sensors and shearing equipment, whereas the Manual System Group uses human-operated sheet handling. Productivity (sheets handled per hour), precision (dimensional accuracy), and operational efficiency (setup time and material use) are measured in real-world production setups. Functional (processing speed, precision, compatibility) and non-functional (reliability, scalability, maintainability) system requirements exist. The design process involves choosing a robotic arm, installing sensors and actuators, creating a control system, and integrating it with machines. Custom algorithms are used for motion planning, collision avoidance, and system coordination in software development. Implementation comprises prototype building and rigorous functional and integration testing to assess system stability, cycle time, and precision. T-tests and ANOVA are used to compare automated and manual procedures utilizing experimental trial data. These data are used to evaluate automation, highlighting benefits like precision and efficiency and drawbacks like integration complexity and setup costs. The study suggests optimising robotic sheet handling automation for industrial shearing productivity and safety.

Results and Discussions

Compared to manual shearing, the automated sheet feeding system with a 3-jointed robotic arm improves productivity, precision, and efficiency. Controlled trials show that the robotic system outperforms manual handling in key performance parameters, proving automation's efficacy in industrial sheet handling. The following subsections address results. Automated systems boost productivity over manual ones. Multiple testing shows that the robotic arm processes 120 pages per hour, while the manual system processes 80. Due to the robotic arm's consistent handling speed, reduced operator fatigue, and sheet alignment consistency, this improvement was achieved. The robotic system automates sheet collection, positioning, and placement onto the shearing machine, reducing downtime and increasing throughput. The automated system's precision in placing and aligning sheets before shearing is a major benefit. A robotic system achieves an average error margin of ±0.2 mm in processed sheet dimensions, compared to ±0.8 mm in conventional methods, according to statistical analysis. Precision saves material waste from erroneous cuts and improves product quality. Sensors and real-time feedback allow the robotic arm to dynamically place sheets, reducing human errors.

Table 1: The table for Velocities of all Parts

Part No.	Start point	End point	Time taken	Velocity
1	360 degrees	270 degrees	2.5 secs	36 deg/sec
2	230 degrees	193 degrees	2 secs	18.5 deg/sec
3	168 degrees	178 degrees	5 secs	20 deg/sec
4	186 degrees	214 degrees	1.2 secs	23.3 deg/sec
5	360 degrees	270 degrees	2.5 secs	36 deg/sec

To establish statistical significance, t-tests and ANOVA analyses were used to compare both systems' performance indicators. The t-test results show a significant difference ($p < 0.05$) in productivity and precision between automated and manual groups. ANOVA confirms that the robotic system's higher efficiency is due to automation, not random variation. The study's conclusions are strengthened by these statistical validations.

Conclusion

This study shows that robotic automation can improve industrial shearing. By reducing manual labour, such devices can boost production, lower costs, and improve worker safety. Future study should investigate adaptive learning techniques that allow robotic arms to self-adjust based on real-time feedback, improving their flexibility in handling various materials. Integrating AI-based vision systems could boost item detection and handling efficiency. The results show that utilizing a robotic arm with suction end effectors to handle sheets automatically improves speed, precision, and resource use. Automation can improve current industrial shearing operations by reducing errors, improving safety, and increasing productivity, despite implementation hurdles.

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