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Numerical modeling and experimental validation of an adaptive pneumatic gripper for collaborative robotic palletizing

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A B S T R A C T

This paper presents the development and experimental validation of an adaptive pneumatic gripper for collaborative robotic palletizing of packages with varying mass and surface characteristics. The main objective is to determine the optimal gripping-force and minimum operating pressure required to ensure stable and safe handling without slippage. A dynamic mathematical model was developed, incorporating the effects of package mass, friction coefficient, contact surface area, and inertial forces during manipulation. Numerical analysis was performed for different friction conditions (μ = 0.30-0.90) and contact configurations, enabling the determination of the minimum required gripping-forces and corresponding operating pressures. Experimental validation was conducted on a real industrial system with a collaborative robot. The results show a linear relationship between pressure and gripping-force, described by $F = 22.152\,p - 17.535$, with a high correlation coefficient ($R^2 \approx$ 0.998). The maximum experimentally obtained gripping-force was approximately 70-75 N at a pressure of around 4 bar. Quantitative deviations between numerical and experimental results (65-75 %) were observed and corrected by introducing a calibration factor ($k_{corr} \approx$ 0.30). The proposed model and experimental system enable reliable optimization of gripping-force and improve manipulation stability under real industrial conditions. The main contribution of this study lies in the integration of analytical modelling, numerical optimization, and industrial experimental validation for collaborative robotic palletizing systems

A R T I C L E I N F O

Keywords:
Adaptive pneumatic gripper;
Collaborative robotic palletizing;
Gripping-force optimization;
Friction-based gripping;
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