Motion Information Transmission for On-neck Communication

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Abstract: This paper introduces a novel form of communication via a combination of muscle sensing by electromyography and stimulation via a skin-stretcher device as a motion monitoring system. After sensing muscle activity through electromyography, the skin-stretcher device provides a skin sensation that confidentially informs or induces movements of the user who wears the device. This paper also introduces methods for translating muscle activities to the skin-stretch sensations, and additional filtering to improve the performance. In this study, we conducted preliminary experiments that demonstrate the potential of our system design.

1 INTRODUCTION

We are developing a skin-stretcher device as a tool for communication that uses skin sensations to transmit motion information or induce motions. The device gently and locally pushes or pulls the skin by contracting or expanding itself via a link structure driven by a servomotor. Although the device was originally designed to induce a motion that is consistent with skin-stretch sensation, it can be also used as a somatosensory communication device.

Informing and prompting appropriate motions provides intuitive support for sports, job training, and rehabilitation (Kawasaki et al., 2006)(Spelmezan et al., 2009). Communicating touch or movement information provides an excellent tool for remote care, nursing, and intimate communication for family members (Doi et al., 2006)(Bentley and Metcalf, 2007). Sharing motion information can also support group activities that require mutual awareness or joint force with coordinated timing.

As an effective means for this type of communication, we focused on skin sensations, in particular, the sensation of skin stretching. Our past experiments have shown that good characteristics of the device, e.g., the head of a person turns proportionally to the length pulled by the device, can make the human-in-the-loop design of a human-supporting system easy.

In this study, we focus on an application of our device to a motion monitoring system for care or nursing scenarios. In the following sections, we introduce the idea of motion communication, its design, the translation of head motion to device actions, and its performance as measured via our experiments.

2 COMMUNICATION OF HEAD MOTION

2.1 Importance of Head Motion

Head motion is a fundamental function for a variety of movements in our daily lives. The human head is continuously controlled to maintain an appropriate position and pose.

A head motion is often an initial step for other important motions in addition to its own motions. When we get out of bed, the motion of raising the head precedes other body motions. Head rotation often reveals the internal states of a person. For example, we often expect that the attention of a person is directed

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toward something frontal to the face (Clark, 1996). Head motions, for example, of seeing a partner and nodding are natural and essential behaviors in natural conversations. In caregiving, head motions are one of the most important signals that require the careful attention of caregivers when monitoring patients. We consulted staff members at Nishikagawa Hospital, and they highlighted several actions that require careful attention. For example, movements for rising or standing need to be noted prevent patients accidents. Details of the doctor and staff are presented in Appendix 6.

Even though there are other important body parts for motion monitoring such as hands or legs, such body parts move more dynamically and interact with other objects (Ivanenko et al., 2004)(Kuan et al., 2010). Such large movements require continuous and intensive attention to grasp the status of patients.

Based on the above considerations, we investigated head motion as a means of communicating persons' states.

2.2 Characteristics of Head Motion

Head motions primarily consist of rotation, flexion, and extension.

We first focus on the mechanism of head rotation. Head motions are caused primarily by the contraction of the agonist and antagonist muscles around the neck (Zangemeister et al., 1982). The dynamics of head rotation can be roughly approximated by the following simple formula:

$$I\ddot{\theta} + B\dot{\theta} + K\theta = T \quad (1)$$

where I, B, K, θ, and T represent the moment of inertia, viscosity coefficient, elasticity coefficient, rotation angle, and rotation torque of the head, respectively.

We can see the rough relation between the rotation angle and the muscle contraction that provides the torque T. However, the antagonism of the muscles reduces the rotation torque and increases the stiffness, which is also an important mechanism for body movements. The antagonism, viscosity, and elasticity cause difficulties for direct estimations of the head movement from the muscle measurements, e.g., electromyography; however, muscle activities can potentially provide a rich source of information concerning body movements, intention, and other states of a person.

2.3 Requirements for Motion Information Transmission

Let us consider the requirements or preferences for motion information transmission by considering caregiving applications, one of the promising applications of such a system.

