Human–Robot Collaboration for Ergonomic Door Panel Assembly

Repository: https://github.com/sophiehauritz/DoorPanelsGroup2.git

Demonstration link: https://youtu.be/NFPV_3pfhms

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Ballerup Campus 2025

1. Introduction & Problem Definition

In many industrial production environments, assembly tasks require operators to manually handle large and heavy components during the installation and fitting processes. These tasks involve holding components in place while performing precise work such as fastening, alignment, or adjustment. As production demands increase and the product variants become more diverse, manual assembly remains common due to its adaptability and flexibility. However, reliance on manual handling alone frequently results in physically demanding and ergonomically detrimental working conditions. This challenge is particularly evident in the assembly of large machine components, where both high weight and precise alignment are critical.

Operators are often required to work in awkward postures, maintain static positions for extended periods, or support heavy components while performing intricate tasks. Over time, such working conditions increase the risk of musculoskeletal disorders, particularly affecting the back, shoulders, and arms. In addition to the health-related consequences for employees, these conditions can negatively impact operational performance. Physical strain and fatigue reduce precision, increase the likelihood of assembly errors, and contribute to lower overall productivity.

Although industrial automation has progressed significantly, fully automated assembly solutions are often not compatible with tasks characterized by high product variety, low production volumes, or frequent design changes. Fully automated systems tend to be costly, complex, and inflexible, making them impractical for many small and medium size production environments. On the other hand, traditional ergonomic aids such as lifting devices or fixed supports offer limited adaptability and do not actively assist the operator throughout the assembly process.

This situation highlights a gap between manual labor and full automation. There is a need for solutions that reduce physical strain without removing the operator from the process. An effective solution must support human workers by handling physically demanding tasks while preserving human control, flexibility, and decision-making in quality-critical operations. Addressing this problem is essential not only for improving workplace ergonomics and occupational health but also for enhancing assembly quality, efficiency, and sustainability in modern industrial production systems.

2. Proposed Solution

The proposed solution to address the problem statement is based on a collaborative robot arm that functions as an ergonomic “third hand” for the operator. The robot arm is integrated directly into the assembly area and takes over the physically demanding and strenuous parts of the process, while the operator continues to perform the fine-motor and quality-critical tasks.

The process begins with the robot arm automatically picking up a door from a horizontal stack using an appropriate gripping solution designed for large, flat components. The robot arm then rotates the door in a controlled manner from a horizontal to a vertical position and places it at an ergonomically correct working height. This allows the operator to install components such as hinges, locking mechanisms, and other fittings without having to hold the door or work in awkward and physically straining positions.

During the assembly process, the robot arm acts as a stabilizing unit, ensuring consistent positioning and enabling fine adjustments during hinge alignment. This reduces the risk of incorrect installation. Once the assembly is completed, the robot arm moves the door and places it vertically, organized side by side with other finished doors. This also eliminates manual handling in the final stage of the process.

The overall solution leads to significant improvements in ergonomics, quality, efficiency, and flexibility. The physical workload is reduced, lowering the risk of back and shoulder injuries, while stable positioning contributes to improved assembly quality. Productivity is increased as the operator can work faster and more precisely without interruptions, and the system can be easily adapted to different door types and assembly tasks through software-based adjustments.

Overall, the solution represents a balanced collaboration between human and robot, where the robot arm supports the operator rather than replacing them. This makes the solution particularly suitable for production environments with high product variability and stringent requirements for both occupational health and quality. In this project, the proposed solution is implemented as a minimum viable product (MVP) to demonstrate the core functionality and ergonomic benefits in a realistic assembly scenario.

3. Existing Solutions

Solution	Link/Reference	Relevance to our project	Pros	Cons
Collaborative Robots (cobots)	Example: Universal Robots Line of cobots (UR3-UR30) capable of collaborative operation with humans, widely used in flexible industrial assembly.	Cobots can work safely alongside humans and take over heavy or repetitive tasks.	Reduces physical strain, safe human-robot interaction and it is flexible.	Still expensive. Requires programming and safety validation. It is not tailored to specific door panel geometry.
Industrial assembly automation (traditional robots)	KUKA assembly robots are used for precision tasks and automated screwing/fitting in multiple industries as a flexible automation solution.	Demonstrates how industrial robots automate complex assembly, but mostly for high-volume automated cells.	High precision and speed. Proven in large scale automation	Least flexible for varied/custom tasks. High cost and complexity; requires fixtures and programming.

