Developing Dance Interaction between QRIO and Toddlers in a Classroom Environment: Plans for the First Steps

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***Abstract*— This paper introduces the early stages of a study designed to understand the development of dance interactions between QRIO and toddlers in a classroom environment. The study is part of a project to explore the potential use of interactive robots as instructional tools in education. After 3 months observation period, we are starting the experiment. The experimental environment, component technologies, and plans for evaluating interaction are described.**

***Index Terms*— humanoid robot, QRIO, the RUBI project, toddlers, long-term interaction, engaging interaction, interactive dance, contingency detection**

I. Introduction

A. Background

This paper documents the early stages of an ongoing study designed to understand the interaction dynamics that develop between children and robots. The study is part of the RUBI project [1] whose goal is to explore the use of interactive robot technologies in education environments. An important part of being an effective teacher is to be engaging, interactive, and to develop positive personal relationships with the pupils. Thus, one of our targets of interest in the project is to investigate the dynamics of the interactions developed between children and robots at multiple time scales and to gain clues about how such dynamics could be improved and how they could be used for education.

One of our motivations for focusing on toddlers is due to the limitation of current verbal language processing technologies. Verbal communication plays an important role in human interaction, but current technologies such as speech recognition and natural language processing are not good enough to sustain engaging interaction for significant periods of time. On the other hand, toddlers even younger than 2 years old are capable of interacting with others, communicating with each other though their abilities for handling explicit verbal language have not yet matured.

B. Our Approach

We recognize that pursuing long-term engaging interaction can be interpreted widely, and also setting a specific goal a priori is difficult. Therefore, we will try more direct, goal-oriented approach which is based on a philosophy of conducting a trial and error study in a non-laboratory environment for a long time period by repeating improvement based on earlier observations. It is important that the observations are made on a daily basis in the toddlers' classroom environment.

In this paper, we introduce a project attempting to tackle this problem by using a small humanoid robot, QRIO, at the Early Childhood Education Center (ECEC) at the University of California, San Diego. We expect that QRIO's excellent motion abilities and its "toddler-like" appearance will be ideal for this study. QRIO will be introduced as part of the daily activities of the toddlers, focusing on periods previously assigned to music playing or dancing. Our first trial will be in Room-1 at ECEC where toddlers, 10-24 month olds are participating. It is important that toddlers' primary communication or interaction is not verbal, and physical activities are dominant, which is proper for QRIO. We are planning to test various technologies in dance interaction between toddlers and QRIO, from non-autonomous choreographed dance to autonomous one. As the autonomous dance technologies, in this paper we will explain two opposing ideas: One is for the passive mode where QRIO reacts to the outside motion segmented by disparity information. This mode provides a type of motion imitation with his partner. The other is for the active mode where QRIO spontaneously moves to maximize the information for the presence of a reactive partner, which is realized by an active contingency detection algorithm [3].

This method can also be implemented with the function of emotion expression of QRIO.

The structure of this paper is as follows: In the next Section II, we will briefly introduce a humanoid robot platform, QRIO. Section III will explain the RUBI project and our experimental environment, the Early Childhood Education Center (ECEC). Section IV will describe our experimental plan with the technologies of QRIO for it, followed by explaining a tool for evaluating interaction, and finally, Section V is a summary of this paper.

II. QRIO: A Small Biped Entertainment Robot

QRIO (Fig. 1) is a small humanoid robot which has been developed by Sony for years [4]–[6]. It is a stand-alone autonomous robot with three CPUs: the first one is used for audio recognition and text-to-speech synthesis, the second one is for visual recognition, short and long term memory, and behavior control architecture, and finally the third one is used for motion controls. In addition to these, remote PCs can be exploited as remote-brains by using its embedded wireless-LAN system. In our laboratory in Tokyo (Sony Intelligence Dynamics Laboratories, Inc.), a PC-cluster system called IDEA which has 352 CPUs (Opteron 248) and a calculation spec of more than 1 Tflops is utilized for real-time operations.

After years of research and developmental efforts, QRIO's ability spreads over very wide range: walking, running, jumping, playing soccer, throwing a ball, swinging a putter, singing songs, recognizing humans by vision and audio, making a conversation (dialogue) in many ways, learning, imitating human motions, etc [4]–[6]. One of the most powerful abilities of QRIO is in its motion generation such as dancing. QRIO is endowed with various choreographed dance sequences, and also is capable of mimicking the motion of its partner in real-time [7]. Another important point for us is its size which is smaller than toddlers (10-24 months). We will try to introduce QRIO to toddlers not as a naive toy but as a peer, for we believe the capacity of robots to form peer-to-peer relationships is what makes it particularly unique as a new teaching tool.

