Wearable sensor network system for walking assistance

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Abstract: A wearable sensor system is proposed as a man-machine interface to control a device for walking assistance. The sensor system is composed of small sensors to detect the information about the user's body motion such as the activity level of skeletal muscles and the acceleration of each body parts. Each sensor includes a microcomputer and all the sensors are connected into a network by using the serial communication function of the microcomputer. The whole network is integrated into a belt made of soft fabric, thus, users can put on/off very easily. The sensor system is very reliable because of its decentralized network configuration. The body information obtained from the sensor system is used for controlling the assisting device to achieve a comfortable and an effective walking training.

Keywords: Wearable sensor system, Network, Man-machine interface, Walking assistance

1. INTRODUCTION

A wearable robot is under development in our team. The robot is for old people or disabled people to support their walking training. Daily training is very important for such people, however, there are several problems in the fields of the training. Walking training requires physically heavy labors for care workers or therapists. Also it is quite hard to ensure the safety of patients because the patients who need walking training usually don't have enough strength to support their body. Therefore, therapists must be very careful to avoid falling accident of patients during the walking training. To solve these problems, our team is working on the development of a robot to achieve a safe, effective and comfortable walking training for those patents. The wearable robot under development and its control system are shown in Figure 1 and Figure 2, respectively. The detail of this robot is reported in papers [1, 2].

