PROGRESS IN THE DEVELOPMENT OF ANTHROPOMORPHIC FLUIDIC HANDS FOR A HUMANOID ROBOT

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Abstract. New lightweight anthropomorphic hands are presented for application in a humanoid robot. These hands possess 13 to 15 degrees of freedom and are driven by flexible fluidic actuators that are integrated in the finger joints. The compact design of the hands contains a pressure unit that is housed in the metacarpus. Alternatively, the pressure unit can be mounted externally, which leads to a further mass reduction. The new design and its performance shall be described in the present article.

1. Introduction

Humanoid robots that are designed to help and assist humans have to complete various tasks. Under the Collaborative Research Project 588 "Humanoid Robots - Learning and Cooperating Multimodal Robots" [1] (Fig. 1), a new anthropoid mobile robot is being developed. An essential part of this research project is to develop lightweight and versatile hands. These hands are to allow stable grasping with an optimized grasping pattern and manipulation of a variety of different objects. Therefore, it is reasonable to mimic the morphology and functionality of a human hand as closely as possible.

In the past decades, many robotic research groups designed fascinating multi-articulated robot hands with several independent degrees of freedom (DoFs) [2-11]. Usually, the actuators were housed at the forearm, but advancing miniaturization has led to hand designs with actuators integrated in the hand [3,8,10]. Different driving principles can be found in the robot hands designed. Some are driven by linear actuators [3,8], others by gearwheel motors [5,6], pneumatic or hydraulic cylinders [4], or shape memory alloy wire (SMA) [9]. However, most robot hands with several DoFs have a relatively high mass resulting from the components used, and a powerful robot arm is necessary to move the hand dynamically. Additionally, systems for the prevention of collisions are indispensable in man-machine cooperation.

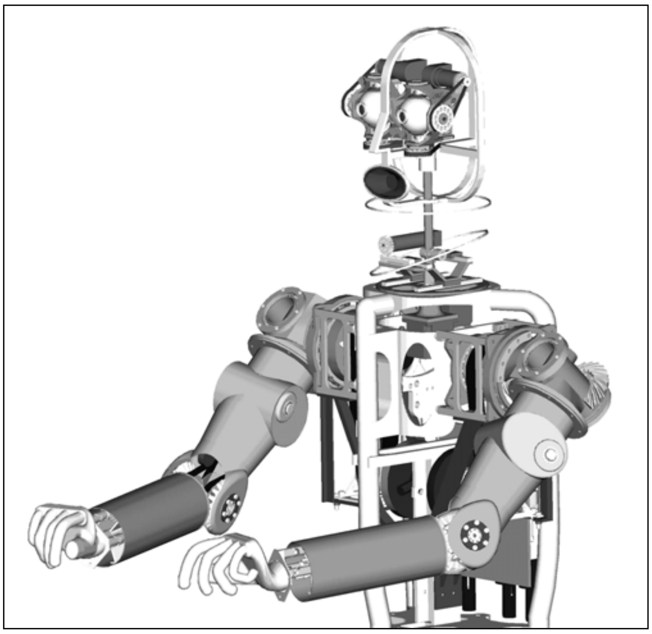

Fig. 1. CAD model of the Humanoid Robot with lightweight humaniform arms and hands. (© MKL, University of Karlsruhe, Germany).

2. Design Requirements

For use in a humanoid robot, the design of robot hands has to comply with the following requirements:

- Light weight

The weight of a robot hand should be as low as possible, because the moments acting on the robot arm moving the hand are reduced in favor of the maximum object weight that can be handled. A second important aspect is that the effect of collision accidents with the user is reduced by a robot with a lower mass, as the impetus is reduced.

- High functionality/ dexterity

Differently sized and shaped objects must be grasped stably by the hands and sufficient independent DoFs must be integrated in the hands for manipulation.

- Compactness

All components necessary to drive an anthropomorphic robot hand should be accommodated in the hand to ensure compatibility with different robot arms.

- Robustness

Humans, who depend on the aid of a humanoid robot, need a robust system to be accepted. The design should be as simple as needed, but as effective as possible. Maintenance can be simplified by a modular design concept of the hands.

