A New Control Architecture for Physical Human-Robot Interaction Based on Haptic Communication

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ABSTRACT
In the near future, humans and robots are expected to perform collaborative tasks involving physical interaction in various different environments such as homes, hospitals, and factories. One important research topic in physical Human-Robot Interaction (pHRI) is to develop tacit and natural haptic communication between the partners. Although there are already several studies in the area of Human-Robot Interaction, the number of studies investigating the physical interaction between the partners and in particular the haptic communication are limited and the interaction in such systems is still artificial when compared to natural human-human collaboration. Although the tasks involving physical interaction such as the table transportation can be planned and executed naturally and intuitively by two humans, there are unfortunately no robots in the market that can collaborate and perform the same tasks with us. In this study, we propose a new controller for the robotic partner that is designed to a) detect the intentions of the human partner through haptic channel using a fuzzy controller b) adjust its contribution to the task via a variable impedance controller and c) resolve the conflicts during the task execution by controlling the internal forces. The results of the simulations performed in Simulink/Matlab show that the proposed controller is superior to the stand-alone standard/variable impedance controllers.

Categories and Subject Descriptors
I.2.9 [**Artificial Intelligence**]: Robotics; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O*

Keywords
Haptics; physical human-robot interaction; variable impedance control; internal force control.

1. INTRODUCTION
To make human-robot collaboration more natural, we need robots that can anticipate the intentions of the human partner and comply with those intentions smoothly during the execution of a collaborative task [1, 2, 3]. Obviously, the intention is a state of mind, which cannot be measured directly. However, we know that humans are good at recognizing each other's intentions during a collaborative task even without a verbal communication. Although the collaborating human partners may use other means of communication to convey their intentions while transporting a table, the haptic channel is more direct and personal when there is a physical interaction. Here, the intended movement of the human can be conveyed to the robot via the direction of the force applied to the table by the human while the force magnitude helps with the speed of the movement [1, 2, 3]. Following the intention recognition, the collaborating human partners successfully adjust their forces to adapt not only to the requirements of the task but also to each other's needs. In this paper, we propose a new control architecture for pHRI involving haptic communication. This architecture has three major components: 1) an intention estimator to detect the intentions of the human via haptic channel using a fuzzy controller, 2) a variable impedance controller to adjust the contribution of the robot to the task based on the intentions of the human, and 3) an internal force compensator to resolve the conflicts during the task execution by controlling the internal forces. We are not aware of any earlier study that integrates these components together in a coherent manner.

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2. CONTROL ARCHITECTURE
In order to demonstrate the proposed control architecture, we assume that the human partner and the robot translate the table between two stations along a straight path. In our architecture (Figure 1), the robot does not know the final destination; hence no positional trajectory is specified for the robot. We use a Kalman observer to estimate the force applied by the human partner since it cannot be measured directly during the task execution. In addition, Kalman observer predicts the desired kinematics of the table. Once the next state of the table is predicted, the force applied by the robot to the table is calculated by an impedance controller in our approach. If we neglect the impedance mass and stiffness (m = 0, k = 0), the force applied by the robot is calculated by a Standard Impedance Controller (SIC) as:

$$F_{des}^{r} = K_p(v_{des} - v) + K_i(x_{des} - x) + bv \quad (1)$$

where b is the controller impedance damping, x_{des} and v_{des} are the desired position and velocity of the end-effector, x and v are the actual position and velocity of the end-effector, K_p and K_i are the proportional and integral motion feedback gains, respectively. In our approach, the impedance damping, b, is adjusted by a fuzzy controller adaptively (Variable Impedance Control – VIC). This algorithm takes the current velocity of the table, v, and the rate of change of the human force estimated by the Kalman observer, $d\hat{F}^h$, and then outputs a gain value representing the human intention, K_{HIG}, which is utilized to calculate the variable damping coefficient later. Two-input-one-output Takagi-Sugeno fuzzy tuner is utilized in this study. Three membership functions (positive, zero and negative) are defined for each input, as tabulated in Table 1.

We scale the human intention gain, K_{HIG} with a constant α to calculate the damping coefficient of the impedance controller as

$$b = b_0 + \alpha K_{HIG} \qquad (2)$$

where, b_0 is the nominal value of the damping coefficient.

Table 1: The singletons associated with the human intentions. The human intention gain for acceleration varies between $0 < K_{HIG} \leq 1$, the human intention gain for deceleration varies between $-1 \leq K_{HIG} < 0$, and $K_{HIG} = 0$ when there is no change.

$d\hat{F}^h$ \ v	Positive	Zero	Negative
Positive	1	0.5	-1
Zero	0	0	0
Negative	-1	-0.5	1

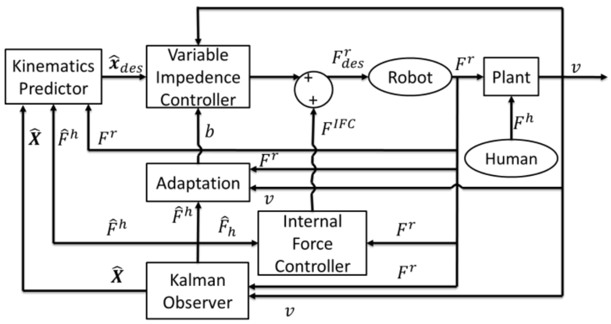

Figure 1. Control diagram for the table transportation task.