Figure 1. The walking assistance robot

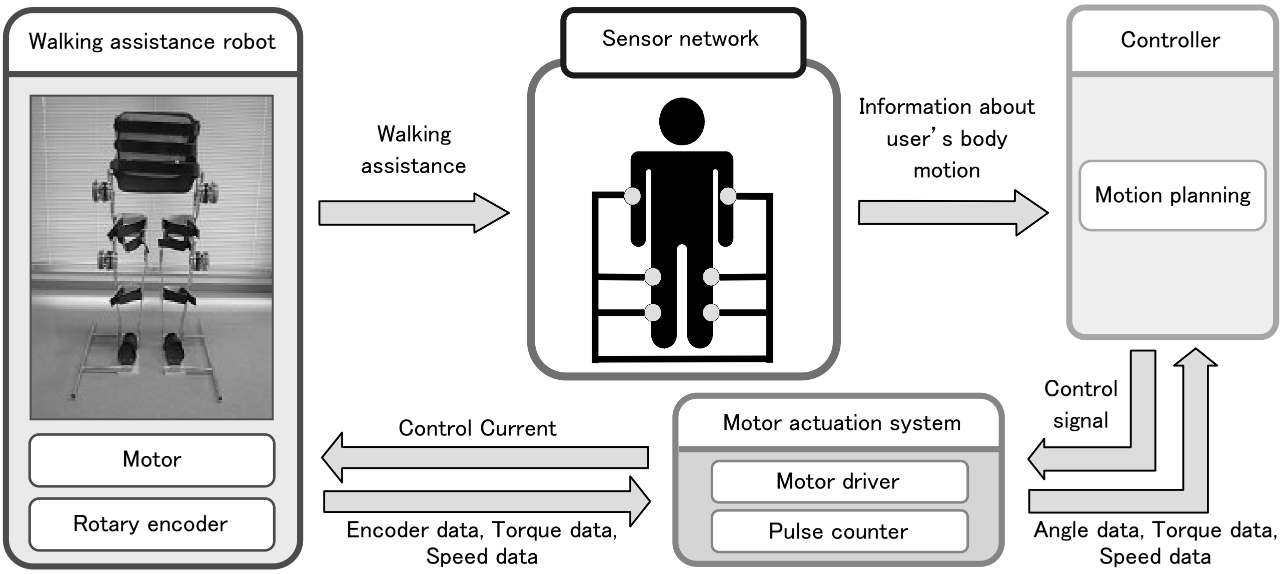

Figure 2. Control system of the walking assistance robot

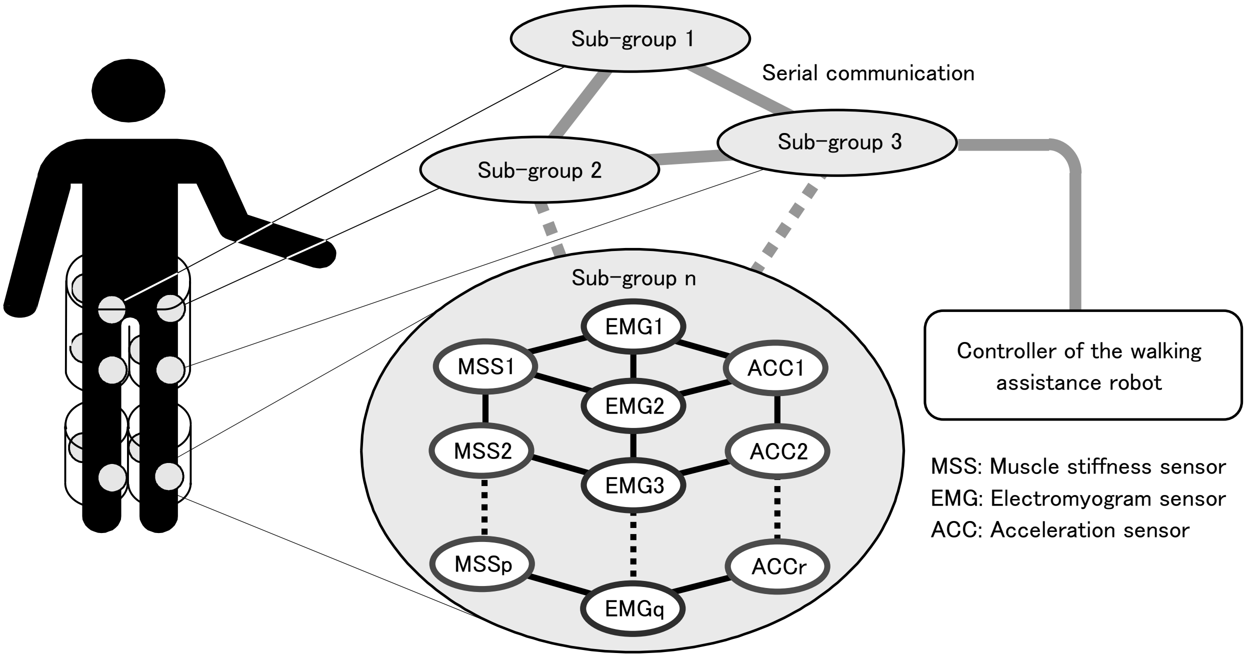

Figure 3. Overview of the sensor network system

2. OVERVIEW OF THE SENSOR SYSTEM

The sensor system proposed in this study is composed of a number of small sensors to detect the information representing the user's body motion such as the activity level of skeletal muscles and the acceleration of each body parts. The muscle activity data is useful information to know the amount of the stress loaded on user's body and what kind of motion the user desires to do. The acceleration of body parts can be used to obtain the information about body movements which is equivalent information available from the motion capture system. Each small sensor has a microcomputer and is connected to the neighboring sensors through the serial communication. All these sensors play a role as both a sensor and a terminal to transfer other sensor's data. Because of its decentralized network configuration, the system can have a simple structure and a reliable sensing ability. The network is integrated into a belt or pants made of soft cloth so that the system can be compact and comfortable to use for users. The overview of the sensor system is shown in Figure 3. Three kinds of sensor, muscle stiffness sensors, electromyogram (EMG) sensors and acceleration sensors are adopted to detect motional information from user's body in this system.

3. SENSORS USED IN THE NETWORK

The detail of the sensors, muscle stiffness sensors, EMG sensors and acceleration sensors used in this system is described in this section.

3.1 Muscle stiffness sensor

The muscle stiffness sensor is an original sensor innovated by authors. This sensor detects the level in which the muscle is stiffened as it acts. The activity level of the target muscle can be estimated from the stiffness data. Figure 4 shows the muscle stiffness sensor. The sensor has two components, a flat disk (38[mm] in diameter) and a button (6[mm] in diameter) in the center of the disk. Two small pressure sensors are used to measure the force loaded on the button and the entire sensor.