Ergonomic human-robot collaborative workstations (research)	Research on human-robot collaborative assembly workstations with ergonomic design guidelines to support worker safety and efficiency.	Focus on ergonomic design but general frameworks. Not specific to door panel tasks.	Highlights ergonomic integration methods in collaborative assembly.	Not a specific product. Needs implementation and is mostly conceptual.
Ergonomic collaborative integration in assembly	Case studies and design frameworks showing integration of cobots to reduce ergonomic risk in assembly.	Shows hybrid workstation approaches where robots assist workers in physically demanding tasks.	Demonstrates physical workload reduction and ergonomic benefits.	Generally limited to specific tasks (block picking/gluing). May not directly translate to door panel mounting.
Human-robot ergonomic monitoring & adaptation (research)	Studies on ergonomics in collaborative tasks and adaptive task sharing to distribute workload and reduce human strain.	Highlights advanced approaches to adapt robot behavior based on human ergonomic state.	Offers dynamic ergonomic improvement and context-aware assistance.	Experimental. Not yet widely commercialized and contains complex integration.

While fully automated industrial assembly robots offer high precision and throughput, they are typically optimized for high-volume production with low product variability. As a result, they are poorly suited for assembly tasks where part characteristics vary, operations are unpredictable, and frequent reconfiguration is required. Collaborative robots (cobots) operate in the middle ground between manual work and full automation, providing safe and effective support for the human operator without the need for complex fixtures or complete task automation. In this context, cobots represent a more appropriate solution for the assembly of components that exhibit significant variability.

4. Design and implementation

4.1 System Architecture

The proposed system consists of a collaborative robotic workstation designed to support the mounting of large door panels on industrial machines. The system integrates mechanical, electrical, and software components to enable safe and flexible human-robot collaboration.

The main components of the system are:

- **Collaborative robot arm**, responsible for lifting, rotating, positioning, and stabilizing the door panel.
- **Gripping solution**, designed to securely handle large, flat door panels without causing damage.
- **Control system**, which manages robot motion, communication with the robot controller, and overall interaction logic.
- **Operator user interface (GUI)**, allowing the operator to log in, select door size, initiate robot actions, and confirm assembly is finished.
- **Data management layer (SQLite database)**, used for user authentication and logging when an order is started and finished, providing traceability.
- **Visual feedback system (LED indicators and on-screen status messages)**, used to guide the operator through the correct sequence and display system status.

The robot arm is integrated directly into the assembly area, allowing the operator to work alongside the system. The architecture is designed to be modular, enabling adaptation to different door sizes, hinge configurations, and machine types through software adjustments rather than mechanical redesign.

