Role Determination in Human-Human Interaction

Nikolay Stefanov* Angelika Peer† Martin Buss‡

Technische Universität München
Institute of Automatic Control Engineering

ABSTRACT

Physical human-robot interaction can be significantly improved when being aware about the role each partner takes in a joint manipulation task. This holds especially in computer assisted teleoperation, where depending on the identified role of the human, different roles can be assigned to the assistance function. This work proposes a method for the determination of two non exclusive roles, an executor and conductor. Hereby the executor refers to the person who mainly contributes to the execution of the task and the conductor to the person who takes the decision and controls the motion. The method is based on the analysis of haptic data, whereby the signs of force and motion signals are evaluated. Two different cases are considered in the analysis: direct interaction of the two partners as well as interaction via an object. The effort each operator makes to either carry out the task or initiate a change in the task is also estimated. The proposed method can be used to actively influence the role assignment, to extract features or for task segmentation.

1 INTRODUCTION

In recent years the trend in robotics is more and more shifting from autonomous robotics to human-robot interaction. While autonomous robots have to be able to take decisions and act on their environment, in human-robot interaction the interaction with a human is of interest. Only little research has been conducted in the field of physical human-robot interaction, whereby the human and the robot are in direct contact with each other. To realize an intuitive and safe interaction an advanced model of human behavior is required. This model can be used to assign roles to the robot when interacting with a human. Such a role assignment is e.g. interesting in the field of computer assisted teleoperation, where different roles can be assigned to the assistance function and thus a user-adapted assistance function can be realized.

Unfortunately, there is only little knowledge about the interpretation of haptic signals in physical human-human interaction and thus realizing an intuitive and tight human-robot interaction is very challenging. In this paper we investigate different roles that are taken by participants when physically interacting with each other by analyzing haptic data.

There are only a few studies discussing roles in human-human interaction. Most of them are related to verbal communication. Hung et al. [3] suggest a model for the estimation of the dominant partner in conversations. In their research dominance is related to the executor in the conversation (see also [1]). An interesting point here is that the dominant person acts like simply replaying a prerecorded sample. The dominant person is also called leader of the task. A similar idea can be found in the analysis of swarm behavior in multi-agent systems, see [2, 9]. Here, also one agent makes decisions while the other react.

Such role allocations were also found when analyzing haptic human-human interaction [7]. As haptic signals are of concern, the executor is obtained very often by interpreting force signals. Reed [6] found that partners take roles in form of an accelerator and decelerator.

Often the dominant partner is assumed to conduct the interaction, whereby she/he expresses her/his intention by applying bigger forces to the system. This idea is also used in some robotics applications that investigate zero force control. Here, typically the human leads the execution of the task, while the robot follows [5, 4]. However, in these scenarios the robot cannot take any active role in the interaction.

We propose the following two roles in haptic interaction: execution and conductorship. Hereby the execution is taken by the person, who contributes mainly to the task and the conductorship by the one who takes the decision and controls the motion. In other words, the conductor uses haptic signals to express her/his desire and the executor contributes to the completion of this desire. It should be noted that the two proposed roles are not exclusive. Each of the partners can take one, both or none of the roles. In detail the following research questions are addressed in this paper: 1) determination of both execution and conductorship from haptic signals considering direct haptic interaction and interaction via an object; 2) determination of phases in interaction related to different role distributions; 3) estimation of the contribution of each partner to the task in terms of performed work.

2 THEORETICAL BACKGROUND

This section presents a short review of the theoretical basis used to determine the roles execution and conductorship. As shown later, our approach evaluates the signs of the force measured at the interaction point as well as its motion. Thus, in the following subsections the interaction force for the case of direct interaction as well as interaction via an object is determined.

2.1 Direct Interaction

Consider two forces applied at a point in static equilibrium. According to the Third Newton law the applied force and the reaction force have the same absolute value and reverse signs. This is illustrated in Fig. 1, where f_1 and f_2 are the action and reaction forces. These forces can be considered as forces applied by each partner during interaction. Imagine an idealized force sensor (with no mass) placed at the interaction point and f_i to be the measured interaction force and define f_i to be positive when the point "is squeezed", see Fig. 1, a) and negative, when it is "stretched", see Fig. 1, b).

