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Multi-Fingered Robotic Hand Employing Strings Transmission Named "Twist Drive" – Video Contribution

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Abstract— **A goal of our research is to produce a light-weight, low-cost five fingered robotic hand that has similar degrees of freedom as a human hand. The joints in the fingers of the developed robotic hand are powered by a newly proposed strings transmission named "Twist Drive". The transmission converts torque into a pulling force by using a pair of strings that twist on each other. The basic characteristics of the transmission are given in the paper. A robotic hand prototype with 18 joints of which 14 are independently powered by Twist Drives was produced. The size of the hand is equal to the size of an adult human's hand and its weight including the power circuits is approximately 800 grams. The mechanical and the control systems of the hand are presented in the paper. Fingers position control and simple pinching and grasping tasks by using open loop force control are presented in the video.**

I. INTRODUCTION

The ultimate goal of robotic hands research is to produce a dexterous hand that would be able to skillfully handle objects like the humans do. A need for universally useful hands attached to robotic arms is becoming apparent in the industry where shortening of production cycles and a need to timely match various requirements is calling for dexterous robotic hands that could cope with various tasks. This is even more evident in non-industrial robotics applications, where the environment is highly unstructured and dealing with various objects and tasks becomes inevitable.

Early multi fingered robotic hands were driven by tendon mechanisms and motors positioned outside of the hand. However, due to reduced size and increased output power of the electrical motors, it is recently possible to mount the motors into the hand itself. In the case of tendon driven joints, it is possible to decrease a pulling force of a tendon and thus generate a free state (zero impedance) of a joint, so that the finger can easily be moved by an external force. This kind of zero impedance is important from the safety point of view, because it reduces impact forces in the case of collision if the joints are in a free state. This kind of safety is difficult to achieve with geared motors in the joints.

In this video we present a robotic hand prototype that uses novel strings transmission named "Twist Drive", in which a pair of strings is used to generate a pulling force. Its functionality is similar to a tendon transmission in a sense that only a pulling force is generated, which can be instantaneously reduced to zero, so that the joint can be set to a free state in any position.

The purpose of this video is to present the joints free state, joints position control, and simple pinching and grasping tasks by using open loop force control.

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II. TWIST DRIVE

To achieve a tendon-like functioning and simultaneously sufficiently high conversion ratio of a motor torque into a pulling force without using any gear reducer, we proposed a mechanism called Twist Drive. Two strings are with one end attached to an output shaft of an electrical motor and with the other end to a driven object as shown in Fig. 1. When the

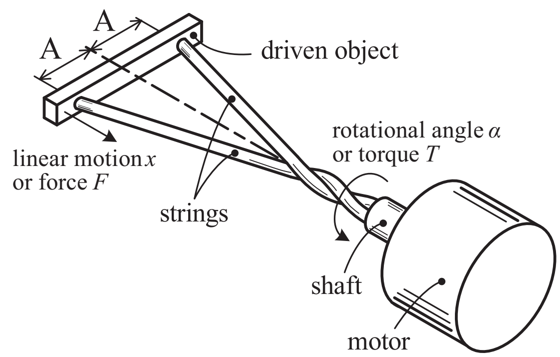

Fig. 1. Twist Drive actuation principle

motor's shaft is rotated for an angle α, or when the motor applies a torque T on the strings, the two strings twist on each other and in this way transform the rotation α into a linear motion x and/or the torque T into a pulling force F.

III. ROBOTIC HAND PROTOTYPE EMPLOYING TWIST DRIVE

A block diagram in Fig. 2 describes a system of a single joint of a finger with employed Twist Drive. Note that the strings are with one end attached to the shaft of a motor and with the other end directly to the link of a finger. In this way the available space in the finger is efficiently used, while the structure of a finger is simple, because there are no pulleys or other intermediate transmission parts. However, because the strings can only pull and cannot push, a spring (not shown in Fig. 2) is employed in each joint for its extension.

Each motor is equipped with three digital Hall sensors for commutation. To save the space, we use the outputs of the same sensors to detect the motor's angular position. Actual position of the motor is managed by a hardware pulse counter, which is a part of a custom made motor driver board.

