Chapter 13
Improving Human-Computer Cooperation Through Haptic Role Exchange and Negotiation

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Abstract Even though in many systems, computers have been programmed to share control with human operators in order to increase task performance, the interaction in such systems is still artificial when compared to natural human-human cooperation. In complex tasks, cooperating human partners may have their own agendas and take initiatives during the task. Such initiatives contribute to a richer interaction between cooperating parties, yet little research exists on how this can be established between a human and a computer. In a cooperation involving haptics, the coupling between the human and the computer should be defined such that the computer can understand the intentions of the human operator and respond accordingly. We believe that this will make the haptic interactions between the human and the computer more natural and human-like. In this regard, we suggest (1) a role exchange mechanism that is activated based on the magnitude of the force applied by the cooperating parties and (2) a negotiation model that enables more human-like coupling between the cooperating parties. We argue that when presented through the haptic channel, the proposed role exchange mechanism and the negotiation model serve to communicate the cooperating parties dynamically, naturally, and seamlessly, in addition to improving the task efficiency of the user. In this chapter, we explore how human-computer cooperation can be improved using a role-exchange mechanism and a haptic negotiation framework. We also discuss the use of haptic negotiation in assigning different behaviors to the computer; and the effectiveness of visual and haptic cues in conveying negotiation-related complex affective states. Throughout this chapter, we will adopt a broad terminology and speak of cooperative systems, in which both parties take some part in control, as shared control

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schemes, but the term "control" is merely used to address the partners' manipulation capacities on the task.

13.1 Introduction

Haptic cooperation involves the interaction of two parties through the sense of touch. Such interaction is often implemented between humans and between humans and machines in order to create a better sense of immersion. Shared control between a human and a computer evolved from the idea of supervisory control since its emergence in early 1960s [1]. Supervisory control has been typically used in teleoperation tasks which are difficult to automate. It allows the human operator (the master) to assume the role of the supervisor or the decision maker, while the robot operated by the computer (the slave) executes the task. However, human-human cooperation is far richer and more complex than this scheme, since the exchange of the roles and the control of the parties on the task is dynamic and the intentions are conveyed through different sensory modalities during the execution of the task. Moreover, negotiation is a significant component of interaction in human-human cooperation.

The shared control systems available today for human-computer cooperation possess only a subset of these features (see the review in [2]). Hence, as cooperative tasks get more complex, such schemes fall short in providing a natural interaction that resembles human-human communication. In order to alleviate this deficiency, a mechanism, where both parties can be employed with different levels of control during the task, is needed. In the last decade, interactive man-machine systems with adjustable autonomy have been developed. Adjustable autonomy is implemented to make teamwork more effective in interacting with remote robots by interfacing the user with a robot at variable autonomy levels [3, 4]. These autonomy levels imply different role definitions for human and computer partners.

Lately, the notion of exchanging roles also emerged in the context of haptic collaboration. Several groups examined role exchange in human-human collaboration. Nudehi et al. [5] developed a haptic interface for training in minimally invasive surgery. The interface allowed to shift the "control authority" shared between two collaborating human operators, based on the difference of their actions. Reed and Peshkin [6] examined dyadic interaction of two human operators in a 1 DOF target acquisition task and observed different specialization behaviors of partners such as accelerators and decelerators. However, they did not comment on the possible reasons or the scheduling of this specialization. Stefanov et al. [7] proposed executor and conductor roles for human-human haptic interaction. In their framework, the conductor assumed the role of deciding on the system's immediate actions and expressing his/her intentions via haptic signals so that the executor can perform these actions. They proposed a model for role exchange using the velocity and the interaction force. This system is especially interesting in a sense that the parties are required to communicate only through the haptic channel, i.e. the conductor is assumed to express his/her intention by applying larger forces. Also in this work, they examined the phases of interaction that lead to different role distributions. In a recent paper, Groten et al. [8] investigated the effect of haptic interaction in different shared decision situations in human-human cooperation, where an operator can choose to agree/disagree with the intention of his/her partner or to remain passive and obey his/her partner in a path following task. They observed that when operators have disagreement in their actions, the amount of physical effort is increased (interpreted as additional negotiation effort) and performance is decreased. They also found that the existence of haptic feedback further increases the physical effort but improves the performance. The findings of this study is in conflict with their previous work in [9], where haptics increased the effort but provided no performance gains. Even though they conclude that this result might stem from the fact that the former task included no negotiation, their findings are conclusive.

Even though the studies mentioned above presented very important observations regarding human-human interaction, only few groups focused on role definitions and exchange in human-computer interaction involving haptics. Evrard et al. [10] studied role exchange in a symmetric dyadic task where a human interacts with a computer partner through an object. They allowed the operators to switch between leader and follower roles during the task. In order to describe role exchange for collaborative interaction, they used two functions to model different interaction behaviors. However, they failed to implement a user-centric and dynamic negotiation mechanism to handle the interaction between a human and a computer. Oguz et al. [11] came up with a haptic negotiation framework to be used in dynamic tasks where a human negotiates with a computer. This framework defined implicit roles in terms of the parties' control levels, and dynamically realized role exchanges between the cooperating parties. They defined two extremes for identifying different roles for sharing control: user dominant and computer dominant control levels. Their haptic negotiation model allowed dynamic and user specific communication with the computer. The role exchanges were performed regarding the magnitude of the force applied by the cooperating parties. The results of this study indicated that the suggested negotiation model introduced a personal and subjectively pleasing interaction model and offered a tradeoff between task accuracy and effort. However, even though they claimed that the framework was built to enable negotiation, their task was strictly collaborative, where the communication addressed a decision making process between the parties rather than negotiation. Additionally, since the users were not informed on the nature of the task that they were performing, the evaluation of the utility of the role exchange mechanism was not feasible.

Table 13.1 presents a comparison of selected shared control studies that implemented roles as explained within this section. The features of the haptic board game and the haptic negotiation game (explained respectively in Sects. 13.3.1 and 13.3.2) developed by us are included in the last two rows of the table. Both games use the negotiation framework suggested in [11] and mainly investigates the effectiveness of haptic cues on communication in collaborative or conflicting situations.

Upon close inspection of the table, we observe that half of the tasks in question focus only on human-human interaction, while the remaining realize human-computer interaction. An immediate examination shows that in all tasks, the parties have a common goal they want to optimize, but only in two (Groten et al. [8] and

Table 13.1 A comparison of several shared control tasks implemented in the recent literature

	Human-Computer Interaction	Simultaneous Shared Control	Sequential Shared Control	Common Goal	Separate Agendas	Separate Roles	Dynamic Role Exchange
Reed & Peshkin [6]	×	✓	×	✓	×	✓	×
Stefanov et al. [7]	×	✓	×	✓	×	✓	✓
Groten et al. [8]	×	✓	×	✓	✓	✓	✓
Evrard et al. [10]	✓	✓	✓	✓	×	✓	×
Kucukyilmaz et al. [12]	✓	×	✓	✓	×	✓	✓
Oguz et al. [13]	✓	✓	×	✓	✓	✓	×

Oguz et al. [13]), they have separate agendas. Also it can be seen in columns 2 and 3 that only Evrard et al. [10] implemented a shared control scheme that is both simultaneous and sequential,[1] however a dynamic role exchange between the cooperating parties has not been considered as it is done in Kucukyilmaz et al. [12].