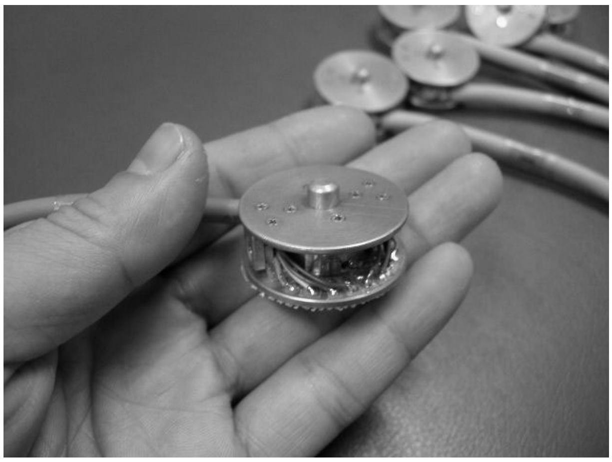

Figure 4. Muscle stiffness sensor

The flat disk of the sensor is attached to the skin surface and the button is indented into the skin. The stiffness data are obtained from the balance between two forces, the force loaded on the button and the force loaded on the disk. The sensor works correctly even if the variable force is loaded on the sensor from outside. It means that the system can be robust against external disturbances. The more detail information about the muscle stiffness sensor is available in our paper [3]. The features of the muscle stiffness sensor are as follows.

- The level of muscle activities is mechanically measured over the skin.
- The sensing from one specific muscle is available.
- Easy to attach and detach. It is available even over the clothes.
- The sensor works correctly even if additional forces are loaded on the sensor from outside.
- The ability in measurements of muscle activity is equivalent to that of EMG sensor.
- The more precise measurement is available by the simultaneous use of the both muscle stiffness sensor and EMG sensor because the sensitive range in the

measurement of the muscle activity is different between these two sensors.

Additional signal amplifier is needed for this sensor. A small terminal box including an electric circuit for the signal amplification and a microcomputer for the communication is developed to bridge between the sensor and the sensor network. A muscle stiffness sensor with new structure is under development. Both the weight and the size of the sensor will be largely decreased in the new design. The terminal box will be integrated into the main body of the sensor in the near future.

3.2 Electromyogram (EMG) sensor

Original EMG sensor is developed for the network system. This sensor also has a microcomputer inside the main body. The microcomputer provides a digital filtering function and a communication function. Therefore this sensor outputs a clear EMG data and the data are transferred effectively and reliably to the controller through the sensor network. The EMG sensor and its configuration are shown in Figure 5 and Figure 6, respectively. This sensor is still too big to be used for the sensor network system. The second version with much smaller size is under development.

Figure 5. EMG sensor

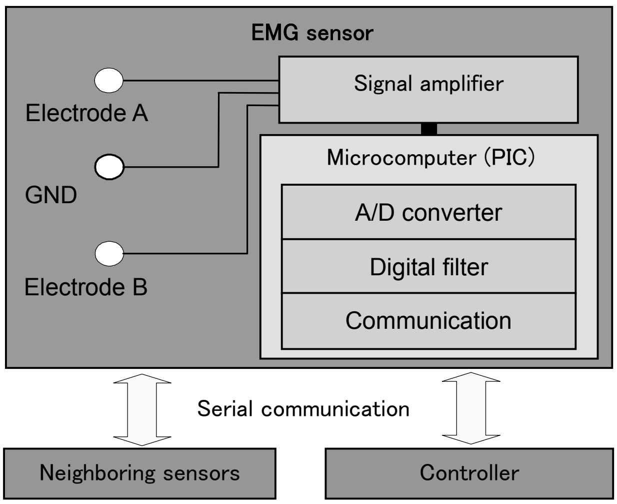

Figure 6. Configuration of the EMG sensor

Measurement of EMG signal is a popular method to evaluate the level of muscle activities. The EMG sensor is widely used as a man-machine interface for artificial limbs. However, EMG has some problems when it is used for devices to assist human motion like our walking assistance robot as a man-machine interface.

