Feedback Assistance with Concern for Others in Cooperative Work

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Abstract

Recently, most of the research on the skill assistance has been aimed at improving individual skills. However, a few assistance techniques consider cooperative skill in conjunction with others in a group. In cooperative work, the operator is affected by other operators. Thus, teamwork is needed in cooperative work. We propose assistance by force feedback in cooperative work using concern for others (CFO) which is one of the factors in teamwork. Each operator is given a force sense similar to a spring by a virtual impedance model that is changed on the basis of the estimated CFO. Experimental results suggest that CFO can be estimated and it was possible for force feedback to assist in cooperative work.

1. Introduction

Most of the researches on skill assistance have been aimed at improving individual skills[1]. Kusaka and Tanaka studied skill assistance by using a semiactive assistance mechanism[2]. Skill assistance has been applied to various fields. However, humans do not only perform tasks by themselves, and there are many tasks performed by multiple people, such as lifting items and machine operations.

Generally, a solo task is different from a group task. In most research on assisting skills, the work is assisted by influencing the input. However, when working with multiple workers, the input by each person must be included effects from others for suitable cooperation. Under such circumstances, not only individual skill assistance but also teamwork assistance is necessary. In spite of this, there are few assistance techniques that considers cooperative skills in conjunction with others in a group.

Teamwork evaluation is needed to assist cooperative skills. Adding a parameter representing teamwork is necessary to assist teamwork. However, there are several problems in using teamwork as a parameter. First, most of the existing teamwork evaluation methods are subjective methods, evaluated by questionnaire. Secondly, teamwork evaluation is difficult to do in real time. Feedback assistance is also thought difficult to evaluate in real time.

As a result, the evaluation of teamwork has mainly been by questionnaire, thus quantification and real-time evaluation were not investigated in previous research. However, these problems can be solved by using concern for others (CFO) which is one element of teamwork. CFO is a numerical value enabling quantitative and real-time evaluation.

In this paper, we propose skill assistance by using quantitative and real-time evaluation method with CFO[2]. Tsujita and Igarashi[3] investigated the relationship between CFO and work performance, and suggested that the relation between CFO and operation accuracy is showed negative correlation. If CFO is small, operation accuracy increases, and as CFO increases, the operation accuracy decreases.

In this paper, teamwork assistance by force feedback using the CFO is proposed. In addition, we evaluate the task performance and elucidate the kinesthetic sense of in case of force feedback assistance.

2. Cooperative Work and CFO

2.1 CFO

In this paper, solo work is considered as performing alone, whereas cooperative work involves other participants. Furthermore, cooperative work also includes actions that involve the consideration of others while being subjected to environmental changes due to the actions of others. The behavior of the workers changes as a result of the intervention of others in a cooperative work. In this research, we defined this as CFO. CFO $\hat{\sigma}_i$ is estimated as the difference between the input of multiple workers $u_i$ and the solo operation is modeled by a neural network $f_{NN}(\cdot)$, where the letter CFO $\hat{\sigma}_i$ according to this definition is represented as follows:

$$\hat{\sigma}_i = u_i - f_{NN}(X_i)$$

where, $X_i (\in \mathbb{R}^n)$ denotes the driving condition at a position where the input command is decided.

2.2 Cooperative work

In this research, CFO is estimated in a driving simulator task by two players after they each perform a solo task with
both hands. The operator is given force feedback by input
device shown in Fig. 1. Each input device uses DD motors.
Moreover, control of a motor is performed taking dynamics
into account. Therefore, the player can perform tasks based
on their intuitive feeling. In the experiments, each player
performs the driving task by themselves. The solo operation
model is learned by a NN. Then, the two players perform the
driving simulator with assistance considering CFO.

3. Teamwork Assistance with CFO

In our previous work, a group with a small CFO performed
better than a group with a large CFO[3]. In this research, we
attempt to improve the task performance while receiving the
assistance of others during cooperative work by assisting for
reducing the CFO.

The teamwork assistance is applied to each player to re-
duce CFOs using force feedback. For example, perform force
feedback on the input so that it becomes an input approximate
to the solo operation model that used at the time of calculat-
ing the estimated CFO. Therefore, the input is approximated
to the input operating as the solo task, and the estimated CFO
would be reduced.

In this way, this research carried out feedback assist using
CFO in this research.