Specifically, this chapter aims to present a perspective to build more natural shared control systems for human-computer cooperation involving haptics. We suggest that a cooperative haptic system will be more effective if the human's and the computer's levels of control are dynamically updated during the execution of the task. These control levels define states for the system, in which the computer's control leads or follows the human's actions. In such a system, a state transition can occur at certain times if we determine the user's intention for gaining/relinquishing control. Specifically, with these state transitions we assign certain roles to the human and the computer. Also, we believe that only by letting the computer have a different agenda than that of the user's, we can make emotional characteristics of touch transferred to the human participant.

In this sense, this chapter gives details on the proposed haptic negotiation model and presents two applications we have developed earlier to investigate how this model can be used to realize natural collaboration and adapted to systems where the computer is programmed to display different behaviors when interacting with the user. In the next section, we present the haptic negotiation model we introduced in [11] in its general form. In Sects. 13.3.1 and 13.3.2, we present two games; one for demonstrating the effectiveness of the proposed haptic role exchange mechanism [12], and the other for demonstrating the use of the proposed haptic negoti-

[1] A general categorization of shared haptic interaction, which is similar to Sheridan's classification, talks about "*simultaneous*" versus "*sequential*" haptic manipulation classes [14]. In simultaneous haptic manipulation, both parties can actively control the task concurrently, whereas in sequential manipulation, they take turns in control.

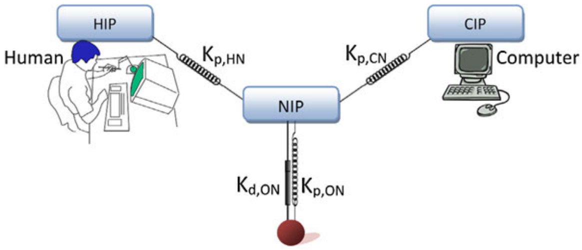


Fig. 13.1 The general negotiation model

ation model to assign different behaviors to the computer [13]. Finally Sect. 13.4 summarizes our results and Sect. 13.5 presents conclusions.

13.2 Haptic Negotiation Model

The proposed negotiation model in its general form is sketched in Fig. 13.1. This model is developed to let the human and the computer participants interact to move a virtual object via a spring-damper system governed by three interface points that act like massless particles. The human and the computer basically interface with the system through individual interface points, which are labeled as HIP (user's Haptic Interface Point) and CIP (Computer's Interface Point) in the figure. These two points are interconnected at a negotiated interface point (NIP), which directly pulls the object towards itself, so that the control is shared between the parties. This system facilitates the operation of assigning different roles (i.e. control levels) to the parties by changing the stiffness and damping coefficients of the system (represented respectively by K_p and K_d values in the figure). $K_{p,ON}$ affects how much the manipulated object is diverted from the negotiated path. The human and the computer are granted different levels of control on the game by changing the stiffness coefficients between CIP and NIP ($K_{p,CN}$) and between HIP and NIP ($K_{p,HN}$), as depicted on the figure. If $K_{p,CN}$ and $K_{p,HN}$ have equal value, the computer and the user will have equal control on the game. The computer will be the dominant actor within the game if $K_{p,CN}$ has a larger value, and vice versa, the user will be dominant if $K_{p,HN}$ is larger.

The negotiation model can be used to realize decision making and negotiation. By dynamically shifting the stiffness of the system in favor of the user or the computer, we can also realize a smooth and natural transition between different roles for the parties. Also programming the computer to execute different behaviors is straightforward because of the disjoint nature of the model and the operations of the parties. This way, a richer interaction can be achieved between the human and the computer. Since a human being will possess a variety of different behaviors and realize many negotiation processes in a dynamic task, using such a model is not only beneficial, but also necessary to come up with a natural human-like communication.

13.3 Applications, Design Approach, and Experiments

In this section, we will present two applications through which we displayed the utility of the negotiation model on different cooperative schemes. Section 13.3.1 presents the haptic board game as presented in [12]. In that study, we extended the work presented in [11] to illustrate that when the users are instructed on how to use the role exchange mechanism, task performance and efficiency of the user are improved in comparison to an equal control guidance scheme. We also augmented the system with informative visual and vibrotactile cues to display the interaction state to the user. We showed that such cues improve the user's sense of collaboration with the computer, and increase the interaction level of the task.

Section 13.3.2 introduces the haptic negotiation game as presented in [13]. In the haptic negotiation game, the computer is programmed to display different behaviors, competitive, concessive, and negotiative; and the extent to which people attributed those behaviors to the computer is investigated. We observed that the users can more successfully identify these behaviors with the help of haptic feedback. Moreover, the negotiative behavior of the computer generates higher combined utility for the cooperating parties than that of the concessive and competitive behaviors. However, there is a trade-off between the effort made by the user and the achieved utility in negotiation.

13.3.1 Haptic Board Game

In order to create a collaborative virtual environment, we implemented the negotiation model and the role exchange mechanism on top of a haptic guidance system in a complex and highly dynamic interactive task [12]. Our task is a simple board game in a virtual environment, in which the user controls the position of a ball with the help of a SensAble Technologies PHANTOM® Premium haptic device to hit targets on a flat board. The board is tilted about x and z axes as a result of the movement of the ball, and the user is given haptic feedback due to the dynamics of the game.

Rules and Design Considerations

Figure 13.2 presents a screenshot of the board game. The board employs a ball and four cylinders. Each cylinder is imprisoned in between two pits which diagonally extend towards the center of the board. The aim of the game is to move the ball to hit the target cylinder and wait on it to the count of 10. The users are asked to perform the task in minimum time and to avoid falling into the pits lying on the left and right side of each cylinder. The pits serve as penalty regions within the game. If the ball falls in a pit, a fault occurs, all acquired targets are canceled, and the timer runs faster as long as the ball is in the pit. Hence, the faults impair the final score of the users. To leave the pit, the user should move the ball towards the entrance of the pit.

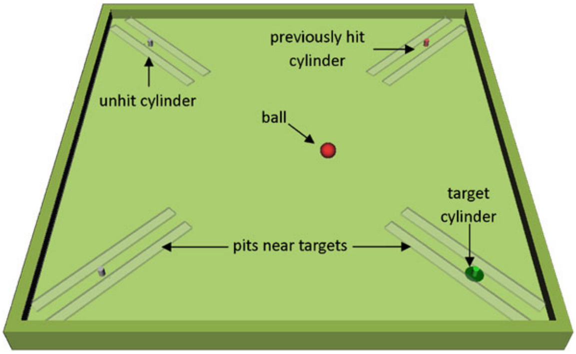


Fig. 13.2 A screenshot of the Haptic Board Game

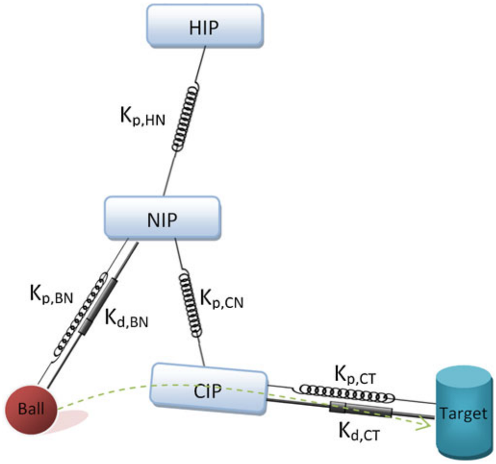


Fig. 13.3 The physics-based model for the haptic board game

Since precision is required to avoid pits, we assumed that the users would benefit from computer guidance especially when they are within the pits. A preliminary investigation of the users' role exchange patterns confirmed this assumption, such that the users indeed requested computer guidance in these regions.