(a) **Transmits Motion Quickly.** Timing is one of the most important factors for caregiving. Patient movements that require a caregiver's support or that might result in dangerous situations need to be informed as soon as possible; predictions may even be necessary in some cases.

(b) **Provides Natural Stimuli That Are Intuitively Perceived.** Noninvasive stimulation is preferable, because the caregiver receiving information may need to concentrate on their own activities.

(c) **Allows a User's Voluntary Movements.** If a caregiver is wearing a motion transmitting device and the device applies a strong force that compels the user to move counter to the user's intention, this may result in dangerous situations or accidents. The device needs to allow the user to ignore the stimulus and prioritize voluntary movements if necessary.

(d) **Confidentially Transmit Information if Necessary.** Patient information is often confidential and is closed to unrelated persons. Audiovisual communications are often inappropriate because they may be observed by nearby persons.

These requirements are also considered important in other situations, such as job training, joint projects, and rehabilitation support.

Based on these considerations, we propose a novel communication method by a combination of muscle sensing via electromyography and stimulation via a skin-stretcher device. With sensing muscle activity through electromyography, we can directly capture muscle contractions for movements and obtain clues concerning the intentions of the movements. The skin-stretcher device provides skin sensation that confidentially informs or induces movements of the user who wears the device. Details are given in the following sections.

3 SYSTEM DESIGN

Figure 1 shows an overview of our motion transmitting system. The system comprises a motion-sensing part using electromyography (EMG) and a motion-indicating part using a skin-stretcher device.

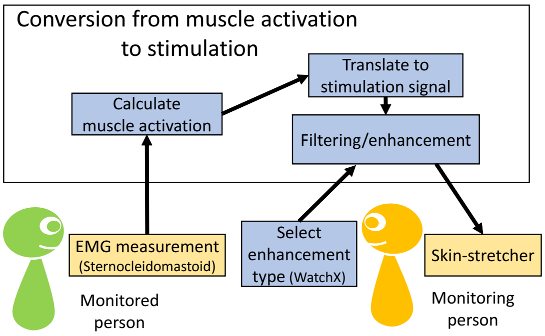

Figure 1: Overview of our motion transmitting system.

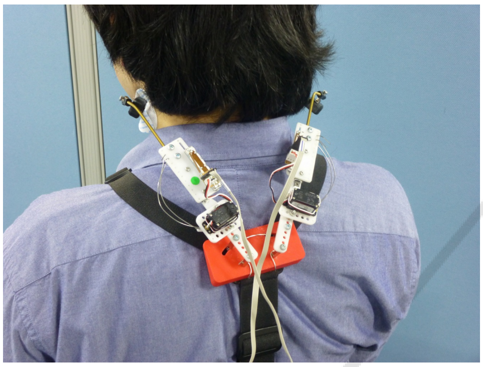

Figure 2: The skin-stretcher device attached to a user's neck.

3.1 Motion Indication

Figures 2 and 3 show the appearance and the configuration of our skin-stretcher device, respectively.

The device is designed to provide a sensation of skin stretching to convey motion information and to induce a motion that is consistent with the sensation; this is in contrast to previous studies such as Refs. (Mizukami et al., 2007) or (Levesque et al., 2007).

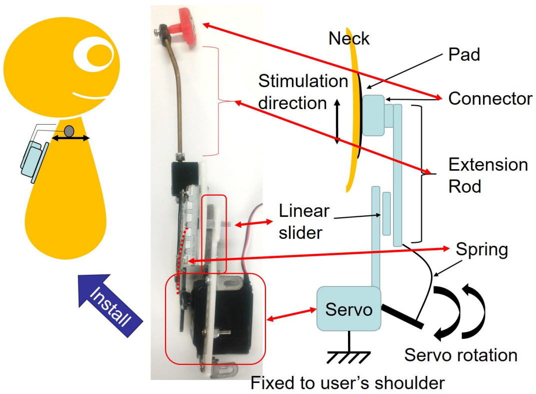

Figure 3: Configuration of the skin-stretcher device. The end connector is attached to the neck with two sticky pads, and the device is fixed to the body with a body-mount harness.

