Development of an Anthropomorphic Hand for a Mobile Assistive Robot

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***Abstract*— In this paper the mechanism, design, and control system of a new humanoid-type hand with human-like manipulation abilities is discussed. The hand is designed for the humanoid robot which has to work autonomously or interactively in cooperation with humans. The ideal end effector for such a humanoid would be able to use the tools and objects that a person uses when working in the same environment. Therefore, a new hand is designed for anatomical consistency with the human hand. This includes the number of fingers and the placement and motion of the thumb, the proportions of the link lengths, and the shape of the palm. The hand can perform most of human grasping types. In this paper, particular attention is dedicated to measurement analysis, technical characteristics, and functionality of the hand prototype. Furthermore, first experience gained from using hand prototypes on a humanoid robot are outlined.**

I. Introduction

THE progress of the development of service-robotics from the first industrial machines in the middle of the last century to the modern general- and single-purpose intelligent systems of our days was very dynamic [1]. At present, the development of service robots is the main objective of different laboratories all over the world. Recently, many prototypes of service robots were designed and constructed for different types of application, such as cleaning and housekeeping, automatic refill, medicine and rehabilitation, edutainment and entertainment [2]-[5]. Fascinating prototypes of artificial hands and grippers were developed for robotic application as well [6]-[9].

Nowadays, the development of humanoid service robots as well as of anthropomorphic grippers, including such aspects as multisensory perception, cognition, and human-robot communication, may well be classified as a key technology. It is the modern vision that a service robot should be mobile and manipulative to be able to interact with human beings or to perform tasks autonomously so as to relieve the human being [5].

The world robotics survey which was produced by the United Nations Economic Commission (UNECE) in cooperation with the International Federation of Robotics (IFR) in 2004, predicts spin-off effects for the market of professional service robots [10].

Currently, service robots for personal and private use are mainly existing in the household area, including vacuum cleaning, lawn-mowing, toy and hobby robots. Over 600,000 household robots are reported to be in use, and about 6.6 million units of service robots for personal use are forecasted to be sold in the period 2004-2007.

It is also projected in [10] that in the long run, service robots will not only be used in households, but in areas of predicted strong growth, such as public relations, laboratory use, underwater systems, defense, rescue and security applications, and many others. It is predicted that 54,000 new service robots will be installed in next three years. Robots will also be able to assist old and handicapped people with sophisticated interactive equipment. At least 24,000 installations for humanoid robots only are forecasted. It is well accepted that the development of versatile hands for humanoid robots is necessary to complete the variety of service tasks.

II. A Human-Like Artificial Hand

A. Mechatronic Design

The new prototype of this robot hand (Fig. 1) is designed

Fig. 1. A prototype of a human-like artificial hand.

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according to biometric data of an anthropomorphic hand. It

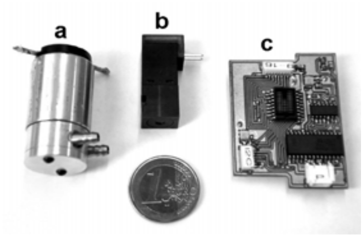

Fig. 2. Components of an artificial hand: a=hydraulic micropump; b=2/2-way valve; c=electronic unit.

consists of an anthropomorphic five-fingered mechanical framework structure with a natural appearance, which is made of lightweight materials, flexible fluidic actuators, valves, electronic, and fluid supply units. All mechanical and electronic components are integrated in the hand.

To design a lightweight hand, the 5-fingered mechanical framework of the hands and fingers is made of aluminum with high tensile strength properties. This construction consists of artificial bones and joints. Together with an artificial metacarpus, they form a structure of high tensile strength that makes the hand durable and stable and includes all other components of the hand prototype.

The prototype of the hand has 8 active actuated joints and 3 passive joints which are not actuated. The index and middle fingers have two actuated joints each. The ring and small fingers have two as well, but one of them is passive. The thumb is different from the other fingers. It has three joints: A base joint that is perpendicular to the middle joint and a passive middle joint. The number of actuators is optimized to achieve not only a human-like appearance of the hand, but also an anthropomorphic functioning and high dynamics of the hand without malfunction of dexterity, for example, during manipulation and grasping of different household objects. All joints and actuators are identical, which simplifies maintenance and reduces the production costs.

The actuation principle of the new prototype of the hand is the same as that of the formerly presented Lightweight Bionic Hand [11]. All active joints are driven by small-sized flexible fluidic actuators which are connected with finger joints. Compared to other actuator technologies and considering several criteria, including stress improvements, bandwidth, intrinsic compliance, packaging, good power to weight ratio, and high dynamics, fluidic actuators have already been identified as being particularly suitable for macrorobotics [12]. Contrary to conventional actuators, the mechanical design of the joint is limited less by the geometry of the fluidic actuator. Moreover, flexible fluidic actuators have lower friction in the actuator itself and production costs are lower.