At the start of each game, all but the first target cylinder are colored in grey. The target cylinder is highlighted in green color. When the user hits the target, it turns red and a new target is automatically selected and colored accordingly. In Fig. 13.2, the cylinder in the upper right corner of the board is previously hit, whereas the target cylinder lies at the lower right corner. The remaining two cylinders are unhit.

The negotiation model used in the haptic board game is sketched in Fig. 13.3. A spring and a damper is added to the system to implement a PD (Proportional-Derivative) control algorithm [15] that lets the computer move the ball towards the targets when it is granted control. The user is presented with force feedback due to the tilt of the board and the guidance provided by the computer if available.

Since the underlying system is highly dynamic, a sophisticated mechanism is required to realize the role exchanges. Hence, we implemented a dynamic role exchange mechanism on top of the board game to allow computer guidance. This

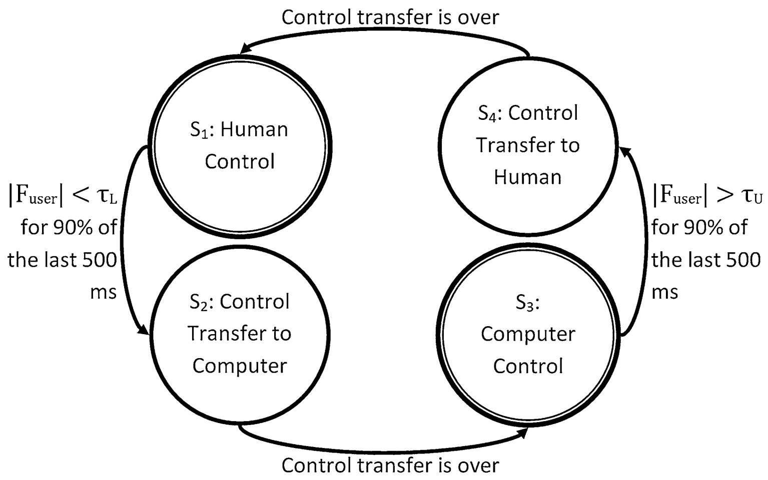


Fig. 13.4 The state diagram defining the role exchange policy

mechanism allows the user to communicate with the computer dynamically through the haptic channel to realize role exchange using a four-state finite state machine as shown in Fig. 13.4. The finite state machine realizes a smooth transition during the exchange of roles. Initially the computer determines thresholds based on the user's average force profile to assign roles to each entity. It is assumed that the user is trying to initiate a role exchange whenever the magnitude of the force (s)he applies is above an upper threshold or below a lower threshold for over a predetermined amount of time. These threshold values are calculated using the average force profile of the user, i.e. the user's average forces and the standard deviation of these forces, and are adaptively updated during the course of the game. In Fig. 13.4, F_{user} denotes the instantaneous force applied by the user. $\tau_{Th,L}$ and $\tau_{Th,U}$ refer to the personalized lower and upper threshold values for initiating state transitions.

The states of the finite state machine also define the interaction states within the system. Initially the system is in the state S1 (*human control*), in which the user controls the ball on his/her own. When the user tries to get assistance, we assume that (s)he will stay below the calculated lower threshold value for more than 90% of the last 500 milliseconds. In this case, the system enters the state S2 (*control transfer to computer*), in which the computer gradually takes control until it gains full control of the ball. The state will automatically change from the state S2 to S3 (*computer control*) after 1000 milliseconds. A similar scenario is also valid when the user decides to take over control, so that a series of state transitions will occur from the state S3 to the state S4 (*control transfer to human*) and the state S1 in succession.

Fig. 13.5 Two different configurations for the role indication icons

(a) Human Control (b) Computer Control

Augmenting Sensory Elements

We also augmented our system with additional visual and vibrotactile cues to display the control state to the users. These cues are meant to make the role exchange process more visible, hence we chose to present all cues simultaneously, so that by acquiring the same information through multiple resources, the information processing is facilitated more effectively for the users.

Visual Cues Two icons are displayed above the board to represent the control levels possessed by the human and the computer as exemplified in Fig. 13.5. The icons grow and shrink gradually to simulate the state transitions that take place when parties exchange roles. The larger icon demonstrates the party that holds a greater level of control on the movement of the ball. For instance, in Fig. 13.5(a), the system is in human control state since the icon for the human (on the right) has maximum size. Similarly, in Fig. 13.5(b), the computer holds control because its icon (on the left) is larger.

Vibrotactile Cues Two different vibrotactile cues are used to signal the state transitions within the system:

Buzzing is presented to the user to signal the initiation of a role exchange. We implemented buzzing as a high frequency vibration (100 Hz) presented through the haptic device.

Tremor is displayed to the user to imitate the hand tremor of the collaborating entity that the user is working with. The tremor effect is generated by varying the frequency (8–12 Hz) and amplitude of the vibrotactile signal when the computer has full control.

Experimental Design

In order to investigate the effect of role exchange on collaboration, we tested four conditions with the haptic board game:

No Guidance (NG): The user plays the game without any computer assistance to control the ball position on the board.

Equal Control (EC): The user and the computer share control equally at all times to move the ball.

Role Exchange (RE): At any point during the game, the user can hand/take over the control of the ball to/from the computer, by altering the forces (s)he applies through the haptic device.

VisuoHaptic Cues (VHC): As in RE condition, the user decides to hand/take over the control of the ball to/from the computer. Also, role indication icons, buzzing, and tremor will be displayed to the user to inform her/him about the state of control during the game.

30 subjects (9 female and 21 male), aged between 21–28, participated in our study. A within subjects experiment, in which each subject experimented all four conditions in a single day, is conducted. An experiment consisted of an evaluation and a post-evaluation session. In the evaluation session, the subjects played the haptic board game 5 times successively in each condition. We presented NG condition at the beginning of each experiment as a baseline condition. Afterwards, we presented the guidance conditions EC, RE, and VHC. However, in order to avoid learning effects, the conditions were permuted and 5 subjects were tested in each of the six permutations of three guidance conditions. The subjects were given detailed information about the conditions and instructed on how to use the underlying role exchange mechanism when applicable. In order to avoid any perceptual biases, instead of naming the conditions, the subjects were shown aliases such as Game A, B, and C. After the evaluation session, the post-evaluation session was started, in which the subjects played under each condition once (i.e. one trial only).

Measures

Quantitative Measures In each trial, we collected the task completion time and the number of faults the user makes, as measures of task performance. Task completion time is recorded in milliseconds. The number of faults is the count of times that the user falls into a pit during a trial. A penalized completion time is computed such that in case of faults, i.e. when the user falls into a pit, the timer is iterated 10 times faster. Hence, the penalized completion time is greater than completion time unless the user completes the game without any faults.