Figure 4: The wristwatch device (WatchX).

The primary features of the device are listed below.

- Skin stretching provides a natural and intuitive stimulus that directly but subtly indicates the direction of the head rotation.
- The device does not apply a strong force that compels the user to move counter to their own intentions. The user can override the stimulus and prioritize voluntary movements if necessary.
- The device can be used not only to induce motions but also to impart the feeling of motion. The user can feel the movement of the pads even if the user does not move as requested by the device.

Despite the above advantages, the device has the following problems.

- The sensation that the user receives may vary depending on the user's characteristics, activity, and the device attachment. The stimuli may be too small, too annoying, or need to be more focused on specific movements.
- Communication via sensations is possible for one-to-one communication; however, it is difficult to resolve if motion signals from multiple persons are transmitted simultaneously and mixed. We require a mechanism for selecting the signal from the specific person that we want to monitor.

To deal with these problems, we use a wristwatch device (WatchX) that can be used to choose signals for stimuli and the characteristics of stimuli, such as gain.

WatchX is an Arduino-based device and has a small display with three buttons as the output as shown in Figure 4. It can communicate via Bluetooth Low Energy.

3.2 Motion Sensing via EMG

We use myoelectric sensing (EMG) based on the following advantages.

- With EMG, we can measure the opposition by the agonist and antagonist muscles, even if they do not appear as actual joint torques.

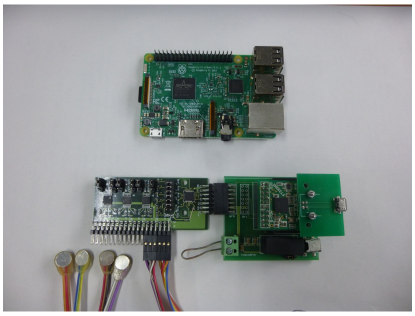

Figure 5: EMG logging device and its host (Raspberry Pi).

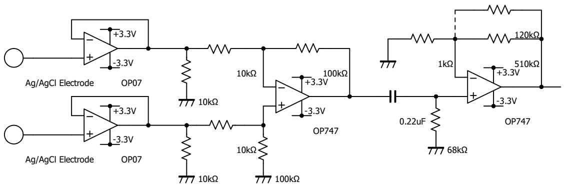

Figure 6: Schematic of the EMG amplifying circuit.

- EMG signals can be detected from earlier stages of movements, often even before the body posture changes.
- EMG signals suggest internal states, such as fatigue or other body conditions.

Despite the above advantages, EMG sensing has the following problems.

- We need to attach electrodes to the skin at the correct portions. Contacting the electrode affects the measurements.
- As mentioned in Section 2.2, estimating the head rotation angle using only EMG signals is difficult.

Other complementary sensors may be added in future designs to address these points.

We measure the sternocleidomastoid muscles, which primarily provide head rotation torque and tonus, as presented in previous studies (Nishimoto et al., 1989)(Pejcic et al., 2016).

Figure 5 shows the EMG logging device and its host (Raspberry Pi). Figure 6 shows the amplifying circuit for the EMG.

We used the index of the muscle activation, which is converted from the raw EMG signal, as follows (Stroeve, 1996).

$$\dot{e} = \frac{u - e}{\tau_{ne}} \tag{2}$$

$$\dot{a} = \begin{cases} \frac{e-a}{\tau_{act}} & (e \geq a) \\ \frac{e-a}{\tau_{deac}} & (e < a) \end{cases} \tag{3}$$

Here, u, e, and a indicate the absolute value of the raw EMG signal, the intermediate value (the excitation), and the muscle activation, respectively. From a previous study (Stroeve, 1996), we used $\tau_{ne} = 40ms$, $\tau_{act} = 10ms$, and $\tau_{deac} = 50ms$ for Eqs. (2) and (3).