In contrast to other artificial hand designs that use gear motors to move the digits [13, 14], the design of the new hand is characterized by a compact electrohydraulic driving system. It consists of a micro gear pump, two (or optionally eight) custom-made 2/2-way microvalves, a fluid reservoir, and a specially designed electronic unit (Fig. 2). Components of the microhydraulic system are integrated in the metacarpus.

B. Control System: Hardware and Software

The concept of the main robot hand control system is presented in [15]. This system has a 3-level hierarchy. The high level is responsible for the selection of an appropriate grip sample. The hand-arm coordination during grasping is carried out on the middle level. The implementation of origin samples using position and force control is realized on the low level of the control system.

The low-level control unit is integrated in a single multilayer small-sized circuit board that fits into the metacarpus of the hand. The electronics consists of a programmable microcontroller PIC16F877 by Microchip® (Microchip Technology Inc., USA), drivers for the valves and the pump, an analog-digital converter, and a serial RS232 interface driver. Miniconnectors are integrated in the same board for direct connection of all periphery units to the electronics. The block diagram of the control system is represented in Fig. 3.

Microvalves can be controlled in parallel. Consequently, the fingers can be controlled separately from each other. Valves are constructed according to the monostable principle and can be opened, if current is applied. They are closed without current, and the position of the fingers can be saved.

The micropump is based on the external gear principle, actuated by the direct current motor, and controlled by pulse-wave modulation. Thus, the fingers of the hand can be closed or opened with different velocities.

The controller has an integrated analog/digital converter and can digitize 8 signals. The angle, force, and pressure sensors can be optionally integrated in the hand and use analog/digital ports to communicate with the control unit.

Data transfer between the controller and a higher-level control of the service robot takes place via a serial RS232

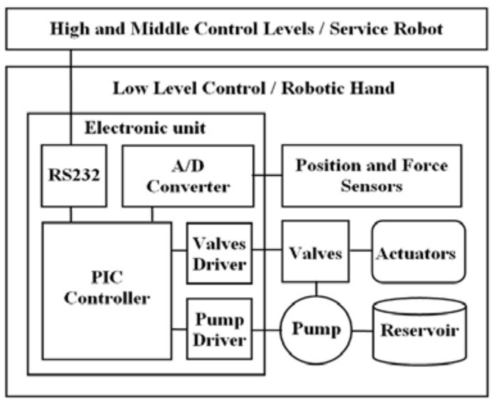

Fig. 3. Block diagram of the control system.

interface. In this way, control signals, such as the joint number and finger angles, are transmitted from the robot to the hand and read by the controller in the loop with a frequency of 200 Hz. This RS232 interface can also be used to diagnose the whole control system from a PC or to transmit other specific data, such as sensor signals, to the service robot.

The controller is the main part of this control system. It is connected with periphery components and uses special software to communicate with these units. The software is designed using a PCW compiler by Custom Computer Services® (Custom Computer Services Inc., USA) and enables the controller to manage the functioning of the pump and valves.

The hydraulic system of the hand prototype consists of a fluid reservoir, pump valves, and actuators and connection elements. The pump transports a hydraulic fluid from the fluid reservoir through valves to the actuators. The volume of the actuators will be increased under pressure; elastic joints will be driven under forces generated by the actuators' expansion that results from the hand digits' flexion movement, whereas the extension movement is performed by a spring element (Fig. 2).

C. Performance

Due to the use of fluidic actuators, a large operating range of hand motion is achieved (Fig. 4). Every digit of the hand with an active base joint can be flexed by up to 90°.

The design of the thumb differs from that of the other fingers. One of the active joints of the thumb is used to perform the opposite movement.

A large number of hand positions can be performed for different tasks of daily life, such as grasping and manipulating differently sized household objects.

A cylindrical power grasp, lateral grasp, tripod grasp, hook grasp, and spherical grasp can be performed. Moreover, the index finger can be used to press a key or to operate a switch.

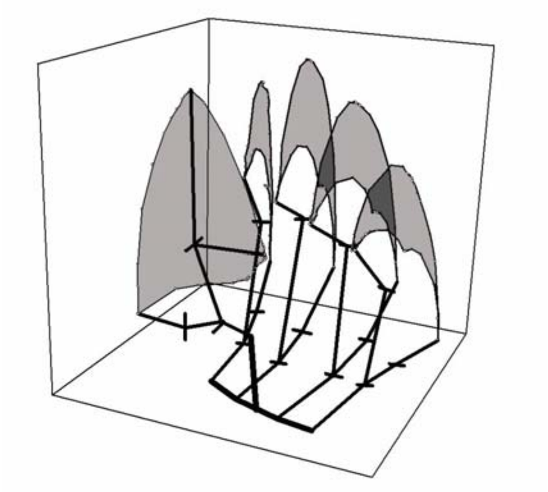

Fig. 4. Range of motion of the robotic hand prototype.