Additionally, we calculated the energy spent by the user during the trial to represent the physical effort (s)he spends in competing the task. This energy is calculated by the dot product of the displacement of HIP and the force exerted by the spring located between NIP and HIP as:

$$energy = \int_{P_H} |F_{HIP} \cdot dx_{HIP}|,$$

where P_H is the path traversed by HIP during the trial, F_{HIP} is the force exerted by the spring between HIP and NIP, and x_{HIP} is HIP's position.

Along with the user's energy requirement, we calculated the work done by him/her on the ball. The work done on the ball is computed regarding the displacement of the ball and the force acting on the ball due to the user's actions:

$$work = \int_{P_B} |F_{HIP} \cdot dx_{ball}|,$$

where P_B is the path traversed by the ball during the trial and x_{ball} equals to the ball's position. We presume that the work done on the ball is a measure of the user's contribution to the task. We suggest that, in an efficient collaborative system, the user should work in harmony with the computer. This way, the user's effort will be spent for completing the task, not in resisting the operation of the computer. Motivated with this conception, we define an efficiency measure as the ratio of the work done by the user on the ball to the energy she/he spends. Our efficiency measure is calculated as:

$$efficiency = \frac{work}{energy},$$

Upon closer inspection, we can see that, as expected, the efficiency is maximized when the user does a large amount of work on the ball with a small effort.

Subjective Measures At the end of each experiment, we asked the subjects to fill a questionnaire to comment on their experiences in the guidance conditions (EC, RE, VHC). For the questionnaire design, we used the technique that Basdogan et al. used previously for investigating haptic collaboration in shared virtual environments [14]. A 7-point Likert scale was used for the answers; and questions were rephrased and scattered randomly within the questionnaire. For evaluation, the averages of the questions, which are rephrased, are used. Some of the variables investigated in the questionnaire are:

- *Collaboration:* 2 questions investigated whether the subjects had a sense of collaborating with the computer or not.
- *Interaction:* 5 questions explored the level of interaction that the subjects experienced during the task.
- *Comfort and pleasure:* 4 questions investigated how comfortable and pleasurable the task was.
- *Trust:* 2 questions investigated whether the users trusted their computer partner on controlling the ball or not.
- *Role exchange visibility:* A single question explored whether or not the users observed the functionality of the role exchange processes during the task.

13.3.2 Haptic Negotiation Game

Our second task requires a human to play negotiation game with the computer. In this game, the computer is equipped with the ability to display different negotiation behaviors to cooperate with the user.

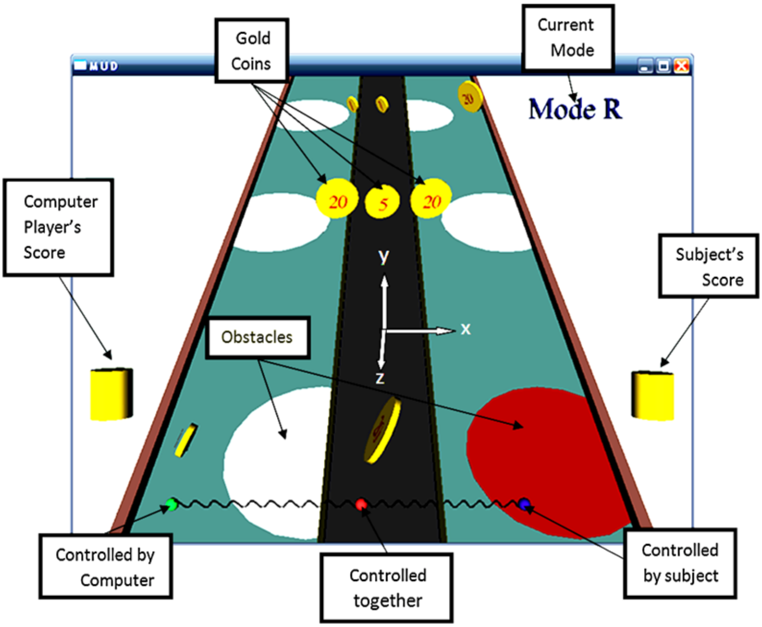


Fig. 13.6 A screenshot of the Haptic Negotiation Game

Rules and Design Considerations

On the screen, the user sees a road divided into 3 lanes (Fig. 13.6). On the left-hand side, the computer player controls CIP (the green ball) to avoid obstacles and collects coins to increase its score. Likewise, on the right-hand side, the user controls HIP (the blue ball) to avoid obstacles and collect coins to increase her own score. The middle lane also has a coin which can be collected by the red ball—referred to as "the Ball" in the rest of the text. The position of the Ball is controlled by the subject and the computer together. As the players control their respecting interface points (IPs) in the horizontal plane, the obstacles scroll down the screen with a constant velocity.

Separate scores are calculated for the user and the computer. The user's score is calculated by summing up the values of coins that (s)he collects from the middle lane and from his/her own lane. The computer's score is calculated by summing up values of coins that it collects from the middle lane and from its own lane. The scores for each player can be seen on the left and right margins of the screen represented as bars that filled with coins collected by the users. When a coin is collected by the Ball, it gets awarded to both players and its value is added to the scores of both dyads. Since the Ball is controlled together by both players, they need to collaborate in order to ensure that the Ball collects the coins in the middle lane. However, certain layouts of the obstacles in the computer and human players' lanes may cause conflicting situations where collecting the coin in the middle lane necessarily requires one of the players to hit an obstacle, hence miss the coin in his/her/its own

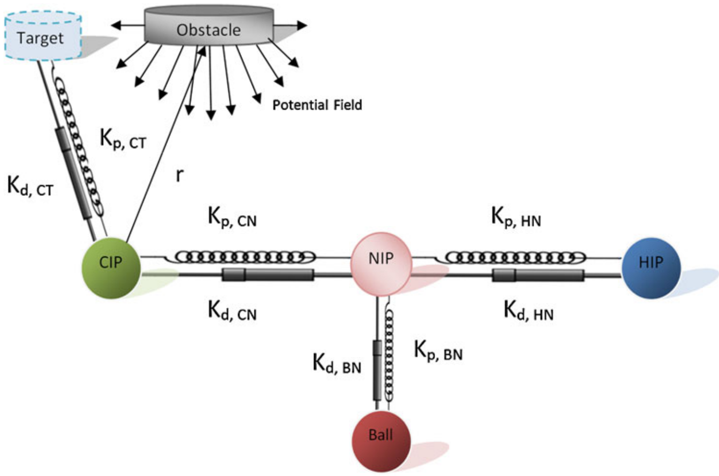


Fig. 13.7 The physics-based model for the haptic negotiation game. All interface points and the ball move on the same horizontal line, but for clarity, the ball is illustrated as if it falls behind the negotiated interface point

lane.[2] By design, players can collect coins in their lanes, but they need to cooperate in order to have the coin in the middle be collected by the Ball if they want to obtain the score of the middle coin. Otherwise, their movements conflict with each other, and the Ball fails to collect the middle coin. In other words, this conflicting situation requires one of the players to concede and thus help the other to acquire his/her/its own coin.

The general negotiation model is modified as in Fig. 13.7. Apart from constraining the movements of HIP and CIP to the horizontal line, CIP is made to be affected also by external forces due to the potential field around the obstacles in addition to the attractive forces moving CIP to the predefined target points along the path. The potential field exerts a force inversely proportional to r^2, where r is the distance between the CIP and the obstacle, hence is used to assist the computer in avoiding the obstacles and reaching the predefined target points. It can be turned on and off according to the behavior assigned to the computer player.