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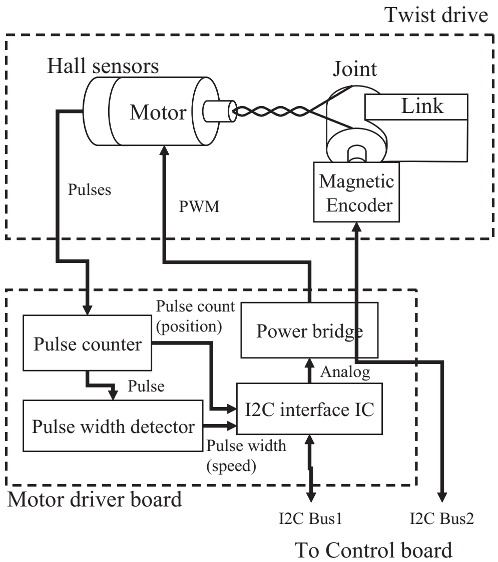

Fig. 2. Joint control system with Twist Drive

TABLE I
SPECIFICATIONS OF ROBOTIC HAND PROTOTYPE

Item	Value
Dimensions	238 x 116 x 72 mm
Weight	approx. 800 g
Joints	18 of which 14 independent
Max. grasp force	10 N
Motors	Brushless DC x 15
Sensors	Joint angle (12 bit) x 14

The motor driver board additionally has a pulse width detector, which is used to detect the motor's rotational speed by measuring the width of the pulses that are coming out of the Hall sensors. The detector is a 12 bit up counter with a synchronized hardware latch and reset functions, and is continually counting the pulses supplied by a 12 kHz clock pulse generator circuit, which is also a part of the motor driver board.

An I2C interface IC is used to communicate the motor position (value of the 8 bit counter), the motor speed (latched value of the 12 bit counter) to a control board, and to transmit a PWM voltage command to a power bridge. A 3 phase power bridge IC with an analog input is used, therefore, a digital command from a control board is first converted into an analog voltage by a simple 8 bit R-2R D/A converter circuit (not shown in Fig. 2).

Different from a geared motor, a Twist Drive does not provide constant and linear relation between the motor angle and the joint angle, therefore, a joint angle sensor was assembled into the joint's mechanism. To avoid the need for initializations, an absolute 12 bit magnetic encoder AS5046, a product of Austriamicrosystems AG was used. The magnetic encoder has a built-in I2C interface, which is used for communication with the control board.

A photo to compare the prototype robotic hand's size with an adult human's hand size is shown in Fig. 3. The main dimensions and other significant parameters of the

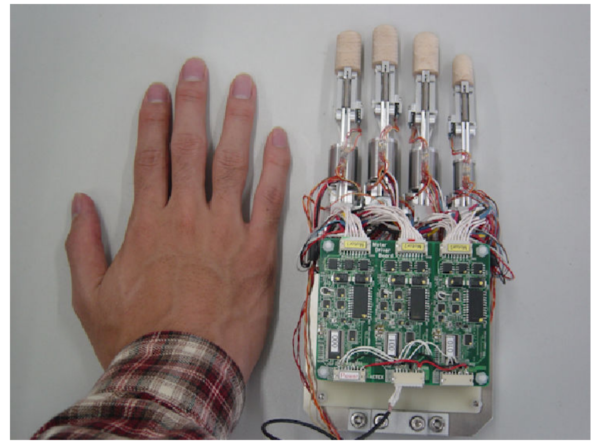

Fig. 3. Prototype robotic hand in comparison to adult human hand

prototype hand are listed in Table I. Note that the total weight of the prototype hand including the motor driver boards is approximately 800 grams, which is quite low considering that the hand has 18 joints of which 14 joints are independently powered. A thumb has 3 DOF, an index finger has 4 DOF (of which 3 are independent), a middle finger has 3 DOF (of which 2 are independent), a ring finger has 4 DOF (of which 3 are independent), and a small finger has 4 DOF (of which 3 are independent).

The control system of a prototype hand is composed of 15 motor driver boards, one for each motor, and five control boards, one for each finger. The control boards (CB) communicate with each other and with a host control board (host CB) by a CAN bus as shown in Fig. 4. The host CB

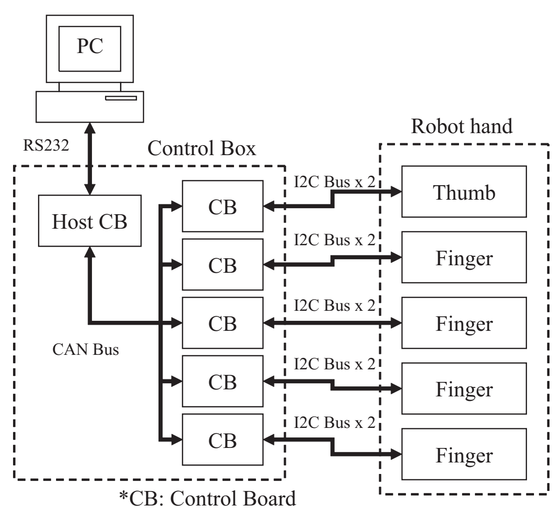

Fig. 4. Robotic hand's control system

also communicate with a PC (personal computer) by a RS232 interface with a function to transmit the data from the hand's sensors to the PC and to receive control commands from PC. High level control and complex calculations including inverse kinematics etc. is performed on the PC, while the low level servo control is handled by the control boards. The host CB is used only for communication.