The EMG signal can be disturbed under the unstable installation condition of the sensor. The EMG signal fluctuates under the variable pressure between the electrodes and the skin. Artificial limbs usually have a socket to fix itself to user's body and EMG sensors are embedded inside the socket. Therefore EMG sensors always fixed to user's skin firmly. However, in the case of the assisting devices such as our walking assistance robot, there is no socket to fix sensors to the skin. Also the structure of the system including the interface must be flexible. Otherwise the device might be the interference not the assistance for user's motion.

It is hard to ensure the reliability of the EMG measurement in the case of the motion assistance devices because of the unstable installation condition of the sensors. The multi-channel measurement through the network system can improve both the accurateness and the reliability of sensor data. The higher reliability could be available in the measurement by the simultaneous use of both muscle stiffness sensor and EMG sensor.

3.3 Acceleration sensor

Tiny acceleration sensors are adopted in this network system to detect user's body movements. The sensor is the single axis accelerometer, ADXL202, manufactured by Analog Devices, Inc. Figure 7 shows the accelerometer used in this study. User's body motion such as the knee joint rotation and the hip joint rotation can be measured by the combination of the acceleration sensors. The information about user's body movements is useful not only for measurement of user's motion but also for correcting the muscle activity data because both the muscle stiffness data and EMG data slightly changes based on the position or the joint angle of the body parts. The more accurate muscle activity data are available by the simultaneous use of muscle activity sensors and the acceleration sensor. Similarly, each acceleration sensor is also connected into the sensor network through a microcomputer.

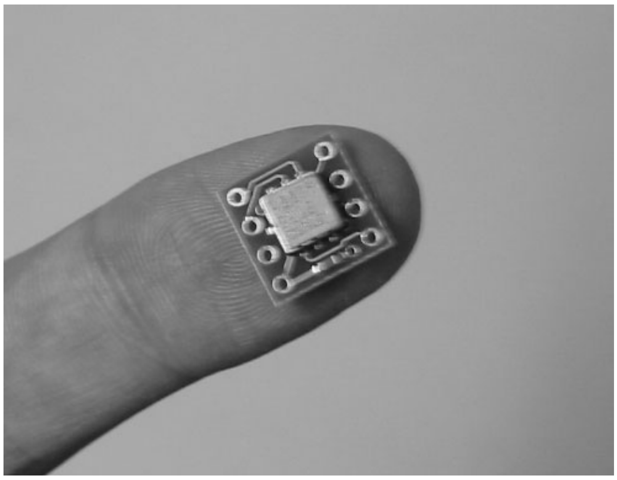

Figure 7. Accelerometer (ADXL202, Analog Devices, Inc)

4. EXPERIMENT & COMPUTER SIMULATION

Two kinds of experimental network system are developed and tested. One is a network including the muscle stiffness sensor and the EMG sensor to detect muscle activities from user's body. Another is a network of acceleration sensors to detect movements of user' body parts. In addition to these experiments, a computer simulation is conducted to observe the failure tolerant feature of the sensor network system.

4.1. A sensor network for muscle activity detection

An experimental sensor network including 5 muscle stiffness sensors and 5 EMG sensors is developed. It is demonstrated that all the sensor data can be obtained simultaneously through the sensor network. Figure 8 shows the experimental data of two sensors which are located in a muscle for gripping function. The examinee is requested to grasp a grip dynamometer three times with different forces, 10kgf, 20kgf, and 30kgf, respectively. It is demonstrated that the level of the muscle activation can be detected by using both the muscle stiffness sensor and the EMG sensor through the sensor network.

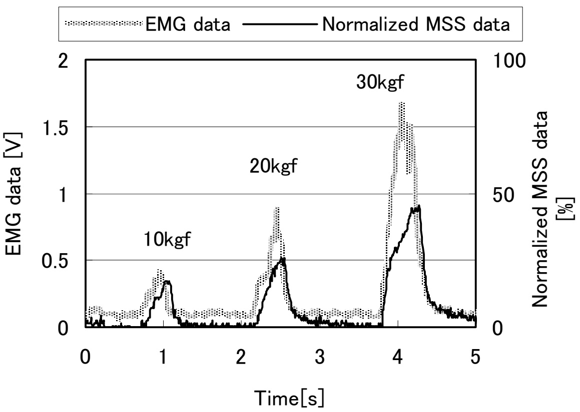

Figure 8. Muscle activation data

An adaptive self-tuning filter is applied to the EMG sensors. EMG signal is easily disturbed by electro-magnetic noises. Especially, it is quite hard to remove the periodical noise comes from AC power supply by using only analog filters. Therefore, a digital filter is configured in the microcomputer of the sensor. LMS(Least mean square) algorithm is introduced for extracting the synchronous signal component for the adaptive filter. The block diagram of the adaptive self-tuning filter is shown in Figure 9. The algorithm of the adaptive filter is shown as follows.