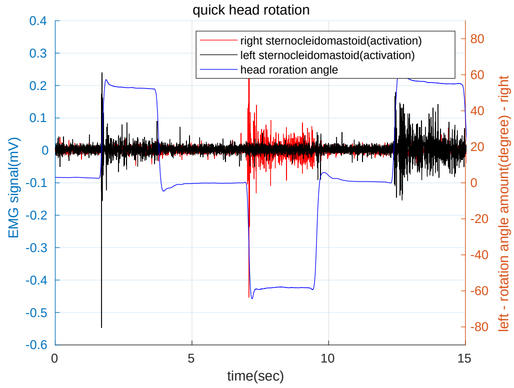

Figure 7: Example of raw EMG signals and the head rotation angle, the red and black lines show the myoelectric signals during head rotation.

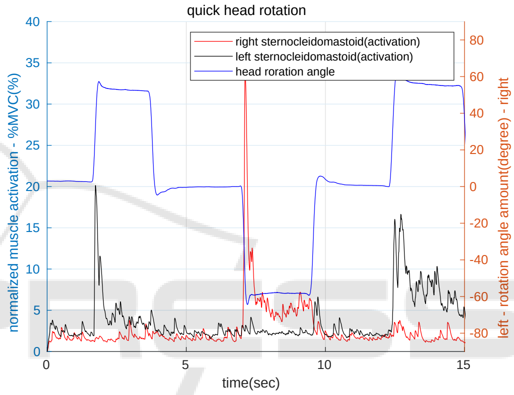

Figure 8: Example of muscle activations and the head rotation angle (converted from the example in Figure 7, the red and black lines show the muscle activations during head rotation.

Figures 7 and 8 show a sample of a raw EMG signal and its conversation result. The red and black lines in Figures 7 and 8 show the signals of the right and left sternocleidomastoid muscles, respectively, and the blue line shows the head rotation angle measured using a magnetic positional sensor.

4 TRANSLATION FROM EMG TO STIMULATION

Sometimes the user (monitoring the motion information) may need to quickly obtain every detail of the motion information, while at other times, the user may need to concentrate on their own activities. The strength, timing, and characteristics of the stimuli provided by the device need to change according to the user's needs.

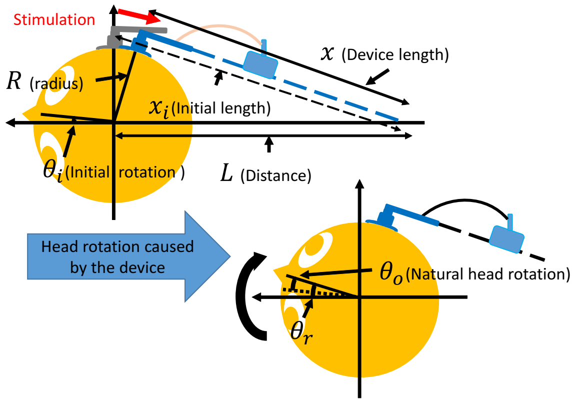

Figure 9: Geometry and action of the device. Calculation of θ_o is explained in Appendix 6.

Therefore, the system needs to provide a variety of transmission modes and leave their selection to the user.

4.1 Skin-stretch as Stimulation

The input and output of the system are the EMG signal and the stimulation via the skin-stretch device, respectively.

Figure 9 shows the geometry of the skin-stretcher device and the head. Based on the head rotation angle of the monitored person, skin stretch is applied to the monitoring user. If the monitoring user rotates their head to an angle at which they feel no skin stretch, this results in a similar head rotation to that of the monitored person, even though such an action is not requested most of the time.

Here, we use the notation in Eqs. (4) and (6) and denote the head rotation angle of the monitored person as θ_p, and the natural head rotation angle at which the monitoring user feels no skin stretch as θ_o. We calculated θ_o as it is explained in Appendix 6, and it represents the output stimulus. In addition, we assume that the muscle activation and $\ddot{\theta}_p$ have the same dimension, as we mentioned in Section 2.2.

Based on the above discussion, we considered several methods of translation from EMG to the skin stretch as follows.