In order to better convey conflicting and cooperative behavior, we apply forces to the haptic device held by the user. We use the haptic channel for conveying the negotiation dynamics. Hence, the users feel the forces due to the Ball's deviation from the initial point, which is the center point of the middle lane. If the Ball moves to the right subsection belonging to the user's path, the user feels a leftward attractive force. On the contrary, when the ball passes to the computer player's side, then the user feels a rightward repulsive force. This haptic information signals a collaboration opportunity to the user, but if the user does not accommodate the computer player, a physical conflict occurs.

[2] 41 out of 45 obstacle combinations cause conflicting circumstances.

Experimental Design

A key issue in human-computer interaction is the communication of the affect between parties. Most work on the synthesis of affective cues have focused on the generation of custom tailored facial animations, displays, gaze patterns and auditory signals conveying affective state. Haptics, on the other hand, has been little explored in this context. Moreover, work on affect synthesis has focused mostly on the generation of the traditional set of six basic emotions [16]. With the second experiment, we focus on how haptic and audio-visual cues can be used to convey a specific set of negotiation behaviors that are accompanied by negotiation-related complex affective states. There are different classifications of the negotiation behaviors in the literature (e.g. [17]). However, we preferred to use broader definitions and implemented three negotiation behaviors, namely *concession*, *collaboration*, and *modified tit-for-tat* for the computer player:

Concession The computer player makes concessions for the benefit of the human. Specifically, the computer player's main goal is to let the Ball collect the coin in the middle lane. This movement allows the human to collect his/her own coin without any compromises. For several conditions that we defined, the computer chooses to concede and help the ball collect the coin in the middle lane. For every obstacle combination, the computer player makes a concession if the value of the coin that the Ball can collect is equal to or higher than its own coin's value. Additionally, the computer player evaluates the difference between the human's benefit and the cost of its concession. The human's benefit is the sum of the values of the coins that the Ball and HIP will collect, whereas the cost of the computer's concession is the value of the coin that it chooses not to collect. If the human's benefit outweighs the computer' cost, then the computer makes a concession. Lastly, the average value of the players' coins is calculated. If this value is less than the value of the coin that the Ball can collect, then the computer player makes a concession. If none of these conditions are met, the computer player ignores the human player, and collects its own coin.

Competition In competition, each party has its own interests which are conflicting with each other. The game theory literature considers the competitive negotiation as a win-lose type of negotiation [18]. We implemented the competitive computer player to value its interests more than it values those of the human player. In case of conflicts, the computer player tends to collect its own coin to increase its score. However, a result of this persistent, non-cooperative attitude, if both parties try to increase their individual utilities, they can miss some valuable opportunities since none of the parties will consider collecting the coin in the middle lane. The computer chooses to compete in two conditions. First, if the computer's coin is more valuable than the coin in the middle, the computer collects its own coin. Second, the computer player evaluates the benefit of making a concession. It weighs the amount of increase in its earnings relative to the value of the human's coin. Unless the incremental benefit exceeds HIP's earning, the computer player carries on collecting its own coin. If none of these conditions holds, then the computer player accommodates the human and helps the Ball to collect the coin in the middle lane.

Modified Tit-for-Tat Tit-for-tat is an effective strategy in game theory for the solution of the prisoner's dilemma problem. Tit-for-tat is a cooperative negotiation strategy. Guttman and Maes [18] classifies cooperative negotiation as a decision-making process of resolving a conflict involving two or more parties with non-mutually exclusive goals. We modified the classical tit-for-tat strategy by incorporating some conditions. Initially the computer player starts with a cooperating move. The computer player continues cooperation until the human player defects.[3]

We investigated whether the subjects could differentiate between these negotiation behaviors or not. We also examined the subjects' perceptions on different playing strategies of the computer player. Moreover, we sought an indication of the effectiveness of different sensory modalities on the negotiation process. Finally, we evaluated the performances of the subjects on how effectively they could utilize these negotiation behaviors.

24 subjects (5 female, 19 male) participated in our experiment. Half of these subjects was tested under a visual and haptic feedback (VH) condition, and the remaining half was tested under a visual feedback only (V) condition. In each sensory feedback condition (V and VH), three negotiation behaviors (modes) were tested. There are six combinations for the ordering of three different negotiation behaviors. In order to eliminate the ordering effects, each combination was played by 2 different subjects. The subjects were informed about the existence of three different playing behaviors of the computer player, and were instructed to pay attention the computer's behavior in each mode.

Initially the subjects practiced with a test game (labeled Mode R), in which negotiation behaviors of the computer were randomized so that the subjects did not acquire prior knowledge about the negotiation behaviors. Afterwards, the actual experiment began and subjects played the game once in each behavior of the computer. While playing the game, subjects were not aware of the negotiation behavior the computer player adopted. While they were playing the game, they could only see a reference to the mode of the computer player, (e.g. Mode A, Mode B, or Mode C), on the screen. Finally, all 3 behaviors were displayed to the subjects in succession in order to enable them to compare the behaviours.

Measures

Quantitative Measures We quantified the subjects' performance in terms of the utility of the game and the average force that the subjects feel through the haptic device. The utility of the game is calculated using the individual scores of the dyads, and the score obtained from the middle lane, which is interpreted as the joint score of the parties.

[3] Defection of the human player means that he or she does not accommodate the computer player in keeping the Ball on its path.

The individual and overall utilities of the process for each negotiation behavior and feedback condition is calculated as follows:

$$\text{Individual Utility} = \frac{\text{Achieved Individual Score}}{\text{Maximum Achievable Individual Score}}, \tag{13.1}$$

$$\text{Overall Utility} = \frac{\sum \text{Achieved Individual Scores}}{\text{Maximum Achievable Overall Score}}. \tag{13.2}$$

The average force that the users feel through the haptic device is calculated using the mass-spring-damper system between the interface points and is assumed to be the definitive indicator of the collaboration or the conflict between dyads.

Subjective Evaluation At the end of the experiment, subjects were asked to fill out a short questionnaire regarding their experience and the behavior of the computer player.[4] The subjects answered 15 questions on a 7-point Likert scale, 7 of which were on personal information. A single question asked for user feedback and 7 questions were about the variables directly related to our investigation. Some of the questions were paraphrased, and asked again, but scattered randomly in the questionnaire. In evaluation, the averages of the responses to the questions that fall into the same category are considered. Questions were asked in four categories:

Performance: We asked the subjects to evaluate the computer player's and their own performance (1 question each).

Perceived Sense of Conflict and Collaboration: We asked the subjects whether or not the subjects had a sense of conflict (2 questions) or collaboration (2 questions) with the computer.

Effectiveness of Modalities: We asked the subjects to rate the perceived effectiveness of the three modalities -audio, visual, and haptics—for helping them identify the behaviors of the computer player (1 question).

13.4 Results

13.4.1 Haptic Board Game

This section summarizes the key results of the experiment conducted with the haptic board game.

Quantitative Measures

As mentioned in Sect. 13.3.1, in the haptic board game, task performance is quantified in terms of task completion time, penalized completion time, and the number of

[4]For the questionnaire design, we adopted the technique that Basdogan [14] used previously in shared virtual environments.