So far, the proposed controller for the robot is designed to comply with the human intentions. However, due to time delays and/or noise in the system, conflicts may still occur. To reduce these conflicts, we utilize the internal force controller (IFC). For this purpose, the forces applied by the partners are decomposed into two components; one contributing to the motion and the other is the internal force, which does not contribute to the motion at all [1,3]. The internal force is calculated as

$$F^{int} = \begin{cases} -F^r, & if\ (F^h F^r \leq 0) \\ 0, & otherwise \end{cases} \qquad (3)$$

In order to eliminate this wasted force (i.e. internal force), a simple PI controller with a set value of zero is utilized (F^{IFC} is the compensation signal that the PI controller generates to reduce the internal force). Thus, the total force applied by the robot is,

$$F^r_{des} = K_p(v_{des} - v) + K_i(x_{des} - x) + bv + F_k^{IFC} \qquad (4)$$

3. SIMULATION RESULTS

We conducted simulations in Matlab/Simulink to test the utility of the proposed approach. In terms of tracking performance, we observe that the overshoot amplitudes are higher under SIC compared to that of VIC (Figure 2). Hence, the positional tracking of VIC is better than that of SIC.

Furthermore, the average forces applied by the human and the robot are reduced under VIC (Figure 3). Also, SIC+IFC reduces the average forces applied by the partners on the table when compared to using SIC alone. However, as it is observed from the Figure 3, there is not much change in the average forces of the partners when the controller is changed from the VIC to VIC+IFC. The average internal force for different controllers is also shown in Figure 3. The amount of disagreement between the partners is the highest under SIC. IFC reduces the disagreement to some extent. Moreover, VIC further reduces the disagreement and the least disagreement is observed under VIC+IFC.

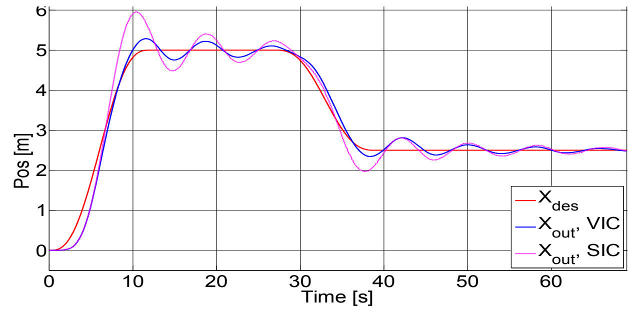

Figure 2. The position tracking performance of VIC and SIC.

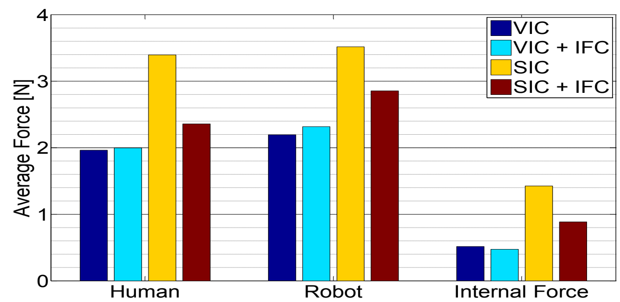

Figure 3. The average force applied by the human partner and the robot on the table and the average internal force.

4. CONCLUSION

We aim to develop a controller for a robot that can intuitively understand the intentions of a human partner and collaborates with him/her naturally and efficiently during a pHRI task. In order to achieve this goal, we have developed a variable impedance controller and compared its performance with a conventional (standard) impedance controller. We modify the damping coefficient of controller to comply with the intentions of the human during the task execution through a fuzzy controller. The robot should react to changes in the human intention immediately in order to reduce the conflicts. In our approach, the level of human intention sets the damping coefficient of the controller. Although the performance of the proposed VIC is better than that of the SIC, the delays and uncertainties in the system may still cause some conflicts between the human and the robot. As a remedy to this, we have implemented an internal force controller in series with the VIC. We observed that this scheme (VIC+IFC) further reduces the conflicts and improves the task efficiency.

5. REFERENCES

[1] Mörtl, A., Lawitzky, M., Kucukyilmaz, A., Sezgin, M., Basdogan, C., and Hirche, S. (2012). The role of roles: Physical cooperation between humans and robots. *The International Journal of Robotics Research*, 31(13):1656-1674.

[2] Oguz, S. O., Kucukyilmaz, A., Sezgin, T. M., and Basdogan, C. (2010). Haptic negotiation and role exchange for collaboration in virtual environments. *IEEE Haptics Symposium*, 371-378.

[3] Kucukyilmaz, A., Sezgin, T. M., and Basdogan, C. (2013). Intention recognition for dynamic role exchange in haptic collaboration. *IEEE Transactions on Haptics*, 6(1):58–68.