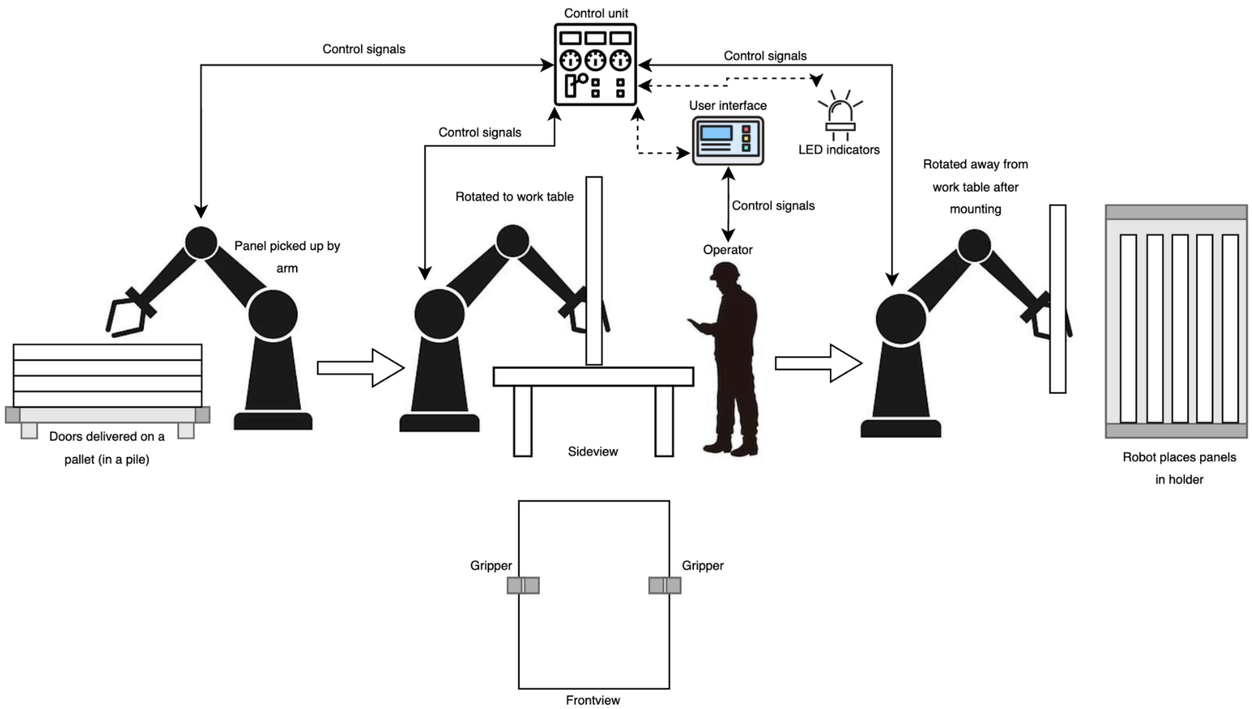


Figure 1: System Architecture

4.2 Control and Flow Logic

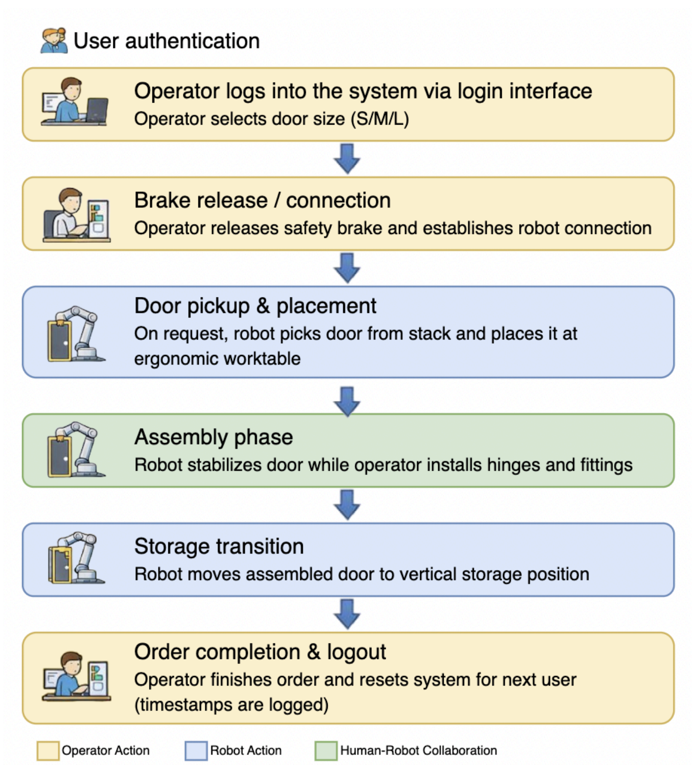
The logic of the system is designed to support a structured and flexible assembly process, where the robot handles physically demanding tasks (lifting, moving) while the operator remains in control of precision and assembly decisions.

The overall process follows the following main steps:

1. **User authentication:** the operator logs into the system through a login interface.
2. **Parameter selection:** the operator selects the door size (small/medium/large), which determines the gripping width and force used by the robot.

3. **Brake release/connection:** the operator establishes the connection to the robot controller and releases the safety brake.
4. **Door pickup and placement:** on request, the robot retrieves a door from the stack and places it at the ergonomic workstation.
5. **Assembly phase:** the robot stabilizes the door while the operator installs hinges and fittings.
6. **Storage transition:** when assembly is complete, the operator commands the robot to move the finished door to a vertical storage position.
7. **Order completion:** the operator marks the order as finished, which records a timestamp and closes the operation.
8. **Logout:** the operator logs out, resetting the interface to the idle state for the next user.

