**Table S1 -** Developments in Automated Assembly Lines with Robots

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| **Results** | Demonstrated advantages in processing makespan, AGVs' efficiency, and machines' efficiency through simulation experiments. Real-world robot experiment yielded processing makespan close to the theoretical lower bound. | Demonstrated reduced complexity in robotic application setup, enabling non-expert users to configure robots in a short time. Proposed economic assessment framework for robotic investments. Improved flexibility compared to traditional automation, opening new opportunities for collaborative robots in small/medium batch production. | This work obtained high robustness in detecting DPs, with the proposed method achieving high precision, F1-Score, and localizing accuracy compared to other methods. Despite moderate time consumption, the proposed approach worked acceptably in industrial vision-based automatic assembly tasks in BLM. | The authors were able to pinpoint areas in which further research on CoALBP may be conducted, highlighting the importance of multi-objective optimization, actual industrial case studies, and experimentation with different layouts. In addition, the authors predicted that the amount and caliber of CoALBP research will increase quickly, providing industry best practices for the use of cobots. | Demonstrated the feasibility of integrating fully equipped flap modules to an airplane's wing spar using AIMMs. Successfully tested deformation compensation capabilities of the end effector in bending experiments. Assembly experiments showed smooth insertion of studs into bolt holes, highlighting AIMMs' capability to assemble large compliant structures. Identified areas for further research include a thorough investigation of system bending behavior and the development of models for predicting flap body deflection. | Found that CP is relatively slower in solving simpler allocation problems but more efficient than MILP when a higher number of constraints are applied and allocation and scheduling problems need to be solved. Computational analysis suggests MILP formulations may perform better for allocation problems, while CP formulations perform better when scheduling aspects are involved. | The proposed simulated robot pedestal is made to support the weight and inertial movement that the robot generates. Adjusting the welding settings also affects the quality of the weld. The design is made such that, while the robot is operating at its maximum torque, the pedestal displays the least amount of displacement. Solid Works software implementation demonstrates useful to analyze thdinamics for this problem. | The proposed approach reached an accuracy of 0.026 mm for countersink depth inspection by using a low-resolution neuromorphic camera. The proposed approach was compared with state-of-the-art methods, showing comparable results with significant speed improvements. | The repurposed robotic cell improves process efficiency, reduces dependence on manual labor, and enhances product quality. By utilizing existing resources, the approach increases economic sustainability and minimizes environmental impact. | Potential for increased production volumes, flexibility in handling different machine designs. Faster and less costly compared to manual winding. Better work environment and winding quality indicated. | Promising integration and computational efficacy within manufacturing settings. Full compatibility with existing hardware and software configurations. Enhanced operational workflows without disruptions. Real-time or near-real-time responses for issue rectification. | High reliability is achieved in obstacle detection, with the potential for extension to process RGB images for obstacle classification. Prior knowledge utilization for indoor obstacle detection. Possibility of programming informed decisions for AGV movement based on obstacle type. |
| **Disadvantages** | The genetic algorithm needs calibration to achieve promising results. | Tasks may lack optimization due to the general nature of skills designed for flexibility. | Time consumption for a single prediction is about 0.6 s, which could be improved for faster inference. | Limited research on CoALBP compared to classical assembly line balancing problems. Requires more real industrial case studies to develop practical models. Additional attention needed for different layouts and multi-objective optimization. | The automatic alignment of the ﬂap needs to be implemented and tested with more control algorithms considering more sensors such as force or haptic devices. | In some cases, models are difficult to solve for the CP formulation and instances the optimal value was not found | Only simulation analysis designed in SolidWorks | The countersink detection approach is based on event-based motion compensation and the mean-shift clustering principle. The applications of deep learning techniques for event-based detection is missing in this work. Moreover, other sensor information such as stereo cameras or lidar should be also required to solve this problem. | The cost and time required for refurbishing and retrofitting old robots need to be further analyzed, as well as compatibility issues with modern manufacturing systems. Additionally, specialized skills in robot programming and integration may be needed to better understand this problem. | May not compete with very high-volume conventional winding automation for smaller machines. Further experimental work is needed on cable handling and robustness. | Potential internal uncertainties in model accuracy were observed. The need for variations in defect characteristics in real manufacturing environments is also open research problem that needs further study. Finally, it is required to refine autonomous corrective action control mechanisms. | Some limitations in processing time and computational resources due to real-time operation and downsampling of point clouds. Further refinement is needed for indoor obstacle detection and classification. Detection of holes in the ground may require additional development. |