Fig. 1. Sony Entertainment Robot 'QRIO' (QRIO is a test prototype.)

III. At Early Childhood Education Center

A. The RUBI project [1]

The research project presented in this paper is part of the RUBI project at the University of California, San Diego [1]. This project is based on the idea that little is known about real-time Human-Robot interaction in everyday environments over extended periods of time (longer than one month). Such knowledge is critical for developing a new generation of robots capable of interacting with human in everyday life and assisting them in their daily activities. Reference [8] is also a pioneering study conducting experiments related to Human-Robot interaction for extended periods of time. The subject in this study is autistic children. Reference [9] reported an experiment in a daily elementary school environment. This research gave an example of introducing a robot into a society, but its function was fixed for the experimental period 18 days. The result is based on the first saturation with no measure of prolonged exposure. In contrast to this, we are not concerned with the quality of only the initial interaction itself. Furthermore our focus is on toddlers and non-verbal interaction.

Through the project, we will explore the benefits of two different robotic platforms, RUBI and QRIO. RUBI is more like a computer kiosk with a touch screen that can be used to present different stimuli. It is currently under development aiming for both a robotic platform for research on real-time social interaction and educational computers to help children practice basic cognitive and social skills. Regarding RUBI, please refer to [1], [2] for more details.

B. Early Childhood Education Center (ECEC)

For 6 months RUBI and QRIO will be interacting with toddlers at the Early Childhood Education Center (ECEC) at the University of California, San Diego for at least one hour day by day. We decided that it is important for the researchers to become part of the environment, rather than observing from a distance. For this reason the researchers spent 3 months volunteering 10 hours a week with the toddlers at ECEC. This allowed us to establish personal relationships with the teachers, parents and children. It also allowed us to identify target situations for robots to be helpful in a classroom environment.

One finding for us through the observation period was the power of music and dance. Toddlers will listen to music and dance for a longer duration than typical toys or games. Teachers also utilize music skillfully in daily activities (e.g. playing slower, relaxing music to prepare the toddlers for sleep time). The time when they play music in a room and toddlers move actively is considered to be one of the best timing for QRIO to be introduced.

Fig. 2. Dance time in Room-1: QRIO is dancing autonomously using the technology presented in Section IV-A.

IV. Experimental Plan with QRIO

We are currently investigating two robot platforms RUBI and QRIO. While RUBI plays the role of an adult teacher, QRIO plays the role of a peer. As such our focus on QRIO is on the development of positive interactions and on investigating whether they could be used as teaching tools. The difficulty is that it is not easy to set a specific experimental purpose from the beginning. Therefore, it is important that our experimental plan is flexible and can be modified when new observations are made. After much consideration, we decided to fix only a frame for daily experiments, and incorporate flexibility within it. In this section, we will explain this experimental frame with QRIO.

In the daily activities of Room-1, there is a time when teachers play music CDs to encourage toddlers to move (dance) and exercise freely (Fig. 2). They like this time and start dancing as soon as the music is turned on. During this time, we try to let QRIO join them for 30-60 minutes a day. The reason why we chose the dance and music period is as follows: Firstly, as we described in Section I, our central interest is on non-verbal interaction, which happens quite naturally during the period. Secondly, toddlers can be more relaxed at the time than others, which is appropriate for observing their interaction.

All experiments will be conducted with one teacher person, and a person in charge of insuring the toddler's safety. There are multiple cameras, carefully placed to view the entire room. The videos will be used for an evaluation phase in which we plan to adopt both subjective and objective ways: The subjective method will be done (ex.) by a continuous dial technique where labelers subjectively rate the levels that toddlers are "engaged" or "bored" to QRIO. The objective method will be done (ex.) by counting the number of interaction, namely eye contact, touch, utterance, and so on.

Next, we explain the behavior components of QRIO which are planned to be tested at the first trial.

A. *Interactive Dance with Visual Feedback [7]*

As we introduced in Section II, QRIO can dance in an interactive manner as well as non-interactive way (choreographed dance). This section explains the former dance.

Thanks to its FPGAs-embedded vision system, QRIO can obtain frame-difference and disparity (distance) information in real-time. By exploiting them a set of moving-regions clustered by each disparity can be obtained in each time (Fig. 3). QRIO can grasp its partner's rough shape and motion dynamics based on them. We developed an interactive dance application by connecting the obtained feature information such as the size, shape, and disparity of clusters into its motor control in multiple ways at the same time (Fig. 4).