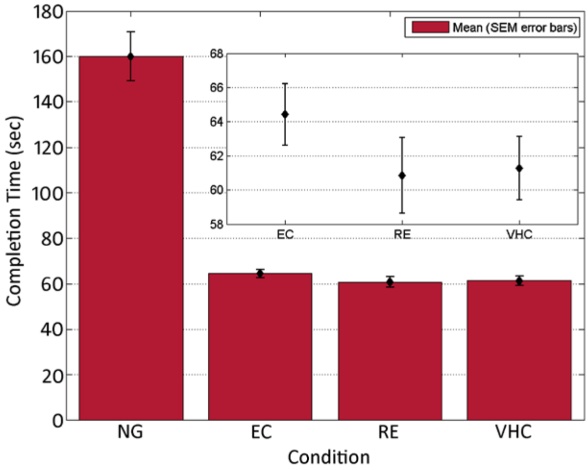


Fig. 13.8 Comparison of the conditions in terms of completion time

faults during trials. For quantitative analysis, we utilized the data collected during the evaluation session. Even though NG was included in the experiment solely to get the users familiar with the system, the data acquired under NG is also presented for the sake of completeness.

Figure 13.8 shows a comparison of the means of the conditions in terms of task completion time. Since the variance of completion time in no guidance condition is much higher than those in the other conditions, the comparison of the guidance conditions is included as a close-up in the upper right corner of the figure. Wilcoxon Signed-Rank Test indicates a statistically significant difference between NG and all three guidance condition in terms of completion time (p-value < 0.01). We observe that role exchange (RE and VHC) improves completion time when compared to NG and EC. The completion time in EC is observed to be significantly higher than it is in RE (p-value < 0.01), and no significant difference is observed between RE and VHC. Hence we conclude that although adding certain sensory cues (VCH) seems to increase the completion time, this time is still close to that in RE.

Figure 13.9 illustrates the differences between the conditions in terms of penalized completion time. Again, due to the high variability in NG, a separate comparison of the guidance conditions is given as a close-up in the upper right corner of the figure. Penalized completion time in NG is significantly inferior than it is the other conditions (p-value < 0.01), whereas it is the best in RE, followed by VHC and EC. Even though the differences is significant between EC and RE (p-value < 0.05), no other conditions exhibit significant differences among each other.

Finally, Fig. 13.10 suggests that adding sensory cues on top of a role exchange mechanism (VHC condition) slightly increases the errors made by the user during the execution of the task. However, this increase is not statistically significant.

Along with the performance measures, we calculated the energy spent by the user in order to complete the task and the work done by him/her. Figure 13.11 shows the mean values and the standard error of means for each condition. As expected, the users spent the largest amount energy under NG, when no guidance is available.

Fig. 13.9 Comparison of the conditions in terms of penalized completion time

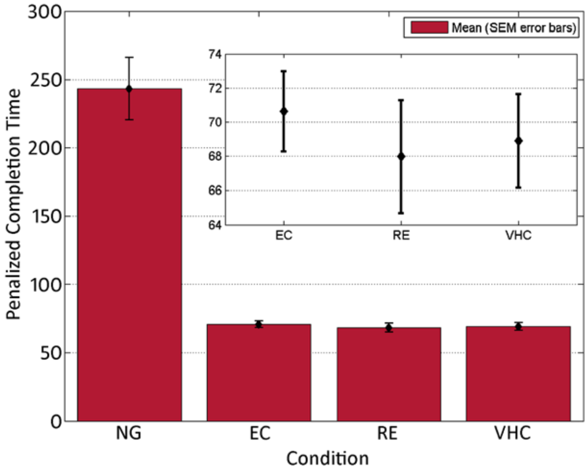
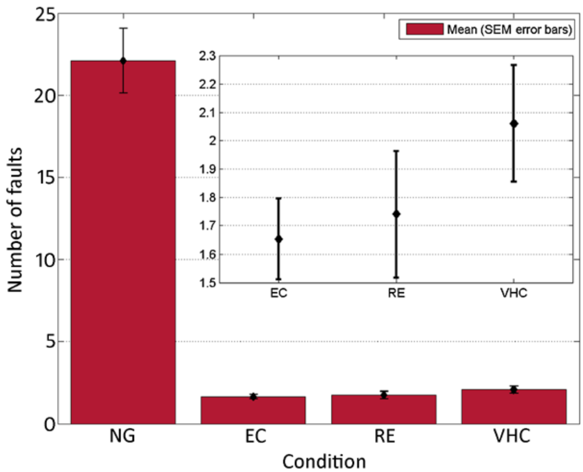


Fig. 13.10 Comparison of the number of faults in each condition



Wilcoxon Signed-Rank Test reveals that the energy requirement under NG is significantly higher than those under the guidance conditions (p-value < 0.001). The guidance conditions display no significant difference, however can be sorted in ascending order of the amount of energy that the users spend as EC, RE, and VHC.

Figure 13.12 illustrates a comparison of the average work done by the user for completing the task under each condition. We observe that the work done by the user towards task completion is maximized in NG. On the contrary, the work done in EC is smaller than those in RE and VHC (p-value < 0.05).

We defined efficiency as the ratio of work done by the user on the ball to the energy (s)he spends. Figure 13.13 displays the average efficiencies of the users for each condition. The efficiency of users is low in NG probably because their control on the ball is not good. Note that the worst completion time and the greatest number of faults are made under this condition. We observe that the efficiency in EC is

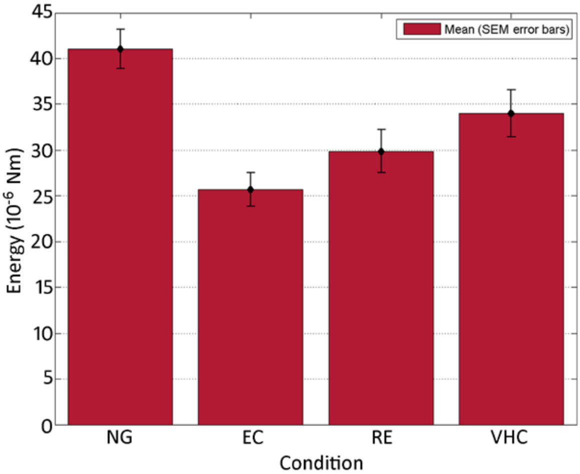


Fig. 13.11 Comparison of the energy spent by the user

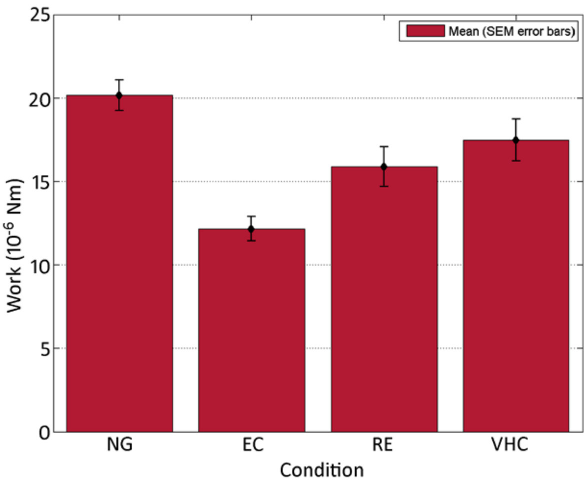


Fig. 13.12 Comparison of the work done by the user on the ball

also as low as it is in NG. On the other hand, the efficiencies under RE and VHC are significantly higher than the efficiencies under NG and EC (p-value < 0.005). We also observed a statistically significant difference between the efficiencies under RE and VHC (p-value < 0.05), RE having the highest efficiency. As a result, we conclude that even though the energy spent by the users is low in EC, the users fail to do work on the ball. Instead they surrender to computer guidance and take less initiative in performing the task, which decreases their efficiency. On the other hand, the efficiencies in RE and VHC are high, indicating that the added effort is effectively used on the task.