$$y_k = W_{1k}\cos\left(\frac{2\pi k}{N}\right) + W_{2k}\sin\left(\frac{2\pi k}{N}\right) \qquad (1)$$

$$W_{1k} = W_{1k-1} + 2\mu\left(x_{k-1} - y_{k-1}\right)\cos\left(\frac{2\pi k}{N}\right) \qquad (2)$$

$$W_{2k} = W_{2k-1} + 2\mu\left(x_{k-1} - y_{k-1}\right)\sin\left(\frac{2\pi k}{N}\right) \qquad (3)$$

$$z_k = x_k - y_k \qquad (4)$$

where,
x: Measured data,
y: Estimated noise,
W: Weight,
μ: Determiner of adaptation speed,
z: Output of the adaptive filter.

An experimental result of the adaptive filter is shown in Figure 10. It is observed that the 60 Hz periodical noise comes from AC power supply is largely removed by using the adaptive self-tuning filter.

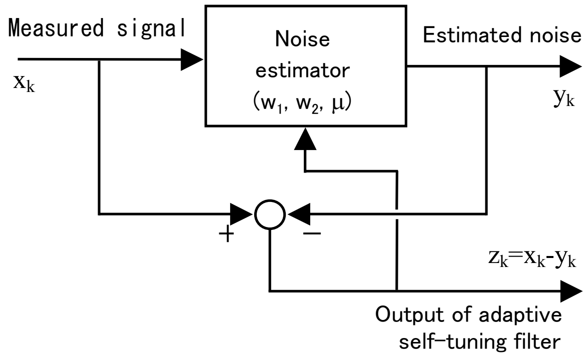

Figure 9. Block diagram of the adaptive self-tuning filter

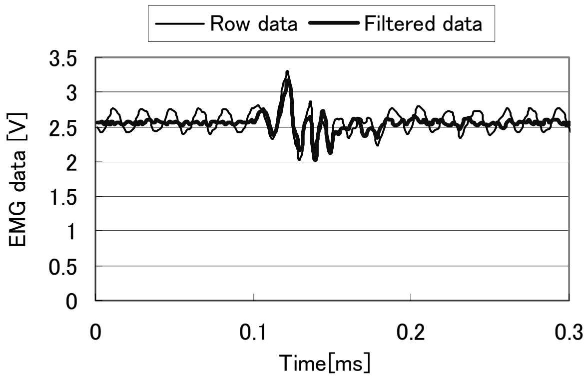

Figure 10. Experimental result of the adaptive self-tuning filter

4.2. A sensor network for body movements detection

Also the experimental sensor networks including acceleration sensors are developed. Figure 11 shows a sample of the acceleration sensor network. In this figure the network includes only two sensors but it is easy to increase the number of the sensor by connecting more sensors with a microcomputer installed the same program. A routing algorithm used for the internet connection is applied for the this network. Even if