Throughout the process, the operator can pause, adjust, or reposition the door as needed. This semi-automated flow ensures precision and adaptability while maintaining a safe, collaborative environment.



A more intricate flowchart of the process can be located in the repository: Flowchart.

4.3 Design Decisions

Collaborative robot instead of full automation

A collaborative robot (cobot) was chosen over a fully automated industrial robot system to accommodate product variability and production volumes. Full automation would require complex fixtures, advanced vision systems, and frequent reprogramming, leading to high costs and reduced flexibility.

Human in charge

The operator remains responsible for alignment, adjustment, and quality assessment. Tasks such as angles, closing pressure, and fit require human judgment and cannot be reliably automated. The robot therefore supports the assembly, rather than replacing the operator.

Stabilization-focused assistance

Instead of performing the entire assembly task, the robot focuses on holding and stabilizing the door panel. This design choice reduces the physical strain of the task while the operator can complete installations and assembly. This preserves flexibility and minimizes system complexity.

Operator-driven control via GUI

A graphical user interface (GUI) was chosen as the primary method for initiating robot actions and transitions between assembly steps. This preserves human decision-making authority, simplifies integration, and avoids unintended motion. Button-based control was preferred over autonomous sequencing to enable confirmation-based operation and reduce safety risks.

Local database for authentication and traceability

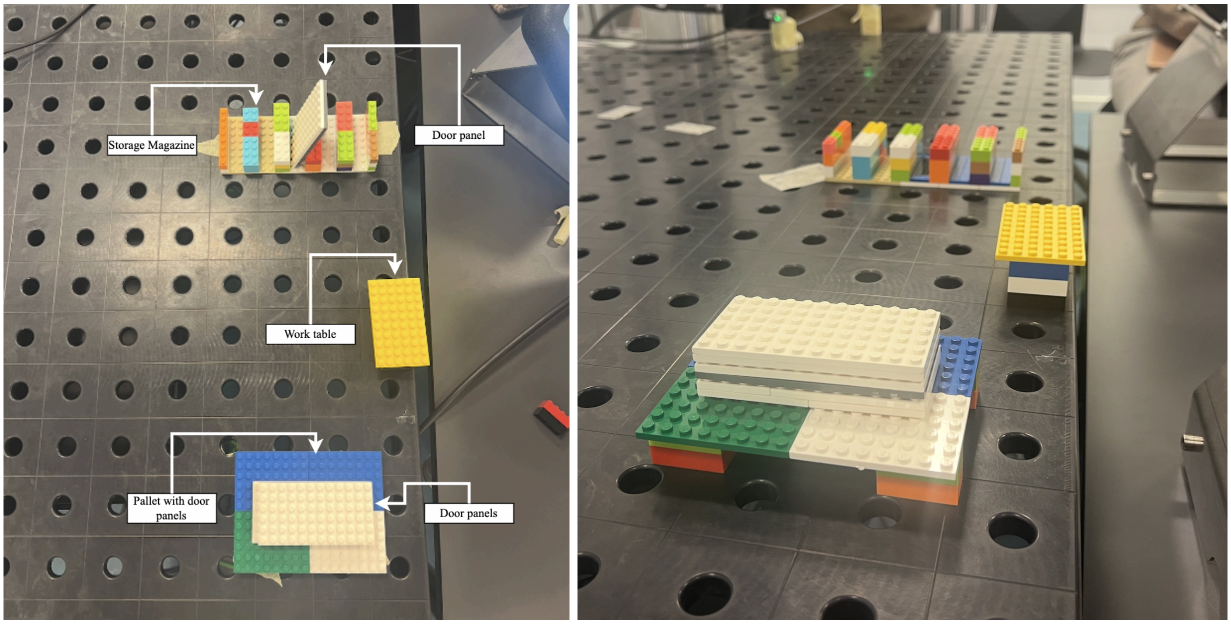
An SQLite database was selected to handle user authentication and to log order start/finish timestamps. This provides basic traceability and accountability without the need for external IT infrastructure. A local database also suits the MVP approach, allowing evaluation of traceability benefits before scaling to more advanced systems.