- Grasping force

The grasping force varies from hand to hand and depends on several factors. From the technical point of view, grasping force depends on the contact area between the hand and the object grasped the friction coefficient and compliance of the hand surface material, and the object and geometry of the hand. But it also depends on the task the hand is to perform. In hands that are able to conform to the shape of an object (adaptive grasping), the grasping forces required are lower [12].

3. Mechanical Design, Performance and Testing of the Hands

The new hands use the same drive principle as the formerly presented robot hand [14], but most components have been reengineered to meet the requirements mentioned above. The mechanical design can be divided into four parts: The mechanical framework, the actuators, the pressure unit, and the sensors. A detailed description of the control strategy is given in [14, 15]. The three sensor systems (joint angle, contact force, and fluid pressure) are presented in [15].

3.1. *Fluidic actuators*

The hands are driven by 8 flexible fluidic actuators [16] that are integrated in the finger joints (Fig. 2). The actuators expand during inflation and generate the flexion movement of the digits, whereas the extension movement is performed by deflation and the assistance of a return spring.

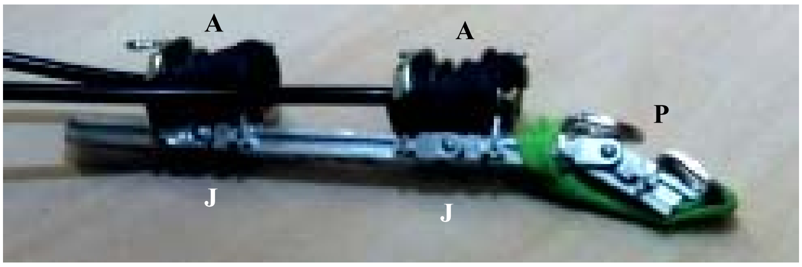

Fig. 2. digit with two fluidic actuators (A) integrated to the joints (J), and one passive joint (P) with return spring.

Every digit of the hand has an active base joint that can be flexed up to 80°. The index and middle finger additionally have a middle joint The ring finger and the small finger either have also an active middle joint, or a passive joint (Fig. 3). The thumb design differs from that of the other fingers. The base joint of the thumb is close to the wrist of the hand and the orientation is perpendicular to the middle joint, which allows to perform opposition movements. From the index to the small finger, the digits have an additional passive base joint so that they can be moved laterally with increasing force from a neutral position in a range of 30°. The joints' lateral movement is limited by a stop unit that ensures stable holding of heavy objects.

The total number of DoFs is 13 to 15; 8 to 10 of them are active and independent and 5 DoFs are passive. Compared to the first fluidic hand [13], the number of active DoFs has been reduced, because the same grasping patterns can be performed, whereas energy consumption and weight have been reduced noticeably. The design of the actuated joints is identical, which simplifies the maintenance and reduces the production costs.

Soft silicone rubber pads with a high coefficient of friction prevent slipping of the objects.

3.2. *Mechanical framework*

For the framework of the hand, a modular design was chosen that is made of high-tensile-strength aluminum. It is connected with the robot arm via a 2 DoF passive joint (Fig. 3 (D)) that allows for flexion/extension and adduction/abduction movements. The framework also houses the pressure unit (B in Fig.3) and the microcontroller.

All finger joints and actuators consist of identical parts that are connected with each other and with the metacarpus via aluminum "bones" of varying lengths. Different hand sizes and hands with more than 10 active DoFs can be designed using this modular structure. The weight of the skeletal framework, including 8 fluidic actuators, the passive wrist joint and the elastic finger pads, is 243 g.

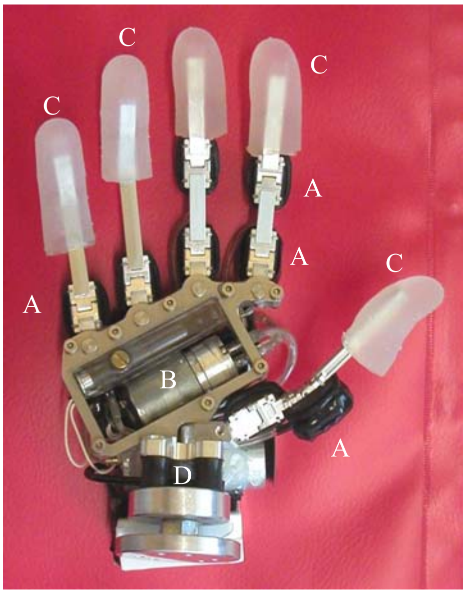

Fig. 3. Humanoid Robot hand with 8 fluidic actuators (A), integrated pressure unit (B), soft finger pads (C) and a passive wrist joint (D)