To provide a better understanding we would like to further recall the working principle of a force sensor. In general, a force sensor consists of a body, a torsion membrane and a lamella, see Fig. 1 c). Consider the action and reaction forces acting at the body and the lamella, respectively. Hence, the torsion element is deformed according to the applied force. In Fig. 1 c) (left) the sensor is "squeezed", which results in a positive force, while in Fig. 1 c) (right) the membrane is "stretched" and the measured force f_i is negative. The positive direction of motion (position, velocity and acceleration) is hereby denoted with $x, \dot{x}, \ddot{x}$.

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[*] e-mail: nikolay.stefanov@tum.de

[†] e-mail:Angelika.Peer@tum.de

[‡] e-mail:M.Buss@ieee.org

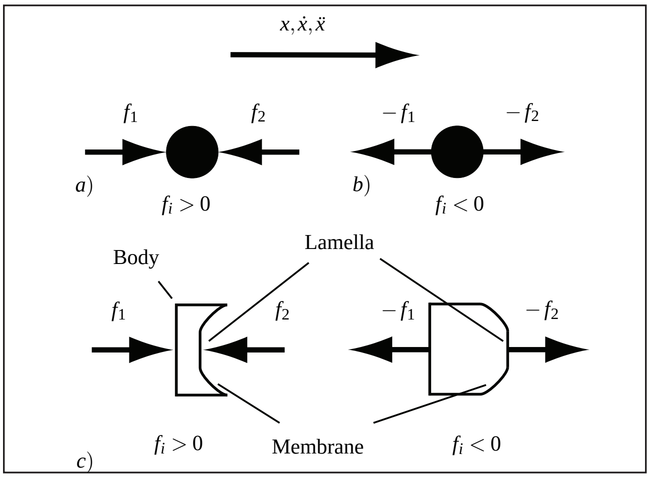

Figure 1: Direct interaction of two partners

Note that the measured force f_i does not affect the motion directly. Motion in positive direction (as well as negative direction) can happen for both, positive and negative force f_i (the persons push or pull each other). In other words looking at the sign of f_i one can not determine the direction of motion.

In the case of direct human-human interaction (the partners interact over their hands) the contact point, at which they apply forces is called interaction point. At this point also the force sensor is placed. This sensor measures the action and reaction forces, which refer to the forces f_1, f_2 applied by the operators. As these forces are measured at the interaction point, they are also called interaction forces f_i and are given by the following equation:

$$f_i = f_1 = f_2.$$

Since the interaction point is assumed to be massless and without friction, every measured force indicates that the partners apply forces against each other. Even if they aim to move their arms into the same direction, forces at the interaction point can be measured, as the partners either push or pull their hands. Of course the particular case exists when the applied forces f_1 and f_2 have the same amplitude and sign; hence zero force is measured at the interaction point. In such a situation there is no haptic information exchange.

2.2 Interaction via an Object

In the next step, consider the situation when partners interact via an object. Without loss of generality, it is assumed that the object is rigid, it moves in the horizontal plane and gravity does not affect motion. Furthermore, the object is carried, such that no friction must be taken into account.

The partners grasp the object at two different points. Hence, there are force sensors attached to each of these points as illustrated in Fig. 2 b). When considering only static conditions the values measured by the sensors have the same magnitude. The coordinate systems are furthermore chosen in such a way that pushing or pulling each other results in forces f_1, f_2 with the same sign. Hereby, the measured forces are positive when the object is ”squeezed”.

In the following paragraph also the dynamic behavior is considered. According to the Second Newton Law, an uncompensated force $f_u = m\ddot{x}$ leads to an acceleration of the object. The presence of uncompensated force indicates, that the measured forces f_1 and f_2 do not have the same magnitude. The term $m\ddot{x}$ describes the inertial force that depends on the dynamic properties of the object. This force is always directed against the uncompensated force. Hence, when the partners apply force to overcome this inertial force, it is possible that they apply forces in the same direction $(sgn(f_1) \neq sgn(f_2))$. In the following paragraphs we derive a formalism to determine the interaction force in case of interaction via an object, whereby the dynamical properties of the object are considered as unknown.

