Development of Robotic Hands for Grasping of Deformable Objects

Felix Hundhausen, Moritz Moosmüller, Daniel Ruffler and Tamim Asfour

***Abstract*— Manipulating deformable objects such as textiles remains a key challenge in robotics, requiring dexterous hardware and tactile sensing. This paper presents the design and development of an anthropomorphic five-finger robotic hand for deformable object manipulation. The fingers are realized using a four-bar mechanism to replicate human finger trajectories. We compare two distinctive thumb designs with two actuated degrees of freedom to allow pinch grasps. Each finger incorporates an embedded tactile sensing system without the need for finger internal cables. A hand-internal embedded system is designed for real-time control and sensor data processing. To evaluate the performance of the hand design in grasping deformable objects, a prototype is currently being built.**

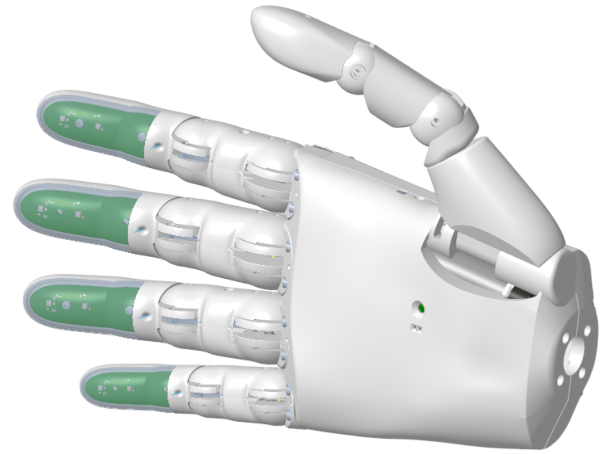

Fig. 1: The first design concept of the ROMANDIC-hand.

I. INTRODUCTION

While industrial solutions for manipulation of soft and deformable objects rely on task-specific grippers, anthropomorphic hands aim to provide greater versatility. Our approach aims at developing a hand in the context of humanoid robotics or prosthetics that allows to reliably handle soft objects, especially cloth-like objects, as it is frequently required in everyday life.

We present the current state of development of an anthropomorphic robotic hand (Fig. 1) developed within the ROMANDIC project for deformable object manipulation. The hand is designed to allow pinch grasps and provides feedback for dexterous manipulation. The hand is intended for integration on KIT humanoid robots, such as ARMAR-7, while remaining applicable to other robotic platforms.

II. STATE OF THE ART

In several fields, researchers propose highly customized grippers for handling soft objects, including the manufacturing industry, medical surgery, food processing, and daily living activities (Gu et al. 2023). For fruit handling, for example, so-called *Fin Ray Fingers* (e.g. Elgeneidy et al. 2019, An et al. 2025, Varghese et al. 2025) are widely used. For garment handling, pneumatic, electrostatic, or intrusive grippers are common (Wang et al. 2023). However, the use of soft fingers provides several advantages, including higher grasping accuracy and force (Wang et al. 2023).

In contrast to the well-studied field of rigid object manipulation, handling deformable objects requires continuous perception and control of the object's state during interaction. This introduces additional challenges in perception, modeling, and manipulation, as described in (Gu et al. 2023).

III. SYSTEM DESIGN

The ROMANDIC hand is an anthropomorphic five-finger hand designed for manipulation tasks, including pinch grasps, sliding motions for edge tracking, surface contact for flattening, and in-air folding operations. For this purpose, the four fingers are integrated with a four-bar mechanism each, and three fingers are coupled for underactuation using a variant of the TUAT/Karlsruhe mechanism (Fukaya et al. 2000), further the design

The authors thank Marlon Braun and Omer Ben Moshe for their contributions to this work.

The research leading to these results has received funding from the European Union's Coordination and Support Actions programme under grant agreement No 101159522 (ROMANDIC).

This work has been supported by German Federal Ministry of Research, Technology and Space (BMFTR) under the Robotics Institute Germany (RIG).

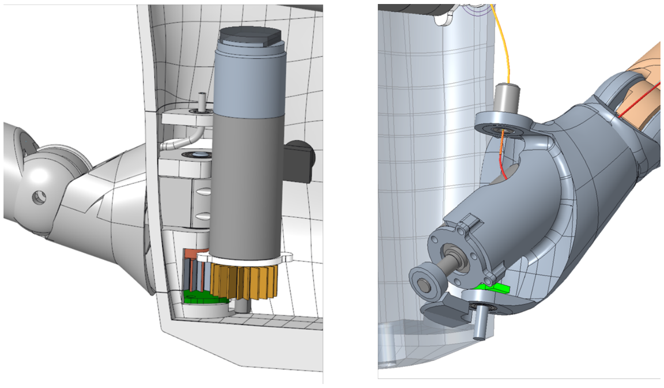

Fig. 2: Conceptual model of the two compared thumb designs. Left: Spur gear transmission; right: Hypoid gear transmission

also includes a two DoF thumb mechanism. For visual perception a multi-zone ToF sensor and an in-hand RGB camera are integrated.

