A Negotiation Model for Affective Visuo-Haptic Communication Between a Human Operator and a Machine

by

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ABSTRACT

Humans communicate with each other through a number of affective cues. The recognition as well as synthesis of these affective cues using machines have been the interest of the affective computing community. In this paper, we show how haptic and audio-visual cues can be used to display negotiation related affective states. We show that the addition of haptic cues provides a statistically significant increase in the human-recognition of the machine-displayed affective cues. We also show that, as in game theory, 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.

ÖZETÇE

İnsanlar birbirleriyle birçok etkisel işaretler kullanarak iletişim kurarlar. Bu etkisel işaretlerin bilgisayarlar ve robotlar tarafından tanınması ve bireşimi uzun zamandır etkisel hesaplamalar alanındaki araştırmacıların ilgisini çekmektedir. Bu çalışmamızda, müzakere ile alakalı etkisel işaretlerin dokunsal, işitsel ve görsel işaretler kullanılarak nasıl ifade edilebileceğini göstermekteyiz. Dokunsal işaretler eklemenin, insanların makine tarafından gösterilen etkisel işaretleri anlamalarında istatistiksel olarak önemli bir artış sağladığını göstermekteyiz. Diğer taraftan, oyun teorisi alanında olduğu gibi, 'eşdeğer kısas' gibi müzakere stratejileri tasarladığımız deneme uygulamasında müzakere tarafları için ortak en yüksek faydayı üretmektedir. Bununla beraber, 'eşdeğer kısas' davranışının insanlar tarafından yapılan iş ve edinilen ortak fayda arasında mükemmel bir denge sağladığı gözlemlenmiştir.

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NOMENCLATURE

HCI	Human-Computer Interaction
IP	Interface Point
HIP	Haptic Interface Point
CIP	Computer Interface Point
NIP	Negotiation Interface Point
VH	Visuo-Haptics
V only	Visual Only

Chapter 1

Introduction

1.1 Motivation and Problem Statement

People continuously go through various mental states. They experience emotions even when interacting with machines. These mental states are reflected in our behaviors, which in turn shape the decisions that we make, influence how we communicate with others, and affect our performance. We can also attribute mental states to others, which allow us to infer their intentions, and predict their actions. The ability to understand people's mental states, also known as "theory of mind" or "mind reading" (Golan et al., 2006), underlies fundamental social skills and is considered to be an enabling technology for achieving natural human computer interaction. Recent studies on affective computing have explored ways of modeling and synthesizing these affective states, and investigated methods for eliciting specific emotions in people.

In this thesis, we focus on the synthesis and perception of three kinds of social behaviors in the context of a computer game based on a two-party human-computer negotiation scheme. Specifically, we show how to design a computer agent capable of displaying specific negotiation behaviors associated with cooperative, concessive and negotiative mental states. We present results from an experiment where human subjects were instructed to play against the computer agent in each mode, and asked to identify the behavior of the computer. In our setup, negotiation behaviors were displayed to the users through visual and haptic channels. We present results from subjective surveys that measure the degree to which the subjects could identify the synthesized behaviors when the behaviors were conveyed through visual and haptic means.

Our work brings together elements from agent based negotiation, haptic collaboration, and multimodal interfaces research. We break new ground by studying a setting where a computer and a human play a game through a visuo-haptic interface that supports real-time negotiation

between the parties. Haptic interaction has proved to be an effective modality in many human-computer and human-human collaboration and guidance tasks. Likewise, there is extensive research on how automated agents can be designed to interact effectively, so that they are able to communicate their respective needs and make compromises to reach a mutually beneficial agreement. Our work draws from, and contributes to, both of these fields of research.

1.2 Approach

In order the study how negotiation-related behaviors can be conveyed through visuo-haptic means, we designed a test-bed application that allows users interact with a computer partner in the context of a multiplayer computer game. The game was designed such that the user and the computer would, at times, end up in situations where their interests would conflict in a way that in effect would require the parties to negotiate in real-time by trying out various alternative actions, and observing the other party's responses. In this dynamic environment, both the human user and the computer player have to plan their actions on a continuous basis. Moreover, our framework provides a multimodal platform where audio-visual cues are supplemented with haptic enabled bilateral interaction. Hence, users can predict and react to the cues acquired from these communication channels.

Based on the negotiation literature, the computer player in our model utilizes three different negotiation behaviors, namely concessive, competitive and a modified tit-for-tat. As a concessive player, the computer considers the other dyad's interests more than its own. This behavior reflects on computer player's actions as it mostly cooperates with the human user in order to maximize his or her utility, even it means sacrificing. For the competitive behavior, the computer player only cares about itself and assumes the human player as a rival. It misses the opportunities that can enhance the overall utility of the system. In effect, these two behaviors favor maximization of individual scores. The tit-for-tat strategy, on the other hand, is a simple yet effective strategy for tasks where dyads have to decide repetitively on actions with recognizable positive or negative results. The tit-for-tat playing mode for the computer begins with a cooperative action and then copies the other dyad's previous behavior. Thus the computer player expresses its willingness for cooperation at the beginning, and in return, expects the reciprocal supportive behavior from its partner.

In summary, the test-bed application provides a dynamic environment, and both the human user and the computer player have to plan their actions continuously, which in turn are based

on their interpretation of other's actions. Based on the negotiation research, the computer utilizes three different negotiation behaviors, namely concessive, competitive and a modified tit-for-tat.

1.3 Experiments and results

We conducted an experiment to measure the degree to which people attributed three main affective qualities of interest – cooperative, concessive and negotiative qualities – to the computer. To assess the utility of the different modalities used for conveying computer behavior, we measured the effectiveness of visual and haptic cues. We also measured how certain haptic-related measures – such as the average force felt by the user and the work done by the user – related to the dyad and individual utilities of the negotiating agents.

Our results show that subjects can successfully identify the three different negotiation behaviors of the computer player. Users can differentiate the negotiation behaviors of the computer more easily when haptic feedback is provided to them. For example, the users were not able to differentiate tit-for-tat strategy from concession at all when only visual cues were available to them. On the other hand, the tit-for-tat strategy offers a good trade-off between the work done by the user and the maximum utility that can be achieved by the dyad when executing a collaborative task involving haptic negotiations. Quantitative analysis shows that the average force felt by the users is highest and lowest when the game is played under the competition and concession strategies respectively, and it is in between under the "tit-for-tat" strategy. On the other hand, the utility of the dyad is the highest under the tit-for-tat strategy though the standalone utilities of the individual users and the computer are highest under the concession and competition strategies, respectively.

Chapter 2

Background

Our study combines ideas from three different research fields: haptic interaction for HCI applications, negotiation theory, and affective interfaces. Hence, this chapter tries to cover areas within those fields that are related to our work. While all these areas are active fields of research, to our knowledge, this is the first study that combines concepts from these areas.

2.1 Haptic Interaction

The concept of haptics enabled human-computer interaction applications is not new. The research fields range from haptic guidance, haptics enabled collaboration to telesurgery and telepresence. Rosenberg (1993) came up with the concept of "virtual fixtures", which motivated the incorporation of haptics into human-computer interaction. Virtual fixtures can help keep a task within a specific boundary using computer generated forces, and are often implemented using potential fields and spring-damper systems. Several haptic guidance mechanisms are implemented to assist sensorimotor tasks, such as steering (Forsyth and MacLean, 2006), calligraphy (Palluel-Germain et al., 2007; Henmi et al., 1998), and surgical training (Basdogan et al., 2004), and inclusion of haptics together with existing modalities proved to be beneficial for training of these tasks.

There are also studies focusing on the interactions of the dyad for human-human and human-computer haptic collaboration. Sallnas et al. (2000) examined human-human collaboration for joint manipulation of a virtual object. They found out that haptic feedback significantly improves task performance and provides a better sense of presence in haptic collaboration. Basdogan et al. (2000) proposed the haptic version of the "Turing Test" in their study to better investigate the mechanisms of haptic interaction between two people in shared environments.

They found that haptic feedback provides a better sense of togetherness when compared to visual feedback.

Recently, there has been a growing interest in defining roles for the entities involved in dyadic tasks. Reed and Peshkin (2008) found that a specialization between dyads: some took the role of accelerator, and others decelerators. Similarly, Stefanov et al. (2009) suggested the execution and conductorship roles for the dyads within a haptic interaction. This role determination assigns the conductor as the decision maker, whereas the executor performs the desired action. Evrard et al. (2009) offered a homotopy switching model that allows dyads to switch between leader and follower roles. Oguz et al. (2010) proposed a role exchange model on a dynamic environment where the computer partner interferes as the human user is in need of assistance. However, all these studies on haptic guidance and collaborative haptic interaction models are based on the assumption that computer partners should always collaborate with human partners. Hence, these models fail to offer necessary interactions where both dyads have their own interests which may sometimes conflict with each other.

2.2 Negotiation

Negotiation research covers a wide spectrum of areas ranging from social science, to politics, and from multi-agent interactions to economics. The most relevant studies for our work are based on multi-agent negotiations. This area has been the focus of researchers and many automated agents designed for bilateral negotiations can be found in the literature (Byde et al., 2003; Coehoorn et al.; 2004; Hindriks et al., 2008; Lin et al. 2008; Traum et al., 2008). However, only a few of these agents are specifically designed to negotiate with human users. Rather, these approaches focus on modeling the agent utility function in the context of multi-issue bilateral negotiations. The underlying assumption in these studies is that the utility function of the other negotiator has the strongest effect on the agent's strategy. Though this assumption might be true for intelligent software agents, people are diverse in their behavior. In other words, there are difficulties when negotiating with people due to the incomplete information about the other party's intentions, and its dynamic behavior. There are studies from social sciences which suggest that people do not follow equilibrium strategies (Erev and Roth, 1998; McKelvey and Palfrey, 1992), or maximize their expected utility.

Some researchers suggest the use of opponent modeling techniques for dealing with uncertain behaviors. Saha et al. (2005) propose Chebychev's polynomials to estimate the probability

function of the opponent. Hindriks and Tykhonov (2008) study a Bayesian learning method to learn the opponent model, which is based on learning its utility function. Even though these studies were successful at modeling the opponent and increasing the outcome for both parties, their effectiveness was not evaluated against human opponents. Coehoorn and Jennings (2004) employ non-parametric kernel density estimation in order to learn opponent models. Oshrat et al. (2009) improve this method by incorporating past negotiation sessions of other users as a knowledge base. Lin et al. (2008) also report an automated agent that can negotiate efficiently with human users. All these models have one thing in common; they only offer solutions for maximizing the utility of an agent in a negotiation process but do not consider the human users' experience and perception of that process. These agents are the products of complex learning algorithms, and are capable of optimizing complex utility functions. However, human users do not follow the same computationally rational and complex paths; hence, it is infeasible for them to appraise the computer agent's behavior using computational models in an attempt to respond effectively. Hence, when the user gets in the loop, one has to bring the human factors aspects into attention in order not to alienate the user. Therefore, our computer models are inspired by the negotiation research, but we emphasize the user experience.

2.3 Affective Computing

Affective Computing research attempts to build computational models of emotion. The basic problems addressed by the community include designing tools for recognizing and eliciting human emotions, as well as building systems that synthesize believable affective displays. The main motivation is to give computers the ability to comprehend, and express emotions, so that they are perceived like human beings (Pickard, 1999).

Emotion research has cognitive, physical, and social aspects. Emotions arise from physiological and cognitive processes, which in turn affect our actions (Gratch and Marsella, 2007). Finally, our actions convey information about ourselves, which influences the behavior of others. In order to analyze an HCI application, these three aspects should be the main design concerns.

Keltner and Haidt (1999) claim that emotion, as the facilitator of coordinated activities, plays a critical interpersonal function. As a social functional mechanism, emotions motivate the

formation of group bonds, trust, identity, and norms (Gratch and Marsella, 2007). Zak (2004) found out that trusting others feels good, whereas Barrett (1995) and Izard et al. (1995) observed harming others feels bad. Hence there is a natural connection between affective interfaces and negotiation. Marsella, Johnson, and LaBore (2000) designed an interactive drama for teaching emotion coping skills to parents of pediatric cancer patients. It was a multi-agent system consisting of a parent and a therapist, where users can influence the parent agent's goals to mirror their own concerns. Feelings of the parent shape the decisions of the agent, and thus, its actions. The parent is able to see the causal relations between a selected intention, the accompanying behavior and the effect that behavior has. As both the selectable intentions and the response behaviors are plausible, this affective interface helps the character to become more human-like. Another example is the Stability and Support Operations (SASO) environment (Traum et al., 2005). The virtual simulator is a training environment for learning about negotiating with people from different cultures, with different beliefs and goals. In the first scenario, the trainee acts as an army Captain negotiating with a simulated doctor. The goal is convincing him to move his clinic to another location. The captain can offer help in moving the clinic and some other benefits like medical supplies and equipments.

Common point of those studies is the realization of the influences of emotion on decision-making processes. Loewenstein and Lerner (2003) also observed similarities between classical decision theory and emotional decision-making. Hence, in our framework, we devised a negotiation application where dyads interact with each other. This reciprocal interaction emphasizes the social aspect of the affective computing research. On the other hand, haptics enabled multimodal interaction provides a physical communication mechanism which helps dyads to express their behaviors and convey their intentions. Lastly, we implemented three different characteristics for the computer player, and analyzed whether the human users could recognize them, and what kinds of qualities they attributed to those behaviors. By including those properties, our multimodal HCI application was enhanced by haptic interaction.

Chapter 3

Haptic Negotiation Game

In this section, we describe the Haptic Negotiation Game as well as the negotiation behaviors we implemented. For comparison, we tested the system under three negotiation behaviors, namely concession, competition and a modified version of tit-for-tat. We compared these negotiation behaviors under 2 different conditions, first with only visual feedback, and second with both visual and haptic feedback. In the remainder of this section, we explain the general design approach we adopted and the application model used in implementing the behaviors.

3.1 Design Approach and Choice of Application

Unlike the common discrete bidding process, dynamic negotiation should allow the human player to change her bids continuously. In return, the computer player should actively respond to the user's new bid. Conversely, when the computer player makes a movement, the subject should be able to identify the computer player's action and react according to her own agenda. In such a setting, a dynamic interaction, and appropriate channels to relay these interaction cues are necessary. Moreover, since we seek out the effectiveness of different modalities on our negotiation model, we need to observe how users react to conflicting situations.

Considering these concerns, we implemented a dynamic and interactive virtual game. Our game consists of conflicting situations where each dyad has to decide on an action. They can either collaborate, or conversely, behave selfishly and compete with the other party. We examined if subjects can differentiate between the negotiation behaviors of the computer player, and further exploit them for maximizing the overall utility. The overall utility of the game is calculated by summing up the scores of the dyads and normalizing it by the maximum achievable score on the game. Additionally, if the user becomes more aware of the other party's intentions, she can act accordingly, which eventually leads to a higher utility

value. Hence, we investigated if a physical communication between dyads would increase the level of awareness of the user.