The specific feature of this prosthetic hand is its ability to conform to the shape of an object when grasping it. It results from a multiple number of degrees of freedom (DOF) and from the fact that all joints are controlled separately from each other. Additionally, the self-adapting properties of the hand result from a compliance of the fluidic actuators and elastic finger pads. Hence, the distribution of contact force during grasping and manipulating objects is similar to that of natural hands.

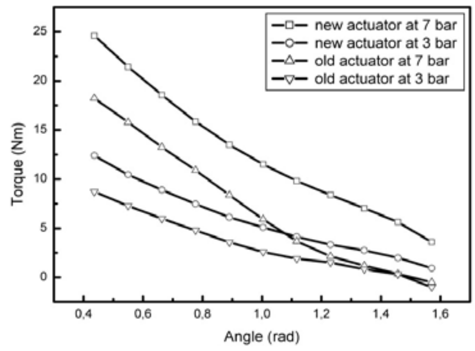

Fig. 5. Comparison of torques of new and old actuators.

D. Technical Characteristics

The technical characteristics of the hand are presented in Table I.

TABLE I
TECHNICAL CHARACTERISTICS OF THE ROBOTIC HAND

Parameters	
hand design	anthropomorphic
functioning modes	6 grip types
hand dynamics	1 rad/s
actuator type	flexible fluidic actuators
actuator medium prototype/optional	distill water/air
degrees of freedom prototype/optional	8/ up to 18
active actuators prototype/optional	8/ up to 16
pump type	external gear
valve type	2/2-way monostable
total weight	0.67 kg
weight of hydraulic system	0.16 kg
weight of mechanical framework	0.245 kg
opening span	0.15 m
holding force (hook grasp)	up to 110 N
average phalange contact force (stable holding with a power grasp)	from 1 N
torque joint (7 bar)	up to 25 Nm
control	high/low-level
sensors prototype/optional	no/joint position, force, temperature and pressure
power supply	DC 10 V
cosmetics of prototype/optional	no/ artificial silicon glove
noise level	47 dBA
interface	RS232

The anthropomorphic design allows for the distribution of prehension forces over a large contact area, and stable holding with low grip forces is possible. Hence, a cylindrical object simulating the handle of a suitcase can be held with a maximum of 110 N in a hook grasp.

Compared to the first prototype presented in [11], fluidic actuators have been re-engineered, and higher torques were measured for new actuators at the same pressure (Fig. 5).

Using the microhydraulic system, the hand can be closed within two seconds.

Mechanical construction of the hand includes small-sized and low-weight components for a low total weight. It amounts to 670 g. The weight of the microhydraulic system is 160 g. The weight of the skeletal framework is 245 g, including 8 fluidic actuators and the elastic finger pads. The stability and durability of the mechanical construction and its parts are verified using the CAD system “CATIA” and confirmed by test results obtained from the real prototype.

III. APPLICATION

The humanoid robot ARMAR [18] has 23 mechanical degrees of freedom (DOF). From the kinematics control point of view, the robot consists of five subsystems: Head, left arm, right arm, torso, and a mobile platform. The upper body of ARMAR has been designed to be modular and of light weight, while retaining a similar size and proportion as an average person. The head has 2 degrees of freedom (DOF). It is arranged as pan and tilt and equipped with a stereo camera system and a stereo microphone system. Each of the arms has 7 DOFs and is equipped with 6 DOFs force torque sensors on the wrist and an anthropomorphic five-finger hand. The current mobile platform of ARMAR consists of a differential wheel pair and two passive supporting wheels. It is equipped with a front and a rear laser scanner. Furthermore, it accommodates the power supply and the main part of the computer network. Different inverse kinematics algorithms [19] are provided for the programming of manipulation tasks.

A. *Integration the Hand in the Robot Control System*

The control architecture is divided into three levels [20]:

--The task planning level specifies the subtasks for the arm and hand during a manipulation task. E.g. a grasp pattern is selected according to the object to be manipulated.