A. Finger Design

The four-bar mechanism is optimized to replicate human kinematics, following the most common grasping trajectory observed in over 90% of grasps (Kamper et al. 2003), and achieves a near-identical trajectory (99^{th} percentile). Tendon-driven underactuation with torsion springs provides coordinated multi-joint flexion and passive extension, minimizing actuators while preserving dexterity. The distal phalanx integrates tactile sensors and is covered with soft silicone for compliant, high-friction contact. A novel data and power interface for the tactile sensor system utilizes the two parallel torsion springs required for finger extension additionally for Power Line Communication (PLC) and thereby eliminates fragile cables and ensures reliable and robust sensor data transmission at a data rate of 30 kbit/s. In initial tests no failures of data or energy transmission were observed.

B. Thumb Circumduction Design

We investigate two actuation variants as shown in Figure 2:

Variant 1 - Hypoid gear transmission: Crossed-axis hypoid gears enable integration of the actuator within the thumb body. This configuration allows for a natural circumduction axis, facilitating diverse grasp types and enabling an efficient use of space. However, the solution increases mechanical complexity with several custom-made parts, imposes stress on the motor wiring, and slows maintenance. Due to actuator positioning, the size and power of the actuators are limited.

Variant 2 - Spur gear transmission: Parallel-axis spur gears provide a robust and reliable solution with higher torque capacity and resistance to dynamic loads. The actuator is angled, slightly increasing the required volume in the hand. Standard components can be utilized, and the design greatly benefits maintainability while reducing complexity.

For the ROMANDIC hand, reliability is prioritized. Therefore, variant 2 will be used for prototyping.

C. Tactile Sensor System

We designed two tactile sensing systems to evaluate different sensing modalities optimized for deformable object manipulation. The data from the sensor module integrated in the distal finger segment is read by a microcontroller and sent to the main embedded system via a PLC interface.

a) Barometric Pressure Sensing: For measuring finger contact forces, we employ two MEMS sensors (Bosch Sensortec BMP384) integrated into soft, silicone-covered fingertips. Each sensor provides a resolution of 16 bits @ 200 Hz data rate. In first experiments, we obtained a high sensitivity regarding the detection of normal forces, however for the current version, the sensitivity is not uniform across the finger surface. Future design iterations will increase the size of the tactile matrix to address this limitation.

b) Optical Slip Detection: Further, we implement an optical slip detection sensor that allows the hand to detect incipient grasp failures before objects are dropped. We evaluated the PixArt PAT9125 optical motion sensor that allows to detect objects in a range of 1–30 mm. On metallic surfaces the sensor provides excellent performance. For textile and diffuse surfaces, it does not allow reliable tracking.

IV. CONCLUSION AND OUTLOOK

We have presented the ROMANDIC hand, an anthropomorphic five-finger robotic hand designed for manipulation of deformable objects. Key innovations include optimized finger kinematics, a novel spring-based electrical connection eliminating fragile cabling, integrated tactile sensors, and a robust thumb mechanism enabling versatile grasping.

The hand is currently in the prototyping phase; future work will focus on design optimization based on experiments and the development of manipulation strategies for deformable objects.

REFERENCES

An, Byeongchan, Taeyong Choi, and Uikyum Kim (2025). “Linkage integrated fin ray gripper capable of safe adaptive grasping for tomato harvesting”. In: *Computers and Electronics in Agriculture* 232, p. 110118.

Elgeneidy, Khaled, Peter Lightbody, Simon Pearson, and Gerhard Neumann (2019). “Characterising 3D-printed soft fin ray robotic fingers with layer jamming capability for delicate grasping”. In: *2019 2nd IEEE International Conference on Soft Robotics (RoboSoft)*. IEEE, pp. 143–148.

Fukaya, Naoki, Shigeki Toyama, Tamim Asfour, and Rüdiger Dillmann (2000). “Design of the TUAT/Karlsruhe humanoid hand”. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. Vol. 3. IEEE, pp. 1754–1759.

Gu, Feida, Yanmin Zhou, Zhipeng Wang, Shuo Jiang, and Bin He (2023). “A survey on robotic manipulation of deformable objects: Recent advances, open challenges and new frontiers”. In: *arXiv preprint arXiv:2312.10419*.

Kamper, Derek G, Erik G Cruz, and Michael P Siegel (2003). “Stereotypical fingertip trajectories during grasp”. In: *Journal of neurophysiology* 90.6, pp. 3702–3710.

Varghese, Finny, Fernando Auat Cheein, and Maria Koskinopoulou (2025). “Finite element optimization of a flexible fin-ray-based soft robotic gripper for scalable fruit harvesting and manipulation”. In: *Smart Agricultural Technology* 11, p. 100899.

Wang, Jianping, Jinzhu Shen, Xiaofeng Yao, and Fan Zhang (2023). “Research progress of automatic grasping methods for garment fabrics”. In: *International Journal of Clothing Science and Technology* 35.6, pp. 997–1022.