MVP-oriented implementation

The system is implemented as a minimum viable product (MVP), focusing on the core functionalities such as lifting, positioning and stabilization. By focusing on the essential features, the MVP enables early validation of the concept without introducing unnecessary technical complexities. This approach reduces development time while still allowing evaluation of improvements, usability and workflow integration.

5. Test & Demonstration

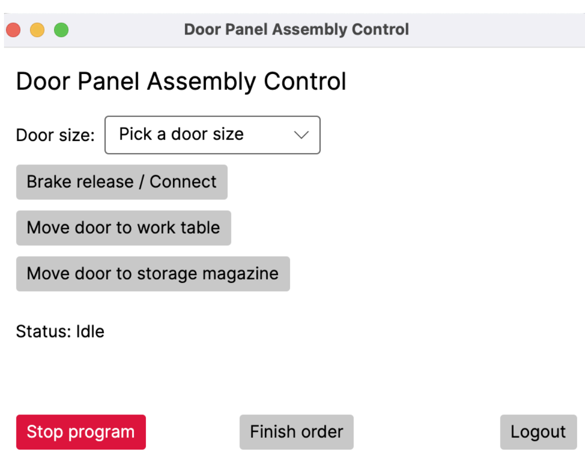
To evaluate the feasibility of the proposed assembly concept, an experimental setup was created in the lab. Since full-scale door panels are impractical for laboratory testing, a scaled LEGO-based representation was constructed. The pallet represented the incoming stack of door panels, the work table represented the ergonomic assembly position for installation, and the storage magazine represented a vertical fixture for completed door panels.

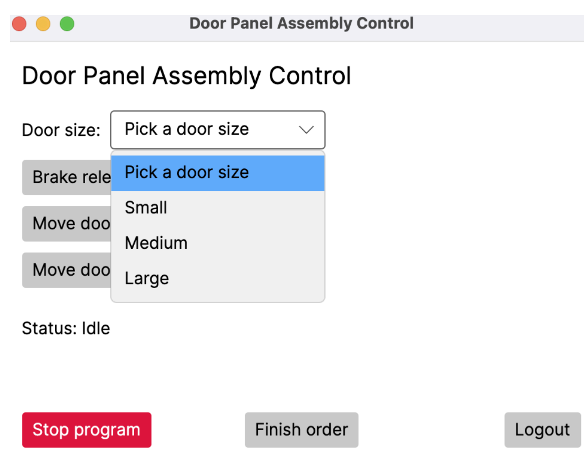


During the initial test, the robot executed the complete cycle across all three stations without pausing for operator interaction. This version of the test served as an initial verification of waypoint definitions, gripper logic and motion path planning. The primary focus at this stage was to confirm that the UR robot could reliably execute the full task cycle and that the geometric model was functional (video link for initial test).

Once the fluid motion version was verified, the setup was modified to support the collaborative scenario, where the robot pauses at the work table for the operator before continuing to storage. A graphical user interface (GUI) was developed using Avalonia (.NET) to mediate control between the operator and the robot. The GUI introduced a drop down menu for selecting door sizes (small/medium/large) and six control buttons associated with the task sequence:

- “Break release / Connect,” initializes communication to the cobot controller and releases the brakes. This button acts as an intentional start/enable action so the robot does not move unexpectedly.
- “Move door to work table,” triggers the robot to pick up the next door panel and place it at the ergonomic work-table position.
- “Move door to storage magazine,” signals that the operator has finished the mounting task and authorizes the robot to move the panel into the storage magazine.
- “Stop program,” works as an emergency button so the operator can stop the program at any time.
- “Finish order,” pressed when sequence is complete to log timestamps and close the order in the database.
- “Logout,” pressed when the operator is finished, resetting the interface for the next user.





The system then records the completion of the assembly and stores both start and end timestamps in the database, enabling traceability and process documentation. Such logging is relevant in a production context, as it allows cycle times to be measured and potential bottlenecks to be identified. Timestamp data can also be used to estimate delivery times and provide customers with more accurate time frames. In addition, associating each finished order with a specific operator supports accountability, quality documentation, and continuous improvement initiatives.