In the first step, the relationship between the object dynamics and the forces measured at the interaction points is determined, see Fig. 2 a):

$$f_1 = f_2 + m\ddot{x}. \tag{1}$$

In the next step, imagine the object virtually split into two parts at the center of gravity and the force sensor placed in the middle as shown in Fig. 2, b). Hereby, the virtual force sensor gives us the interaction force f_i we are interested in. Taking further into account (1) this intersection force can be calculated as follows:

$$f_i = f_1 - \frac{m\ddot{x}}{2} = f_1 - \frac{f_1 - f_2}{2} = \frac{f_1 + f_2}{2} \tag{2}$$

Using this equation, the interaction force f_i can be determined for any rigid object with arbitrary geometry.

2.3 Tristate Logic

Since a role must be assigned to one of the partners (only interaction with two participants is considered) and roles refer mainly to the signs of the measured signals, logic expressions and dependences are evaluated. Situations, however, with zero force, velocity or acceleration occur often in human-object-human interaction. Thus, the boolean logic does not allow to describe the system completely. On this account, a ternary logic is used instead [8]. The meanings of the states $\{-1, x, 1\}$ are given in Table 1.

Table 1: Interpretation of tristate logic values

Logic value	Measured signals	Role assigned to
-1	< 0	left partner
x	$= 0$	not defined
1	> 0	right partner

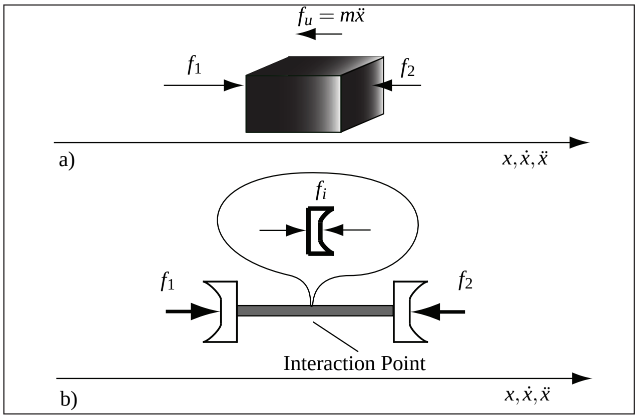

Figure 2: Interaction of two partners via an object

3 METHOD DESCRIPTION

This section describes how the forces acting on the interaction point can be used for the determination of the two roles execution and conductorship. In our method we use force and position data as well as position derivatives. Direct as well as indirect interaction via an object is considered.

3.1 Execution: a force - velocity relationship

Consider the interaction point is moving with positive velocity (to the right) and the measured force f_i is positive. Then partners are “pushing“ against each other and according to Fig. 1 a) the active force is applied by the left partner while the reactive force is applied by the right one. Hence, the left partner can be considered as the executor of the task, because the direction of the force he applies coincides with the direction of motion. Imagine now the right partner applying more force so that the direction of motion changes (velocity becomes negative), see Fig. 3 a). Hence, for positive interaction force and negative velocity the right partner executes the motion. One can conclude, that as long as the interaction force f_i is positive, the executor is determined by the sign of the velocity. Analogous results can be worked out also for negative f_i. Consequently, it can be stated that when looking at the sign of the velocity and the interaction force, it is possible to determine which partner executes the task. This person is called executor and the associated role execution, in the following denoted with λ. It can be described by the following analytical expression

$$\lambda = -sgn(f_i)sgn(\dot{x}).$$

The dependency of the execution λ from the signs of the interaction force and the velocity of the interaction point can be also expressed with a logical XNOR by using the following equation

$$\lambda = sgn(f_i)\underline{\vee}sgn(\dot{x}).$$

Refer to Table 1 for the interpretation of the measured signals. The corresponding truth table is shown in Table 2.