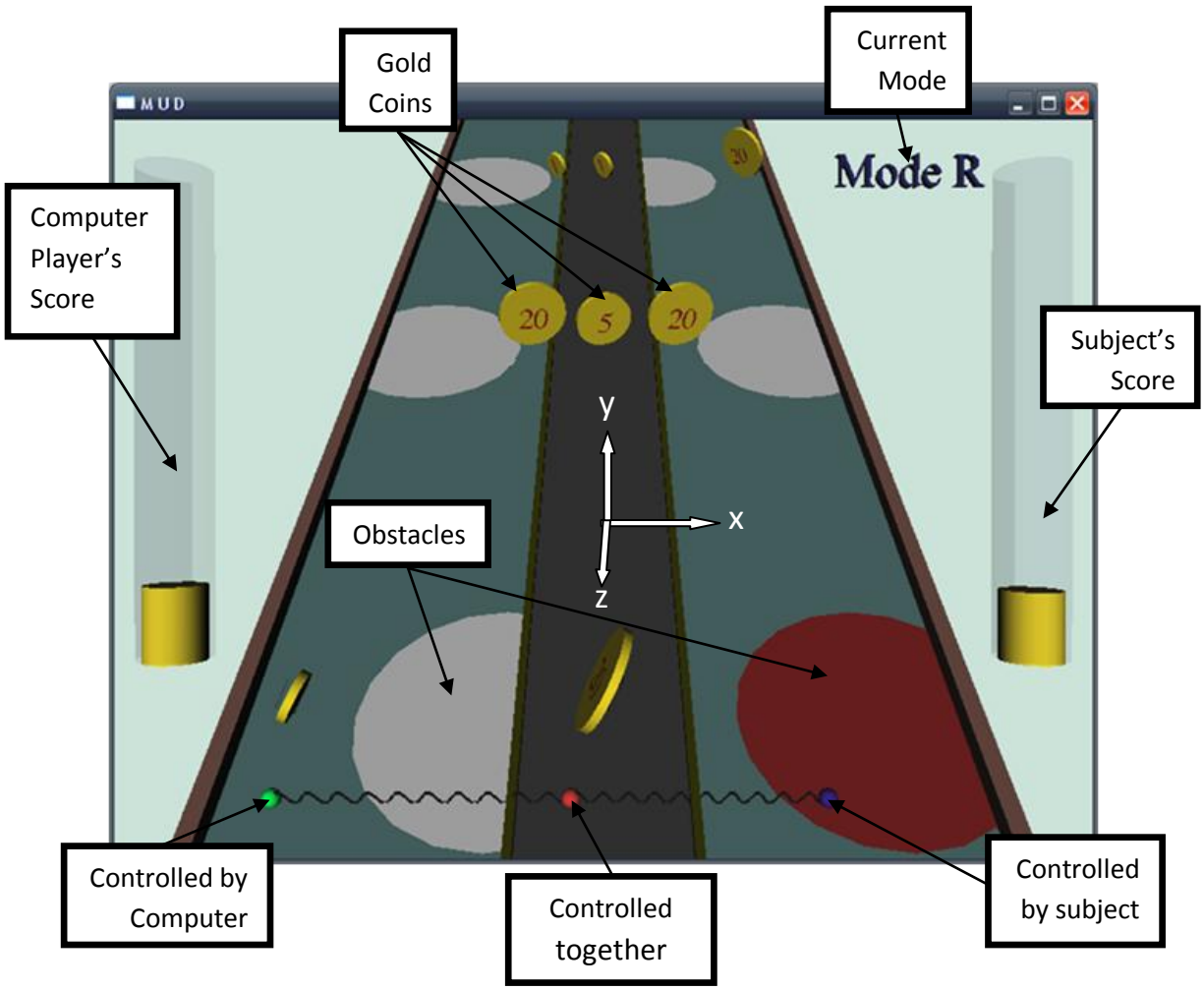


Figure 1: A screenshot of the Haptic Negotiation Game. Two interface points, represented as little spheres on the left and right side, and the Ball, in the middle, can be seen. CIP, the green ball, is controlled by the computer player, whereas HIP, the dark blue ball, is controlled by the subject. The red ball (Ball) is connected to a negotiation interface point (NIP) which is, in turn, connected to both CIP and HIP with a spring and damper system, and hence its control is shared between dyads.

Our experiment requires subject to play a simple negotiation game with a computer player. On the screen, subject sees a road divided into 3 lanes. On the left-hand side, computer player controls the green ball to avoid obstacles and collects coins to increase its score. Likewise, on the right-hand side, subject controls 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. The position of the red ball is controlled by the subject and the computer together. As the players control their respecting interface points (IPs), the obstacles move closer to them with a constant velocity. Separate scores are calculated for the subject and the computer. Subject's

score is calculated by summing up values of coins that she collects from the middle lane and from 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 leftmost and rightmost of the screen represented as bars that are filled with coins as players collect them (see Figure 1).

Our models for implementing the computer player's strategies originated from the negotiation research. Hence, when designing our game, we need to incorporate both conflicting, as well as collaborative components in it. The three disjoint lanes belonging to each interface point and the Ball provide a visual separation between collaborative and conflicting elements. Since the main goal of the users in the game is getting higher scores, the coins provide a motivation for the players to develop their own agendas. Additionally, the Ball in the middle can also collect its own coin, which is added to the scores of both dyads. Since the Ball is controlled together by both players, they need to collaborate with each other. However, certain layouts of the obstacles in the computer and human player's sections may cause a conflicting situation (actually, 41 out of 45 obstacle combinations cause conflicting circumstances). By design, the players can only collect 2 out of 3 coins; hence, they need to cooperate such that the coin in the middle is 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 cannot collect its own coin. In other words, this conflicting situation requires one of the players to concede and thus help the other to acquire his or her own coin while the Ball can still collect the coin in the middle.

Our haptic negotiation game reflects the intended game mechanics visually and through audio. The human user controls the haptic interface point (HIP), and the computer player controls the computer interface point (CIP). These two IPs are connected to the Ball through another IP, which we call negotiation interface point (NIP). The HIP and CIP are represented as small spheres in our game. Aside from the positioning of the obstacles, we also included two virtual springs, one between the HIP and the Ball, the other between the CIP and the Ball. These springs extend as the interface points move further away, and compress as they come closer. Hence, the physical model is reflected to the players visually.

Another visual cue takes place when the dyads do not collaborate. In that case, the Ball goes out of its path, and the two sides of the road flash and notify the players about the conflicting behavior. An additional visual design choice is restricting the players to have their own separate subsections which enforce them to form their own agendas. On the other hand, there is another subsection for the Ball which imposes a collaborative action from both sides since

it is controlled by the dyads together. Neither the CIP nor the HIP can move out of their corresponding roads, whereas, the Ball can move freely. Hence, the dyads need to find a solution within their own spaces, even if that means impairing their initial interests.

Finally, the audio cues come into play when the dyads are collecting their coins. We recorded three different sounds which are played based on how many coins are collected on that round. Hence, subjects could easily understand whether the other dyad has collected its coin or not.

While emphasizing the collaborative and conflicting nature of the game through audio and visual cues, we also need to provide a proper way of communicating these feelings to the users with the help of haptic feedback. We intended for the users to sense the conflicting behavior through the forces applied due to the Ball's deviation from the center of the lane. Clearly, when they collaborate, the Ball stays on its road, which results in equilibrium between the springs, and as a result the users do not feel any force, as intended.

Another key part of creating an interactive game with collaborative and conflicting components is the values of the coins. Different values for the coins will have dissimilar effects both on users' and computer player's motivation. When designing the game, three different coin values, which are 1, 5, and 20, are selected. We chose 9 out of 27 coin combinations, such that, they complemented our aim of creating unique conflicting situations where computer player would behave differently while executing separate negotiation behaviors (see Table 1). Those nine combinations are repeated five times, totaling 45 coins for each dyad. Details of the negotiation behaviors will be given in Chapter 4.

3.2 Physical Model

Human-Computer interaction applications should offer a smooth, unambiguous, and uninterrupted communication between dyads. These requirements are generally delivered through audio-visual and haptic channels. These channels can complement each other so that they present an opportunity for human users to easily comprehend the other dyad's intentions. Moreover, such information channels help human users to immerse themselves with the application, and even perform better on the task. Our haptic negotiation game also takes advantage of such complementary information from different channels. Visual components of the game were already presented in the previous section. In this section, we will focus on the physical model and the interaction.

Coin Values			Behaviors			
				Tit-for-tat		
CIP's coin	Ball's coin	HIP's coin	Concede	Not Conceded	Conceded	Compete
1	1	20	ball's coin	ball's coin	ball's coin	own coin
5	5	5	ball's coin	ball's coin	own coin	own coin
20	20	1	ball's coin	ball's coin	ball's coin	own coin
1	5	20	ball's coin	ball's coin	own coin	own coin
1	20	5	ball's coin	ball's coin	ball's coin	ball's coin
1	20	20	ball's coin	ball's coin	ball's coin	own coin
5	1	20	ball's coin	ball's coin	own coin	own coin
20	5	1	own coin	ball's coin	own coin	own coin
20	5	20	ball's coin	ball's coin	own coin	own coin

Table 1: Combinations of the coin values that we chose, and the decisions of the computer player depending on its negotiation behavior are shown.

For the physical model, we adopted a similar physical framework from our previous study (Oguz et al., 2010). User controls HIP, represented as a dark blue ball on the right hand side, and the computer player controls CIP, represented as a green ball on the left hand side of the screen. These two interface points are connected to a negotiation interface point (NIP), which provides the only physical connection with the Ball. Hence, the Ball is controlled by these three interface points and all these physical connections are made with mass-spring-damper systems. In other words, the forces due to the movements of HIP and CIP are summed up on NIP, and only then, they are reflected on the Ball with another mass-spring-damper system (see Figure 2).

Even though we adopted the physical model of our previous work, there are also some differences compared to the previous implementation. First, players can control their interface points only on the x-axis. The obstacles move in the positive z-direction (towards the IPs), hence the players try to avoid the streaming obstacles by moving left and right. Second, due to the potential field of the obstacles, there is also exterior force acting on the CIP. This potential field exerts a force inversely proportional to r^2, where r is the distance between CIP and the obstacle (see Figure 2). The potential field of obstacles is a secondary tool for helping the CIP to avoid obstacles and reach its goal. It can be turned on and off according to the computer player's negotiation behavior and its current decision.

Lastly, we make a distinction between the physical model that the user is interacting with and the model where the force is calculated to feed the user. NIP's and therefore the Ball's

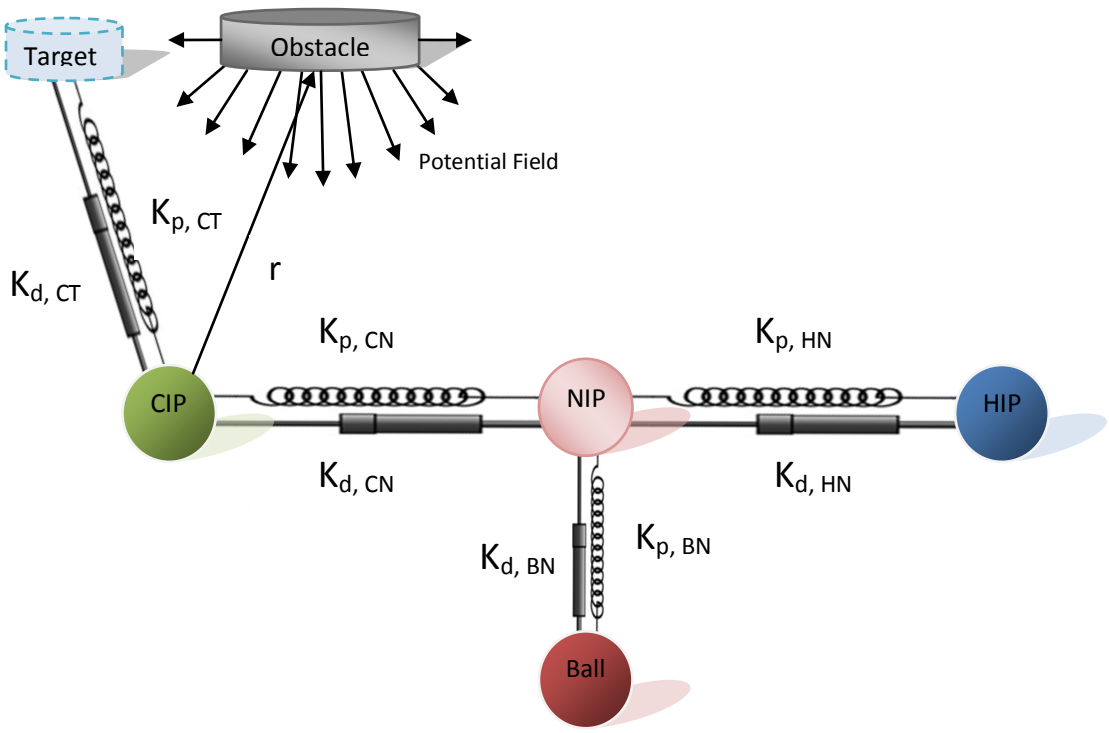


Figure 2: The physical model for the haptic negotiation game. K_p and K_d values in the figure represent the spring and damper coefficients. Actually, the Ball also lies on the line between CIP and HIP, but for simplicity, it is drawn as if it is behind the NIP.

positions are determined by the physical model described (see Figure 2), but the force fed to the user is calculated with a different model. We wanted to 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 middle of its own road. As the Ball passes to the right subsection, which belongs to the user's path, then the user feels an attractive force on the negative x-direction, i.e. to the left. On the contrary, when the ball passes to the computer player's side, then the user feels a repulsive force on the positive x-direction, i.e. to the right. This haptic information presents an opportunity for the user to collaborate, but if the user does not accommodate to the computer player, then a physical conflict occurs. Hence, when the ball deviates from its path, the computer player can choose to accommodate or concede in order for the Ball to collect its coin.

Chapter 4

Negotiation Behaviors

Rosenschein et al. (1994) define negotiation as a form of decision-making where two or more parties search together a space of possible solutions with the goal of reaching a consensus. As Shell [2006] points out there is a spectrum of negotiation that ranges from concessive to competitive. Shell [2006] identifies five negotiation behaviors, namely accommodating, avoiding, collaborating, competing, and compromising. Since those five styles have some social behaviors attached, it is not feasible to cover all these properties with only visual and haptic cues. Hence, we narrowed down these five behaviors to three, and implemented those for modeling our computer player. These three behaviors lie on the spectrum of the aforementioned range of negotiation styles (see Figure 3).

Since both concession and competition lie on the two ends of the range for the negotiation behaviors, there is a clear separation of action choices between the two. On the other hand, in the modified Tit-for-Tat, the actions are formed by blending the other two behaviors' decision-making processes. In other words, tit-for-tat strategy shares elements from both competitive and concessive behaviors. In order to implement these negotiation behaviors, we constructed a set of conditions for each one of them. These conditions both help us in implementing the desired decision-making attitudes for the computer, and also provide some variations within a given negotiation behavior. For example, the compromising player does not always make concession. Likewise, the competitive computer player sometimes accommodates to the human user. The details of these behaviors will be given next.

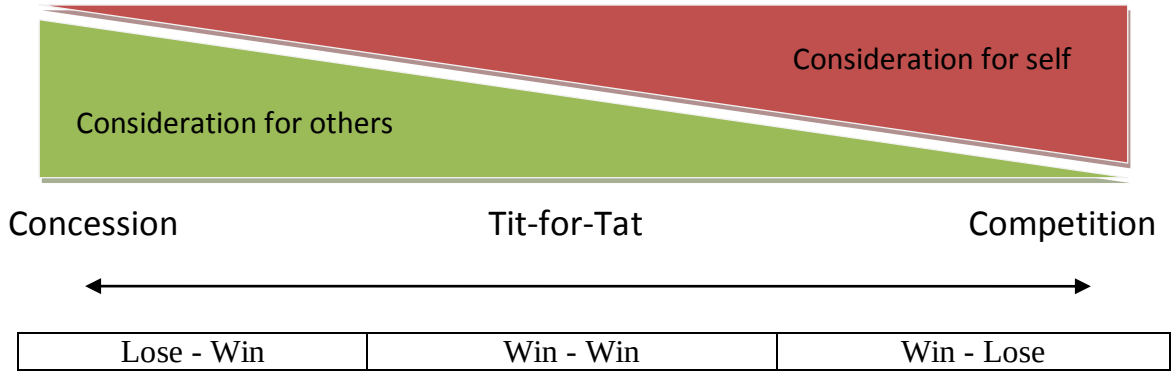


Figure 3: Spectrum of computer player's negotiation behaviors. Concession and Competition stand on the two ends, and Tit-for-Tat lies in between. The two ends often end in a win–lose situation since one party favors itself. However, tit-for-tat can help utilize the stronger aspects of the other negotiation behaviors, thus allows a win–win case.