Table: Accounts

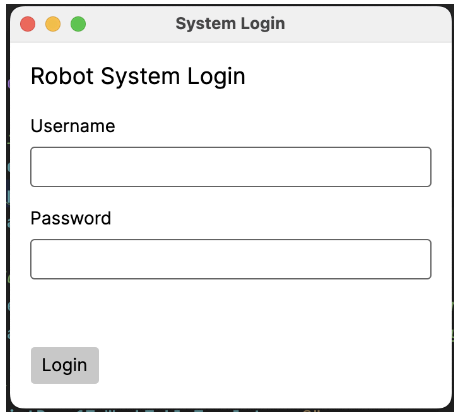
	Username	Salt	SaltedPasswordHash	isAdmin
1	Laerke	BLOB	BLOB	1
2	Sophie	BLOB	BLOB	1
3	Sofie	BLOB	BLOB	0
4	Ida	BLOB	BLOB	0

Table: OrderLogs

	Id	Username	DoorSize	StartedAt	FinishedAt
1	1	Sophie	Small	2026-01-15 11:01:55.349606	2026-01-15 11:02:26.776203
2	4	Ida	Medium	2026-01-15 11:09:19.427963	2026-01-15 11:09:43.173335
3	5	Laerke	Large	2026-01-15 11:10:23.25267	2026-01-15 11:10:44.580694
4	6	Sofie	Small	2026-01-15 11:10:59.054394	2026-01-15 11:11:20.427787

With this GUI, the test setup changes from a fully automated cycle to a collaborative assembly workflow. The robot still handles the heavy lifting and positioning, but the operator decides when each phase begins and can interrupt motion at any time. The “Stop program” button is particularly important from a safety perspective, as it gives the operator a simple and direct way to stop the robot any time in the cycle.

As an additional safety and security measure, access to the robot control interface was gated behind a simple login page. Before the operator is allowed to interact with the GUI and send commands to the robot they must enter valid credentials. Only after successful login does the GUI display the control buttons. This prevents unintentional or unauthorized use of the robot. (final demonstration video link).