Hereby, the second column refers to the interaction force f_i, the third to the velocity $\dot{x}$, and the execution λ is given by the fifth column. The fourth column is related to the accelerations and the sixth column to the conductorship discussed in the next subsection. The relation between force, velocity and execution is shown in the first four plots of Fig. 3 a), b), c) and d).

As the role execution describes a force-motion relationship, it is also worth discussing this role in a context of mechanical energy. The executor is the person, who injects energy into the system, while the partner dissipates it. Consequently, all rows in Table 2, where no role is determined, have the following explanation: First, when the interaction force is zero, there is also no energy exchange between the partners. Second, even if the partners apply force but there is no motion ($\dot{x} = 0$), again, there is no energy exchange and thus, no role can be determined.

All the above made conclusions hold for a massless interaction point. When the partners, however, interact via an object, both of them can apply forces in the same direction to overcome the inertia of the object. As a consequence, the task execution is not necessary performed by a single operator and thus, it is not possible to nominate a single executor. In this case, the executor is defined as the person, who mainly contributes to the execution of the task.

Table 2: Execution and conductorship in ternary logic representation

No.	f_i	$\dot{x}$	$\ddot{x}$	Execution λ	Conductorship χ
1	<0	<0	<0	-1	-1
2	<0	<0	0	-1	$n.d$
3	<0	<0	>0	-1	1
4	<0	0	<0	$n.d$	-1
5	<0	0	0	$n.d$	$n.d$
6	<0	0	>0	$n.d$	1
7	<0	>0	<0	1	-1
8	<0	>0	0	1	$n.d$
9	<0	>0	>0	1	1
10	0	<0	<0	$n.d$	$n.d$
11	0	<0	0	$n.d$	$n.d$
12	0	<0	>0	$n.d$	$n.d$
13	0	0	<0	$n.d$	$n.d$
14	0	0	0	$n.d$	$n.d$
15	0	0	>0	$n.d$	$n.d$
16	0	>0	<0	$n.d$	$n.d$
17	0	>0	0	$n.d$	$n.d$
18	0	>0	>0	$n.d$	$n.d$
19	>0	<0	<0	1	1
20	>0	<0	0	1	$n.d$
21	>0	<0	>0	1	-1
22	>0	0	<0	$n.d$	1
23	>0	0	0	$n.d$	$n.d$
24	>0	0	>0	$n.d$	-1
25	>0	>0	<0	-1	1
26	>0	>0	0	-1	$n.d$
27	>0	>0	>0	-1	-1

3.2 Conductorship: a force - acceleration relationship

Having assigned the role of the executor and thus, knowing who mainly carries out the task, it is still unclear who initiates the motion. This is the case, because only the sign of the velocity is considered, but not the rate of change. To determine which partner is responsible for changes in the motion, the dynamics of the motion must be investigated. Consider the following two cases that have in common that changes in the magnitude of the force each partner applies (f_1, f_2) do not cause changes in the sign of the measured interaction force. In the first case, the executor increases the force she/he applies and consequently the velocity increases. This results in a positive acceleration. In the second case, her/his partner increases the force, and consequently the velocity decreases. This case can be interpreted as a decision of one of the partners to change the direction of motion, which then finally leads to a change in the sign of the velocity. On the other hand, regardless of the increased magnitude of the interaction force f_i, the velocity can not change its sign immediately. Thus, we have to consider a phase of deceleration provoked by the applied force of one of the partners.

As a consequence, also another role in the interaction can be assigned, which refers to the intention or the decision of each of the partners and that can be detected by changes of the acceleration. This function is called conductorship and is denoted with χ. The related partner, who takes this role is called conductor. In the following paragraph the physical meaning of the conductorship and a method to derive the conductorship from force and motion signals is discussed.

The procedure is similar to the one used already for the execution. In the situation described above, f_i has positive sign, while the acceleration becomes negative. This indicates that the follower applies a force that slows down the system. The interaction force f_i remains positive, while the acceleration $\ddot{x}$ becomes negative. Thus, the right partner can be considered as conductor. Analogously, if f_i changes its sign, the executor decides to change the direction of motion, she/he becomes also conductor, as her/his force increases.