4.1 Concession

In negotiation research, concession, in its broad definition, is described as consideration for others. On the other hand, Cooperation Theory, which was proposed by Axelrod and Hamilton (1984), puts concessions as a key factor in negotiation and focuses on the exchange of concessions. It is suggested that an agreement can be reached through a process in which negotiators cooperate by matching each other's concessions. The compromises of one dyad yield benefits to their opponent (Johnson and Cooper, 2009). When a dyad makes a concession, he or she expects a similar concession by the other dyad. Cooperation theory describes the typical actions of negotiators result from the existence of a powerful norm of reciprocation, which in turn, enforces us to be obligated to future repayment of favors, such as concessions (Eisenberger et al 2001; Rhoades and Carnevale 1999). Rhoades and Carnivale (2001) reported that individuals matched their opponents by making concessions and *yielding* strategies. Other negotiation studies have found that the rate and size of concessions tend to be matched (Druckman and Harris 1990; Stoll and McAndrews 1986).

However, there can be negative side effects of making concessions. One dyad makes an offer that supports other dyad's interests while there is an accompanying reduction of benefit to the dyad making the offer. Even though one dyad benefits from the other's concession, the excessive consideration for the opponent may lead to a lose-win situation since the reciprocity is not achieved [Johnson and Cooper 2009].

When designing our concession strategy, we made use of the definitions and properties as specified in the negotiation research. With some exceptions, the computer player makes concessions for the benefit of the user. Specifically in our negotiation game, the computer player makes concessions in order for the Ball in the middle to collect its coin. Therefore, this movement allows the opponent to collect his or her own coin without any compromises. As a result, the utility of the computer player decreases for the sake of maximizing the other dyad's utility. Overall, this trade-off tends to result in a mediocre utility value for the whole process. The concession protocol of the computer player depends on several conditions (see Table 2). For every obstacle combination, the computer player firstly checks whether 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 its opponent's benefit and the cost of its concession. The cost of making concession for the computer player is its coin's value. The human user's benefit of a possible concession by the computer is the sum of the values of the coins the Ball and the HIP will collect. Hence, if this benefit outweighs the cost of computer player, then it makes a concession. Lastly, the average of dyads' next coin values 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. Since the Ball's coin value adds up to both dyads score, the concession is justified for the computer player. If those conditions are not met, the computer player ignores to the human player, and collects its coin.

Conditions	Action
1. check if c =< b	Concede, and help the Ball to collect the coin in the middle.
2. check if c < h+b	
3. check if b >= avg(c,h)	

Table 2: Conditions and the resulting action for the computer player playing with the concession strategy. If one of those conditions holds, then the computer player makes a concession, and thus, it helps the Ball to collect the coin in the middle. *c*, *b* and *h* represent the values of coins belonging to CIP, Ball and HIP, respectively.

4.2 Competition

Guttman and Maes (2006) describe competitive negotiation as the decision-making process of resolving a conflict between two or more parties over a mutually exclusive goal. In other words, each party has its own interests, and these interests are conflicting with each other. However, if both parties insist on a competitive attitude then the resolution cannot be

achieved. The Game Theory literature considers the competitive negotiation as a zero-sum game. From that perspective, the value of the item being negotiated lies along a single dimension and it shifts in either party's favor, consequently one side is better off while the other is worse off (Rosenschein 1994). In the short term, both parties seem to benefit from that approach, but in the long run, they lose their trust in each other. As a result, the overall process fails to come close to the possible maximum utility value. Hence, the game theory literature describes competitive negotiation as a win-lose type of negotiation (Guttman and Maes 2006).

Conditions	Action
1. check if c >= b	Compete, and collect the coin on your side.
2. check if h >= b-c	

Table 3: Conditions and the resulting action for the computer player adopting the competition strategy. If one of those conditions holds, then the computer player competes, i.e. it does not try helping the Ball to collect the coin in the middle; instead it collects its own coin. *c*, *b* and *h* represent the values of coins belonging to CIP, Ball and HIP, respectively.

Our competitive strategy for the computer player reflects those properties. The competitive computer player values its interests more than the other party's interests. With some exceptions, whenever a conflict occurs, the computer player chooses to collect its own coin, and thus, increases its own utility. However, its persistent, non-cooperative attitude may prevent the other party to make further concessions. As a result, even though both dyads increase their individual utilities, they miss the opportunities that might be more valuable. For that reason, two dyads cannot fully utilize the outcome of the negotiation process, like the concessive strategy. The protocol for the competition strategy includes two conditions (see Table 3). First, the computer player compares its own coin, *c*, with the Ball's coin, *b*. If the computer will earn more with its coin than the Ball's coin value, then it does not concede, rather aims for collecting 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 HIP's coin. Unless the incremental benefit exceeds HIP's earning, the computer player carries on collecting its own coin. If none of those conditions holds, then the computer player accommodates the human user and helps the Ball to collect its coin in the middle.

4.3 Modified Tit-for-Tat

The dictionary definition for the tit-for-tat is "equivalent retaliation". It is also an effective strategy in game theory for the prisoner's dilemma problem. The strategy was firstly suggested by Anatol Rapaport for the Prisoner's Dilemma tournament, designed by Robert Axelrod (Axelrod 1984). Axelrod (1984) based the iterated Prisoner's Dilemma game as a framework for understanding the achievement of mutual cooperation. Tit-for-tat was the winner, and since then, it was proved to be an effective strategy on simulations where cooperation was sought between dyads. We adopted the same strategy and incorporated some additional conditions for our game. Tit-for-tat is a cooperative negotiation strategy. Guttman and Maes (2006) classifies cooperative negotiation as a decision-making process of resolving a conflict involving two or more parties with non-mutually exclusive goals. Hence, the game theory literature describes cooperative negotiation as a non zero-sum game where there is a possibility for all parties to be better off. In that sense, cooperative negotiation is a win-win type of negotiation.

Conditions	Action
1. check if c+h >= 2*b	If both conditions hold true, then collect your coin.
2. check if conceded for the previous coin combination	

Table 4: Conditions and the resulting action for the computer player playing with the tit-for-tat strategy. If one of those conditions does not hold, then the computer player makes a concession. The computer player accommodates to the actions of the human player in order to help the Ball to collect its coin. *c*, *b* and *h* represent the values of coins belonging to CIP, Ball and HIP, respectively.

In our experiment, computer player executing the modified tit-for-tat strategy starts with a cooperating move. Then, unless the user defects, the computer player continues to cooperate. Defection of the human player means that he or she does not accommodate the computer player for keeping the Ball on its path. On the other hand, cooperation of the computer player means that the computer player makes concessions as long as it increases the overall utility value. In return, the computer player can earn the trust of the human player and expect similar concessions from its opponent. Hence, the two parties share a non-mutually exclusive goal which results in higher utility values. For the computer player to accommodate or make concession, the history of the process is critical. Table 4 summarizes the two conditions for the computer player to make a concession. If the computer player notices a defective action by the other dyad for the previous decision-making process, then it may retaliate. A retaliation

decision is given if the overall utility of the process will not increase, i.e. twice the value of the middle coin does not exceed the sum of the values of CIP's and HIP's coins.

Chapter 5

Experiments

5.1 Objectives and Approach

We investigated whether the subjects could differentiate between different negotiation behaviors or not. Subjects' perceptions of different playing strategies of the computer player were also examined. Moreover, we sought an indication of the effectiveness of different modalities on the negotiation process. Finally, we evaluated the performances of the subjects on how effectively they could utilize these negotiation behaviors. The main hypotheses that we aimed to test were:

H1 Subjects can differentiate between different negotiation behaviors.

H2 Tit-for-tat strategy will help subjects to utilize the negotiation process more than the other 2 strategies.

H3 Haptic enabled bilateral communication will have a higher impact on the subjects' perception and awareness

5.2 Experiment

24 subjects (5 female, and 19 male) participated in our study. Twelve of these subjects were tested under the visual and haptic feedback (VH) condition, and the remaining twelve were tested under the visual (V) condition. There are six combinations for the ordering of three different negotiation behaviors. In order to eliminate the ordering effects, each combination was played by two different subjects so that all of these combinations are covered.

Since most of our subjects were unfamiliar with a haptic device, we introduced the haptic device to each user verbally and through the use of certain training applications. We provided

subjects with an instruction sheet that covers how to play the game, as well as, the rules, and the goals of the game. They were informed about the existence of three different playing strategies of the computer player, and alerted for paying attention to how the computer plays in each of these modes. An experiment took about half an hour, and we paid attention to provide the same physical setting for all the subjects.

Before the actual trials started, subjects were given the opportunity to practice with a test trial, improve their understanding of the game, and get familiar with the haptic device. During the test trial, the computer player's negotiation behaviors were randomized so that the subjects did not acquire prior information about these behaviors. After the test trial, the actual trials began. First, subjects played the game once in each mode of the computer. When they were playing the game, subjects were not aware of what negotiation behavior the computer player adopted. They even did not know the task was about negotiation. 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.

For the test trial the computer player's mode is written as Mode R, for highlighting its random nature. A short break was given after each mode. Finally, each subject played all 3 modes (A, B, C) in succession in order for them to make a final decision. At the end of the experiment, subjects were asked to fill out a short questionnaire regarding their experience and the modes of the computer player. During the experiments, the full system state (i.e. positions of CIP, HIP, NIP, and Ball, the entire individual forces of each spring-damper system, whether or not the coins are collected, etc.) was recorded at 1 kHz.

5.3 Metrics

5.3.1 Subjective Evaluation Metrics

After each experiment, the users were given a questionnaire. Users were informed about the different playing strategies of the computer player. However, these strategies were randomized for each subject and they did not know in which order they were playing. For the questionnaire design, we adopted the technique that Slater et al. (2000) used previously in shared virtual environments. A total of 15 questions were answered by the subjects. Seven of the questions were about personal information, one was reserved for users' feedback and the remaining seven were about variables directly related to our investigation. Some of the questions were paraphrased, and asked again, but scattered randomly in the questionnaire.

While evaluating the questionnaire, we considered the averages of the responses to these questions that fall into the same category. Questions were asked in four categories:

1. *Performance:* Subjects were asked to evaluate both the computer player's and also their own performances by rating on a 7-point Likert scale.

2. *Conflict:* We asked the subjects whether they had a sense of computer player working against them. Two questions with different wordings were asked within the questionnaire.

3. *Collaboration:* We asked the subjects whether they had a sense of collaborating with the computer or not. Like the *conflict* case, two questions related to collaboration were asked.

4. *Effectiveness of Modalities:* Subjects rated their perceived effectiveness of the three modalities – audio, visual and haptics – for helping them identify the behaviors of the computer player displayed in the game on a 7-point Likert scale.

5.3.2 Objective Performance Metrics

Since we investigate how haptics enabled bilateral negotiation can affect the interactive process, the force interactions can provide valuable information. Since the resulting force is due to the mass-spring-damper system between the interface points, it is the definitive indicator of the collaboration, or the conflict between dyads. Likewise, the individual scores of the dyads, and the score obtained from the middle Ball present helpful data for evaluating the interaction between the two parties, since we use the scores as the utility value of our game. Hence, we evaluate subjects' performance with two objective performance metrics; one is the average force the users felt, and the other is the utility of the overall game. For each negotiation behavior, we calculated the averages of the force values that were fed to the subjects by the haptic device. While assessing the utility of the individual dyads and the overall game, we normalized the final scores of each dyad by their corresponding highest possible score. Due to the chosen combinations for the coins, the maximum possible scores of each entity differ from each other. Hence, the normalization of the scores allows us to compare the utilities of the human users and the computer player.

Chapter 6

Results

6.1 Subjective Evaluation Results

For each of the three negotiation behaviors, the questionnaire was designed to measure the self-perception of users' performances, as well as the computer player's performance. Moreover, the subjects evaluated the collaborative and competitive aspects of the negotiation models without knowing which one the actual behavior was. The subjects also rated the perceived effectiveness of each modality, which consists of audio, visual and haptics channels. From those results[1], we identified whether there are significant differences between the three negotiation behaviors perceived by the subjects, and whether the effectiveness of any modality is higher than the others, or not.

Our results show that the subjects can successfully differentiate between the behaviors of the computer. With both conditions, V and VH, subjects were successful at identifying the characteristics of the computer player. For the V condition, there are cases, where significant differences cannot be observed between the negotiation behaviors. However, there is a clear distinction for all the behaviors in the VH condition (see Table 5). For example, the subjects' perceptions of the computer player's performance were not statistically significant between the tit-for-tat and the competitive behavior (*p-value* > 0.1). Likewise, the subjects could not differentiate between the tit-for-tat and the concession behavior while evaluating how much the computer player was working against them (*p-value* > 0.1). The evaluation of all the other responses revealed significant differences between each behavior. For all the four questionnaire categories, there are statistical differences between all the pairings for the VH

[1] Answers of all the subjects to the questionnaire can be found in Appendix A and B, for the visuo-haptics and visual only conditions, respectively.

condition (see Table 5-a). These results evidently suggest that the subjects experienced and identified the diversity of the computer player's negotiation behaviors, especially under the VH condition.

Visual & Haptic		
TfT-Con	**TfT-Com**	**Con-Com**
Successful (Self)		
0,096	0,025	0,009
Successful (Computer)		
0,041	0,072	0,019
Conflict - Working Against		
< 0,001	< 0,001	< 0,001
Collaboration - Accommodation		
< 0,001	< 0,001	< 0,001

a

Visual		
TfT -Con	**TfT-Com**	**Con-Com**
Successful (Self)		
0,017	0,006	0,006
Successful (Computer)		
0,017	0,210	0,014
Conflict - Working Against		
0,151	0,004	< 0,001
Collaboration - Accommodation		
0,044	0,004	0,001

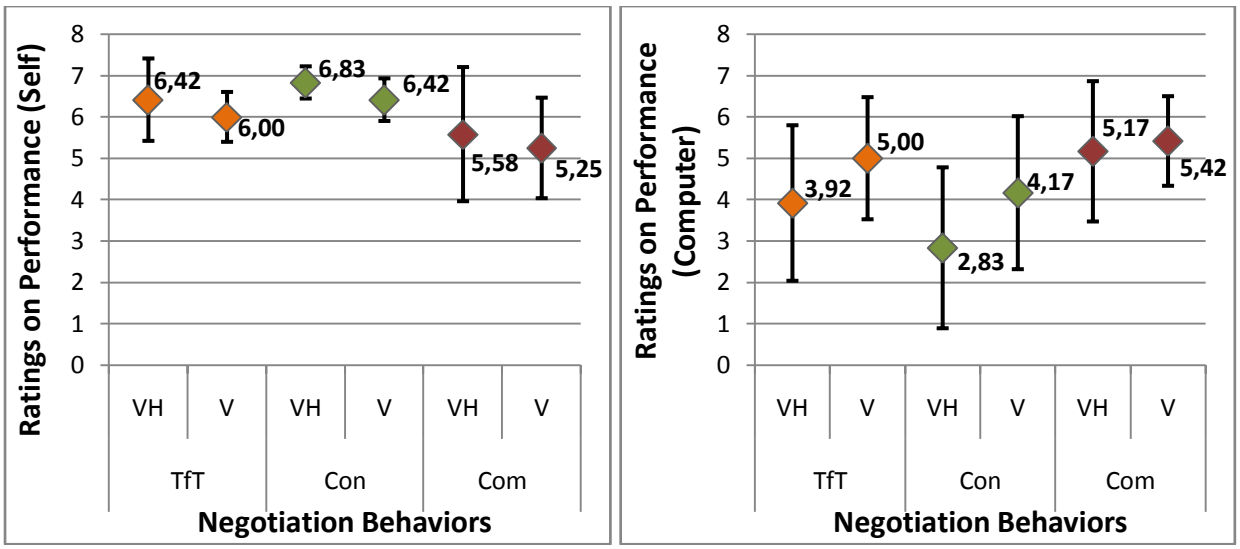
b

Table 5: p-values from the t-test for the responses to the questions regarding subjects' evaluation of **a)** themselves, and **b)** computer player on how well they performed. Highlighted values indicate the absence of significant difference.