Designing sympathetic interaction process should combine a number of entrainment-factors at the same time. An entrainment factor corresponds to any kind of a concrete paired relationship between a human and a robot. For example, if we design a robot that shakes his hands to correspond to the speed of a moving-region in its visual field, then this relationship is an entrainment factor. If we add another function to the robot, such as jumping in the rhythm of clapping, then there are two entrainment factors in this system. We consider designing multiple entrainment factors in an interaction system. Fig. 5 illustrates one interaction scene where there are four entrainment factors designed in it. We can see that one of them is inactive now; active

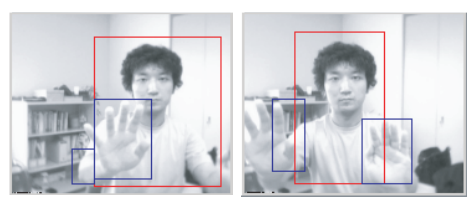


Fig. 3. A set of moving-regions obtained by QRIO's stereo cameras: They are clustered by disparity (distance) information.

Fig. 4. Interactive dance application with QRIO: It reacts to the partner human's movement so as to follow its global rhythm and shape.

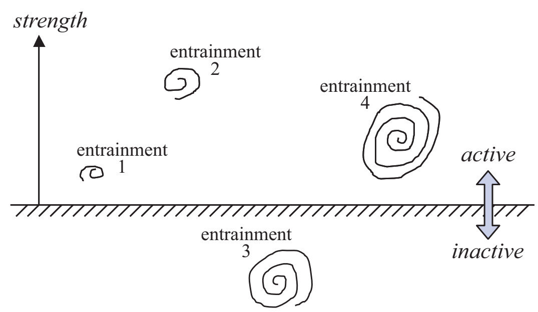


Fig. 5. The concept illustration of an Entrainment Ensemble Model [7]: An entrainment factor can correspond to any paired relationships between a human and a robot. For instance, in Fig. 4 QRIO's arm-pitch follows the trajectory of the central point of the biggest moving-region (Fig. 3), this forms one entrainment factor. Multiple entrainment factors can be set similarly, each of which has its own strength. QRIO can control the level of imitation by changing the order of strengths.

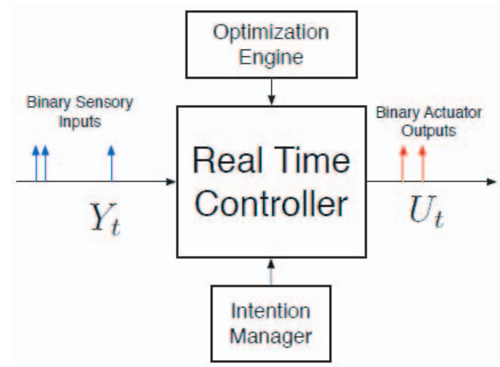


Fig. 6. A bare-bones social robot with infomax controller [3]: An intention manager sets utility functions: Currently this part is designed by a human programmer.

ones have their own strength of exhibition. Making a system based on entrainment factors can be accomplished by any computational approach, such as a naive rule-base, many kinds of oscillators [10], [11], a recurrent neural network [12], etc. We call a model with multiple entrainment factors an Entrainment Ensemble Model (EEM) [7]. By changing parameters in both a local (inside each entrainment factor) and a global (relative strength between multiple entrainment factors) level, QRIO can react and dance flexibly to keep its human partner engaging.

B. Exploiting the Active Detection of Contingency

In the interactive dance application explained in Section IV-A, QRIO was purely passive because its behavior was determined only by outside motion information. Considering active behavior should also be needed. We employ the idea of active contingency detection by the method of infomax control theory [3]. This approach is originally formulated by two players: A social agent and a robot. Both are in an environment that produces some level of random background activity. The role of the robot is to discover as soon and as accurately as possible the presence of contingent social agents. A bare-bones robot (Fig. 6) is characterized based on binary sensory inputs and outputs. The optimization engine and real-time controller produces a sequence of actions that maximizes the information gained about some aspect of the state of the system giving a set of observations and action sequences in the past. Based on this framework, the problem of contingency detection is formulated by Bayesian inference [3]. The robot's belief about whether there is a contingent (responding) agent present is updated through the statistics of action and sensor sequences. This approach was tested in the auditory domain where a robot strategically emitted a sound to maximize the information about whether there was a human responding to the robot [13].