The analytical expression for conductorship is given by

$$\chi = -sgn(f_i)sgn(\ddot{x}),$$

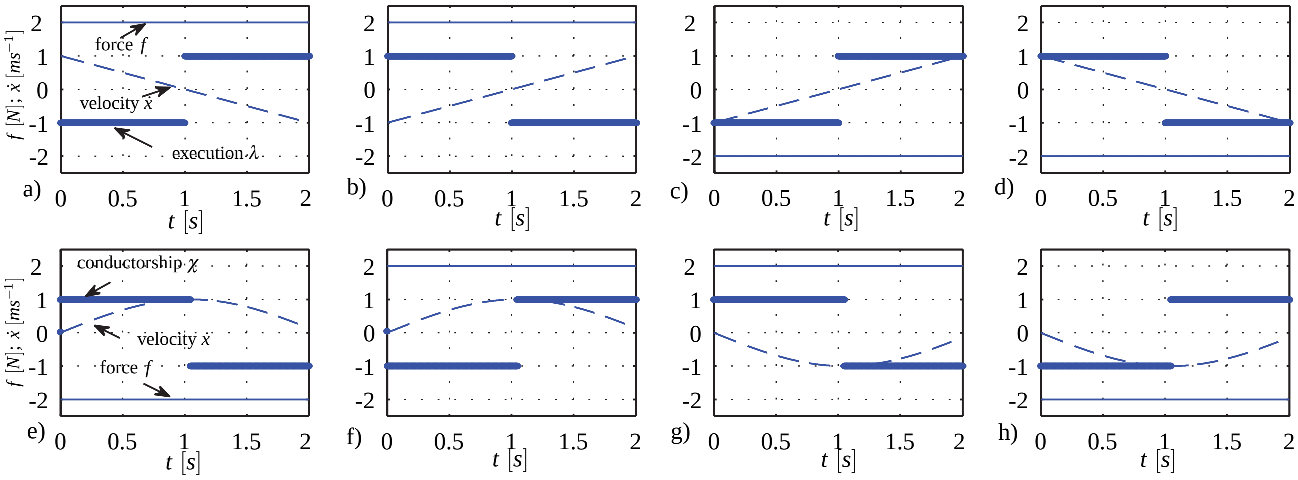

Figure 3: Simulated changes in execution and conductorship

or using the boolean operator XOR

$$\chi = f_i \veebar \ddot{x}.$$

The truth table for the conductorship is shown in Table 2. Fig. 3 e) f) g) and h) finally show all possible conditions that lead to a change in conductorship .

Considering Table 2 it can be seen that when no interaction force is measured there is no haptic information exchange and when the acceleration is zero there is no one who applies higher force. In these cases conductorship can not be determined.

Note again, that conductorship and execution do not describe complementary roles. They define roles, whereby each partner can take one, both or none of them. Taking the conductorship does not always lead to a change in the execution. Especially, when interacting via an object, one person can take the conductorship to reduce the velocity while letting the other person lead. On the other hand, the execution can be transfered between the operators either by first taking the conductorship or also directly, which happens when the follower changes the direction of the applied force. While in the first case, the direction of motion changes, in the second one it remains the same.

3.3 Phases of Interaction

Fig. 4 illustrates the role assignment by looking at an idealized example. The first diagram shows the input signals, whereby the solid line indicates the force, the dashed line the velocity and the doted one the acceleration. Using these input signals and taking into account the considerations made above, the changes in execution and conductorship can be determined for the case of direct interaction. The execution is shown in the second plot and the conductorship in the third one. Negative values (-1) in the diagrams stand for execution and conductorship of the left partner, while positive values $(+1)$ refer to the right partner. Changes in conductorship or execution, determine different phases of interaction, which are separated by vertical lines.

At the beginning the force and velocity are negative but, are increasing over time. Thus, the acceleration is positive. The left partner injects energy, while the right one dissipates it. Hence, the left one is the executor. When $\ddot{x}$ becomes positive, the right partner becomes conductor.