For evaluating the differences between the two conditions, we applied Mann-Whitney U-test. Since this statistical test is a non-parametric significance test, we can compare whether the two independent samples of observations, i.e. V and VH conditions, have equally large values. The results of this test also show a greater awareness with the VH condition than the V condition. Subjects believed that they performed better on all the negotiation behaviors while under VH condition. Moreover, the evaluation of subjects' self performance is significantly higher for the tit- for-tat and concession strategy under the VH condition than the V only condition (see Figure 4 & Table 6). While the subjects playing against the tit-for-tat strategy rated themselves as successful on the average of 6,42 for the VH condition, the same score for the V only condition is 6,00. Likewise, against the concessive player the average is 6,83 for the VH condition, whereas it is 6,42 for the V only condition. The tests indicate a significant difference between the VH and V only conditions for those two negotiation behaviors (*p-value* = 0,075 for tit-for-tat, *p-value* = 0,042 for concession – see Table 6).

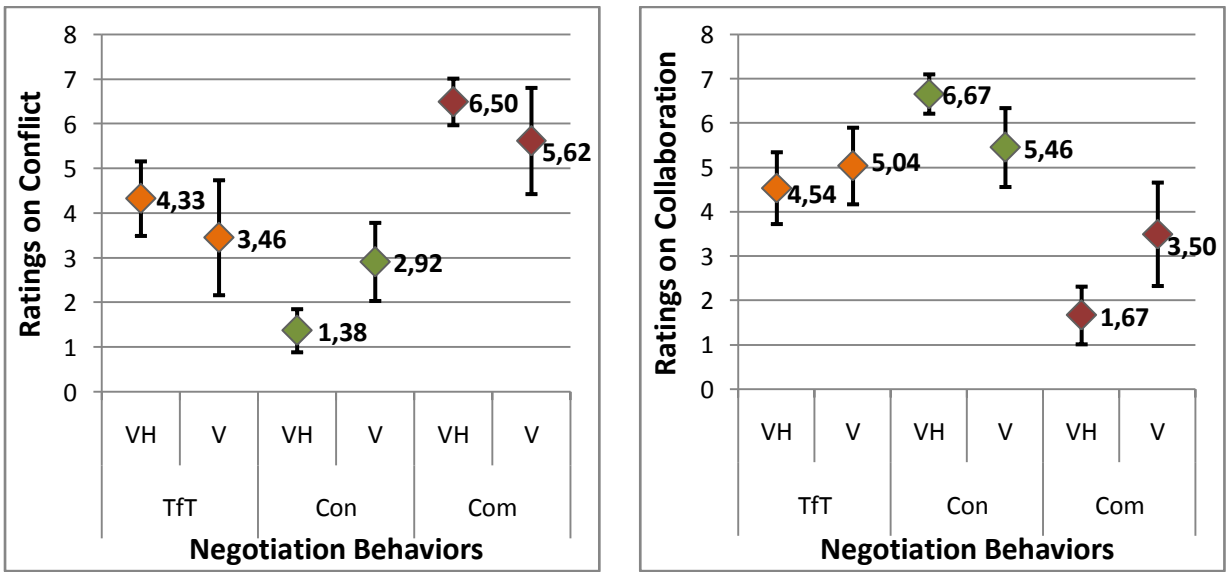
We could not find an indication of significant difference between the subjects' evaluation of the computer player's performance. However, the ratings are always lower when the subjects play under the VH condition (see Figure 4-b). For the collaboration question, we observed that the gap between the negotiation behaviors is wider under VH condition, but, the

differences get smaller under the V only condition. The degree of collaboration is significantly different between the negotiation behaviors under different conditions (see Table 6). Considering these results together with the subjects' indifference between the tit-for-tat and concession strategies for the observed degree of conflict, we conclude that the haptic feedback helped increase the awareness of the users. Hence, they were able to differentiate between the different characteristics of the three behaviors easily.



a b

Figure 4: Average responses to the questions regarding subjects' evaluation of **a)** themselves, and **b)** computer player on how well they performed under Visual only and Visuo-Haptics conditions.



a b

Figure 5: Average responses to the questions regarding the degree of **a)** conflict, and **b)** collaboration the subjects felt under Visual only and Visuo-Haptics conditions.

Finally, we examined how effectively the three modalities support the subjects to differentiate between the behaviors of the computer player. For the VH condition, the effect of the haptic feedback is superior to the audio-visual channels. On the average, subjects rated the effectiveness of the haptic channel as high as 6,33 where as the visual and audio channels only achieved the ratings of 5,25 and 2,25, respectively (see Figure 6). These ratings indicate statistically significant differences between the haptic feedback and the other two modalities (*p-values* < 0,05). Hence, the haptic feedback is proved to be an effective initiator for the subjects to comprehend the cues of their negotiation with the computer player.

Successful (Self)			Successful (Computer)			Conf-Work. Against		
TfT	**Con**	**Com**	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**
0,075	0,042	0,423	0,136	0,107	1,000	0,052	0,000	0,078

Collab-Accomm			Features		
TfT	**Con**	**Com**	**Visual**	**Haptic**	**Audio**
0,173	0,000	0,000	0,338	0,000	0,156

Table 6: p-values from Mann-Whitney statistical test evaluated for the differences between the VH and V only conditions.

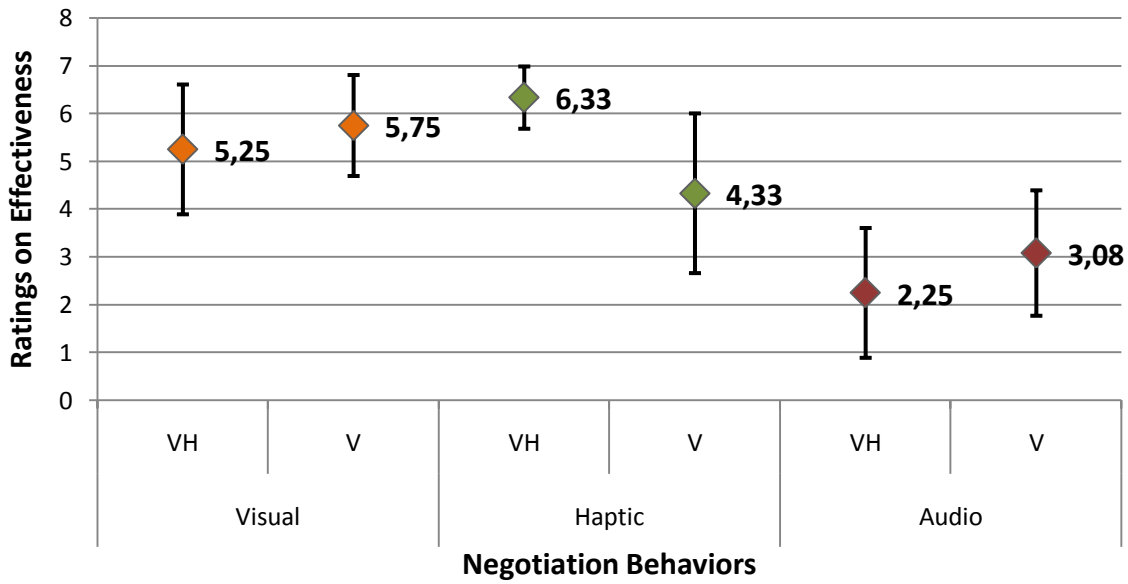


Figure 6: Average responses to the questions regarding the effectiveness of the three modalities under V only and VH conditions.

6.2 Quantitative Measurements

We investigated how human users interacted with the computer player executing different negotiation strategies. We looked into whether they could utilize any of those strategies or not. We also studied how the haptic force feedback played a role on these interactions. Hence, we computed the average force values that the users felt, and the total utility of the process for each negotiation behavior and condition. Upon closer inspection, we observed that the utility is the worst when the computer player performs a concessive strategy. On the other hand, the utility is maximized when the tit-for-tat strategy is carried out by the computer player. We applied paired t-tests to examine the statistical differences between the negotiation behaviors. According to paired t-tests results, for both VH and V only conditions, there are significant differences between the tit-for-tat strategy and the other two strategies. We calculate the utility of a game by normalizing the sum of the dyads' scores by the maximum available score that can be achieved on a single game. For the VH case, the average utility of the game while the computer player makes use of the tit-for-tat strategy is 0,85. This is significantly higher than the average utility of the concession strategy which is 0,79 (*p-value* = 0,003). Likewise, it is significantly higher than the average utility of the competitive strategy which is 0,80 (*p-value* < 0,001). The ranking of the utilities are same with the V only condition. Highest utility is obtained by the tit-for-tat strategy, and it is followed by the competitive and then the concessive strategies (see Table 7). Moreover, the difference between tit-for-tat and the other two strategies are significant (*p-value* = 0,012 for concession, *p-value* = 0,004 for competition). Even though we cannot find a significant difference between the two conditions, the games played under the VH condition have higher overall utility values than the games played under the V only condition for all the negotiation behaviors.

Visual & Haptic		
Average Utilities		
Tit-for-Tat	**Concede**	**Compete**
0,85	0,79	0,80

Visual		
Average Utilities		
Tit-for-Tat	**Concede**	**Compete**
0,83	0,78	0,79

Table 7: Average utilities of the games for the three negotiation behaviors under two conditions, which are V only and VH.

One major outcome of this study is the existence of differences between the individual utilities of the dyads while playing with three negotiation behaviors. Both concessive and the competitive strategies tend to favor one of the two dyads' individual utility. For example, the

computer player making numerous concessions increment the individual utility of the human user. In other words, the computer player sacrifices from its interests for the sake of the other dyad's utility. Unlike the concessive strategy, the competitive computer player cares only about boosting its utility, and thus, it impairs the utility of the human user (see Figure 7). In essence, these two strategies created either a win-lose or a lose-win situation. On the other hand, the tit-for-tat strategy favors the overall utility without sacrificing the individual utilities of the dyads. Hence, the tit-for-tat strategy is beneficial on the tasks where the maximized outcome of the joint work of two parties is targeted / valued more. Essentially, it offers a win-win case for both parties.

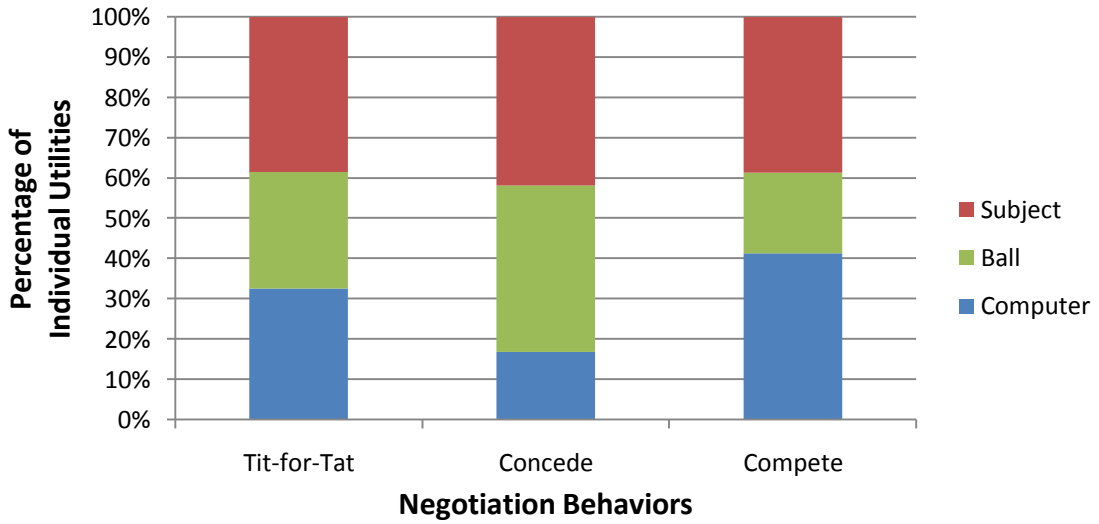


Figure 7: Percentage of the individual utilities while normalized by the overall utility.

The three behaviors of the computer player result in different utility values for the individual players. In order to compare the efficiencies of the dyads based on their acquired scores, we have calculated the maximum utility that can be achieved in our game. Then we computed the individual utilities of the human user and the computer player when that maximum utility is achieved. The individual maximum utility values are 0,91 and 0,96 for the computer player and the human user, respectively. The distributions of the individual utilities are shown in Figure 8. Moreover, the clustering of the three negotiation behaviors based on the utilities of the dyads clearly shows the distinction of achieved utility values. The average utility value for each negotiation behavior is also shown in Figure 8, at the center of the enclosing ellipses. When we consider the distance between those average utilities to the achievable maximum utility value, we observed that the tit-for-tat strategy is the closest one to that value. This is

another confirmation that the dyads utilized this strategy, and with some minor adjustments they could have achieved the expected maximum utility of the system.

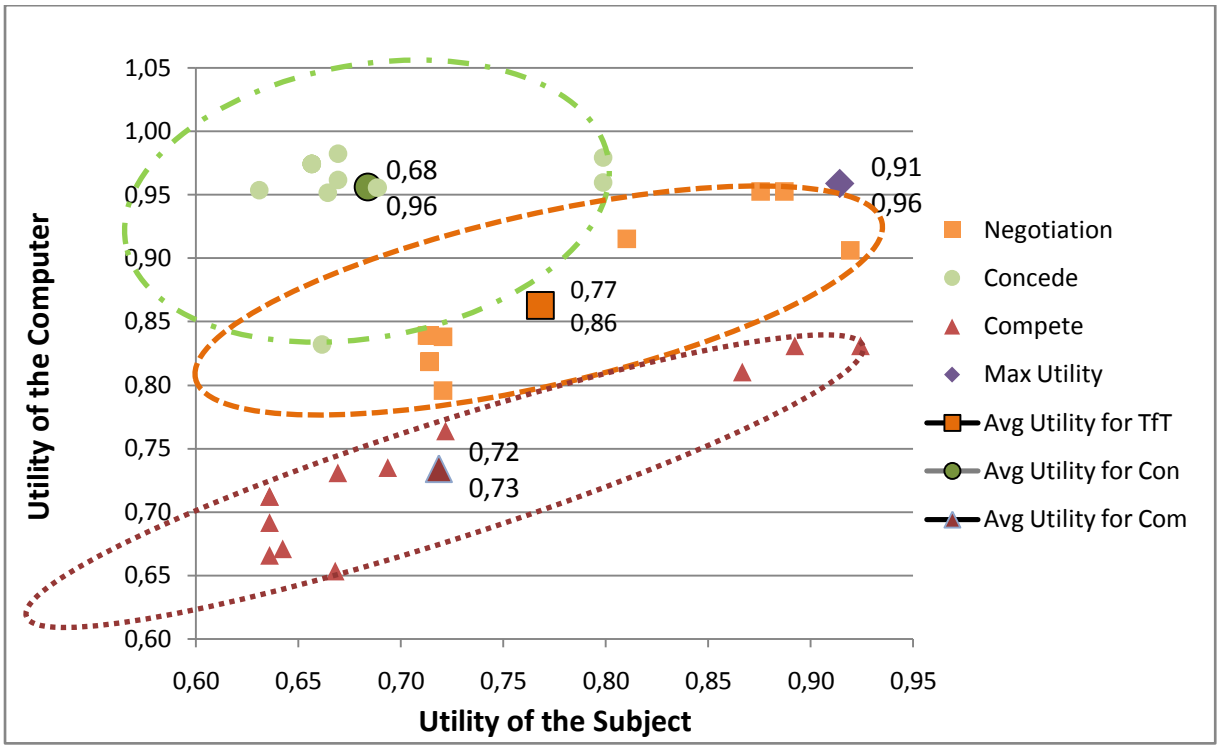


Figure 8: Utility distribution of the subjects, their means and the eclipses showing the clustering of the different negotiation behaviors under VH condition.