We apply the infomax controller into the motion domain where QRIO actively moves in timing to maximize the information about the existence of reacting human by using visual features to detect motion explained in Section IV-A (Fig. 7). By interleaving the infomax controller method with the passive interactive dance, explained in Section IV-A, a more flexible and engaging dance is also expected to be produced. One question is how to combine these two methods, in other words, when should QRIO switch to passive or active mode. This is related to a research topic around turn-taking, and we plan to decide the best way through daily experiments that we are now conducting. We will soon report it with the latest experimental results.

C. Robotic Emotion Expression

So far we described two technologies which are planned to be tested during the dance interaction between toddlers. They played totally different roles each other, whereas in this section we will consider adding another function to both of them.

Through experiences in volunteering at ECEC, we realized the importance of emotion expression. Though toddlers are at the beginning of development in language acquisition, they can communicate with others using non-verbal or limited verbal communication skills. Emotion expression undoubtedly plays a crucial role in both non-verbal and verbal communication skills.

As we explained in Section II, QRIO's motion control and its whole body physical movements are very powerful. Emotion expression can be done not only by its facial expression such as changing the color of LEDs but also by whole body gestures. The behavior and motion control are based on the EGO (Emotionally Grounded) architecture [14], where each behavior is selected by sensor information and internal states,

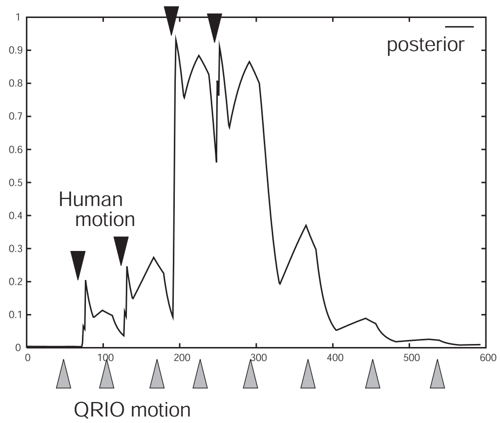


Fig. 7. The transition of QRIO's belief (posterior) about whether there is a contingent (responding) dance partner present. The horizontal axis shows time steps. The gray triangles indicate points when QRIO actively moves. This timing policy is determined by infomax control theory [3]. The black triangles indicate the presence of a contingent human detected by its motion. We can see the belief increases when the partner reacts and decreases when the reaction stops. An interesting finding is that during the decreasing phase, sometimes (around 370t and 440t) it increases for a while as if QRIO is thinking. Correlating emotion expression with the infomax controller produces a surprisingly realistic impression (Section IV-C).

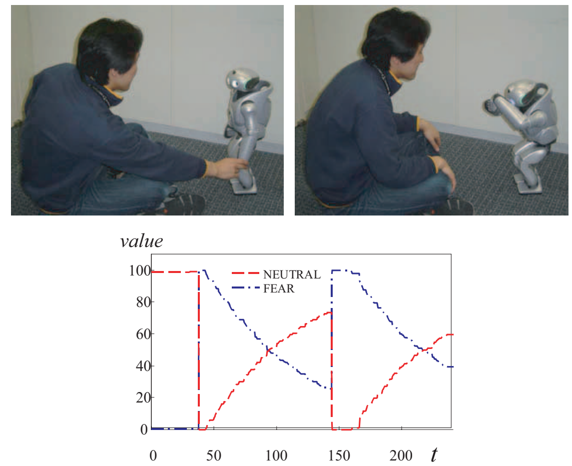


Fig. 8. Associated emotion and its expression in QRIO: A man twists QRIO's hand at $t = 50$ (TOP-LEFT) and it expresses the emotion of FEAR utilizing the whole body (TOP-RIGHT). The man leaves for a while and QRIO's emotion gradually becomes NEUTRAL. The man comes in front of QRIO again at $t = 150$, and this time it expresses FEAR just seeing the man (: his identity is determined through face recognition). The associated emotion is realized by a neural network and a simple reinforcement mechanism [15].

including an emotion model [15]. The behavior control is based on homeostasis, where QRIO selects its behaviors to regulate its internal state within an acceptable range. QRIO can associate the change of emotion with corresponding situations such as the detection of specific human recognized by the facial image or encountering an object that also is recognized by visual information [15] (Fig. 8). By combining the associated emotion with expression, human-robot interaction is expected to be more engaging. We plan to evaluate this assumption through experiments at Room-1.