The right operator becomes executor at the moment the velocity becomes positive. Since the velocity increases she/he also takes the conductorship. The next role change is invoked by the sign-change of the force. As a consequence the left partner becomes conductor and executor at the same time, because she/he changes the direction of the applied force, which leads to changes in the sign of the interaction force f_i.

Concerning the role distribution, principally two different situations can be distinguished: Both roles are either taken by the same partner or are distributed among them. Phase 1 shown in Fig. 4 shows an example, where *one of the operators takes the execution and the other the conductorship*. Such a phase cannot persist for an arbitrary long time. Two events can cause it to end. On the one hand, when the velocity changes its sign the conductor becomes executor as well. On the other hand, this phase ends when the magnitude of the force applied by the conductor becomes smaller than the force applied by the executor. Then, the former conductor looses her/his role - the former executor becomes conductor. Such a phase in which one partner is executor and the other is conductor is called *transition* phase, as it occurs when the execution is transferred between the operators. Note that such a transition occurs only, when $\mathrm{sgn}(\dot{x}) \neq \mathrm{sgn}(\ddot{x})$.

In the following, consider the case where the *same partner is executor as well as conductor*. In contrast to the case analyzed before, this case can persist for an arbitrary long time. This phase is called *persistent* phase. It ends when the force or acceleration change their sign. When only the sign of the force changes, both execution and conductorship switch to the other partner. But when acceleration and velocity reach opposite signs again a transition phase occurs.

3.4 Mechanical Work during Interaction

Now consider the work the operators perform during interaction. It can be expressed in terms of mechanical work as shown in the following equation:

$$W = \int f_i dx.$$

It can be calculated for every change in the position, but it has various meanings for each of the phases defined in the previous subsection. The calculated work during a persistent phase expresses the effort of the executor to carry out the motion. The work in this phase is called persistent work. This is shown with a solid line in the second and third diagram of Fig. 5.

The calculated work in the transition phase indicates the effort the conductor makes to change the direction of motion. Analo-

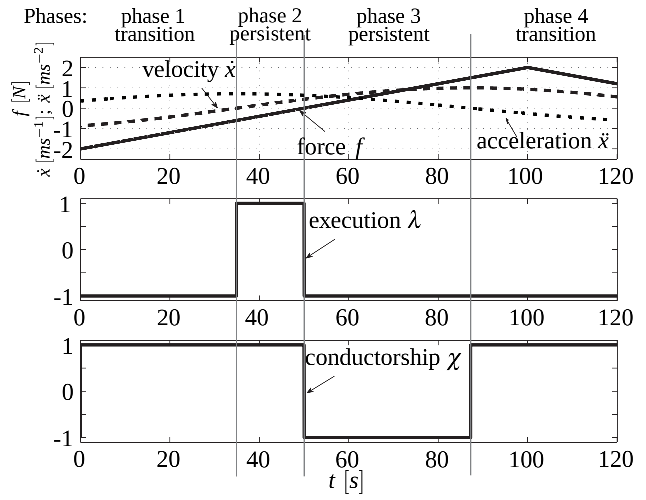

Figure 4: Phases of interaction

gously this work is called transition work and is shown with dashed line in Fig. 5. Of course in both, the persistent and transition phase each partner performs work, but only the work of the partner who is currently acting as a conductor is considered.

When one and the same partner has the execution and conductorship the calculated work is assigned to this person as persistent work. When one has the execution and the other one the conductorship the mechanical work is called transition work and is assigned to the person, who has the conductorship . For each phase the work can be assigned to the related role as shown in Table 3. Note that the calculated mechanical work is always assigned to the conductor, regardless of the execution. Note also, that for $\dot{x} = 0$ mechanical work is zero. Thus, no interpretation for these cases is given in Table 3. Here, another important conclusion can be drawn: Roles, derived from haptic signals during human-human interaction, can only be determined for a moving interaction point. If the interaction point does not move, there might still be haptic interaction, but no roles can be assigned.