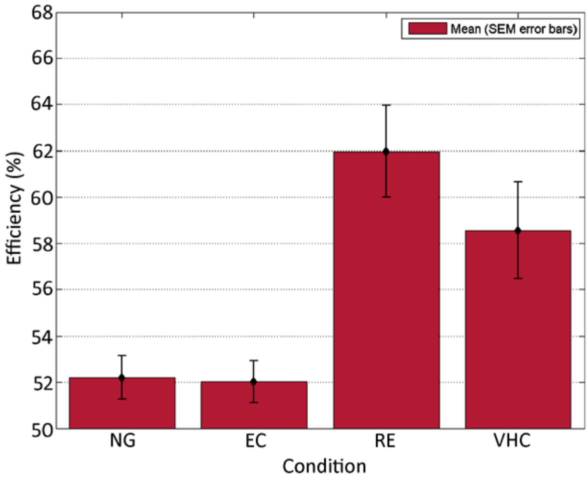


Fig. 13.13 Comparison of the efficiency of user

Table 13.2 Means of the subjective measures for different guidance conditions

	EC		RE		VHC	
	Mean	SD	Mean	SD	Mean	SD
Collaboration	4.2[a]	1.35	4.47[a]	1.14	5.01[b]	0.86
Interaction	4.12[a]	1.17	4.47[a]	0.87	4.84[b]	0.67
Comfort and pleasure	4.12[a]	1.04	4.32[ab]	0.91	4.62[b]	0.93
Trust	4.18[a]	1.57	4.57[a]	1.47	5.2[b]	0.92
Role exchange visibility	3.27[a]	1.99	3.87[a]	2.03	4.67[b]	1.56

Subjective Evaluation

The subjective evaluation was done only for the guidance conditions EC, RE, and VHC. Table 13.2 lists the means of the subjects' questionnaire responses regarding the evaluated variables. Pair-wise comparisons of the guidance conditions are obtained by Wilcoxon Signed-Rank Test using p-value < 0.05. Different letters in the superscripts indicate that the conditions bear significant differences for the corresponding variable.

The subjective evaluation results can be summarized as follows:

- *Collaboration:* Additional sensory cues significantly improve the sense of collaboration during the task when they are displayed to the user to indicate the control state.
- *Interaction:* Additional sensory cues significantly improve the interaction level of the task.
- *Comfort and pleasure:* When compared to an equal control condition, the users find the interface significantly more comfortable, enjoyable, and easier to perform, only if additional sensory cues are provided to them.
- *Trust:* A role exchange scheme lets the users trust in the computer's control during collaboration, such that they believe that it will move the ball correctly. This sense of trust is significantly higher when additional sensory cues are present.

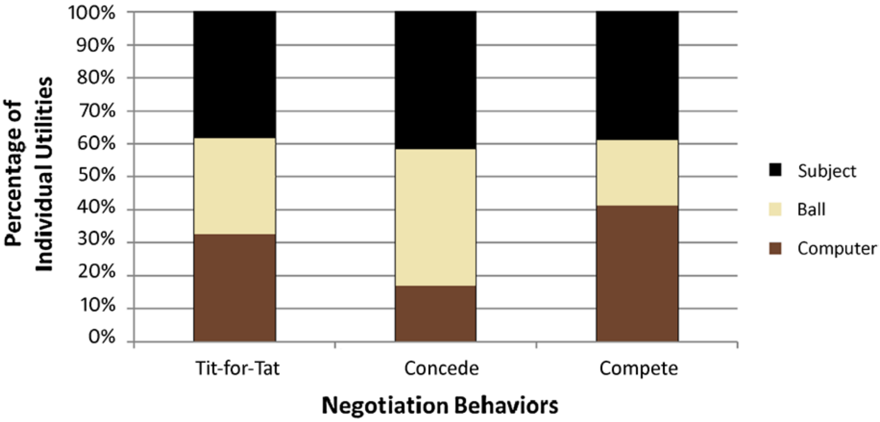


Fig. 13.14 Percentage of the individual utilities while normalized by the overall utility

- *Role exchange visibility:* Additional sensory cues make the role exchange process significantly more visible so that the users can track the current state of the system more successfully when these cues are present.

13.4.2 Haptic Negotiation Game

This section presents the results of the experiment conducted with the haptic negotiation game.

Quantitative Measures

We investigated how humans interact with a computer that executes different negotiation strategies. We looked into whether the users can utilize any of those strategies in the haptic negotiation game or not. We also studied the role of haptic force feedback on these interactions. Hence, we computed the average force values that the users felt, as well as the individual and overall utilities of the process for each negotiation behavior with each feedback condition using (13.1) and (13.2).

We observed differences between the individual utilities of the dyads while the computer player is playing with three different negotiation behaviors. As expected, in concession and competition, a single player's individual utility is favored. For example, the computer player making numerous concessions result in higher individual utility for the human user. Figure 13.14 displays the utility percentages of the human and the computer players. In the figure, the joint utility of the dyads is marked as the ball's utility. Clearly, in concession, the computer player's utility is low since it continuously makes concessions to improve the human player's utility. In competition, the computer player focuses only improving its individual utility,

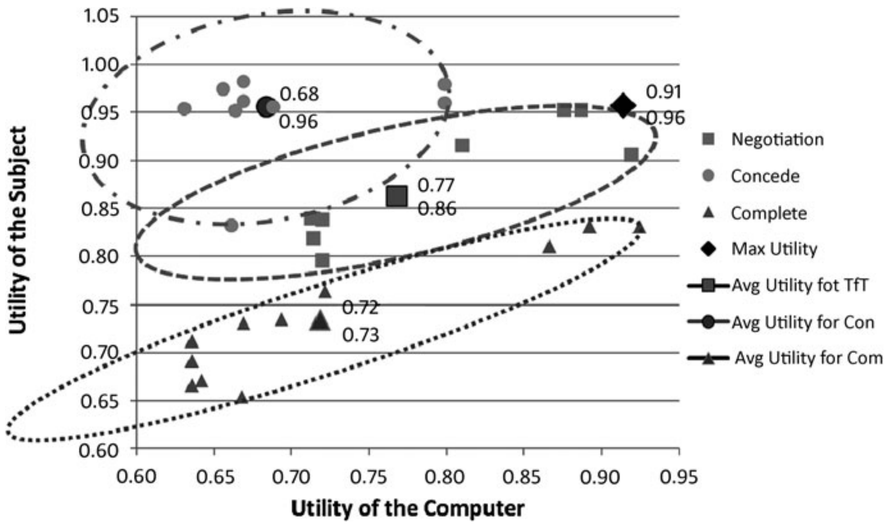


Fig. 13.15 Utility distribution of the subjects, their means and the ellipses showing the clustering of the different negotiation behaviors under VH condition. (Tft: tit-for-tat, Con: Concession, Com: Competition)

hence it impairs the utility of the human player and the joint utility. On the other hand, the tit-for-tat strategy favors the overall utility without sacrificing the individual utilities of the dyads. Hence, we observe a more uniform percentage distribution in both the players' and the joint utilities.

