Safe collaborative framework for compliant industrial manipulators

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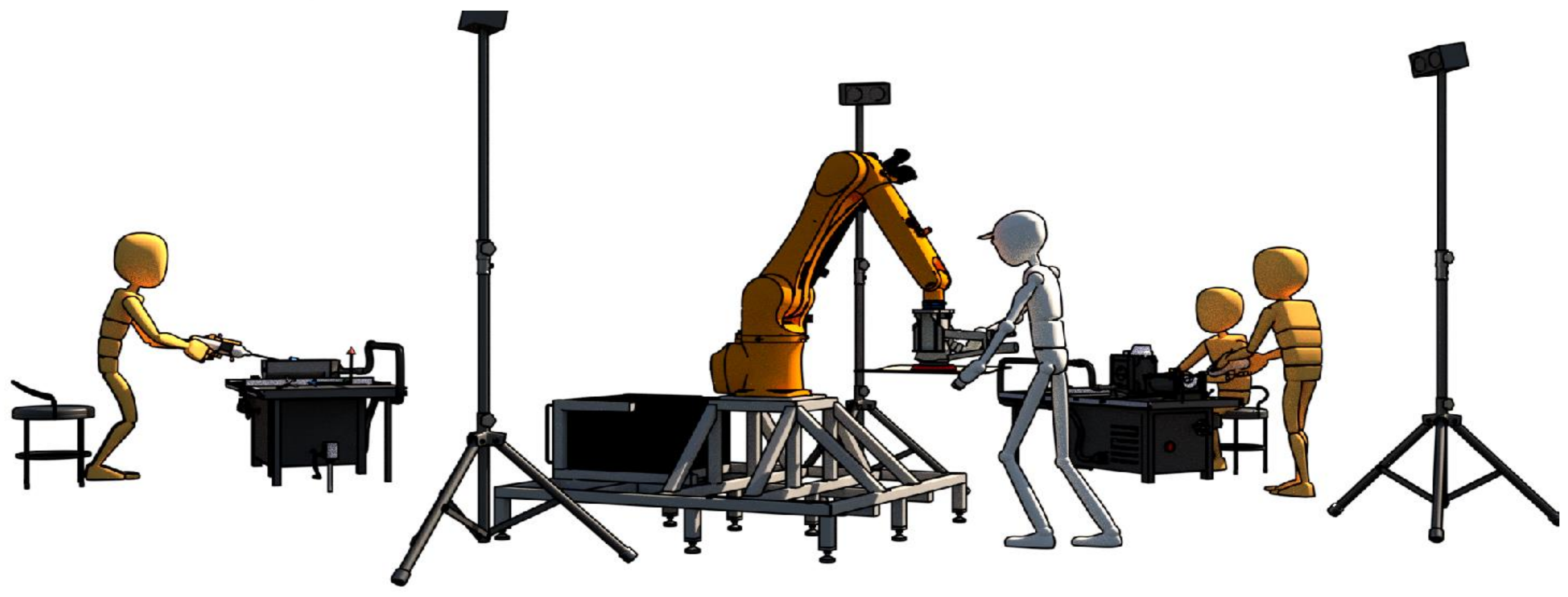
1. Introduction

