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ADVANCED MANUFACTURING

Safety for Human-Robot Interaction with a Shared Autonomy

Robots were placed under fixed safeguards in the early stages of robotics development. Safety and real-time risk assessment are not easy, especially when robots are in places that co-exist with humans. However, robot and human interaction have essential applications in human physical assistance, human-robot task coordination and cooperation. This paper presents our proposed new approach to developing shared autonomy under safety. We derive the shared autonomy policies and explain how safety is quantified. After demonstrating an experiment result, the paper describes open problems that will be investigated in future research activities. It also covers how it can have potential applications in industry, welfare, and rescue.

Keywords:
Robotics, safety, human-robot interaction, compliant actuators.

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INTRODUCTION

Robots are getting into every aspect of life. In particular, assistive robots are the next great innovation leap that will be included in the different tasks, such as the physical assistance of humans. Human-robot interaction has a significant challenge. The human model is mainly assumed to be a BlackBox without a clear understanding of whether human motion is safe and stable. And there must be real-time feed from the environment and humans about their stability and normal motion behaviour. This problem gets more challenging when the situation requires the human and robot to work in cooperation.

Ignoring the human model has certain limitations for assistive robots [1-2]. This issue from the human aspect stops robots from getting into human's nearby workspace. The main challenge is finding the human intention and doing risk assessment in real-time while assisting the person with a robot. For example, Vianello et al. [3] did studies for predicting the posture of human body limbs, but this study could have constraints due to developed leader-following motion controls. In addition, the heavy computations make these strategies challenging for real-time human-robot interactions [3-4].

The next challenge is developing a shared autonomy between humans and assisting robots. There have been some attempts to develop shared autonomy between inputs from human counterparts and manipulator robots' controllers [5-6]. For instance, Javdani et al. [6] proposed a partially observable Markov decision process (POMDP) to guess the object the user wants to pick. In this problem, it was assumed automated robot does not know the priori goal (without desired configuration). The study shed light on controller design with no desired states, but there are remaining open problems. In this regard, the arm robot mainly ran with an internal controller and did not consider any complex trajectory that the person/patient wanted to control the joystick. However, assistive mobile robots may follow highly complex paths, spontaneously changing decisions for the desired goals.

Based on the motivations mentioned earlier, we were able to quantify the safety of human upper body motion by using a spring-damper predictive model in our previous study [9]. Also, we proposed an assistive controller based on differential geometry that created corrected velocity inputs based on user joystick inputs and mobile wheelchair robot's states [10]. In this paper, we propose a new shared autonomy policy that combines the predictive safety model that gets human conditions by IMU with our assistive controller and an onboard motion planner. Additionally, our problem is more challenging since there is an assistive walker robot that, with an onboard navigation system, tries to correct its assistance to the user (see Fig. 1) based on inputs from the user, assistive controller and motion planner.

First, we describe the shared autonomy concept under safety. Next, we find out the policies for the shared autonomy. Next section, we explain the predictive safety model and its sensory design. Finally, the experiment results are shown for an example case.

SHARED AUTONOMY POLICIES

This section explains how shared autonomy is derived with respect to the safety and assistive controller. Next, the formulation is explained between robots and humans.

Fig. 1 presents an example scenario where the patient uses an assistive mobile robot. In this problem, the person's information is captured with inertia measurement sensors (IMU). The whole concept of multi-robot cooperation for human assistance is given in our previous study [7]. Similarly, a wireless IMU sensor is attached to a person's chest. Also, an assistive walker robot can autonomously navigate through the environment using the LiDAR sensor. The walker robot has a differential wheel model, and users with joystick inputs can get assistance. To simplify the problem the robot is underactuated; hence the information from user directly corresponds to the velocity and orientation of the walker but actuators work as breaks to support the patient during the move from one place to another.