6. Discussion

6.1 Goal Evaluation

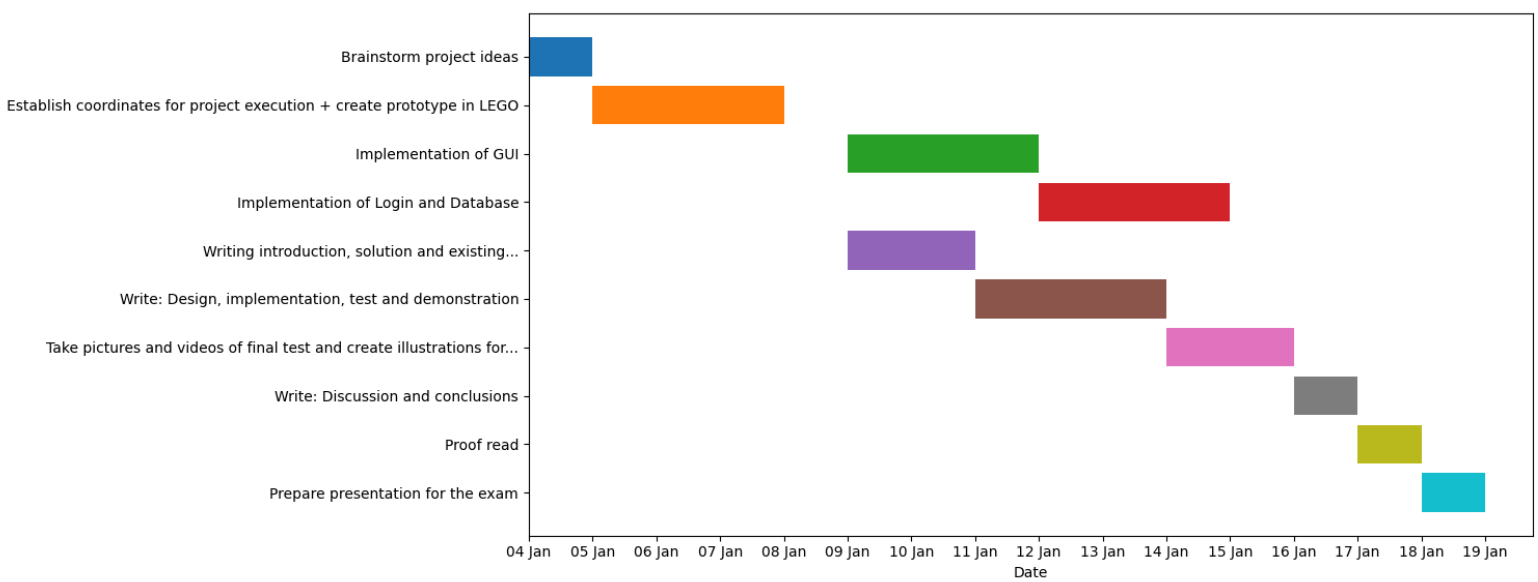


Figure 3: Project timeline (Jan 4- Jan 19)

The project timeline demonstrates the plan and execution according to a set of predefined milestones, all of which were successfully achieved within the allocated timeframe, as illustrated in the project timeline. The work began with identifying and conceptualizing, followed by creating the coordinates to emulate the functions, and the creation of a LEGO-based prototype to validate the physical setup. The next milestone focused on implementing a graphical user interface as well as login and database functionality. Alongside working on writing the introduction, solution, and existing solutions sections of the report. The later phases concentrated on system design documentation, testing, demonstration, and the creation of visual material. Finally, the last milestone was concluded with discussion, proofreading, and preparation for the exam presentation. All milestones were completed within the planned timeframe, indicating effective planning and coordination throughout the project.

6.2 Limitations

The model demonstrates a functioning proof of concept. Despite successfully illustrating the core idea, several limitations must be acknowledged. The system represents a Minimum Viable Product (MVP) developed within a limited timeframe and with restricted resources. As a result, the implementation focuses on validating the ergonomic assistance concept rather than delivering a fully industrialized or production-ready solution.

One key limitation is the level of automation and adaptability. While the robot arm is capable of stabilizing and positioning the door, the actions rely on manual input and predefined sequences. The system doesn't currently adapt dynamically to variations in door size, weight, or operator behavior (such as aligning the door to the operator's wishes). In the current model, the system only contains four GUI input options, which are only applicable manually. Therefore, more advanced sensing and control strategies, such as force feedback or vision-based adjustment, were outside the scope of the project.

Additionally, safety mechanisms are relatively simple. Visual guidance is currently limited to basic LED signals, which are sufficient for demonstrating the concept but may not provide enough contextual information for more complex assembly tasks. Furthermore, the login system is implemented using a basic credential structure with two administrator and two standard user accounts. While this ensures controlled access to the system, it does not yet support more advanced role management or scalable user authentication.

Finally, testing was carried out under controlled conditions with a limited test scenario. The prototype uses LEGO components to represent doors, the layout, and the workstation. While suitable for conceptual validation, long-term reliability, performance under varying conditions, and overall robustness were not evaluated. Consequently, the test results should be understood as demonstrating hypothetical feasibility rather than definitive operational performance.

Overall, these limitations reflect deliberate decisions to focus on demonstrating the core concept. They also indicate clear directions for future development if additional time, resources, or industrial-grade components were available.

6.3 Future Improvements

If more time and resources had been available, the solution could be further developed. This includes integrating sensors, camera-based recognition of door panels, and a more advanced user interface. With a camera system, the height and width of the door panels could be detected automatically, allowing the gripper to adapt its grip to the specific door type without manual input.

Another improvement would be the implementation of a more advanced GUI, enabling the operator to rotate, adjust, and change the height from the floor through user input. This would provide improved ergonomics and greater flexibility, allowing the operator to perform the assembly task more effectively. To increase the industrial realism of the project, the door panels could also be manufactured using materials similar to those used in real production environments.

Finally, the quality of the project could be further improved by integrating sensors to register completed door panels as soon as they are placed in the storage magazine. Once a door is detected as fully assembled, the sensor can send a signal to the MES system, which automatically updates the production status and communicates this information to relevant departments such as sales and finance. This integration would increase the level of automation and create a more coherent and efficient production flow.

7. Lessons Learned

7.1 Programming

During the first part of the 10-credit course (13 weeks), we were introduced to the theoretical foundation within programming, control systems, and automation. In the second part of the course (3 weeks), we applied this theory in practice through project work.