(1) Rotation Angle: The approximated rotation angle θ_p of the monitored person is given to the monitoring user. θ_p is approximated by the second-order integral of torque $\iint T dt$ which is also approximated by the muscle activation $\iint a$. This is intuitive and easy to understand; however, if the postures (the head rotation angles) of both persons are very different, the stimulus may be too extreme. Conversely, when the motion of the monitored person is small, the stimuli often become to be too small to be perceived.

(2) Rotation Angular Velocity: The angular velocity $\dot{\theta}_p$ can be approximated by $\int T dt$, which can also be approximated by $\int a$. This method provides strong stimuli if the head rotation of the monitored person is fast and weak stimuli if the head rotation is slow. We expect that motions can be characterized by their velocity and are less affected by the pose changes of both persons. This method may partially transmit motion information; however, estimations of the actual rotation angle are difficult.

(3) Rotation Torque: The rotation torque T, which is derived from a, is a rough approximation of the angular acceleration. This method transmits details of even small motions, even though it does not provide the actual head rotation angle. Consequently, this method transmits every attempt at movement but can be annoying to the monitoring user.

In addition, we considered a method for transmitting simultaneous contractions of both the right and left sternocleidomastoid muscle.

(4) Co-contraction: Muscle activation on both sides are transmitted, and both sides of the skin are pushed to the front by the device. This method also enables the transmission of motion attempts for flexion, extension, and a state in which the neck is strained with the stiffness increased.

4.2 Filtering and the Emphasis of Signals

The following problems arise from the utilization of skin sensation via the simple attachment of a device to the skin.

- The condition of the device installation may affect the user's perception.
- Small displacements of the skin are often imperceptible, which results in a region of imperceptibility.
- The sensation of skin displacement gradually becomes imperceptible if no change occurs.
- Frequent or continuous stimulation can be annoying and feel unpleasant.

To handle those problems, we considered the application of filters to selectively emphasize or smooth the signals.

(a) Emphasizing. Considering the above problems (1), (2), and (3), we consider a filter that emphasizes the output to a sufficient level as follows.

$$\theta_m = \begin{cases} \theta_o & (\theta_o > \theta_{th}) \\ \theta_{th} & (\theta_o \leq \theta_{th}) \end{cases} \quad (4)$$

Here, θ_o, θ_m, and θ_{th} are the stimulus defined in the previous section, the emphasized stimulus, and the threshold, respectively.

(b) Thining. The input signal can be quantized and the frequency of the stimulated outputs can be decreased as follows.

$$\theta_m = \lfloor \frac{\theta_o}{C_{reso}} \rfloor \cdot C_{reso} \quad (5)$$

Here, θ_o, θ_m, and C_{reso} are the input, output, and unit of quantization, respectively.

(c) Dealing with Elasticity. When the head rotation angle is large, the user requires muscle contraction to keep prevent rotation countering the elasticity of the neck mechanism. This muscle contraction may result in a continuous stimulus. This filter suppresses this effect by emphasizing the initial change and attenuating the rest of the signal.

$$\theta_m = \begin{cases} \theta_o & (t \leq t_{th}) \\ \theta_o \exp(-\frac{t-t_{th}}{\tau_{dec}}) & (t > t_{th}) \end{cases} \quad (6)$$

Here, θ_o, θ_m, θ_{th}, t, t_{th}, and τ_{dec} are the input, output, elapsed time after muscle activation, threshold of the time, and time constant for attenuation, respectively.

5 PRELIMINARY EXPERIMENTS

5.1 Experimental Setting

We conducted preliminary experiments in the following setting. We asked one participant to perform the following three behaviors as a monitored person and measured the muscle activations using EMG.

(a) Simple Head Movement: Rotating the head right and left, and shrugging the shoulders.

(b) Conversation: Rotating the head in a conversational situation.

(c) Daily Movements: Standing up or getting up motions.

Then, we asked the rest of the participants to wear the device, discriminate the activity, and subjectively evaluate the quality of the system based on the following points; which task is performed, and their feeling concerning the effectiveness and comfort of the stimulation. During the experiment, participants did nothing except feel the stimuli of the system while remaining seated.