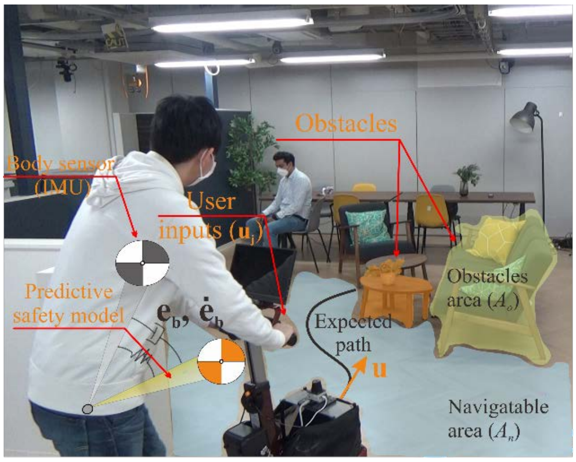


Fig. 1. Shared autonomy scenario.

The principal inputs formula with shared autonomy policy is proposed as follows:

$$\mathbf{u}(\mathrm{t}) = \frac{1}{\sum_{i=1}^{k} \lambda_{\mathrm{i}}} \left(\sum_{i=1}^{k} \lambda_i \, \mathbf{u}_i \right) \tag{1}$$

where $\lambda_i \in [0-1]$, $\mathbf{u}_i$ and k are the trust ratio, arbitrary velocity vector and maximum number of inputs. In this problem, the inputs are planner, assistive controller and walker joystick, $k{=}3$. The inputs and trust factors for each system are defined as motion planner $(\mathbf{u}_p, \lambda_p)$, assistive controller $(\mathbf{u}_a, \lambda_a)$ and human push $(\mathbf{u}_j, \lambda_j)$. Then, we have proposed two shared autonomy policy as follows:

$$\mathbf{u}_\mathrm{t} = \lambda_s \left(\frac{\lambda_j \mathbf{u}_j + \lambda_a \mathbf{u}_a}{2} \right) + (1{-}\lambda_s) \left(\frac{\lambda_a \mathbf{u}_a + \lambda_p \mathbf{u}_p}{2} \right) \tag{2}$$

$$\mathbf{u}_\mathrm{t} = \lambda_o \left(\frac{\lambda_a \mathbf{u}_a + \lambda_p \mathbf{u}_p + \lambda_j \mathbf{u}_j}{3} \right) + (1{-}\lambda_o) \lambda_p \mathbf{u}_p$$

where λ_s and λ_o are safety quantifier ratio and obstacle inclusion ratio on the scene, respectively. To give better understanding of how inputs are decided based on the level of risk and environment information, we can show their extreme conditions as follows:

$$\begin{aligned} Policy\ 1 &= \begin{cases} \mathbf{u}_\mathrm{t} = \frac{\lambda_j \mathbf{u}_j + \lambda_a \mathbf{u}_a}{2}, & \lambda_s \to 1 \\ \mathbf{u}_\mathrm{t} = \frac{\lambda_a \mathbf{u}_a + \lambda_p \mathbf{u}_p}{2}, & \lambda_s \to 0 \end{cases} \\ Policy\ 2 &= \begin{cases} \mathbf{u}_\mathrm{t} = \frac{\lambda_a \mathbf{u}_a + \lambda_p \mathbf{u}_p + \lambda_j \mathbf{u}_j}{3}, & \lambda_o \to 1 \\ \mathbf{u}_\mathrm{t} = \lambda_p \mathbf{u}_p, & \lambda_o \to 0 \end{cases} \end{aligned} \tag{3}$$

It is clear from Eq.3 that when the trust λ_s is not high in human condition (safety input gives high error in human upper body motion), the input of robot actuators mainly relies on the assistive controller and motion planner.

This helps to avoid unstable behaviour of the user inputs e.g., this can be direct force/moment to the walker by the user. However, when the trust is near one, the control input consists of human and assistive control input. In the second policy, the problem is a little different since the risk-assessment happens with the number of seeable obstacles in the scene where we have simply defined it by $\lambda_o = (A_n \,/\, A_o)$ where A_n and A_o are areas that can be navigated and obstacles. Thus, when the risk is low due to existing low number of obstacles, the human input is followed with correction through the assistive controller with motion planner. And the planner is mainly considered with existing high levels of obstacles.

We can easily develop the shared autonomy by solving the equations (2) for two trust ratio variables of lambda sub p planner and lambda sub o human inputs. Since the computation might be highly complicated, we leave the details of the stability and boundedness to another study.