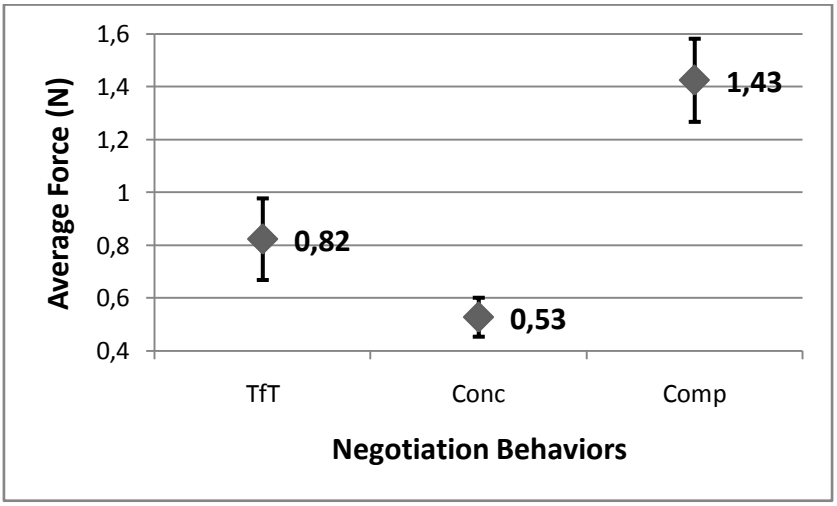


Figure 9: Average force values that the users have felt by the haptic device for each negotiation behavior.

Since one of the aims of this experiment is to test the effectiveness of the force feedback on a negotiation framework, we calculated the average force values the users have felt.

Unsurprisingly, the maximum effort was made with the competitive computer partner. Since the computer player insisted on collecting its coins, the users found themselves in conflict with the computer most of the time. Due to these conflicting situations higher force values were generated and fed back to the user. On the contrary, with the concession strategy the computer player dedicated itself to accommodate to the other dyad. It resulted in less conflict hence the user felt less force. Finally, the force values generated in the tit-for-tat strategy falls in between the other two strategies. Hence, the tit-for-tat provides a trade-off between the effort and the utility. In other words, with a little more effort made by two parties, they can maximize the overall utility of the application. Notice that, even though the subjects spent more energy with the tit-for-tat strategy, the overall utility of the application was maximized (see Table 7 & Figure 9).

Chapter 7

Conclusion & Future Work

7.1 Conclusion

In this study, we developed a negotiation model for affective visuo-haptic communication between a human operator and a machine. Our model realizes a dynamic interaction consisting of collaborative and conflicting components. Moreover, it incorporates audio-visual and haptic cues for displaying negotiation related behaviors. Subjects successfully differentiated between concessive, competitive, and tit-for-tat strategies of the computer player. Haptic interaction proves to be a beneficial facilitator for the recognition of computer player's behavior. Subjects who played the game with haptic feedback were significantly better at making a distinction between the behaviors than the other subjects who played with only visual cues. Additionally, the utility of the game is maximized with the tit-for-tat strategy. Utility with the tit-for-tat strategy is significantly different than the utilities of the other two styles in both VH and V cases. Quantitative analysis shows that the average force the users felt is highest with the computer's competition strategy. Concession allows users to feel the least force due to its accommodating nature. On the other hand, tit-for-tat strategy offers a trade-off between the effort made by the user and the achieved utility value. The average force that the users felt lies in between the average force values calculated for the concession and competition strategies. Clearly, human-computer or human-robot interaction can benefit from a negotiation based behavioral computer model when the task has collaborative as well as conflicting components. Moreover, cooperative models, like tit-for-tat, maintain higher utility values for the overall system than the concessive and competitive models.

7.2 Future Work

In the current experimental setting, we have tested 2 conditions, one with only visual cues, and the other is with visuo-haptic cues. The auditory cues were always present. Hence, we tested the effectiveness of haptic interaction. Though we compared the effectiveness of three modalities subjectively, other communicative channels can also be individually turned on and off, and thus, their effectiveness can also be tested quantitatively.

Moreover, current game allows subjects to see the actions of the computer player. In order to increase the uncertainty of the environment, another system can be designed to test where users can only see their own and the middle ball's subsections. Hence, the effectiveness of the haptics may change, e.g. the users may have to rely more on the haptic cues.

Another future direction would be to test agents, which were designed for the other negotiation procedures in the literature, on how they would perform on our system. On the other hand, subjects' perception of those agents can also be evaluated. We'd like to investigate the other aspects of the affective computing components. For example, adding virtual avatars would help us to synthesize more humanlike emotions for the computer player; hence, effects of those emotions and the behaviors they elicit can be analyzed.

Lastly, our current game can be altered to test the interaction while two human players are playing together. We can analyze the differences of responses between playing against a human and a computer. The results may lead us to build more humanlike avatars, hence enhance the interaction.

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APPENDIX A

VH Condition	Successful (Self)			Successful (Comp.)			Conflict			Collaborative			Features		
Subjects	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**Visual**	**Haptic**	**Audio**
1	7	7	7	7	6	6	4	1	7	4	7	1	7	6	1
2	4	6	2	4	6	2	4,5	2	6	3,5	6	2	6	6	4
3	7	7	4	4	3	6	4	2	6,5	4	6,5	2,5	5	6	4
4	7	7	7	2	1	6	5	1	6	5	7	2	4	7	4
5	6	7	6	5	2	5	4	2	5,5	4	6,5	2	4	6	1
6	5	7	5	3	4	4	5	2	6	3,5	6	2,5	5	7	4
7	7	7	6	5	1	7	5,5	1	7	6	7	1	7	7	2
8	7	7	7	3	2	7	4	1	6,5	4	7	1,5	7	6	1
9	6	6	4	2	1	6	2,5	1	7	5,5	7	1	6	5	2
10	7	7	5	7	5	5	3,5	1	7	5	7	1	3	7	2
11	7	7	7	1	1	2	5	1	7	5	7	1	5	7	1
12	7	7	7	4	2	6	5	1,5	6,5	5	6	2,5	4	6	1
Avg	**6,42**	**6,83**	**5,58**	**3,92**	**2,83**	**5,17**	**4,33**	**1,38**	**6,50**	**4,54**	**6,67**	**1,67**	**5,25**	**6,33**	**2,25**
StDev	**1,00**	**0,39**	**1,62**	**1,88**	**1,95**	**1,70**	**0,83**	**0,48**	**0,52**	**0,81**	**0,44**	**0,65**	**1,36**	**0,65**	**1,36**

Table 8: Answers of the subjects to the questionnaire for the visuo-haptics condition.

APPENDIX B

V only Condition	Successful (Self)			Successful (Comp.)			Conflict			Collaborative			Features		
Subjects	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**TfT**	**Con**	**Com**	**Visual**	**Haptic**	**Audio**
13	5	6	3	4	4	6	4	4	5,5	3,5	3,5	4,5	3	5	3
14	6	6	6	7	7	7	3,5	3	7	5,5	5,5	2	7	6	4
15	6	7	4	4	2	6	4	2	7	5	6,5	2	5	1	4
16	6	6	5	6	6	5	2	3	5,5	6	5,5	3,5	6	5	4
17	5	6	4	5	4	6	4,5	2	6	5	6	3	6	5	2
18	6	6	6	6	3	6	3	2,5	4	3,5	4	3	7	5	1
19	6	7	5	3	2	4	1	3	7	6	6	4	6	6	1
20	7	7	7	6	5	5	6	5	4	5	6	6	6	1	5
21	6	7	5	2	1	3	3	2	7	6	5,5	4	6	5	2
22	6	6	6	6	5	6	4	3	4,5	5	6	4,5	6	5	4
23	6	6	5	6	5	5	2,5	2,5	4,5	5,5	6	3	6	4	4
24	7	7	7	5	6	6	4	3	5,5	4,5	5	2,5	5	4	3
Avg	**6,00**	**6,42**	**5,25**	**5,00**	**4,17**	**5,42**	**3,46**	**2,92**	**5,63**	**5,04**	**5,46**	**3,50**	**5,75**	**4,33**	**3,08**
StDev	**0,60**	**0,51**	**1,22**	**1,48**	**1,85**	**1,08**	**1,29**	**0,87**	**1,19**	**0,86**	**0,89**	**1,17**	**1,06**	**1,67**	**1,31**

Table 9: Answers of the subjects to the questionnaire for the visual only condition.

APPENDIX C

Questionnaire

Please take a few minutes to fill out this questionnaire. Please note that this is not a test and there are no right and wrong answers. We thank you in advance for your co-operation.

Because this experiment will be ongoing for a month, **please do not discuss any aspect of it with others.**

1. What is your gender? (Circle one) Male Female

2. What is your age? ----------

3. Did you understand the task properly? (Circle one) Yes No

4. Did you experience any problems during the task? (Circle one) Yes No

5. If yes, what were they?

   _____

   _____

6. I use computer in my daily life very much.

Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
← X	X	X	X	X	X	X →

7. I am familiar with this type of force-feedback/touch equipment.

Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

8. **I** was successful in playing the game.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

9. The computer player was successful in playing the game.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

10. **I** had a sense of conflict with the computer player.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

11. **I** had a sense of collaboration with the computer player.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

12. The computer player accommodated me when it had the chance.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

13. **I** had a sense of computer player working against me.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Mode A:							
Mode B:							
Mode C:							

14. Which feature(s) of the game helped you identify the computer player's mode? Please rate each effect below.

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Visual :	X	X	X	X	X	X	X
Haptic :	X	X	X	X	X	X	X
Audio :	X	X	X	X	X	X	X

15. Please write down any further comments that you wish to make about your experience. In particular, what things helped you differentiate between different modes? What were the differences?

_____

_____

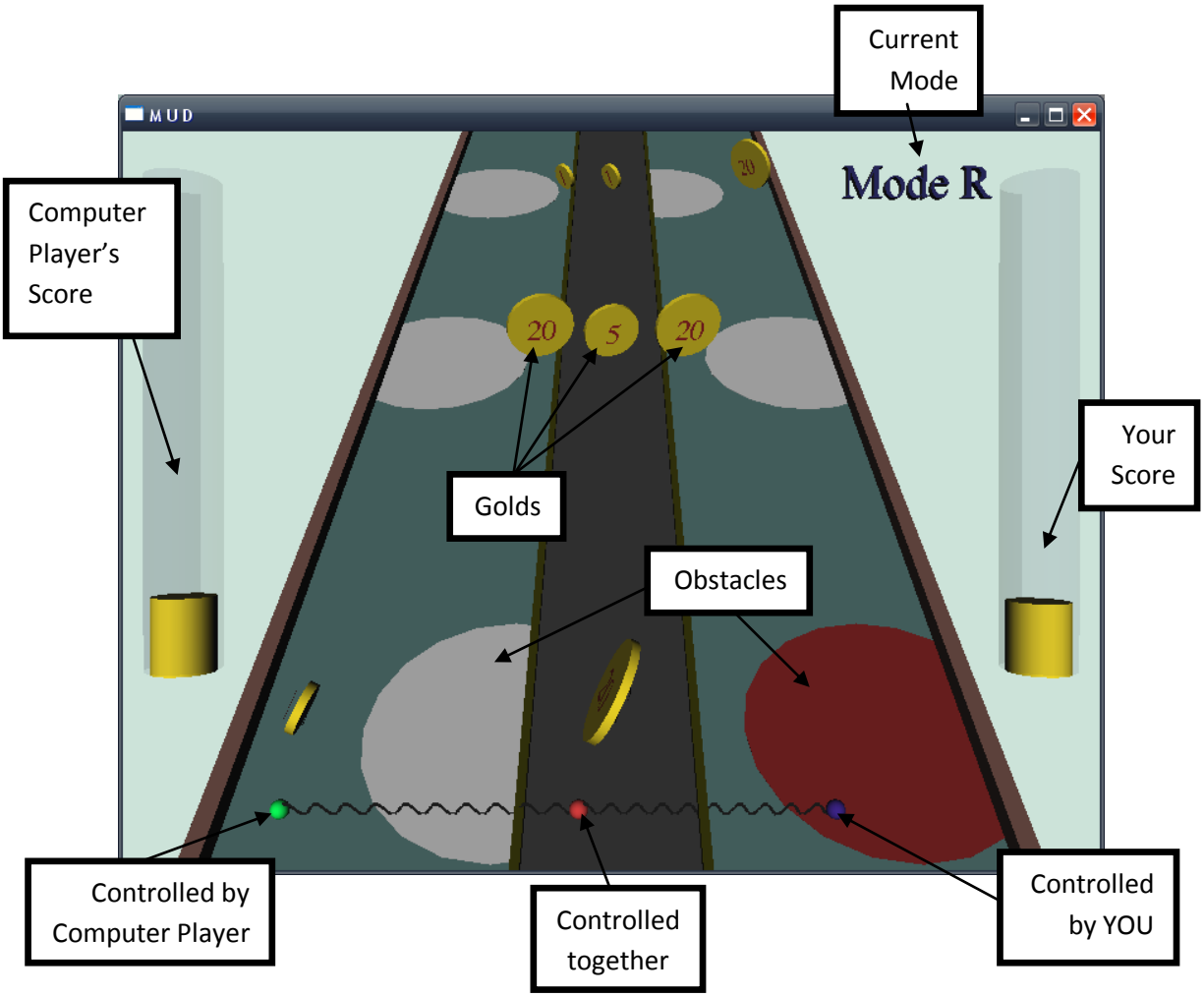
_____

THANK YOU!

APPENDIX D

Instructions

Thank you for volunteering to participate in this study. Please read through this information sheet and ask any questions that you may have before the experiment begins. **<u>The experimenter will not answer any questions afterwards.</u>**



<u>GAME in GENERAL:</u>

This experiment requires you to play a simple obstacle avoidance game with a computer player. On the screen, you will see a road divided into 3 subsections. On the left-hand side, computer player controls the green ball to avoid obstacles and collects coins to increase its score. Likewise, on the right-hand side, you control the blue ball to avoid obstacles and collect coins to increase your own score. The middle lane also has a coin which can be collected by the red ball. The position of the red ball is controlled by you and the computer together.

Separate scores are calculated for you and the computer. Your score is calculated by summing up values of coins that you collect from the middle lane and from your 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 leftmost and rightmost of the screen represented as bars that are filled with coins as players collect them.

Your Score = coin collected on your side + coin collected in the middle

Computer's Score = coin collected on computer player's side + coin collected in the middle

GOAL:

Your **primary goal** is to maximize your own score. Your **secondary goal** is to identify the playing mode (behavior) of the computer. The computers' playing mode will be either

1. in its own favor,
2. in your favor or
3. in between (sometimes in your favor, and sometimes in its own favor based on your behavior).