The practical part allowed us to translate our theoretical knowledge into concrete solutions. Working with a collaborative robot arm strengthened our understanding of how hardware, software, and human interaction must be coordinated. At the same time, the project highlighted the importance of structured and well-documented programming in the development of functional and secure automation systems.

7.2 Industrial Automation

Working with industrial automation highlighted the complexity of integrating mechanical components, control logic, and human interaction into a cohesive system. One key lesson was the importance of defining clear system boundaries and responsibilities between the robot, the control system, and the operator, as well as understanding how automation can support human workers by improving productivity and safety. Even in a simplified laboratory setup, coordination between these elements proved critical for achieving safe and reliable operation.

The project also reinforced that industrial automation is not solely about maximizing autonomy, but about finding an appropriate balance between automation and human involvement. Designing the robot as an assisting unit rather than a fully automated system demonstrated how collaborative automation can improve ergonomics and task efficiency without sacrificing flexibility. Working with a simplified prototype further illustrated how automation contributes to improvements in safety, robustness, and standardization.

7.3 Collaboration

Collaboration within the group worked well throughout the project. With four members, we maintained open and constructive communication, and everyone actively contributed ideas and technical input. Programming with multiple people at a single computer proved challenging, so we chose to take turns coding while the other group members focused on report writing, documentation, and other project tasks. This approach ensured efficient use of time and a smooth workflow. Clearly defined tasks and continuous knowledge sharing contributed to a well-functioning collaboration and a cohesive final result.

8. Conclusion

This project has demonstrated how a collaborative robot can be integrated into an assembly process to support the handling of large and heavy door panels. By focusing on a human–robot collaborative approach rather than full automation, the solution addresses both ergonomic and practical challenges while maintaining flexibility and operator control. The developed system shows how a robot arm can take over physically demanding tasks such as lifting, rotating, and positioning, while the operator remains responsible for precision work and decision-making.

Through the implementation of a minimum viable product, the core concept was successfully tested in robotlab. The system architecture, control logic, and user interface together form a coherent solution that enables safe and structured interaction between the operator and the robot. Even though the prototype was simplified and tested using a scaled setup, the results indicate that the concept is feasible and relevant for industrial applications with high product variability.

Overall, the project has strengthened the understanding of how programming, industrial automation, and system design come together in a real-world context. It also highlights the potential of collaborative automation as a balanced solution that improves process efficiency while preserving human involvement. While there are clear limitations due to time and resource constraints, the project provides a solid foundation for future development and further industrial implementation.

9. Use of Artificial Intelligence (AI)

Throughout the project, Artificial Intelligence was integrated as a supportive tool for understanding complex material, improving grammar, sourcing information, and creating visual content. During the early phase, ChatGPT aided in brainstorming, structuring ideas, and outlining the primary themes and suggested strategies for addressing the assignment. AI further contributed to strengthening the written text by enhancing its grammar, structure, and technical vocabulary.

Moreover, AI contributed to the research process by assessing source validity and suggesting relevant webpages to support efficient information gathering. It was additionally utilized to review code and offer structured solutions in situations involving errors or uncertainty regarding the appropriate method.

Lastly, AI contributed to the creation of visual imagery used in the project. In general, Artificial Intelligence functioned as an effective support tool, improving productivity, workflow, and speed. It helped keep the process organized and structured, while ensuring the work itself remained independently conducted.

10. Task Allocation Table

Main Area	Subtasks	Primary Responsible	Supporting Contributors
Introduction & Problem Definition	Background, problem framing, motivation	Lærke	All
Proposed Solution	Concept development, process description, scope definition	Ida	All

Existing Solutions	Literature review, comparison table, relevance analysis	Sophie	All
Design and Implementation	System Architecture, Control and Flow Logic, Design Decisions	Sophie & Sofie	All
Test & Demonstration	Test Setup, Test Results, Demonstration (photos & video)	Sophie	All
Discussion	Goal Evaluation, Limitations, Future Improvements	Lærke & Ida	All
Lessons Learned	Programming Industrial, Automation, Collaboration	Lærke, Sofie & Ida	All
Conclusion	Summary, reflection, final alignment with goals	Sofie	All
Coding	Robot control logic, GUI implementation, system integration	Sophie, Lærke, Sofie & Ida	All