Table 3: Assignment of transition and persistent work

No.	Executor	Conductor	Work
1	-1	-1	persistent
2	-1	$n.d$	persistent
3	-1	1	transition
7	1	-1	transition
8	1	$n.d$	persistent
9	1	1	persistent
19	1	1	persistent
20	1	$n.d$	persistent
21	1	-1	transition
25	-1	1	transition
26	-1	$n.d$	persistent
27	-1	-1	persistent

Simulation results describing the distribution of the mechanical work between the partners are shown in Fig. 5. Here, the same force, velocity, and acceleration signals are used as in Fig. 4. In the first plot execution and conductorship are shown. During the first phase, the left partner is executor and the right one is conductor. While the transition occurs, the calculated mechanical work is assigned to the right partner as she/he is conductor. In the next phase the same partner also becomes executor and consequently the related work is considered to be persistent work. Between the second and third phase only the force changes its sign and as execution and conductorship have changed, the mechanical work in this phase is assigned to the left partner.

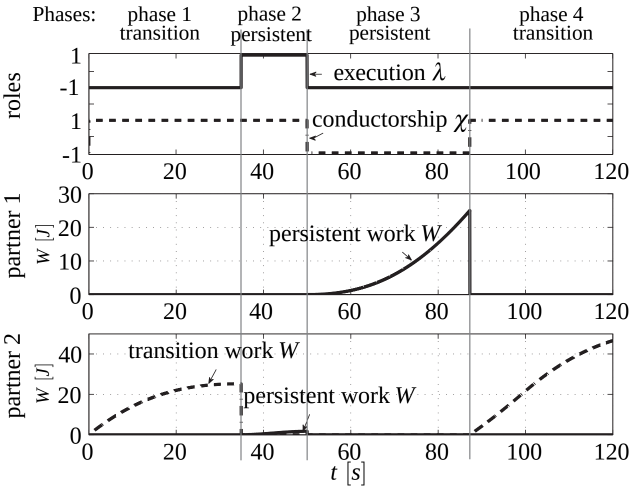

Figure 5: Work assignment during different phases

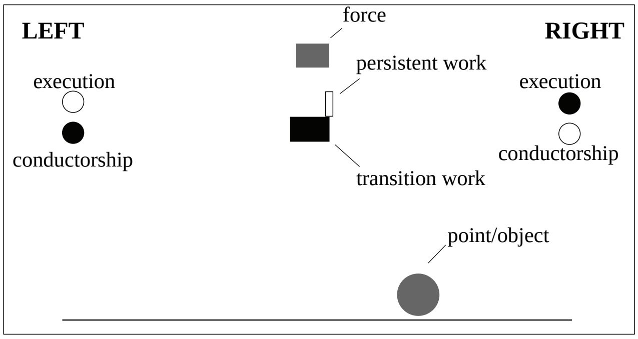

Figure 6: Virtual reality simulation used in the experiment

4 EXPERIMENT

To analyze the developed theory a first, preliminary experiment is performed. A more extensive psychological evaluation, which aims to find a correlation between the determined roles and the subjective feelings of the partners, is subject to future research.

The experiment is designed as follows: The persons interact with two haptic interfaces and move a massless point or a mass in virtual reality. To provide haptic feedback to the partner two 1 DOF linear haptic interfaces are used. Please note that to overcome the difference between interaction via a mechanical device and a real object, the experiment can be also performed with a physical object. In addition to this haptic feedback, also visual feedback is provided to the participants, see Fig. 6. Hereby, the object is visualized as a sphere. Also information about the identified execution and conductorship as well as the applied force and mechanical work is displayed.

Some preliminary results are shown in Fig. 7. The first plot shows the role execution (solid line) that is estimated from force (dashed line) and velocity (doted line) inputs. The conductorship is shown in the second plot. The third and the fourth plots illustrate the mechanical work assigned to the left and the right partner, respectively. In these plots the transition work is indicated with a dotted line, while the persistent work is given with a solid one.