Please, pay attention to in which mode the computer plays the game.

HOW TO PLAY:

There will be a haptic device on the right hand side of the computer. You shall hold this device **REALLY TIGHT** with your right hand to move your ball (blue) to left or right.

First, you will play the game once in each mode (behavior) of the computer (Mode A, Mode B, and Mode C). A short break will be given after each mode. Note that the computer's playing mode will be displayed on the screen. Please pay attention to how the computer plays in each of these modes. Finally, you will play all 3 modes (A, B, C) in succession. An instruction sheet showing the flow of the experiment will be supplied for your reference. At the end of the experiment, you will be asked to fill out a short questionnaire regarding your experience and the modes of the computer player. Before the game starts, you will be given the opportunity to practice with a test trial, improve your understanding of the game, and get familiar with the haptic device.

The experiment is expected to take approximately 30 minutes.

Please note

- No identifying information about you will be published in any form.
- Please turn off any electronic devices before the experiment begins

APPENDIX E

Reference Sheet

Ask any questions about the game before the experiment begins. **<u>The experimenter will not answer any questions afterwards.</u>**

---

1. Test Trial and Adaptation (4 minutes)

---

2. Play the game in Mode A (3 minutes)
3. Break (1 minute)
4. Play the game in Mode B (3 minutes)
5. Break (1 minute)
6. Play the game in Mode C (3 minutes)
7. Break (1 minute)

---

9. Play A, B, C in succession (4 minutes)

---

10. Fill out the Questionnaire (10 minutes)

APPENDIX F

Additional Figures & Tables

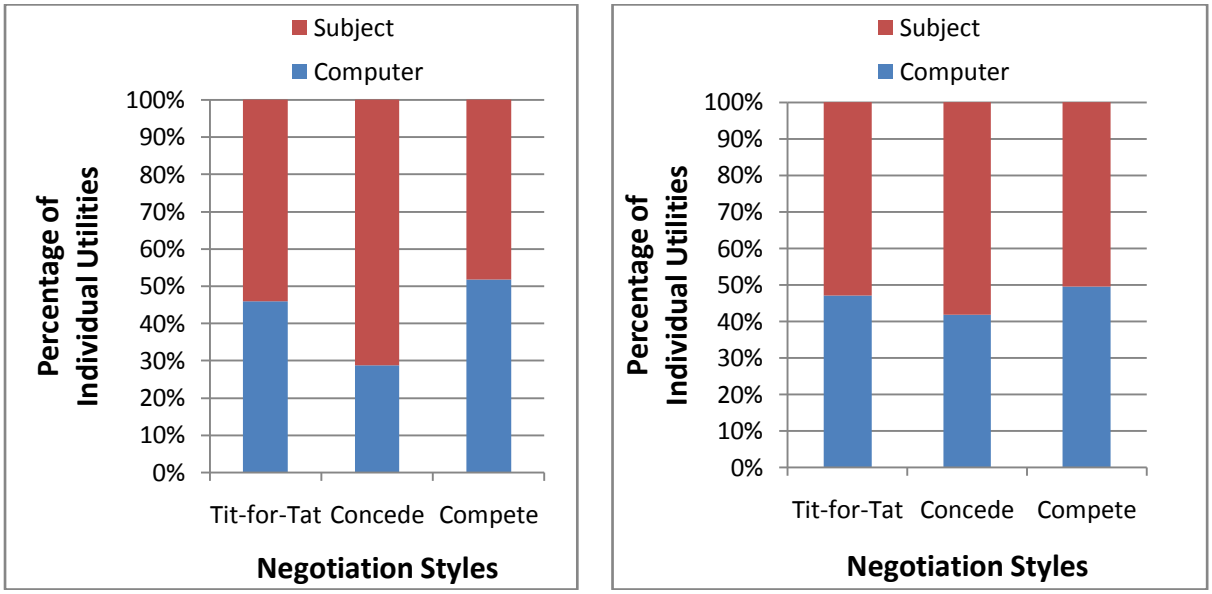


Figure 7- Alternatives: Left: Percentage of Individual utilities without considering ball's utility. Right: Percentage of Individual utilities plus the Ball's utility.

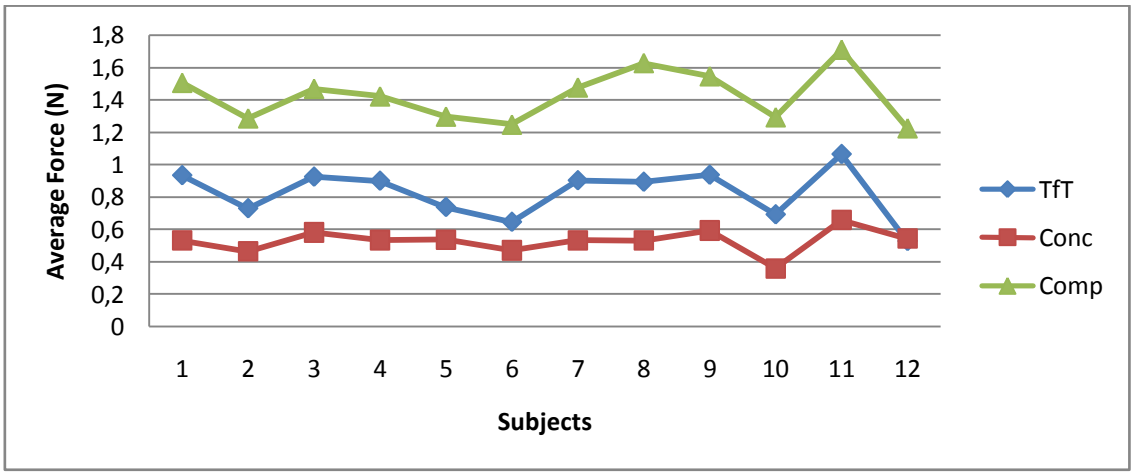


Figure 9 - Alternative: Average force values that the users have felt by the haptic device for each negotiation behavior.

APPENDIX G

Haptic Negotiation and Role Exchange for Collaboration in Virtual Environments

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Haptic Negotiation and Role Exchange for Collaboration in Virtual Environments

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Abstract

We investigate how collaborative guidance can be realized in multimodal virtual environments for dynamic tasks involving motor control. Haptic guidance in our context can be defined as any form of force/tactile feedback that the computer generates to help a user execute a task in a faster, more accurate, and subjectively more pleasing fashion. In particular, we are interested in determining guidance mechanisms that best facilitate task performance and arouse a natural sense of collaboration. We suggest that a haptic guidance system can be further improved if it is supplemented with a role exchange mechanism, which allows the computer to adjust the forces it applies to the user in response to his/her actions. Recent work on collaboration and role exchange presented new perspectives on defining roles and interaction. However existing approaches mainly focus on relatively basic environments where the state of the system can be defined with a few parameters. We designed and implemented a complex and highly dynamic multimodal game for testing our interaction model. Since the state space of our application is complex, role exchange needs to be implemented carefully. We defined a novel negotiation process, which facilitates dynamic communication between the user and the computer, and realizes the exchange of roles using a three-state finite state machine. Our preliminary results indicate that even though the negotiation and role exchange mechanism we adopted does not improve performance in every evaluation criteria, it introduces a more personal and human-like interaction model.

Index Terms: Human Factors; Evaluation/Methodology; Haptic I/O; Haptic User Interfaces; Haptic Guidance; Dynamic Systems and Control; Multimodal Systems; Virtual Environment Modeling; Human-computer interaction; Collaboration

1 Introduction

Although there has been substantial research in human-robot interaction in virtual environments as a research topic, little effort has been put into haptic guidance systems for collaborative tasks. By providing the user with appropriate feedback, haptics can improve task performance [8]. For many tasks, human-computer interaction requires collaboration, for which the user and the computer take on complementary and/or supportive roles. In this work, we adopt the collaboration definition given by Green et al.[5]: "working jointly with others or together especially in an intellectual endeavor". Such a collaboration scheme offers an exciting new way of interaction, in which computers can infer people's intentions and communicate with different people in different ways. It is worth noting that the utility of a collaborative system cannot be evaluated merely in terms of performance and efficiency, but one should also take into account the quality of the interaction such as how much interaction can be realized and how comfortable and favorable the interaction is. This work is a preliminary study that investigates the benefits of guidance with collaborative role exchange mechanisms over simple guidance methods. Recent studies on collaborative dyadic interaction displayed the need to define certain roles for the partners [9, 13, 2]. However, defining the roles for a guidance scheme by examining human-human communication and replicating this interaction by replacing one of the dyads by the computer as a mean of providing guidance proves to be nontrivial especially as the task gets more complicated. In order to offer a comfortable experience in a dynamic complex environment, a sophisticated model is required. Collaboration is more than two partners working together. It requires defining a shared goal and in order to achieve this goal, two partners should create an agreement upon their courses of actions. Such an agreement is only achievable through negotiation. Our system employs a novel negotiation mechanism that realizes role exchange between a human and a computer partner using a three-state finite state machine. The primary advantage of the proposed scheme is that it creates a sense of togetherness while providing acceptable task performance. With this scheme, users can come up with different strategies and have the feeling of collaborating actively with another partner towards a common goal. Our initial findings suggest that using this scheme introduces a trade off between the accuracy in task performance and the effort of the user.

As a test bed application, we designed a multi-player haptic board game, where the user can share control with a computer partner. The user controls the position of a ball that can be moved on the board by tilting the board about two axes. The aim of the game is to hit randomly positioned targets in a specific order with the ball. The dynamic behavior of the game allows users to come up with different preferences. Some users felt comfortable in one of the axes and manipulated this axis more lightly and precisely than they did the other. Some regarded the order of the cylinders and moved very fast till they approached the target and then used the inertia of the ball to hit the target. These kinds of strategies requires the computer to provide guidance more *actively*. We designed a haptic guidance system in which the degree of computer's control can be varied independently in each axis during the performance of the task. In this system, the computer varies its level of participation in the task based on the actions of the user it collaborates with. We define certain roles for such a system where the user can either work collaboratively with the computer in equal terms or dominate the system. In other words, throughout the game, the computer and the user negotiate to take on control at varying levels. A role exchange occurs when the user's intention of gaining/releasing control is detected.

We designed an experiment to test the added benefit of our novel role exchange mechanism. In this experiment, we compare the performance of users in three conditions. In the first condition, the users play the game without guidance. In the second condition, guidance is provided, yet no negotiation takes place. Finally, the third condition implements our negotiation and role exchange

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mechanism. We quantify user performance and the utility of providing haptic guidance by measuring the task completion time, the deviation of the ball from the ideal path, integral of time and absolute magnitude of error (ITAE), and work done by the user. In addition, we evaluate the users' subjective self evaluation through a questionnaire.

In section 2, we briefly discuss related work on guidance in collaborative virtual environments and role determination in haptic communication. The architecture of the Haptic Board Game, certain guidance mechanisms that are provided to the users, and our negotiation model are presented in section 3, while the design of the experiment is discussed in section 4. Finally, the results of this study, which illustrate the potential benefits of negotiation and role exchange mechanisms in collaborative haptic guidance, and conclusions are presented in sections 5 and 6, respectively.

2 Background

The concept of haptic guidance is not new. In 1993, Rosenberg [10] came up with the concept of "virtual fixtures", which motivated many scientists to integrate haptics into human-computer interaction. A virtual fixture is defined as "abstract sensory information overlaid on top of reflected sensory feedback from a remote environment". Similar to a ruler guiding a pencil in line drawing, virtual fixtures are used to reduce mental processing and workload of certain sensory modalities as well as to improve precision and performance of the user beyond human capabilities. Virtual fixtures can help keep a task within a specific boundary using computer generated forces, and are often implemented using potential field and spring-damper systems. However, Forsyth and MacLean [4] report that these approaches can be problematic since the users' reactions towards the implemented guidance mechanism can cause oscillations within the system.

Several haptic guidance mechanisms are implemented to assist sensorimotor tasks, such as steering, calligraphy, and surgical training, and inclusion of haptics on top of existing modalities proved to be beneficial for training of such tasks. Recent work shows that haptics can be especially useful when combined with visual cues in teaching a sequence of forces [8]. Feygin at al. [3] conducted tests for spatio-temporal trajectory training and found out that the temporal aspects of the trajectory can be learned better with haptic guidance while visual training is more effective for learning the trajectory shape.

Although there have been some studies on haptic guidance and communication in shared virtual environments, only a few focused on defining roles for human-human and human-computer haptic collaboration. Sallnäs et al. [11] examined human-human collaboration for joint manipulation of a virtual object. They found out that haptic feedback significantly improves task performance and provides a better sense of presence in haptic collaboration. Basdogan et al. [1] proposed the haptic version of the "Turing Test" in their paper to better investigate the mechanisms of haptic interaction between two people in shared environments. They found out that haptic feedback provides a better sense of togetherness when compared to visual feedback.

Current systems involving computer guidance are generally implemented to let the human partner take on the leading role where the computer partner follows the human partner's actions [6, 7]. These prove to be beneficial in terms of task performance, yet are limited in providing a sense of collaboration since the computer is merely passive.

Reed and Peshkin [9] examine dyadic interaction to illustrate that partners specialize as accelerators and decelerators within a simple collaborative task. The specialization is said to be subconscious and occurs after several trials but improves performance. However applying the observed specialization scheme to the computer to collaborate with a human was not successful, probably due to a lack of careful examination of the negotiation process and how and why specialization occurs between dyads. Similarly, Stefanov et al. [13] propose execution and conductorship roles for haptic interaction. Specifically, the conductor decides what the system should do and expresses this intention via haptic signals, while the executor performs the actions as determined by the conductor. The conductor is assumed to express its intention by applying larger forces to the system. They suggest that by looking at the sign of the velocity and the interaction force, it is possible to determine which partner executes the task and propose a neat model for role exchange. They examine the phases of interaction that lead to different role distributions using a ternary logic, since each partner can take on one, both or none of the conductor or executor roles. This work presents important observations regarding communication for role exchange, yet employs no information on how this scheme can be used for human-computer interaction. Evrard et al. [2] similarly define leader and follower roles between which the partners continuously switch. In order to describe physical collaborative interaction, they use two distinct homotopy time functions that vary independently. Each partner can claim/give up leadership using these functions. For testing their model, they designed a symmetric dyadic task where a human interacts with a computer partner through an object. Despite the deficiencies in experimental design, they illustrate the potential use of homotopy functions in modeling different interaction behaviors. However unlike our approach, they have not implemented a user-centric and dynamic negotiation mechanism to handle the interaction between a human and a computer.

3 Haptic Board Game

In this section, we describe the Haptic Board Game application as well as the guidance and the role exchange mechanisms we developed. For comparison, we tested the system under three conditions, namely no guidance, guidance without negotiation, and role exchange with negotiation. In the remainder of this chapter, we explain the general design approach we adopted and the application model used in implementing the conditions.

3.1 Design Approach and Choice of Application

We implemented an interactive game in a virtual environment in order to investigate how collaboration is achieved in dynamic environments and also to model and improve human-computer interaction. This game will be called the Haptic Board Game in the rest of this paper. Especially in dynamic, virtual, and shared worlds; it is not easy to program computers for providing generic assistance in interaction with the users. The Haptic Board Game involves controlling the position of a ball on a flat board to reach arbitrarily positioned targets with the help of a haptic device. The visual representation is reflected to the user as if the ball is moving by tilting the board about the x and z axes. The goal of the game is to hit 8 randomly placed cylinders with the ball in a specific order . At the beginning of a game, all the cylinders but the target are gray, and the target cylinder is highlighted with blue. When a user hits the target, its color turns red and the new target turns blue so that users can easily keep track of the current target, as well as the previous ones throughout the game (See Figure 1).