QUANTIFYING THE SAFETY IN HUMAN MOTION AND ASSISTIVE CONTROLLER

Quantifying the safety concerning human motion is important since the real-time risk assessment help assistive robots be more agile and dynamic in environments with humans. Therefore, considering human body motion stability and normal motion realisation rather than as Blackbox would be highly crucial in different scenarios.

Our previous work [8] defined safety as human tenancy to have an unstable or abnormal motion concerning standard/natural motions. To include the safety of the problem of navigation and human-robot interaction, we have used the chest (onboard IMU) information. A predictive safety model is utilised where the system is based on a spring-damper safety model with a reduced-dimension dataset [8]. This model quantifies and tracks how much human posture (upper body) deviates in orientation and velocity $(e_b,\ \dot{e}_b)$ as shown in Fig. 2 based on probability dataset shown in Fig.3. Because the ultimate goal is to feed the information of safety for share autonomy, we have defined a trust ratio $n_s \in [0 - 1]$ (smaller better) as follows:

$$\lambda_s = k_p \frac{\|e_b\|}{e_m} + k_d \frac{\|\dot{e}_b\|}{\dot{e}_m} \tag{4}$$

where k_p and k_d are the constant gains and $(e_m, \dot{e}_m)$ is the maximum error value for orientation and velocity.

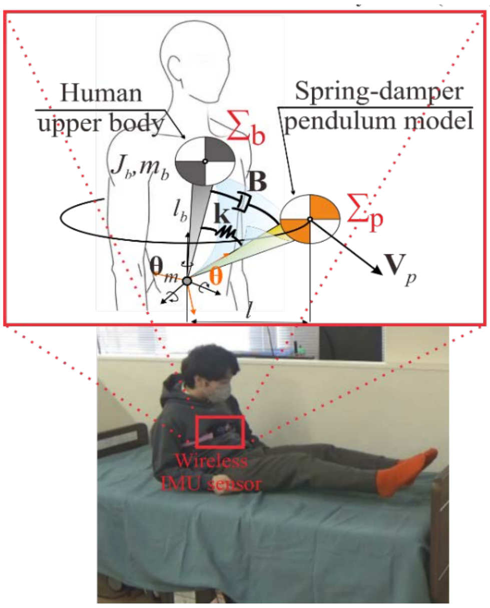


Fig. 2. Predictive safety model (PSM) using IMU on patient chest.

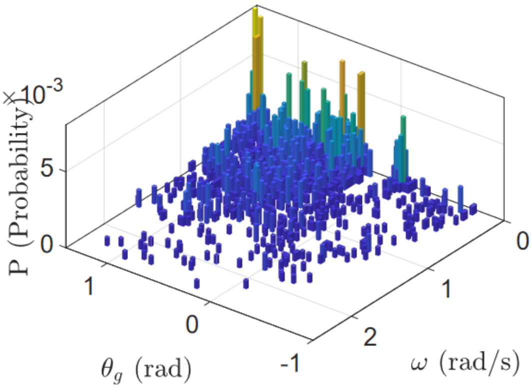
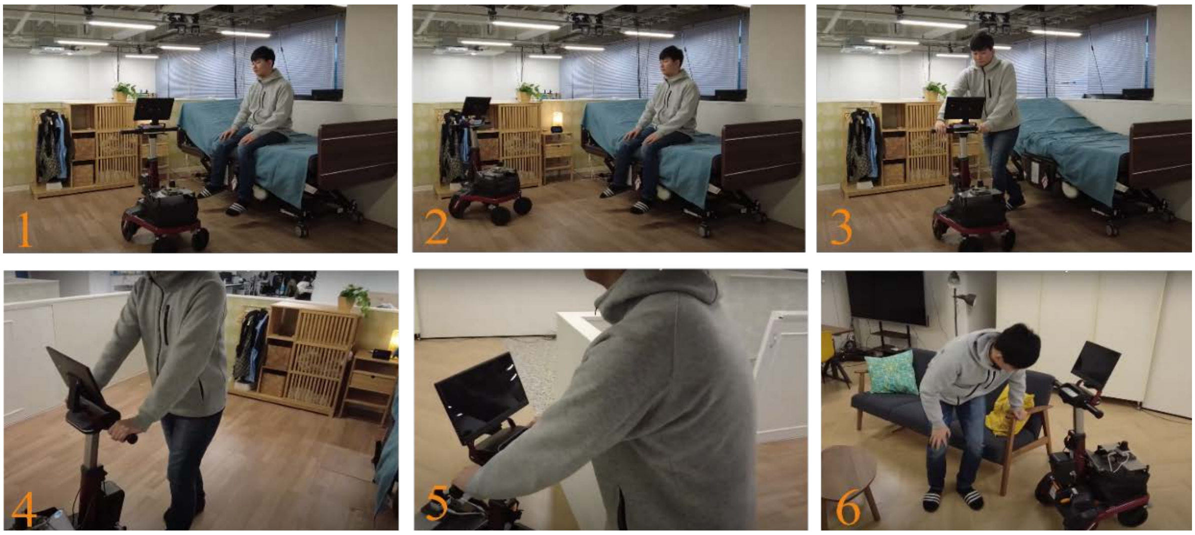