3.1 Force feedback

Force feedback is performed by using the DD motors. A
block diagram of motor control is shown in Fig. 2. \( \theta_n \) is the
input command of the operator for the left and right motors.
The estimated reaction torque \( \hat{\tau} \) is estimated by introducing
a disturbance observer (DOB)[4] and a reaction torque ob-
server (RTOB)[5] into the motors.

Figure 2: Block diagram of motor control

The DOB is a control method that estimates and reduces
disturbance, whereas the RTOB is a control method that can
estimate the reaction torque \( \hat{\tau} \) without a torque sensor. \( \hat{\tau} \) esti-

mated by the RTOB is used for the dynamics. The dynamics
is composed of a moment of inertia term \( J_V \), viscosity term
\( D_V \), and elastic term \( K_V \). The equation of motion in this
research is defined as follows;

\[
J_V \ddot{\theta}_n + D_V \dot{\theta}_n + K_V (\theta_n - \theta_0) = \hat{\tau}
\]

where, \( \theta_0 \) is the reference term of the virtual spring. Thus,
using the estimated reaction torque \( \hat{\tau} \) gives the controller the
position, velocity, and acceleration of the dynamics were ap-
plied.

By applying the Eq. (2), the motors are controlled by a vir-
tual impedance model. The force sense given to the operator
by the motor is realized by changing \( J_V, D_V \) and \( K_V \).

Therefore, the operator can feel a force sense similar to a
spring applying the virtual impedance model to the input.

3.2 Solo operation model

The solo operator model is a model of the input charac-
teristics of each operator created using NN[6]. The NN was
learned by giving data as input commands by the left and the
right input devices. A back propagation method is applied
the NN which has nine input layers, 20 hidden layers and one
output layer with learning coefficient 0.005. The inputs of the
NN are the motor positions, the position of the motor on
the other side position, reaction torque, position error, and angle
error relative to the target point. The input commands to the
motors Are given to the NNs as teaching data.

As a result, the NN models the input characteristics of the
operator through learning and creates a solo operation model.
The results of input prediction by the NN are shown in Fig.
3.

The CFO can be decreased by changing the reference point
of the spring \( \theta_0 \) relative to the predicted input in the solo op-
eration model using Eq. (2). In this research, the force feedback is performed on the input prediction command of the solo operating model by considering the correlation between the change in the CFO and the task performance.

4. Experimental Method for Driving Simulator Task

In this paper, a driving simulation is employed as the experimental task. The driving simulation is displayed on a screen as shown in Fig. 4. In the simulator, the goal to follow is a red target point while traveling on a yellow target line within the time limit. The two evaluation indexes in the driving simulator task are shown in Fig. 5. The difference between the target line and the position of the operator own position was defined as the position error $x_e$. Furthermore, the angle between the direction of the operator in the virtual space and the target point was defined as the angle error $\theta_e$.

The experimentation time is 80 [s]. When doing a solo task, the NN learned from the input commands for 60 [s] and set as the output of the predicted command of the NN to confirm the prediction for 20 [s]. In the cooperative work carried out by two people, the NN does not learn. The predicted command output from the model is continuously output during the experiment. When there is assistance, the reference point of the spring is changed so that it becomes the same as the predicted value. In the case of no assistance, experiments were carried out with the fixed spring reference value of the spring.

5. Results

In this paper, we conducted experiments on ten subjects in 10 groups. The average frequency of the CFO with and without assistance is shown in Fig. 6. In addition, the maximum value of each CFO average estimated value was normalized.

Additionally, the task performance with and without assistance is shown in Fig. 7. The task performance $P_I$ is calculated as follows:

$$P_I = \frac{y_{max}}{x_e}$$

$y_{max}$ is y coordinate of the highest reached point in the task. Additionally, $x_e$ is the average position error. As a result, a reduced CFO improved the task performance were
6. Conclusions

We proposed skill assistance using a quantitative and real-time evaluation method with CFO. CFO is estimated in a driving simulation task performed by two players after each performed a solo task with both hands.

As a result, a reduced CFO and improved task performance were confirmed by force feedback assistance with considering CFO. However, the rate of reduction of CFO was not enough. This is considered to be caused by small force feedback. Some of the subjects could not feel a difference between with and without assistance. By varying the value of the $K_V$ term in Eq. (2), the elastic force of the spring received by the operator increases. However, if the force provided is too high, it may interfere with the operation.

In the future, we will conduct an new experiment that takes these problems into consideration. Moreover, we will evaluate the teamwork assistance with three or more workers task with CFO.

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