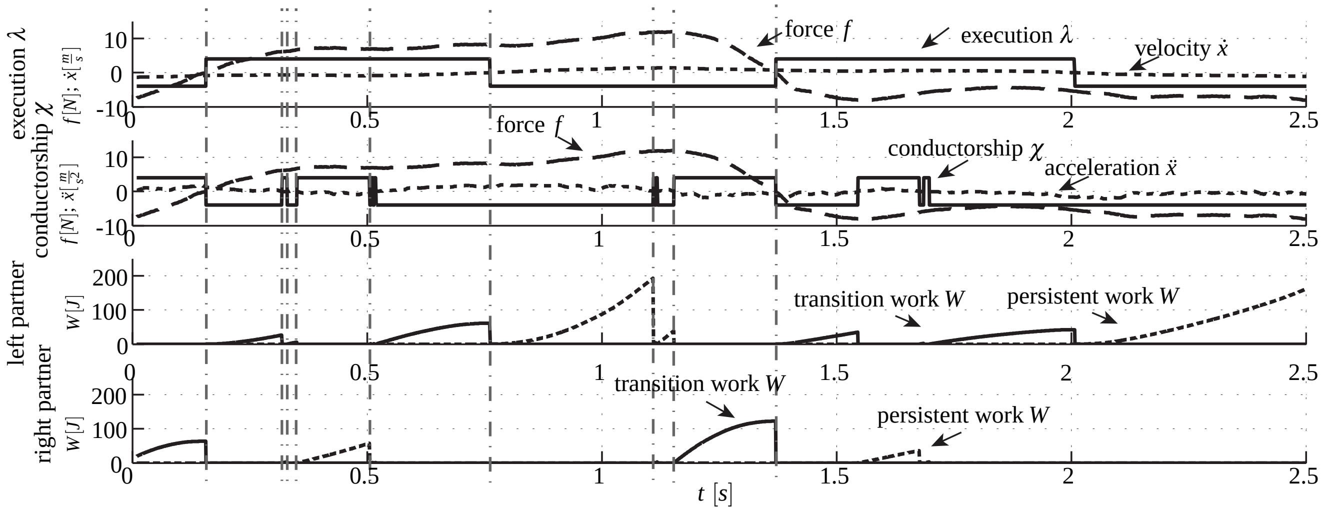

Figure 7: Experimental results

The performed experiment shows that the proposed method to estimate roles in haptic interaction can be applied for real measurement data. Although the first tests indicate that the roles also correlate with the subjective feeling of participants, the results are not statistically validated. The proof of these results is subject of future research.

5 SUMMARY AND CONCLUSIONS

In this work a new approach for the identification of roles in human-human interaction by analyzing haptic data was presented. Two roles, namely execution and conductorship were defined. The proposed method uses velocity and acceleration of the interaction point and the force applied to it. Hereby direct interaction and interaction via an object was considered.

The proposed algorithm for role determination can be applied in several application areas ranging from task segmentation and task modelling over interaction control to the analysis of human behavior. Segmentation of haptic data based on force and position measurements is very challenging because of the interdependency of the data. While most of the existing approaches are focused on motion segmentation only and incorporate prior knowledge in the segmentation process, the proposed role determination algorithm uses force and motion signals and allows to easily segment a task by preserving an intuitive interpretation of the single segments. The proposed method also helps to become rid of the often used zero force control that is typically used in physical human-robot interaction. Transferring knowledge about the roles that are taken during real human-human interaction to human-robot interaction can help to create a more reactive robotic partner. Such a partner can either be represented by a physical robot interacting with the human or an assistance function that supports the human, e.g. in a teleoperation task. Another application area is the analysis of human behavior: As the mechanical work is distributed among the partners we can calculate the contribution of each of them to the total persistent and transition work when carrying out a certain task. The resulting distribution of the work gives insights into the stability of taken roles and the quality of the interaction.

Above only situations were considered where the partners interact directly with each other or via a rigid object. Hereby only the measured force was considered to determine execution and conductorship. However, this method is limited when friction must be taken into account. This case namely implies that the object is under permanent influence of forces, that cannot be measured. This makes the determination of a transition phase complicated, because deceleration can be caused from both, friction force and force applied by the conductor. There is no possibility to distinguish between these two sources. One idea to overcome this problem is to take into account the magnitude of the forces applied at the grasping points by each of the interaction partners. Such an extension of the proposed method will be considered in future research.

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