Typical responses from the participants concerning the input-output translation methods were as follows.

- All translation methods worked well for simple head movements, and the identification of the task was easy.
- It was easy to distinguish conversational behaviors from other behaviors.
- Identifying the behavior of getting up required concentration because the motion happens over a short period of time and the signals were small.
- The translation method (1) sometimes gave ambiguous stimuli for identifying the standing up and getting up tasks.
- Fast stimuli, i.e., pulling the skin faster, made recognition easier.

As highlighted above, translation method (1) did not provide sufficient stimulations for complex or continuous motions because small motions are often difficult to perceive with this method. Quantization slightly improves the performance; however the performance was not satisfactory compared to translation methods (2) and (3). We did not find clear performance differences between translation methods (2) and (3); we need further experiments to address this point.

For the filtering methods, typical impressions of the participants were as follows.

- The Emphasis filter helped with the perception of small movements.
- Continuous small stimuli were unpleasant, and filtering (the thinning filter) was necessary.
- Emphasizing the initial part of the head movements helped with the identification of behaviors, e.g., this helped with distinguishing actual head rotations from increased stiffness for stabilization.

The above results imply that the emphasis filter and quantization had the beneficial effects that we expected. These experiments and results are preliminary and do not cover all the necessary situations for our purposes. Further experiments for systematic verifications and evaluations are necessary, and we are planning to continue our investigation.

6 CONCLUSIONS

In this paper, we introduced a novel system for motion monitoring. The proposed system transmits motion information using muscle sensing via EMG and skin sensations transmitted via the skin-stretcher device. We also introduced methods to translate muscle activities to skin-stretch sensations as well as filtering to improve the performance of the device.

Our preliminary experimental results show the potential of our system design.

We need further investigations with systematic experiments to verify our framework and examine the performance of our system.

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APPENDIX

Opinions of Doctors and Caregiving Staffs in Nishikagawa Hospital

We consulted doctors and the nursing staffs members in Nishikagawa Hospital in the city of Mitoyo, Kagawa, Japan. We discussed the purpose and requirements of motion monitoring and obtained the following opinions.

- **The Detecting and Support of Getting Up, Standing Up, and Starting Walking Behaviors Are Extremely Important.** Elderly people tend to have accidents during the initial steps of these behaviors, and they have a lower likelihood of accidents after they have passed the initial steps. Therefore, motion monitoring of these behaviors would greatly help nursing or caregiving staff members.
- **Give Support Only When Necessary.** Ideal caregiving involves letting patients act by themselves except in situations in which they really need or want help. Motion motoring is also useful in that patients can behave naturally and caregivers can notice situations where assistance is necessary. This contributes to maintaining the patient's self-esteem and quality of life.

Calculating the Natural Head Rotation

Figure 9 shows the geometry of the device and the head. The device is initially attached with the condition that the extension rod is parallel to the tangent of the neck. We approximate the relation between the natural head rotation and the device length by the following formulas:

$$R^2 + x_0^2 = L^2 \tag{7}$$

$$\cos\left(\frac{\pi}{2} - \theta_r\right) = -\frac{R^2 + L^2 - x^2}{2RL} \tag{8}$$

where R is the approximated radius of the neck, L is the distance between the center of the device and the center of the neck, x and x_i are the actual and the initial length of the skin-stretcher device, respectively. θ_r is the head rotation at which the user feels no skin stretch. It is represented by the angle between the orientation from the center of the neck toward the pad and the vertical axis as shown in Figure 9. θ_i is the initial head rotation.

As we consider the above mechanism as a man-machine system, the natural head rotation angle of monitoring person θ_o is the head rotation angle requested by the skin displacement, which is caused by $\theta_r - \theta_i$. We do not directly use the rotation angle of the servo motor for calculating the input value because the extension rod and the servo motor are connected by the elastic link, i.e., the rotation angle of the servo motor and the displacement of the rod do not hold stable relationships. Alternatively, the displacement Δx is directly measured by the potentiometer installed in the device. Thus the natural head rotation angle θ_o can be estimated using Δx by the above equations.