Our goal is to come up with a collaboration mechanism that can improve users' performance under this dynamic environment in terms of time, accuracy, and/or work done by the user; and also make them feel as if they are working with an intelligent entity. To achieve this, a force negotiation mechanism is developed, where each party can express his intentions and sense the other's. Since we are concerned with human-computer interaction, the computer should sense the user's intentions and act accordingly. Hence, we needed a model that provides more than simple automated com-

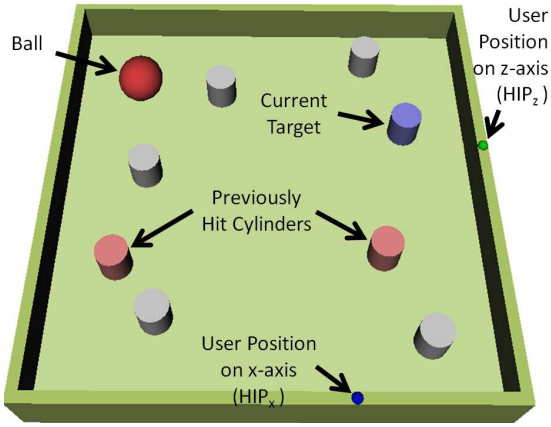

Figure 1: A screenshot of the Haptic Board Game. Red ball and randomly positioned eight cylindrical targets can be seen. The little half-spheres on the boundaries represent user controlled haptic device's position in x-z plane. The haptic device's current position, in x and z axes referenced within the game frame, are indicated respectively by the blue and the green half-spheres.

puter guidance, and that can express intelligent reactions. Before conducting preliminary experiments, we implemented several models on how one should control the board and/or the ball. One of our initial designs included a system where the board was heavier and the ball's mass was negligible, letting the user feel the forces created by the inertia of the board. As another design, we modeled the board lighter and the ball heavier so that the user could feel the forces created by the ball's inertia more clearly. Yet, neither of these models, alone, met our expectations of creating a highly dynamic environment that can be realized by the user through both the visual and the haptic channels. Finally, we came up with a physical model (see Figure 2) that is more interaction oriented. More precisely, with this model users could feel not only the forces generated by the inertial movements of objects, but also those generated due to the haptic negotiation process with the controller. Moreover, the developed model provided us with a dynamic environment to test our hypotheses. Different parameter sets providing various guidance and collaboration mechanisms, were also investigated to optimize the system. The details of this model will be explained later on this section.

While experimenting on the choice of the system model, three conditions were tested on each design:

Both Axes Guidance (BG): Both the user and the computer have control on both axes, and each affects the system equally. Both axes guidance is implemented with a classical PD (Proportional-Derivative) control algorithm. The controller adjusts the orientation of the board such that the ball automatically moves towards the target. The user feels the forces applied to the ball by the controller and the resistive spring-like forces due to his/her actions. The user can affect the behavior of the ball, while the computer guidance is given regardless of the user's interventions.

Role Exchange (RE): The computer negotiates with the user, based on the user's force profile, to decide on how they should share control. The magnitude of computer control can be either equal to that of the user's or smaller. When partners share control equally, this condition becomes identical to both axes guidance. On the other hand, when the computer control switches to a rather loose level, the computer's forces are reduced, hence the user becomes *dominant* on controlling the ball while the computer becomes the *recessive* partner. In between these states, computer's control is blended from equal control to looser control or vice versa.

No Guidance (NG): The user feels spring-like resistive forces due to the rotation of the board, but no haptic guidance is given to control the ball position on the board.

3.2 Physical Model and Conditions

Considering our hypotheses and observations, we devised a novel negotiation model for role exchange and compared it to one of the classical control methods, namely PD control, implemented as both axes guidance (BG) condition in our experiments. Additionally in the role exchange (RE) condition, the degree of provided guidance is adjusted dynamically via a role exchange policy. In our role exchange policy, we model the force negotiation between the user and the computer using a simple mass-spring-damper system. In this system, the ball is controlled by three virtual control points as shown in Figure 2: Haptic interface point (HIP), controller interface point (CIP), and negotiated interface point (NIP) which are all regarded as massless particles. HIP, CIP and the ball are interconnected at NIP, which is the only element that interacts directly with the ball.

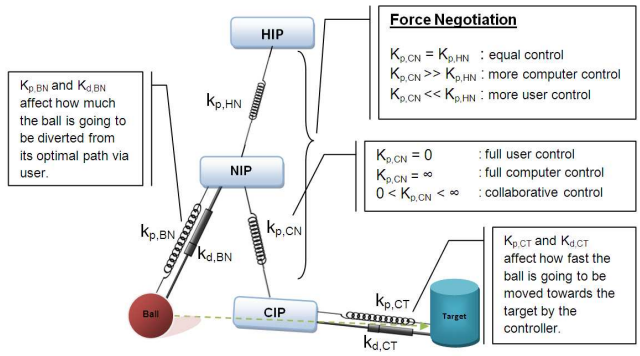

Figure 2: The physical model for role exchange and both axes guidance conditions. K_p and K_d values in the figure represent the spring and damper coefficients.

3.2.1 Both Axes Guidance

For both axes guidance, the system is basically controlled by haptic and controller interface points. The flow diagram of the physical model of the game is shown in Figure 3. Users control the haptic interface point by a PHANToM Omni (SensAble Technologies Inc.) haptic device, whereas controller interface point is controlled by the PD control algorithm. When guidance is provided, at any given time, the controller computes an optimal force (F_c in Figure 3) as if to control the ball. However, rather than applying this force directly to the ball, it is applied to the system through controller interface point; so that controller interface point moves towards the target and pulls the ball to itself. Hence, in the lack of user interference, the controller can easily control the ball, and play the game smoothly. The user participated in the task by controlling haptic interface point in order to move the ball. The user applies a force to the system through haptic interface point. Based on the new positions of haptic and controller interface points, the position of negotiated interface point can be calculated to put the system into equilibrium. The forces that act on negotiated interface point, due to controller's and the user's interventions, are F_{CIP} and F_{HIP}, respectively (see Figure 3). Negotiated interface point can be thought as the position of the ball agreed by both parties. Also, the ball also applies a force, F_{ball}, on negotiated interface point, due to the spring-damper system modeled between negotiated interface point and itself. Therefore, the new equilibrium position of negotiated interface point, for the next time step ($t + \Delta t$), is calculated according

to the net forces acting on it. The force that would act on the ball, F_{ball}, is determined by the position of the ball and the new position of negotiated interface point. As illustrated in Figure 3, the board is oriented in order to provide the needed force, F_{ball}, to be applied on the ball. Then, the ball's new state can be calculated based on the orientation of the board, by Euler integration. Finally, the force, ($-F_{HIP}$ in Figure 3), created by the spring system between negotiated and haptic interface points is fed back to the user. Hence, by this physical interaction flow, the dynamic nature of the Haptic Board Game is reflected to the user through both the visual and the haptic channels.

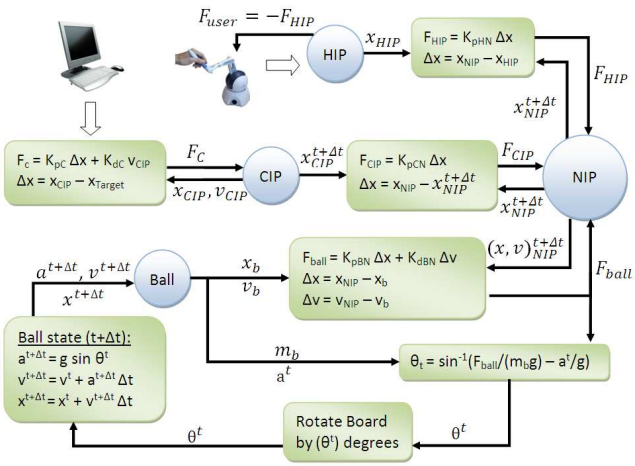

Figure 3: The flow of interactions within the Haptic Board Game's physical model. x, v, and a represent position, velocity, and acceleration of the *ball*, respectively. g is the gravitational acceleration, whereas θ is the orientation angle of the board.

3.2.2 Role Exchange

The interaction points and the physical model of interaction for role exchange is identical to those of both axes guidance condition. However, role exchange takes a step further by dynamically changing the role of the controller, i.e. the degree of control it provides. The system is designed to allow haptic negotiation between partners by sensing the user's intentions. For this purpose, the user's average forces and the standard deviation of the forces on each axis are calculated under no guidance condition at the beginning of the experiments (see Section 4 for details). Then, lower and upper force threshold values are calculated for each axis using the average force and standard deviation of the user playing the game.

It is assumed that role exchange occurs whenever the magnitude of the force that the user applies is above the upper threshold or below the lower threshold values for over a predetermined amount of time. This amount is fixed as 500 milliseconds in our implementation. In order to realize a smooth transition during role exchange, we defined a finite state machine with three states as shown in Figure 4. Initially the system is in the *user dominant* state, in which the user is mainly in control of the game, while the controller gently assists him. If the force applied by the user stays below the calculated lower threshold value for 90% of the last 500 milliseconds, then the controller assumes that the user requires more assistance. Thus, role exchange occurs in favor of the computer and the system enters *role blending* state in which the computer gradually takes control until its level of control reaches that of the user's. The system stays in the *role blending* state for a period of 1000 milliseconds. After this period, the system enters the *equal control* state, where the system acts identically as in both axes guidance condition. Clearly, another state transition may occur from the *equal control* state to the *role blending* state, if the controller realizes that the user wants to take over control. Then, the same procedure applies but in the opposite direction where the computer releases control and the user becomes the dominant actor of the system.

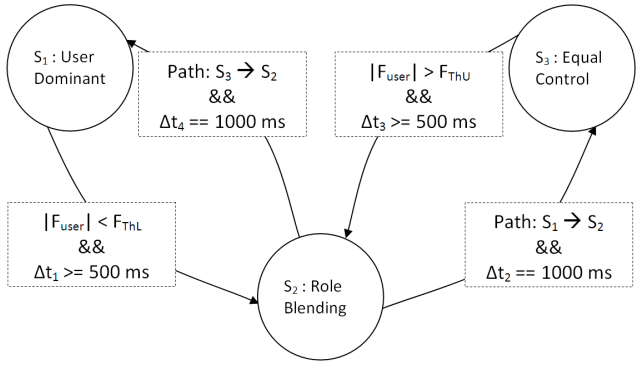

Figure 4: The state diagram defining the role exchange policy. F_{user} is the force that the user applies. F_{ThL} and F_{ThU} are the lower and upper threshold values, respectively, for determining the state transitions. S_1*: User dominant* state indicates user is the dominant actor, and S_3*: Equal control* state indicates both computer and user have equal degree of control on the system. Finally, S_2*: Role blending* state indicates a role exchange blending phase is taking place where controller's role is shifted between *user dominant* and *equal control* states.

As stated earlier, in both axes guidance condition, the computer shares control with the user throughout the game to help the user complete the task by providing guidance in *both* axes of the board, based on the position and direction of the ball. However, in our preliminary studies, one of the observations was that the force profiles of users on each axis did not show similar patterns. For instance, a user could have preferred to be attentive in one axis and aligned the ball on that axis first, then she/he switched her/his attention and tried to control the ball on the other axis. Hence, we concluded that the users did not pay attention to both axes equally at the same time. This may be due to the random positioning of the target cylinders, i.e. some consecutive targets were positioned diagonally, whereas some were in parallel to each other on one axis. Another possible reason can be that the users might not feel comfortable controlling the ball diagonally and prefer a sequential control on axes. Hence, we extended our role exchange method by allowing state transitions to occur on each axis separately. In other words, computer can give full guidance on one axis whereas it just remains *recessive* on the other and let the user remain the *dominant* actor on that axis. An example of this state transitions can be seen in Figure 5. For example, at the fifth second , a transition occurs from *user dominant* state to *role blending* state for the x-axis, i.e the controller starts to get more control on the x-axis. Around one-half of a second later, another state transition occurs from *user dominant* state to *role blending* state again, but on z-axis. Spending one second on *role blending* state, another transition from *role blending* to the *equal control* state takes place, first for x-axis then for z-axis. At around sixth second of playing, controller becomes as effective as the user for controlling the ball, hence the condition becomes identical to both axes guidance. By allowing role exchange on each axis separately, this condition becomes more adaptive to differences between users' playing styles. Finally, the user feels a spring-like force that is generated due to the positions of haptic and negotiated interface points, like in the both axes guidance condition. Notice that users can feel the controller's applied forces, as well as the transitions that it makes, through negotiated interface point. For example, assume the controller is in *equal control* state, so that the negotiated interface point lies just in the middle of controller and haptic interface points if they do not happen to coincide on the same position

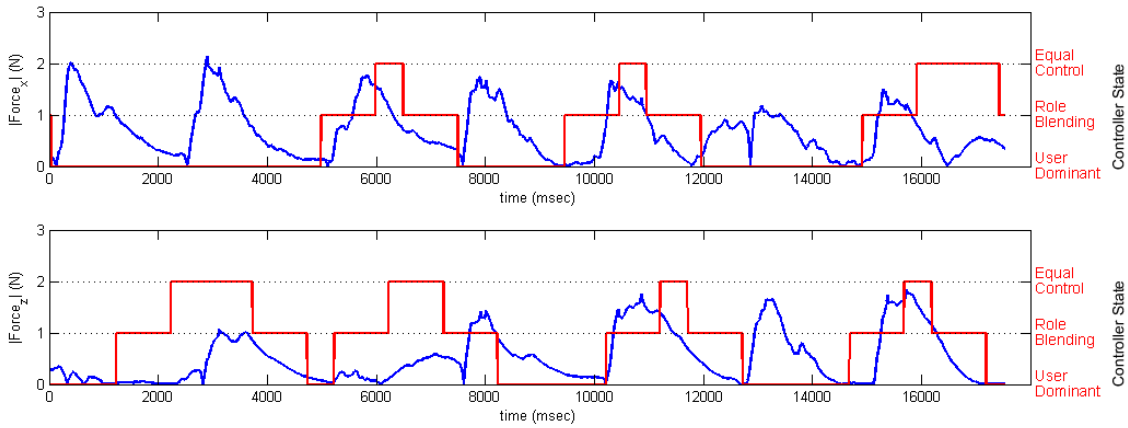

Figure 5: A cross-section of a user's force values (in blue lines) in each axis throughout a single game with role exchange. The state of the controller, which shows the current role of the controller (in red bold lines) in the related axis, is represented as a square waveform. The role is determined by the state variable indicated on right hand side y-axis. The upper and lower plots represent the information in x and z axes respectively.

(the inertial forces of the ball is neglected for the sake of simplifying the example). Hence, the user feels a conflicting force. If the user and the controller have discordant preferences, this conflicting situation continues, which eventually enforces the controller to enter the *role blending*, and then the *user dominant* states. Since the controller loosens its control, the negotiated interface point starts to be pulled by haptic interface point stronger. As negotiated interface point moves closer to haptic interface point, the force that is fed to the user decreases, alleviating the conflicting situation. Moreover, due to the blending phase between *user dominant* and *equal control* states, users may feel a smooth transition, so that they do not get distracted by the role transitions of the controller.

3.2.3 No Guidance

Finally, as the base case, we implemented the Haptic Board Game with no guidance. In this condition, controller interface point basically coincides with negotiated interface point and is never disconnected from it. Therefore, only haptic interface point affects negotiated interface point, which in turn pulls the ball towards itself. In other words, the model in Figure 3 does not produce F_{CIP}, but the remaining forces continue acting on the system. As a result, the user feels $-F_{HIP}$ due to the spring system between haptic and negotiated interface points.

