Paper:

Stand-Alone Wearable Power Assist Suit
–Development and Availability–

Mineo Ishii, Keijiro Yamamoto, and Kazuhito Hyodo

Kanagawa Institute of Technology
1030 Shimo-Ogino, Atsugi, Kanagawa 243-0292, Japan
E-mail: yamakei@we.kanagawa-it.ac.jp

[Received May 13, 2005; accepted August 22, 2005]

The stand-alone wearable power assist suit we developed gives caregivers the extra strength they need to lift patients while avoiding back injuries. To put this suit to practical use, we improved sensing system and the mechanisms. To stabilize muscle tenseness sensing more, we developed an all-in-one sensor that built the sensor into a mesh belt and improved sensing characteristics. We expanded the movable range and function of the suit. We increased actuator output torque by increasing the number of cuffs inserted into actuators. Based on equations derived from static body mechanics using joint angles, joints torques required to maintain a position are calculated by an embedded microcomputer and required joint torques was combined with muscle sensor output signals to generate control signals. We developed an exoskeleton for measurement having the same frame and potentiometers as the suit and measured muscle force by having a user wear the exoskeleton, and proved that each unit of the suit transmitted assistance torque directly to each joint. We also found that a user wearing the suit could lift weight using half or less muscle power, i.e., muscle power doubled.

Keywords: power assist suit, exoskeleton, muscle tenseness sensor, pneumatic actuator, embedded microcomputer

1. Introduction

Studies on robots for carrying people began in the 1970's, typified by Mel Kong [1] and Nurcy [2], a master-slave robot, but none were put to practical use. Support device R&D has since progressed, typified by transfer care assistance device [3] and a take-up assistance device [4] that reduced the burden on a caregiver's lower back. Both devices used a motor. Other developments include walk assistance typified by an exoskeleton leg [5] using a motor and ball screws, a raising tool [6] using air-bag pneumatic actuators, a muscle suit [7] using McKibben air actuators, and an exoskeleton leg [8] using hydraulic actuators. All were intended to assist in walking or getting up, however, not to reduce the hard labor of caregivers.

In 1991, we proposed a pneumatic power-assist suit [9] that substantially reduced the physical burden of the caregiver wearing it and developed a wearable assist suit [10–13]. We worked to eliminate of pipes and wires and used small air pumps, exhaust valves, Ni-Cd cells, and embedded microprocessors to produce a completely wearable suit [14–16].

This paper deals how we worked to make this power assist suit practical and compact while improving function. We measured assistance characteristics and confirmed the suit's practicality. By fabricating integrated detection system with sensors in a mesh belt, we developed an all-in-one muscle sensor easy to put on and take off providing stable detection. We improved in the structure and mechanism to expand the suit's movement range and increase freedom of movement. We also improved actuators to enhance assistance. We developed an exoskeleton for measurement to quantify assistance properties and conducted experiments on the exoskeleton and actual suit uses and clarified properties through comparison.

2. Power Assist Suit

The exoskeleton suit (**Fig.1**) consists of shoulders, arms, a spine, a waist, and legs. Each joint has an angle sensor (potentiometer) and the elbow, waist, and knee joints have a direct-drive pneumatic actuator having rubber cuffs covered with cloth to which small DC motor driven air pumps and solenoid exhaust valves are directly connected. This actuator generates soft assistance via air compressibility and rubber cuff elasticity that does not prevent users from moving smoothly operation. The Ni-Cd cell power source (12V, 30mm ϕ and 300mm long) is mounted on each femur of the leg.

The aluminum suit leaves a caregiver's front free to enable physical contact between the caregiver and the person being assisted.

Suit control system is shown in **Fig.2**. As the caregiver moves, muscle sensors on the upper arms, knees and back detect muscle power driving each joint. We used 50% of each joint torque calculated using a quasi-static physical dynamics model based on the angle signal of each joint, the estimated weight of the person to be assisted, and the weights of the wearer and suit as the reference value for