3.3. ***Hydraulic pressure unit***

The hydraulic pressure unit of the hand consists of an outer gear pump that generates a pressure of up to 8 bar, a reservoir, and 8 microvalves (Fig. 3). It can be operated with 6 to 12 volts from a battery or from an external power supply. The total mass of the hydraulic pressure system is 140 g and can be integrated in the envelope of the hand, if a compact robot hand is needed. It can also be mounted externally (Fig. 4), which results in a displacement of the center of the mass relative to the torso. The pressure unit is controlled by an Infineon C164CI microcontroller. The drives of the valves and micropump are combined on one small multilayer circuit board. Data transfer between low-level control and the higher level is accomplished by a serial RS232 interface or bluetooth technology for wireless data transmission between PC and PDA.

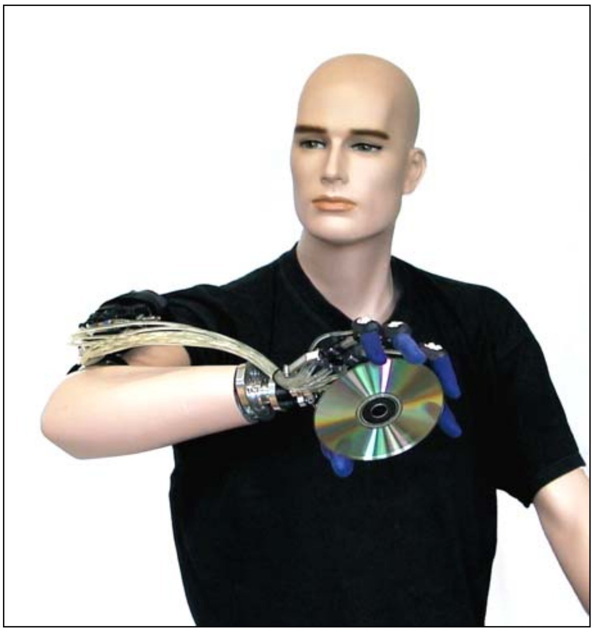

Fig. 4. Manikin wearing a fluidic hand with external pressure unit at the upper arm. The opening span of the hand of 150mm allows for grasping large objects .

3.4. ***Performance***

The tangential grasping force resulting at the tip of a single finger depends on the operating pressure and increases by approximately 1.1 N with a pressure increase of 1 bar. The maximum force of 7.8 N is reached at 7 bar operating pressure. This allows for holding a cylindrical object with a mass of 110 N in a hook grasp [17]. As the hands are able to conform to the shape of an object due to multiarticulation, inherent compliance of the fluidic actuators, and the elastic finger pads, the contact force is distributed over a large contact area and the grip force required for holding an object is reduced [12].

The characteristics of flexible fluidic actuators and the fraction of the spring element are given in Fig. 5. With decreasing filling pressure, the moment of the actuator is reduced by the spring element. The fraction of the spring element is 33% at an angle of 44° and 2 bar filling pressure and decreases to 13% at 6 bar.

This property is beneficial, as the moment of the actuators also decreases with the flexion angle, which results in a higher moment. The moment of the actuator decreases more than the moment of the return spring. Consequently, the moment fraction of the return spring is maintained also at a higher flexion angle. At an operating pressure of 6 bar, the moment fraction of the return spring is 10.4% and 16.2% at 30° and 70° flexion, respectively.