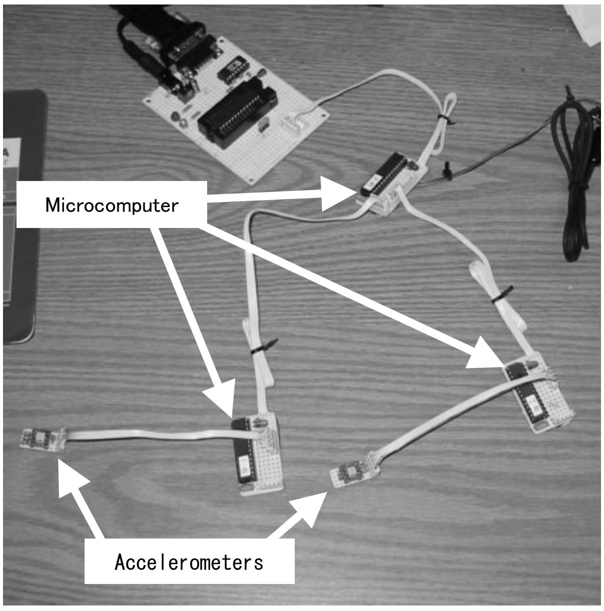

Figure 11. Prototyped network of acceleration sensor

some parts of the network have damages, the sensor network still can works correctly and provides all the sensor data to the controller. A sketch that shows how flexibly the decentralized network system works under an accident is shown in Figure 12.

This failure tolerant feature of the sensor network is confirmed through the computer simulation. The virtual network on the computer screen is shown in Figure 13.

Both the excellent sensing abilities and the high reliability of the sensor network system are demonstrated through both experiments and computer simulations.

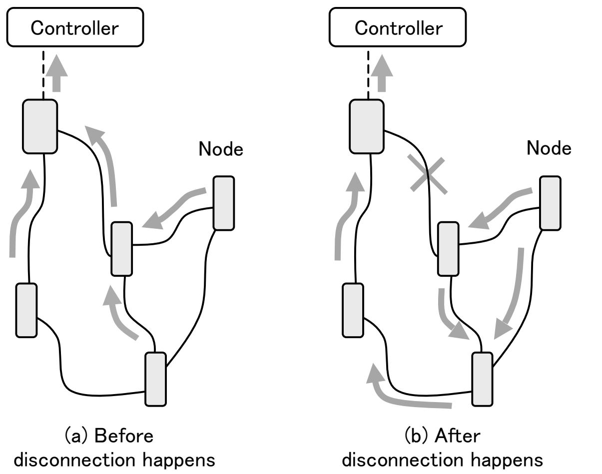

Figure 12. A sketch of the decentralized network connection

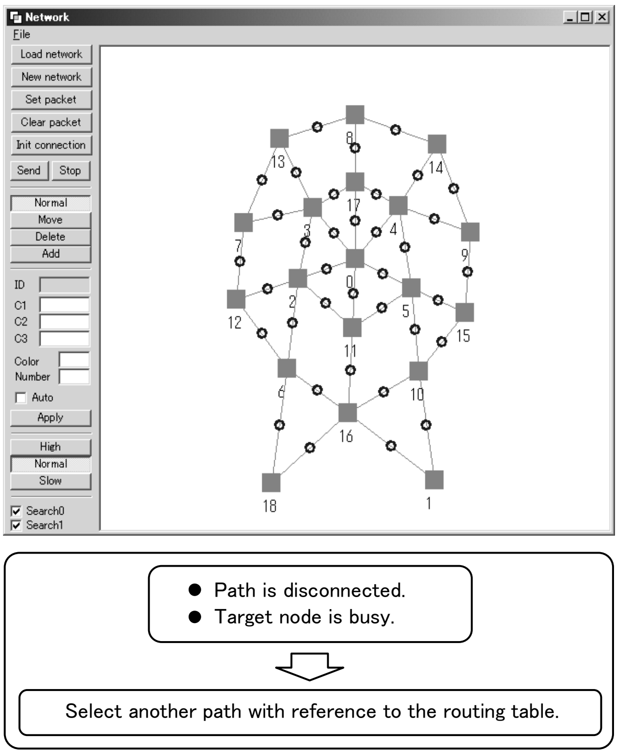

Figure 13. Computer simulation of the decentralized network connection

5. SUMMARY & CONCLUSION

A wearable sensor network system is proposed as a man-machine interface to control a device for walking assistance. This sensor network system is easy to wear and comfortable to use for users.

Original sensors such as muscle stiffness sensors, EMG sensors and acceleration sensors have been developed for this system. These sensors include a microcomputer and connected into the network by using its communication function. The reliable system has been achieved by employing the decentralized network connection.

The elemental technologies to build the sensor network have been developed and their excellent performances have been separately demonstrated through several experiments and computer simulations. As a next step, the development of a sensor network system will be accomplished as a total system by integrating all these elemental technologies.

6. ACKNOWLEDGEMENTS

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