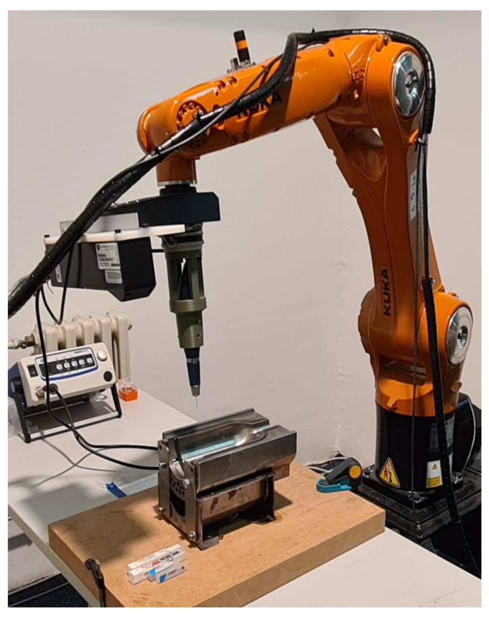
Industrial manipulators have undoubtedly become the workhorse of modern industry, usually performing repetitive and hazardous tasks that require high precision. The rapid development of the industry raises the problem of the flexibility of such systems, since any change in the environment requires a significant engineering effort to adapt. Similarly, there is a significant gap when it comes to delicate tasks that still rely on the manual skills of operators. All these challenges opened a new research field in robotics, collaborative robots. However, it soon became clear that collaborative robots lack not only physical capabilities but also economic justification for a truly disruptive impact on modern factories. With this in mind, the goal of this research is to develop a safe collaborative framework built on top of standard industrial manipulators.



2. Problem Description

The main advantages of collaborative manipulators arise from the fact that the robot is torque controlled. This allows the robot to sense contact with the environment, but also to be programmed by demonstration. Since the off-shelf available collaborative manipulators lack the payload, accuracy, and precision needed in industry, this research aims to enable standard stiff position controlled manipulator to behave like collaborative robot while taking advantage of the main benefits of industrial manipulators.

This research addresses following issues:
- Sensing the contact with the environment
- Robot compliance to both soft and rigid environments
- Safe collaboration between human and robot
- How to enable fast and easy programming by demonstration

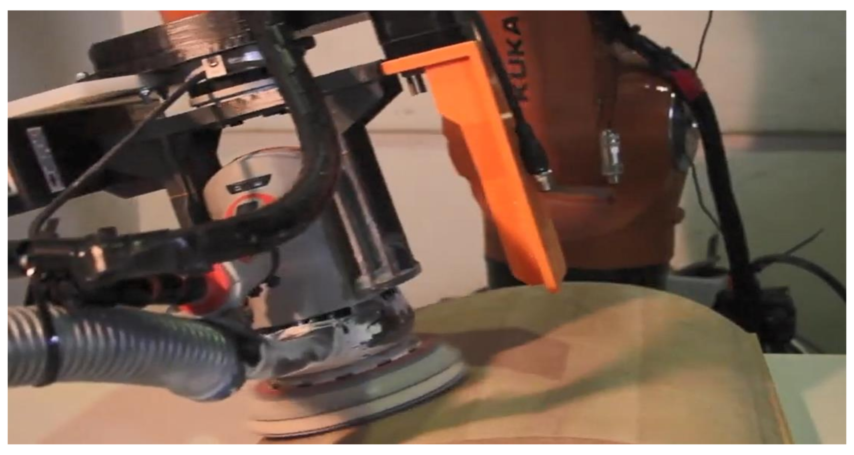


3. Methodology

To develop a safe collaborative framework based on industrial manipulators, this research includes the following activities:
- Development of a **compliance control system** for industrial manipulators
- Compliance control system for **soft and rigid contacts**
- **Safe collaborative human-robot interface**
- **Programming by Demonstration**
  - Guiding end-effector of the robot
  - Expert demonstration recording system
- Safety aspects related **to ISO/TS 15066**
- **Experimental verification of characteristic industrial applications** such as micro drilling, plastering and polishing