Fig. 3. Probability distribution for analyzing safety model of human upper body where and are the angular direction of gravity and norm of angular velocity [8].

Fig. 4 (below). Captured frames for the user that uses assistive walker with our proposed shared autonomy.



The motion planner that was targeted for this problem was considered is the time elastic band (TEB) planner. The motion planner not only gives the desired control inputs $\mathbf{u}_p$ for reaching the robot based on local and global maps with avoiding obstacles in the scene but also feed the obstacle information (A_n, A_o) to calculate λ_o. The assistive controller that is utilized is from our previously proposed model [9] based on differential geometry where it takes the vehicle velocity and user inputs and tries to give a corrected smooth velocity inputs $\mathbf{u}_a$ as follows:

$$\mathbf{u}_a(\mathrm{t}) = \begin{bmatrix} \mathrm{u}_{\mathrm{v,a}} \\ \mathrm{u}_{\omega,\mathrm{a}} \end{bmatrix} = \delta \begin{bmatrix} 1 + R_v \gamma_s \\ \alpha_s \end{bmatrix} \tag{5}$$

where $[\mathrm{u}_{\mathrm{v,a}}, \mathrm{u}_{\omega,\mathrm{a}}]$ is the linear and angular velocity inputs and $\{\gamma_s, \alpha_s, \delta\}$ are the geometric functions [9] for creating the assistive input with respect to user inputs $\mathbf{u}_J$. However, we have here improved the controller by dynamically changing its values of trust n_a with proportional to user disability and characteristics.

RESULTS AND DISCUSSION

To study the proposed shared autonomy behaviour, we have tested the concept at an example scenario.

Fig. 4 presents the results, the scenario at the Tohoku University Living lab. At first, the patient is standing up from the bed as the sensors are tracking the patient's safety level. Next, he requests to go out and a walker-supporting robot is sent. While the walker robot tries to navigate to the patient, using onboard sensors, it scans the environment for obstacles. After successfully stopping in the proper location, the user stands up and grabs the walker robot. Next, the assistive controller tries to react to the person's inputs from grippers by giving the assist through the motion planner. In this part, the shared autonomy policy gets more into the picture. Finally, the video shows how the user navigates safely to the desired location, and the person sits on the couch. This confirms that the strategy of shared autonomy works properly.

Although the strategy is promising, there are still open problems to research. For instance, if the user suddenly stops giving input, the shared autonomy policy might saturate and could not create a proper response based on the nature of equations (1)-(2). This confirms that the strategy has certain singular points and more careful design requires for real-world practical applications. Additionally, the delay in sensor communication and lack of high-level understanding of a person's intention requires further study; hence, the assistive robot can be more responsive with considering self-efficacy.

CONCLUSIONS

In this paper, we propose a new shared autonomy policy considering human safety. We confirmed our studies with a simple experiment scenario. Also, the potential open problems in this field are discussed.

Conflicts of interest
The authors declare no conflict of interest.

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