| **Methodology** | Developed a Petri net model and a genetic algorithm-based look-ahead scheduling algorithm (LASA) with processing sequence conflict-free. Integrated chain task strategy to enhance LASA's performance in AGV deficiency scenarios. | Introduced Interactive Refinement Programming (IRP) approach, where engineers translate assembly operations into preliminary code, followed by non-expert users providing input parameters. Developed a pyramidal parametrized approach for skill-based programming. Validated through a real industrial case study. | Proposed a texture-less surface matching method based on gray-scale images, utilizing augmented and normalized gray-scale vectors to represent the texture-less surface in a low-dimensional space. Employed cosine distance for similarity calculation and shape-based matching (SBM) for improved robustness. Evaluated using an image database from actual production lines, outperforming NCC, SBM, YOLOv5s, and YOLOv5x methods. | Reviewed the cobot assembly line balancing problem (CoALBP) using the 4M1E framework for categorization. Analyzed existing literature on CoALBP, comparing articles and summarizing key features. Offered guidelines for further research on CoALBP.\end{tabular} | Developed a concept for high-rate assembly of flap modules using AIMMs and a lightweight end effector with integrated Stewart platform for deformation compensation. Reported on conceptual design, end effector design, realization, and successful experimental demonstration at 1:1 scale. | Investigated and compared MILP and CP models for solving partially automated assembly line balancing problems with varying degrees of automation and allocation/scheduling complexities. Evaluated the performance of both approaches across three different cases. | Designed the robot pedestal using SOLIDWORKS and conducted static analysis to ensure it can withstand the load and inertial movement produced by the robot. Adjusted welding parameters such as current, speed, and wire feed rate to determine the quality of welding. | The proposed detection approach based on event-based motion compensation and mean-shift clustering and robust event-based circle detection can be used for high-precision depth estimation in countersing inspection applications. Tested the approach on over 50 trials with three countersink workpiece variants, achieving a 10x speed improvement compared to conventional methods. | This work involves adapting an obsolete robotic cell for use in plastic injection production lines to insert components into injected parts. Through mechanical and automation design, the equipment is refurbished and integrated into the production process, reducing cycle time and replacing manual labor. | Introducing automated stator cable winding for rotating electric machines. Evaluating robot positioning and reach for different machine designs through simulations. | Implementation of computer vision as a cost-effective digital transformation technology in manufacturing facilities. Utilizing a digital twin application with computer vision algorithms for quality control and autonomous correction. | Development of an autonomous navigation system for AGVs to detect and avoid obstacles using depth data from a frontal depth camera. Utilization of RANSAC and Euclidean clustering algorithms to process 3D point clouds for obstacle detection. |
| **Problem** | Automated guided vehicles (AGV) scheduling in a no-buffer assembly line with processing sequence conflicts (PSC). | Simplifying the programming process for collaborative robots in small-scale production environments, while maintaining high flexibility and adaptability. | Developing a robust texture-less gray-scale surface matching method for accurately detecting diffuser plates (DPs) in a liquid crystal display TV backlight module (BLM) assembly system, despite challenging image backgrounds. | A review of assembly line balancing in the context of human-robot collaboration (HRC) was presented, specifically addressing the challenges posed by equipping workstations with appropriate cobots and scheduling collaborative tasks for workers and cobots. | Addressing the challenge of handling and assembling compliant structures, such as thin-walled and lightweight composite structures in airplanes, using autonomous industrial mobile manipulators (AIMMs) equipped with lightweight assembly jigs capable of deformation compensation. | Comparison of generic approaches, mixed integer linear programming (MILP) and constraint programming (CP), for balancing partially automated assembly lines, considering different levels of automation and allocation and scheduling complexities. | Desing a robot pedestal and fixture for OTC FDV8 MAG commercial welding robot. This approach is aiming at improving welding quality and accelerating the welding process through automation. | Countersink inspection in automated assembly lines, especially in aerospace and automotive sectors, requires expedited processes due to high latency and measurement uncertainties with motion in conventional sensing pipelines. | The authors introduce out-of-service robots as an opportunity to automate the plastic injection industry to increase productivity and quality while minimizing environmental impact and resource consumption. | Automated Cable Winding for Rotating Electric Machines | Leveraging computer vision towards high-efficiency autonomous industrial facilities | Obstacle Detection for Autonomous Guided Vehicles through Point Cloud Clustering Using Depth Data |
| **Cite** | (Wang & Li, 2013) | (Giberti et al., 2022) | (Li et al., 2024) | (Chutima, 2023) | (Neitmann et al., 2022) | (Dimény & Koltai, 2023) | (Natesan et al., 2023) | (Salah et al., 2023) | (Costa et al., 2022) | (Hultman, 2022) | (Yousif et al., 2024) | (Pires et al., 2022) |