4. Results

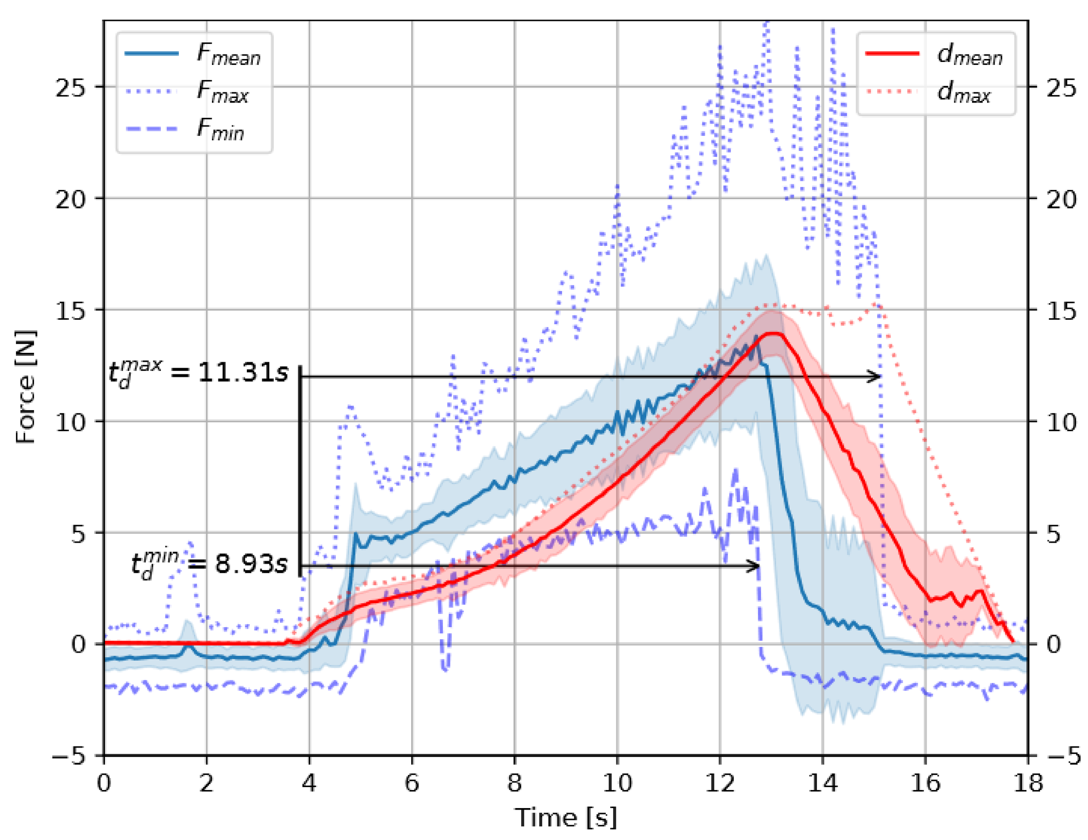
The developed algorithms provide **a compliant behavior** of the industrial manipulator in direct contact with the environment. This is indirectly used to **program the robot by demonstration**, where a human operator can guide the robot's end-effector and teach it to perform a specific task. Since guiding the robot's end-effector sometimes pushes the operator out of his comfort zone and significantly affects the demonstration, **a special recording system for delicate industrial processes** has been developed. The system is able to record the position and velocity of the trajectory demonstrated by the expert, but also the force and torque applied to the tool.



Delicate sanding

Deep-micro-hole drilling

Experimental verification in industrial scenarios:
- Plastering and delicate sanding of complex-shaped surfaces used in the aircraft manufacturing industry
  - Increase of **the robot treated surfaces by up to 60 %** using the 6DOF compliance control system
  - Increase of **the robot treated surfaces by up to 96 %** using the programming by demonstration approach
- Deep micro-hole drilling and polishing cast iron moulds used in glass container production
  - On-site recording of the expert demonstration
  - Increase of **the number of holes drilled with the robot by almost four times** for some mould types



The graph on the left shows the drilling force and depth profiles achieved by the robot. To show consistency of the proposed system, a 95% confidence interval is shown for each profile, along with the maximum and minimum values.

5. Conclusion

In summary, this research enables the use of industrial manipulators available through the industry for collaborative tasks. Suitable sensing equipment and specially developed algorithms built on top of standard industrial manipulators provide a safe collaborative environment for human-robot interaction. Special attention was paid to programming by demonstration approaches that showed significant benefits in experimentally validated industrial scenarios.

Acknowledgments

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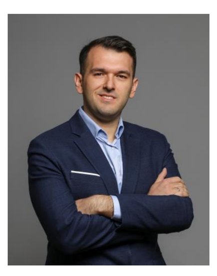

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