4 Experiment

4.1 Objectives and Approach

We sought an indication of the effectiveness and acceptability of a negotiated haptic interaction method, as modeled by the role exchange condition, relative to the classical PD controller based guidance and to no guidance at all, for performing dynamic tasks. The main hypotheses that we aimed to test were:

H1 Role exchange has measurable benefits over other conditions.

H2 Users will subjectively prefer role exchange over other conditions.

4.2 Experiment

10 subjects (5 female, and 5 male) participated in our study[1]. In order to eliminate learning effects on successive trials, the order of experimental conditions was mixed, with at least three days between two successive experiments.

Since none of our users were familiar with a haptic device, we introduced the haptic device to each user verbally and through the use of certain training applications irrelevant to the board game. Each user utilized these applications for about 15 minutes until they felt comfortable with the haptic device. An experiment took about half an hour, and in each experiment the users played with either no guidance, both axes guidance, or guidance with role exchange. We paid attention to provide the same physical setting for all experiments, such as the positioning of the haptic device, the computer, and the users' seats. Subjects were instructed to grasp the stylus in the most effective and comfortable way possible. During the experiments, the full system state (i.e. positions of HIP, CIP, NIP, and ball; all the individual forces of each spring/spring-damper system, etc.) was recorded at 1 kHz.

In the no guidance and both axes guidance conditions, each user played the haptic board game 15 times for a single experiment. As explained earlier in Section 3, a single game consists of hitting the ball to eight randomly placed cylinders in a specific order, by controlling the ball. When a single game finishes, all the cylinders turn gray again, and the game restarts without interrupting the system's simulation. To avoid possible fatigue, users took a break after the 5th and the 10th games. For the role exchange condition, the users played an additional game at the beginning of each block of 5 games for the purpose of determining the thresholds, so a total of 18 games were played by each user. During these extra games, users played with no guidance. In order to create the user's force profile, the average and the standard deviation of the user's forces were calculated during these first games, so that the lower and upper threshold values could be determined for the next 5 games.

4.3 Metrics

4.3.1 Subjective Evaluation Metrics

After each experiment, the users were given a questionnaire. Users did not know about the different conditions we were testing, nor did they know whether they took these experiments with different conditions or not.

For the questionnaire design, we adopted the technique that Slater et al. used previously in shared visual environments [12]. A total of 18 questions were answered by the subjects. Eight of the questions were about personal information, one was reserved for users' feedback and the remaining nine were about variables directly related to our investigation. Some of the questions were

[1]After an initial analysis, we found that one subject did not report any sensation of computer control in the questionnaire, therefore the remaining questions, which were about the nature of computer control, were rendered inapplicable. Hence, we excluded his responses from further analysis, and analyzed the remaining 9 users for all conditions.

paraphrased, and asked again, but scattered randomly in the questionnaire. For evaluation, the averages of these questions, that fall into the same category, were calculated. Questions were asked in five categories:

1. *Performance:* Each user was asked to assess his performance by rating himself on a 5-point Likert scale.

2. *Human-likeness:* We asked the subjects whether the control felt through the device, if any, was humanlike or not. Two questions using a 7-point Likert scale were included within the questionnaire.

3. *Collaboration:* We asked the subjects whether they had a sense of collaborating with the computer or not. Two questions with different wordings were asked within the questionnaire. Two more questions were asked to determine whether the control made it harder for the subjects to complete the task or not. Answers to these 4 questions were evaluated using a 7-point Likert scale.

4. *Degree of User Control:* We asked the subjects about their experience during the experiment, specifically the perceived degree of their control on the task. There was a single question, which used a 7-point Likert scale for the answer.

5. *Degree of Computer Control:* We asked the subjects about the perceived degree of computer's control on the task. There was a single question, which used a 7-point Likert scale for the answer.

4.3.2 Objective Performance Metrics

User performance can be quantified in terms of task completion time, total path length during the game, deviation of the ball from the ideal path and integral of time and absolute magnitude of error (ITAE).

For the board game, we defined the ideal path between two targets to be the straight line segment connecting the centers of the targets. Hence, between two targets, the deviation is defined to be the area of the region formed by the ideal path between those targets and the actual path of the ball. Total deviation in a single game is calculated by summing the deviations between consecutive targets throughout the course of the game.

ITAE criterion is defined as:

$$ITAE = \sum_{i=1}^{7} \left(\int_{t=T_i}^{T_{i+1}} t\,|e(t)|\,dt \right).$$

Note that we calculate ITAE for consecutive target pairs and sum these to get the ITAE of a game. Here, time T_i is taken as the moment when the ball reaches i^{th} target. Error $e(t)$ is the length of the shortest line segment connecting the ideal path and the ball's actual position at time t during the game. The ITAE criterion has the advantage of penalizing the errors that are made later. In other words, we choose to punish the users more severely if they deviate from the path when the ball gets close to hitting the target.

We also examined work done by the user due to the spring located between NIP and HIP. This spring acts as the bridge between the system and the haptic device and any force exerted by it is sent indirectly to the user. Hence we assume that this force is the force felt by the user. Let T be the completion time of the game, k be the stiffness constant of the spring, and $x(t)$ be the extension of the spring at time t. Then the work done by the spring is basically:

$$W = \int_{t=0}^{T} \frac{1}{2} k\, x(t)^2.$$

5 Results

5.1 Subjective Evaluation Results

For each of the three conditions, the questionnaire was designed to measure the self-perception of users' performance, the human-likeness and the collaborative aspects of the system, as well as the degree to which the users felt they or the computer were in control.

For the level of perceived collaboration, the subjective evaluation results implied a higher sense of collaboration for the role exchange and both axes guidance conditions ($p < 0.01$) compared to the no guidance condition. There was no significant difference between the level of perceived collaboration in both axes guidance and role exchange conditions (see Figure 6).

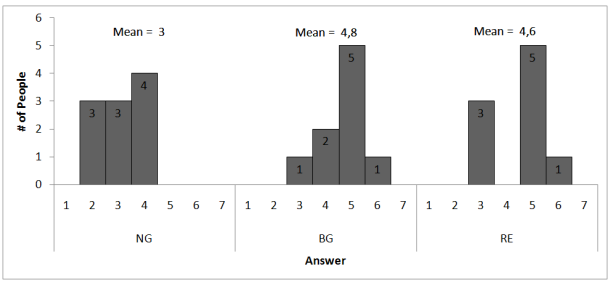

Figure 6: Responses to questions regarding how much the subjects felt collaboration for each condition.

Regarding the subjective evaluation of user performances, subjects believed that they performed better on both axes guidance and role exchange compared to the no guidance condition. The differences were statistically significant for both axes guidance and role exchange when compared to the no guidance condition with the *p-value*s of 0.005 and 0.02, respectively. Again, there is no significant difference between the both axes guidance and role exchange cases (see Figure 7). Subjects claimed that they had similar level of control throughout the game in all three conditions. On the other hand, they also felt no difference between the level of computer control on different conditions. However, regarding the averages of the answers to the control questions, we observed that the subjects' feeling of being in control and their perception of computer's involvement get closer to each other in role exchange condition, as illustrated in Figure 8. Even though the subjects perceived reduced control over the game, they had a stronger sense of computer participation. This may also be a sign of subjects' increased perception of collaboration in the role exchange condition.

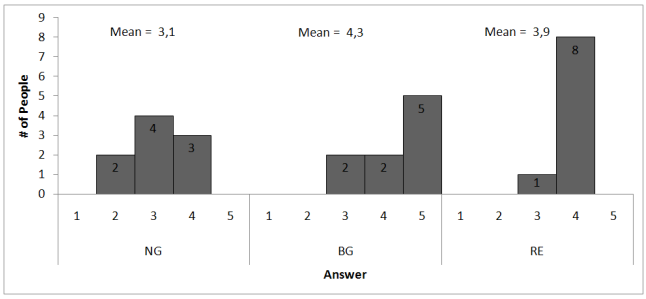

Figure 7: Responses to questions regarding subjects' self evaluation of how well they performed in each condition.

Finally, regarding the humanlikeness question, subjects did not think there was a significant difference between both axes guidance and role exchange conditions. On the other hand, subjects felt that role exchange condition's negotiation strategy was more humanlike ($p\text{-}value = 0.02$) compared to no guidance condition (see Figure 9).

Our negotiation model allows role exchange and provides the controller with the ability to take over/release the control of the game.

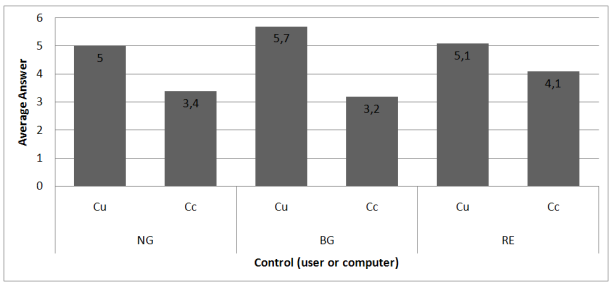

Figure 8: Average responses to questions regarding how much the subjects felt in control, and how much they felt the computer was in control for each condition. *Cu* and *Cc* represent control of user, and control of computer, respectively.

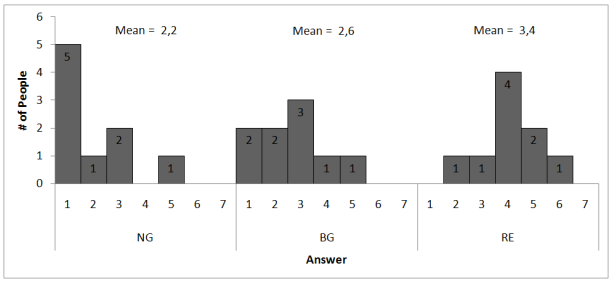

Figure 9: Responses to questions regarding how much the subjects felt humanlike response for each condition.

5.2 Quantitative Measurements

We computed the average computation times, total path lengths, deviations from the ideal path, and ITAEs of each condition. Upon closer inspection, we observed that performance is the worst when no guidance is given, and the best when guidance without any negotiation, while guidance with the role exchange mechanism falls in between the two. We applied paired t-tests, with *p-value* set to 0.05, to test the difference between the conditions. According to paired t-test results all three conditions display significant difference from each other. As seen in Figure 10, for all these parameters, the paired differences of conditions follow a similar trend. Clearly, the largest difference is between the no guidance and both axes guidance conditions. We also observe that the role exchange and both axes guidance conditions are the closest conditions regarding the paired differences.

Figure 11 illustrates the average energy on the spring, which is a measure of the work done by the user. Even though in the no guidance and role exchange conditions, the completion time and path errors were higher compared to the both axes guidance condition, the users spent less energy in these conditions. The paired t-test results on the average work done by the user did not indicate significant difference between the no guidance and role exchange conditions, whereas both are statistically different from the both axes guidance condition. As the results above show, both axes guidance has higher energy requirements, while no guidance has inferior completion time and spatial error properties. The role exchange mechanism allows us to trade off accuracy for energy without causing user dissatisfaction.

We also examined the role exchange trends of users. As seen in Figures 12 and 13, the results show that the average number of transitions as well as the average time the controller stays at a given state varies from user to user. This is a sign of the existence of user

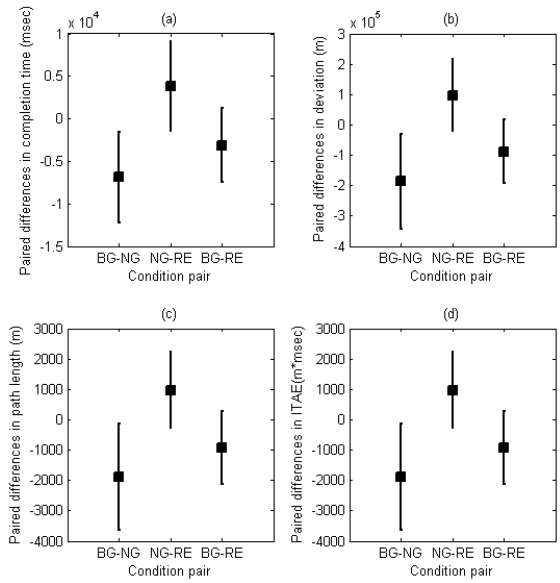

Figure 10: Means and standard deviations of paired differences of (a) computation times, (b) path deviations, (c) path lengths, and (d) ITAEs per condition (NG: no guidance, BG: guidance without negotiation, RE: guidance with negotiation and role exchange)

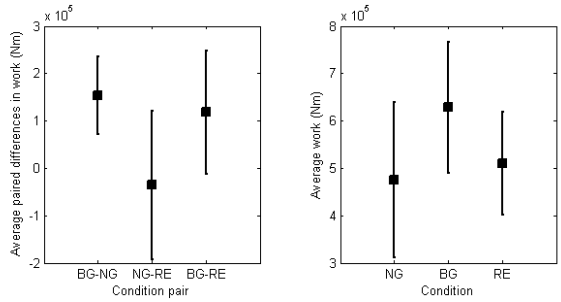

Figure 11: Means and standard deviations of energy on the spring between NIP and HIP per condition and paired differences of energy (NG: no guidance, BG: guidance without negotiation, RE: guidance with negotiation and role exchange)

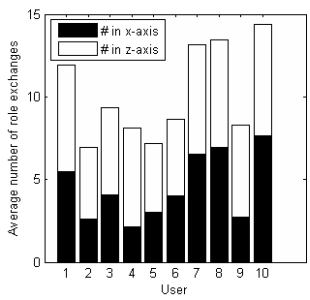

Figure 12: Average number of role exchanges of each user over 15 games. Each user ends up with a different number of role exchanges, indicating that they adopt certain strategies during the course of the game.

preferences during game play. Even though subjective evaluations suggest that the development of these preferences is subconscious, this is a strong indication that our role exchange mechanism provides a more personal experience compared to classical guidance mechanisms.

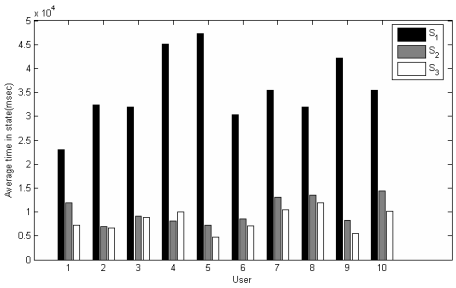

Figure 13: Average time spent by users in each controller state. S1, S2, and S3 represent *user dominant*, *role blending*, and *equal control* states respectively, as depicted in Figure 4

6 Conclusion

In this paper, we developed a model for haptic negotiation and role exchange between a human user and a computer in a collaborative task. Our model works in a highly dynamic setting and aims to realize collaboration naturally and without disturbing the user. The nature of our task forced us to build a sophisticated dynamic negotiation mechanism between the user and the computer. Furthermore, we defined the role exchange mechanism using a finite state machine that allowed us to realize fluid interaction. As the results imply, with our role exchange mechanism, the users are presented with an option to choose and optimize between accuracy and energy.

7 Future Work

In the current experimental setting, we did not inform the users about the mechanisms that were tested. Hence the users were not made aware of the existence of the states of the role exchange mechanism. As future work, we intend to extend this experiment to let users play the game with a priori knowledge about the existence of the different conditions, so that we can better evaluate our collaboration scheme.

The current system implements a specific negotiation and role exchange mechanism. We'd like to use the Haptic Board Game application as a test bed for developing and testing alternative negotiation and role exchange methods. For example, we'd like to explore the potential use of sophisticated machine learning based methods for detecting user intent for initiating negotiation. Likewise, we'd like to study how the use of accompanying multimodal displays would effect the dynamics of role exchange and negotiation.

We would also like to carry out further experiments tailored to measure aspects of the interaction that we haven't studied yet. For example, teasing out the precise cause of the perceived humanlikeness is a nontrivial task that we haven't addressed here.

Acknowledgements

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