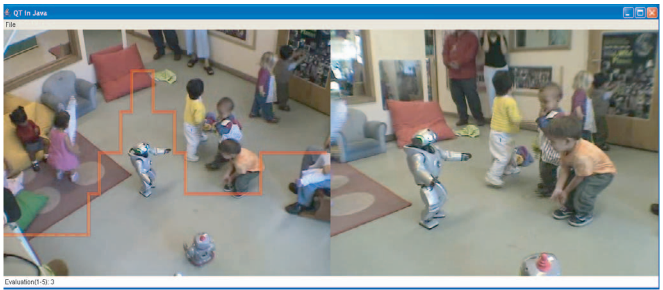
We can apply and exploit the idea and methodology of contingency detection here also. By using a posterior calculated by the algorithm of contingency detection, we can utilize a new process to express robotic emotion. The posterior can be viewed as a confidence of a contingent partner. Then a natural extension is that controlling parameters in the expression of robotic emotion is in accordance with the posterior. For instance, if the confidence increases, then QRIO strengthens the feeling of joy. Compared with the approach where programmers pre-designed simple rules for the expression, a more natural emotional shift can be produced and this has the possibility of giving the human partner a positive impression.

D. Conducting the First Steps

Our first trial will be the comparison of these technologies and choreographed demonstration dances both of which are implemented on QRIO. As we described in Section II, QRIO has the functionality of a wireless-LAN networking. We can remotely control QRIO in various levels, from inputting joint-angles information to more abstract behavior IDs (e.g. walking any steps in particular directions, showing predesigned gestures, vocalizing sounds and speeches using TTS: Text-To-Speech, changing the colors of LEDs, etc.) We can compare dance applications as well by sending IDs each of which is assigned to one mode. There is a control room which is separated by a one-way view window from the classroom where QRIO and toddlers are there, and the IDs are sent from an operator inside the control room. QRIO moves sometimes in an autonomous mode. Therefore it is also important for the operator to stop QRIO's movement whenever it may cause any danger to the toddlers.

As we described in Section I, we will not adhere to single experiment. Our goal is to develop the dance interaction process between QRIO and toddlers by repeating tests and improvement. If we find a difference between the interactive dance application presented in this paper and the choreographed dance by one week experiment, then we will move to another experimental setting considered by knowledge obtained during the week.

These sessions are recorded by multiple cameras. The videos are coded on a daily basis by a team of 5 judges. After trying various methods, we found continuous audience response methods borrowed from marketing research to be efficient. Every day the judges view the videos and evaluate the goodness of the interaction between QRIO and toddlers by putting a label (from 1 to 5) continuously by using software which is capable of labeling on the play of QuickTime



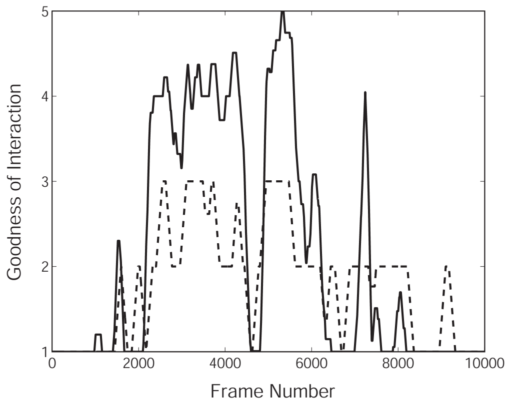


Fig. 9. (TOP:) Each judge continues putting a label (from 1 to 5) for the goodness of the interaction between QRIO and toddlers by using a labeling program implemented by QTJava. Two synchronized movies taken by two cameras are combined into one movie. The judge can see the history of evaluation which is superimposed on the movie as a red transition graph. (DOWN:) An example of labeling results by two judges. Now we are conducting labeling for about 20 days videos by 5 judges. Quality control is crucial there, and we periodically check correlation between them to maintain valid quality for evaluation.

movie (Fig. 9). According to a similar trial with RUBI [1], it was found that this method provided good inter-observer reliability and was sensitive to changes in the quality of the interaction between robots and children.

V. Conclusion

In this paper, we introduced a project with a small humanoid robot QRIO, participating in the daily activities of a toddler class at an Early Childhood Education Center. The goal of this project is to investigate the idea of interactive robots as tools to assist teachers. In this study we are focusing on understanding the development of short-term and long-term interactions between QRIO and toddlers during dance episodes. We use the philosophy of continuing the process of test and improvement for months in the non-laboratory, real world environment. We put QRIO's specialties into account, which include flexible and highly behavior generation abilities, whole bodily motion like dancing, and a size smaller than toddlers 10-24 months old. Along with explanation of QRIO's behaviors which would be tested at the beginning, we presented new applications in exploiting the methodologies of the active detection of contingency. We applied the idea into a motion domain, and presented a new way of robotic emotion expression by using a posterior calculated by the algorithm. Finally we also explained plans for evaluating interaction by the method of continuous audience response methods.

Acknowledgment

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