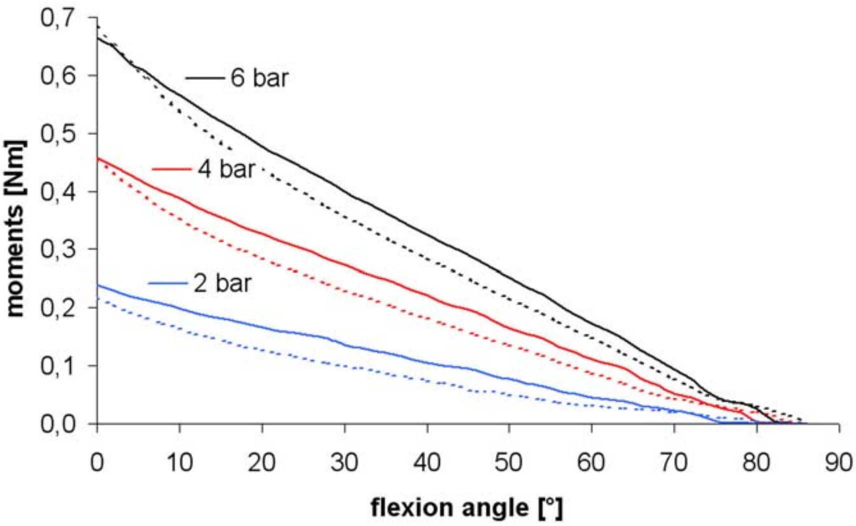

Fig. 5. The moment characteristic of a flexible fluidic actuator at three different filling pressures (2,4,6 bar), (solid lines) and the influence of the spring element (dotted lines).

3.5. *Mechanical testing*

Each component of the hands and the complete system were tested for their mechanical stability. To optimize the stability of the digits, for instance, the mechanical construction was first simulated using the FEM tool CATIA™. External loads on the joints, such as traction, flexion, and torsion, were simulated.

In the simulation, the joint is loaded with a traction force of up to 420 N. The highest stress of 419 N/mm² appears at the junction of the joint lever and the component that contains the flexible fluidic actuator (Fig. 6), but only plastic deformation was found for this component. In contrast to this, fractures were detected in the clamping element (with a stress of 335 N/mm²), axle bearing (230 N/mm²), and the aluminum joint connector

(339 N/mm²) (Fig. 7). Consequently, the materials of these components were changed and reinforced to withstand higher loads.

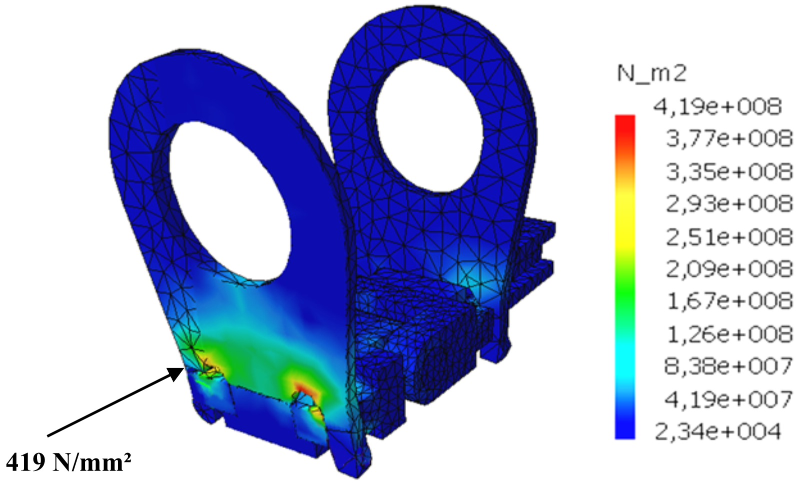

Fig. 6. FEM simulation of stresses on the joint.

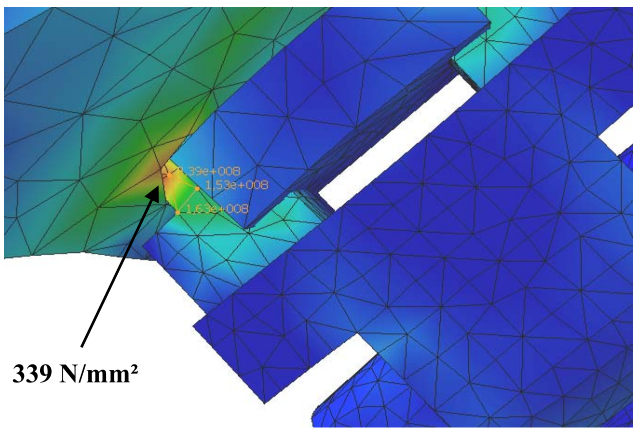

Fig. 7. FEM stress simulation. Detail of the joint connector.