Figure 13.15 displays the distributions of the individual utilities for each of the three negotiation behaviors. The utility values of the negotiation behaviors are clustered as shown in the figure, that clearly shows the distinction of achieved utility values as indicated by the dashed ellipsoids. The average utility value for each negotiation behavior is also shown in Fig. 13.15, at the center of the enclosing ellipses. When we consider the distance between those average utilities to the achievable maximum utility value, we observe that the tit-for-tat strategy is the closest one to that value. This confirms that the dyads were able to utilize this strategy, and can achieve utility values which are closer to the ideal condition.

In order to test the effectiveness of force feedback on a negotiation framework, we calculated the average forces that are felt by the subjects in VH condition as plotted in Fig. 13.16. We interpret the force felt by the user is an indication of the effort (s)he spends. Unsurprisingly, the competitive computer player required the human player to make the greatest effort. With this strategy, the human players faced conflicting situations most of the time, and due to these conflicts, higher force values were generated and fed back to the user. On the other hand, the concessive computer player accommodated the human player, and created fewer conflicts. As a result of this, the user, spending the least effort, felt a small force. Finally, the forces generated with the tit-for-tat strategy fell in between the other two strategies. Hence, we conclude that tit-for-tat provides a trade-off between the effort and the utility.

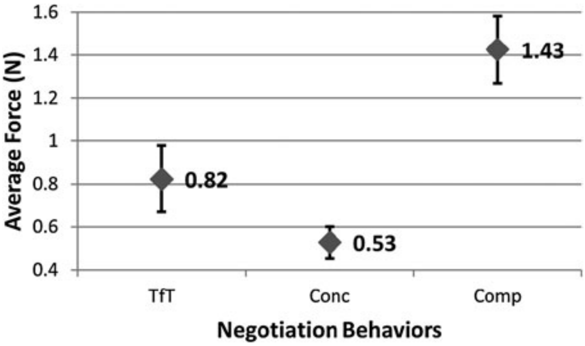


Fig. 13.16 Average forces that the subjects felt through the haptic device for each negotiation behavior. (Tft: tit-for-tat, Conc: Concession, Comp: Competition)

Table 13.3 The means of the subjects' responses to the perceived sense of conflict and collaboration questions for each negotiation behavior and each sensory feedback condition. The significant differences are marked according to t-test results for p-value < 0.05

	V			VH		
	Tft	Con	Com	Tft	Con	Com
Sense of Conflict	3.46[a]	2.92[a]	5.62[b]	4.33[a]	1.38[d]	6.5[b]
Sense of Collaboration	5.04[a]	5.46[b]	3.50[c]	4.54[a]	6.67[d]	1.67[e]

In other words, with a little more effort made by two parties, they can maximize the overall utility of the application. Our analysis is in line with the assumptions presented in the negotiation literature, hence indicate that the negotiation behaviors have been successfully implemented in the haptic negotiation game.

Subjective Evaluation

The subject's responses to (a) self success, (b) computer player's success (c) perceived sense of conflict, (d) perceived sense of collaboration, and (e) effectiveness of modalities are used as variables to evaluate the statistical significance of the differences between negotiation behaviors.

Our results show that the subjects can successfully differentiate between the behaviors of the computer. Table 13.3 shows the means and significant differences between negotiation behaviors under V and VH, obtained by t-test using p-value < 0.05. Significant differences for a variable are indicated by different letters in the superscripts. We observed that all variables exhibit a clear distinction between the negotiation behaviors, when visual and haptic feedback is presented simultaneously (VH). In both V and VH conditions, the subjects were successful at identifying the collaborative and conflicting characteristics of the computer player. We observe that there is a clear distinction for all the behaviors in VH. However, under V, there are cases where significant differences cannot be observed between the negotiation behaviors. For example, the subjects could not differentiate between the tit-for-tat and the concession behavior when evaluating how much the computer player was working against them (p-value < 0.05). These results evidently suggest

Table 13.4 The means of the subjects' responses to the perceived sense of success questions for each negotiation behavior and each sensory feedback condition. The significant differences are marked according to t-test results for p-value < 0.05

	V			VH		
	Tft	Con	Com	Tft	Con	Com
Self Success	6.00[a]	6.42[b]	5.25[c]	6.42[ad]	6.83[d]	5.58[c]
Computer's Success	5.00[a]	4.17[b]	5.42[a]	3.92[a]	2.83[b]	5.17[a]

that the subjects experienced and identified the diversity of the computer player's negotiation behaviors, especially under the VH condition.

We also observed that the subjects' perceptions of the computer player's performance were not statistically significant between the tit-for-tat and the competitive behavior (p-value < 0.05). Likewise, the subjects could not perceive a significant difference between their own performances in tit-for-tat and the concessive behavior under VH (see Table 13.4).

Finally, we examined how effectively the three modalities support the subjects to differentiate between the behaviors of the computer player. In VH condition, the effectiveness of haptic feedback is found to be superior to the audio and the visual channels. Subjects rated the effectiveness of the haptic channel with an average score as high as 6.33, whereas they rated the visual and audio channels respectively with 5.25 and 2.25, respectively. The difference between these scores display statistical significance between the haptic and the other two feedback modalities (p-value < 0.05) according to Mann-Whitney U-Test. Hence, the haptic feedback proves to be an effective initiator for the subjects to comprehend the cues of their negotiation with the computer player.

13.5 Conclusions

Haptic human-computer cooperation has applications in entertainment, teleoperation, and training domains. As such applications are becoming common, a need to develop more sophisticated interaction schemes between a human operator and a computer emerged. The proposed research lays foundations for a natural and human-like cooperation scheme by examining the interaction dynamics between the parties. This chapter reports the results of two experiments conducted to examine the possible usage of a dynamic role exchange mechanism and a haptic negotiation framework to enable and improve human-computer cooperation in a virtual environment.

The proposed negotiation model can be used to realize decision making and negotiation. This model is tested through two cooperative games to display collaboration and conflicts between the parties. We developed a set of scales for objective and subjective evaluation of the users in these games. The results suggest that the negotiation model can be used (1) as a role exchange mechanism and (2) to enable negotiation between the parties and assign different behaviors to the computer. This model, when used as a role exchange mechanism in a dynamic task, increases the task performance and the efficiency of the users. It also provides a natural and seamless interaction between the human and the computer, improving collaborative and interactive aspects of the task. The same mechanism can be used to display negotiation related affective states. We showed that the addition of haptic cues provides a statistically significant increase in the human-recognition of these machine-displayed affective cues. If the same affective cues are also recognized by the computer, then more user-specific cooperation schemes compensating for the weaknesses of the human operator can be developed. Also, we showed that, certain negotiation strategies, such as tit-for-tat, generate maximum combined utility for the negotiating parties while providing an excellent balance between the work done by the user and the joint utility.

As a future work, we will explore the utility of statistical learning models to investigate certain classifications for the human user and extract behaviours for the computer that works best for each human class. These ideas can further be extended to realize the haptic version of the Turing test, where the computer will be programmed to mimic the haptic interactions between two human beings.

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