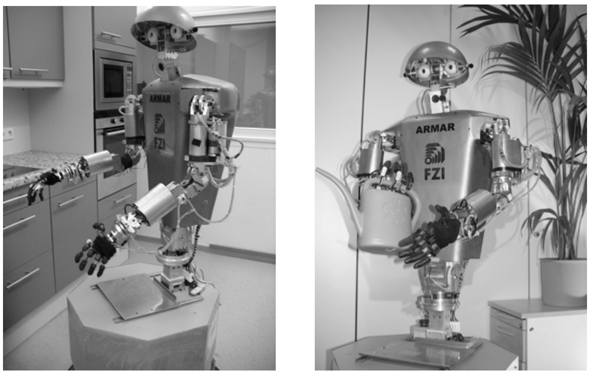

Fig. 6. The humanoid robot ARMAR.

--The task coordination level allows for a coordinated operation of sequential/parallel action primitives of the arm and the hand.

--The task execution level is characterized by control theory to execute specified sensor-motor control commands. For the implementation of the control architecture, the modular controller architecture (MCA2, http://mca2.sourceforge.net) was used as framework. It is a standardized module framework with unified interfaces. The modules can be arranged easily in groups for a more complex functionality. These modules and groups can be operated under Linux, RTAI-Linux, and Windows and communicate beyond operating system borders.

B. *Experiments*

Simple manipulation tasks were performed in a kitchen environment. Fig. 7 presents first grasping experiments performed by the hand and the arm. The objects used were common objects like bottle, cups, drawer handles, and dishwasher handles. The experiments revealed that the hand is able to grasp and hold objects with the fingers and the palm by adapting the grip to the shape of the object, through a self-adjustment functionality.

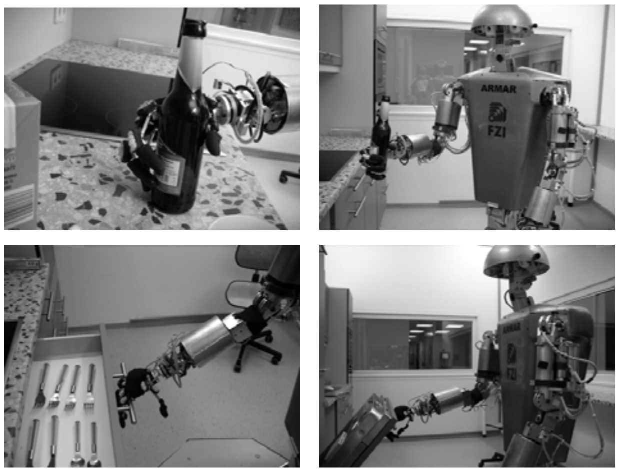

Fig. 7. Manipulation experiments.

IV. CONCLUSION

The development of a mobile assistive robot at the University of Karlsruhe is the main objective of the Collaborative Research Centre 588 project “Humanoid Robots – Learning and Cooperating Multimodal Robots” [16]. The new mobile robot has a humanoid design, human-like motion system, and intelligent control, aiming to assist elderly and disabled humans in activities of daily life. Working directly in cooperation with the user, the robot system will be able to learn with the aid of a human, remember unknown tasks, and apply this knowledge correctly in the future. The robot will be able to communicate with the user using speech, gesture, and haptics.

The development of a human-like artificial robotic hand at Forschungszentrum Karlsruhe (Germany) is part of the Collaborative Research Centre 588 project. This artificial hand meets special requirements of design, functionality, and control, such as an anthropomorphic construction, precision, flexibility, and dexterity. These allow for the execution of different grasping tasks. The hand is compact and lightweight, as a result of which usage is safe and danger for humans is avoided. The sensor-aided intelligent control allows for a high dynamics and correct distribution of contact forces during object manipulation and grasping.

The first prototype of the hand has simplified control functions. At the moment, position of the fingers is accomplished by varying the "opening" time of two valves and by pulse-wave modulation of the pump. Future integration of eight valves and sensors for angle, pressure, and force control will allow for different hand movements. For this reason, modular construction allows for a hand design with a higher number of actuated joints. Up to 16 degrees of freedom can be achieved for the hand, if desired. To achieve a higher dexterity, a special joint for wrist rotation and a mechanism for spreading the fingers should be integrated as well. Additionally, the software allows for controlling all joints of the hand separately from each other by using control signals for the joint number and the desired open angle of this digit. Thus, the basis of a close-loop control system is obtained.

The development of a lightweight artificial hand is also part of the German Federation of Industrial Cooperative Research Associations "Otto von Guericke e.V." (AiF) project (grant 113ZN) [17]. The main objective of this project is the development of a personal assistant system "FRIEND" for disabled people with upper-limb impairments, who depend on aid for daily life situations and in the working environment. This system should increase the independence of disabled people and reintegrate them in a job. The "FRIEND" system consists of an electric

Fig. 8. A personal assistant system "FRIEND".

wheelchair equipped with a robot arm and is controlled by a computer (Fig. 8).

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