In order to verify the results of the simulation, traction experiments with two real parts were performed and the results compared with each other. In a tensile test of the first joint, the non-elastic range was between 1260 N and 1390 N and fracture could be observed at 1811 N (Fig. 8). The second joint had an elastic limit of 1250 N and broke at

1995 N. The simulation result lies between the two results obtained from tensile testing of real objects with a rupture at 1900 N.

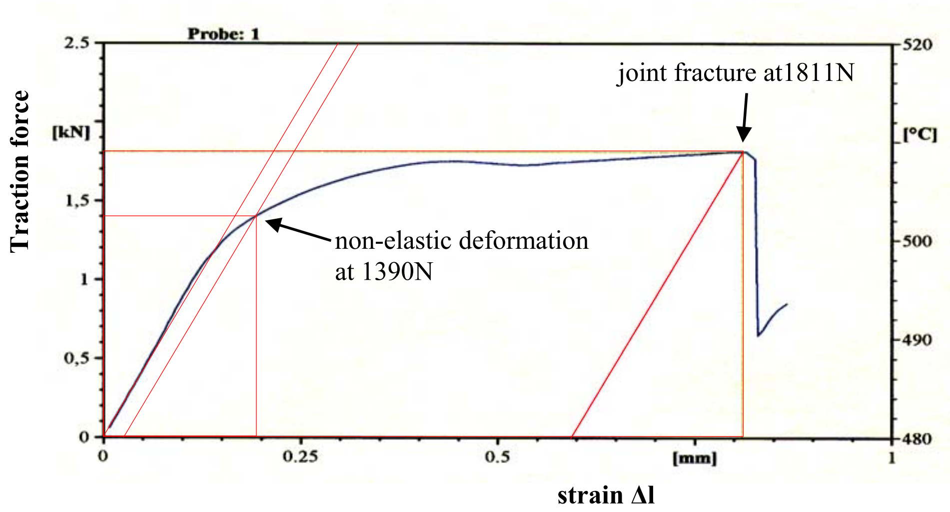

Fig. 8. Stress-strain diagram of a joint.

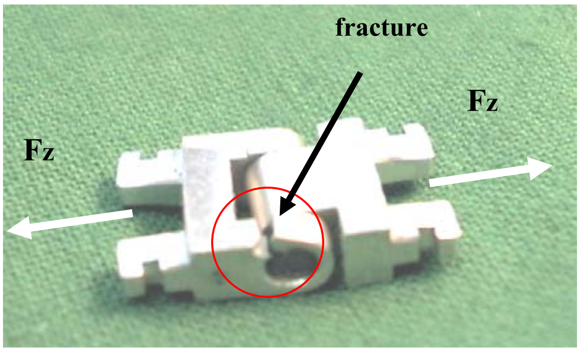

Fig. 9. Fractured joint from tensile testing

Additionally, the loads acting on a joint were simulated for the case of stress being applied perpendicular to the joint axis and during torsion of the joint. The stresses are in the range of those obtained from the traction simulation.

4. Conclusions

New anthropomorphic fluidic hands have been presented that are designed for use in a humanoid robot. The design corresponds to that of a natural hand and also mimics its kinematic capabilities. It has 8 to 10 active DoFs and 5 passive DoFs that are integrated in the digits and wrist. This allows for a compact and lightweight design, as a result of which the effect of an injury is significantly reduced in case of a collision with the user. Contrary to the former hand design, a micro hydraulic pressure unit is fully integrated in the new hand design, resulting in a total mass of 383g. If a further mass reduction is necessary, the pressure unit can be arranged externally, which results in a hand weight of 243 g. Different hand geometries or hands with a higher number of actuated joints can be designed easily due to the modular construction. Every active joint can be flexed by up to 80°, thus enabling the digits to conform to the shape of different objects that are grasped safely.

5. Acknowledgment

This research project is supported by the Deutsche Forschungsgemeinschaft (DFG), Cooperative Research Project SFB588.The authors would like to thank the DFG for their help and support.

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