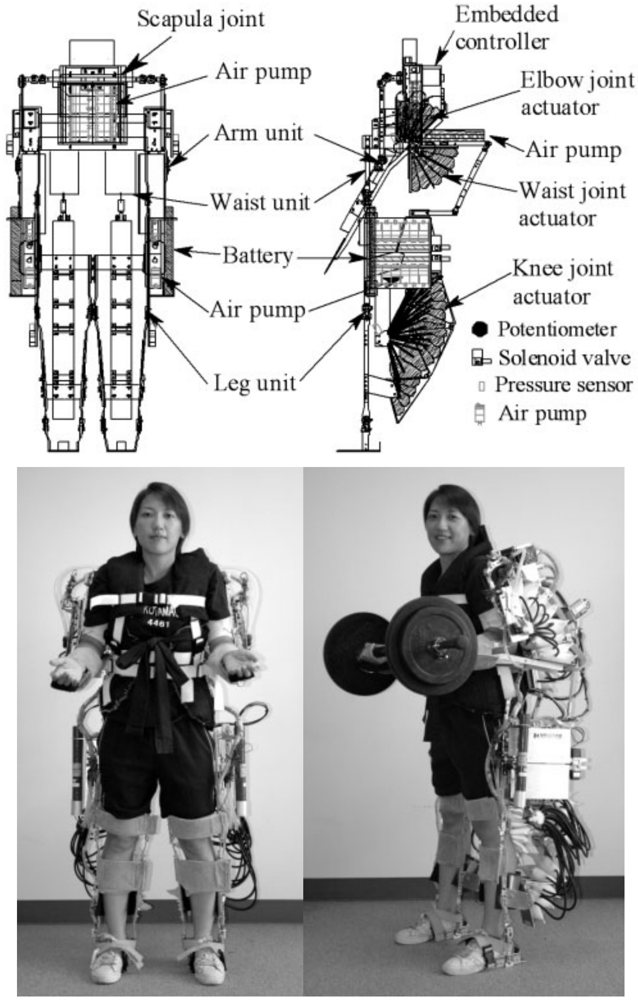

Fig. 1. Power assist suit.

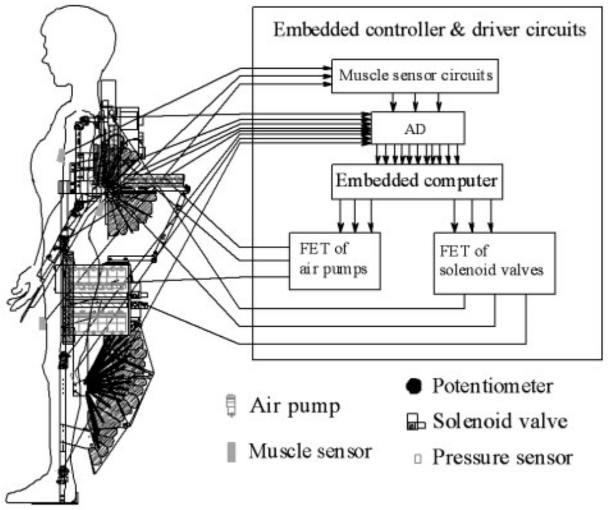

Fig. 2. Sensing and control of power assist suit.

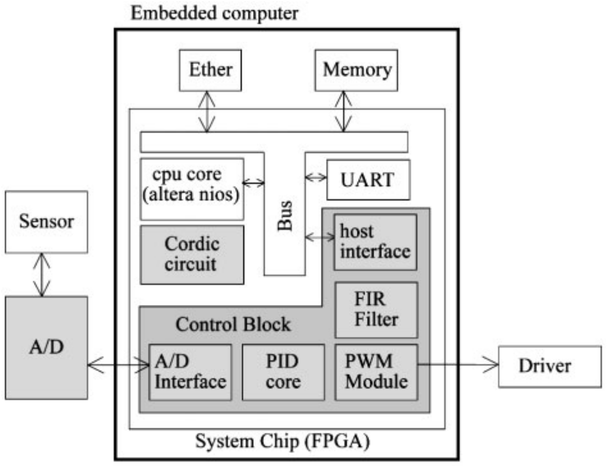

Fig. 3. Microprocessor block diagram.

assistance torque, which was added by the maximum of ±20% of the reference value for each joint torque based on the signal of the muscle sensor. This value was used as assisting torque value that should be generated by the actuator. Assuming the value calculated by the model to be T_c, the output of muscle sensor S and maximum $S_{\max}$, assistance torque is represented by the following equation:

$$T_a = T_c \cdot \left\{ 0.5 + \left(\frac{S}{S_{\max}} - 0.5 \right) \cdot 0.4 \right\}. \quad . \quad . \quad . \quad (1)$$

This assistance torque is calculated by the embedded microcomputer, and a PWM voltage signal is output to the small air pump and the exhaust solenoid valve. Air pressure in the actuator is adjusted so the actuator outputs assistance torque and auxiliary power is generated in each joint, which is needed for suit operation. The internal pressure of the actuator is PID-controlled.

3. Controller

We used a System on a Programmable Chip (SOPC) for controllers to make the suit wearable. The controller board holds a Field Programmable Gate Array (FPGA) (Altera APEX20K200E: 200K gates, 9 × 12cm^2 and 2.5cm high), A/D converters, the Ethernet controller, and SRAM and EEPROM.

The controller core consists of a Nios 2.0 processor (32 bits) and a control block module (**Fig.3**). The control block consists of a 24-channel PWN module (18 bits), A/D converter interfaces, finite impulse response (FIR) filters, and a PID control core (16 bits). The stand-alone block's clock frequency is 33MHz and the operation cycle is 20 clocks. The Nios processor conducts nonlinear operation, sets up the control block parameters, and provides control via a LAN.

We also developed a control block design tool to easily change the type and number of sensors and actuators based on the caregiver. The control block is represented by a combination of a 24-channel PWM (18 bits), interface logic for A/D, FIR, and PID core (16 bits). The development environment uses a graphic user interface and the user combines required functional modules on the GUI to