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A Chase-Game to Teach Children on a Robot to Follow Moving Objects

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***Abstract*— Due to lack of mobility, children are limited in their interaction with others. This lack of interaction with peers leads to emotional problems in children with special needs, behavior disorders, and social maladjustment. These social problems continue even when these children become adults. Hence, it is important to promote social skills at a very early age. In this study, we suggest a new training paradigm for young infants and toddlers seated on mobile robots, using force feedback joystick, to bring them closer to their peers so that it can facilitate interaction. Four healthy children participated in a game as they chase a caregiver. A haptic force feedback strategy teaches how to follow the caregiver. The force feedback guidance strategy is tested as a training tool to bring the children in close proximity to their peers.**

I. INTRODUCTION

The lack of mobility in special needs children results in other delays in their development milestones. The walking and crawling in children leads to the development of cognition, perception, and socialization [1], [2]. Studies show that there is smaller social interaction between children with special needs and their typically developing peers in class rooms, gymnasium, or playground [3], [4]. This lack of social experience causes emotional depression, maladjustment in classrooms, and behavioral disorders [5]. Toddler and preschool age is a crucial period to acquire social skills [6]. Previous research has shown that intervention in these age groups benefits children with low social interaction [7], [8] and also reduces their offensive behavior [9]. Difficulties in social interaction in preschool carries over to elementary school [10]–[12]. Repeated rejections from the peers in the early childhood may lead to early interaction difficulties [13] and difficulty in learning social behaviors at a later time. Early development or intervention of social skills can reduce the risk of rejection from the future peers.

One of the reasons for the delay in social development of the children with low mobility is their lack of close proximity to their peers. Smart wheel chair technology has evolved over the years for automatic obstacle avoidance, shared control, and path planning [14]–[16]. These developments in the field can be used to detect obstacles and modify wheelchair trajectory to avoid collisions in the environment [17]. In our previous studies, smart wheel chairs were provided to children with special needs and the interactions of these children with their peers was observed. We noticed that even though the children gained mobility with the smart wheel chair, their interaction with their peers and teachers still remained modest [18], [19]. We concluded that novel forms of intervention is needed that can foster a child with special needs to be closer to their peers in order to facilitate socialization.

In our previous studies, we showed that training with a force feedback joystick can facilitate children to learn higher level navigation skills such as tracking paths with turns and avoiding obstacles [20], [21]. The underlying training strategy proposed in current work is *assist-as-needed* force field, where the hand feels a virtual force if the child moves the joystick away from a target direction. This approach enables the child to learn directed movement to a given goal as it changes over time. If the goal is set as a moving member in the peer group, the child can continuously follow the peer group member. This paper presents a pilot study to evaluate the feasibility and effectiveness of this strategy.

In this pilot study, a chase game is designed with the following considerations. First, in this game, a chaser should tag the other child to win the game. The force feedback guidance is used within the game to promote directional movements towards the peer. Second, the game involves a social structure and rule [22]. A child is assigned to be the chaser and is urged to catch another child or a caregiver who is running away. This role can result in the children to interact with others unconsciously. Third, this game is simple and is easy to explain to the participants. We found that all children enjoyed to participate in this experiment. We feel that this experiment involving a chase game can be an effective test bed for social skills training of children with mobility impairments.

II. HARDWARE SET UP

The set up in this study consists of a mobile robot, a lidar scanner, and a force feedback joystick as seen in the Fig. 1. The lidar scanner was placed on the robot to detect obstacles and map the space around the robot. A Ubisense 3D Indoor Positioning System (IPS) was used to identify the position of a tag attached to the robot as well as to a moving goal. Four IPS receivers were mounted on the walls

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*This paper includes a supplementary video clip.

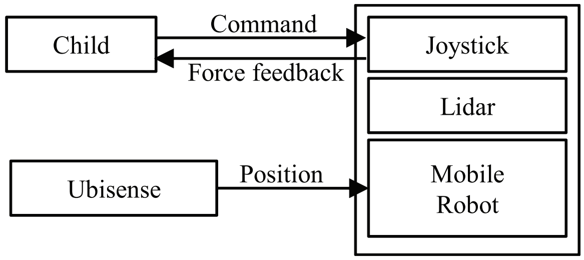

Fig. 1. A schematic of the experimental set up with the robotic wheel chair

of a gymnasium of an Early Learning Center where these experiments were conducted. Encoder data was added to the IPS position data of the robot to ensure accuracy of 0.15 m with a properly designed Kalman filter [23].

A reference path is needed to guide the child driving the robot towards a caregiver. Before building this reference path, the environment should be mapped for the presence of obstacles. A certainty grid map is used for recording static or slow moving obstacles with rectangular grids [24]. The space is divided into 10 x 10 cm grids and nodes on the grid are checked with the lidar scanner to update the occupancy. This certainty grid map is a powerful tool for sensor fusion with sensor uncertainties. Trajectory planning is essential to move the robot towards a given goal. Many numerical algorithms have been presented to build a trajectory between start and goal points [25]–[27]. As we explored the environment using the certainty grid map, grid based algorithm was chosen to build a new trajectory between the robot and the caregiver. A* is a typical grid based algorithm which results in an array of nodes with the best cost among the candidate nodes [26]. For the initial set up of each node, the largest obstacle free square is investigated and the distance from the parent node is assigned as the cost. The trajectory planning for our child drivers includes many challenging problems. First, fast planning time is needed, since children become impatient very soon. Second, the other children are moving around the robot with different speeds. Also, the caregiver labeled as the goal is continuously moving around playing with the other children. To overcome these challenges, a switching strategy from Pathak [28] is integrated with the A* algorithm. This switching strategy in Table I classifies the cases for re-planning, depending on the position of the robot and obstacles. It enables to build an obstacle free trajectory toward the moving goal autonomously.

TABLE I

SWITCHING STRATEGY FOR REPLANNING A NEW PATH

```
Algorithmn: Switching strategy
if inside the current square then
    if the current square is not the final goal then
        if the next goal is not blocked then
            Move on to the next goal and return it
        else
            Replan a path with A* algoritghm
        end if
    else
        Return the current goal
    end if
else
    if the robot is inside the previous square then
        Return the current goal
    else
        Replan a path with A* algorithm
    end if
end if
```

The resultant nodes of the A* algorithm are used as the intermediate goals for the potential field controller to find the appropriate velocity input of the robot. Every node has an obstacle free square assigned from the initializing process of the A* algorithm. Inside this square, the desired linear and angular velocity towards the current intermediate goal is computed through the potential field controller [20]. The desired linear velocity v and angular velocity w are computed as follows.

$$\begin{pmatrix} v \\ w \end{pmatrix} = -(K_1 B^T + K_2 F)\nabla U$$

where

$$K_1 = \begin{pmatrix} k_1 & 0 \\ 0 & k_1 \end{pmatrix}, K_2 = \begin{pmatrix} k_2 & 0 \\ 0 & k_2 \end{pmatrix} \qquad k_1, k_2 > 0$$

$$B^T = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}, \mathbf{F} = \begin{pmatrix} 0 & 0 & 0 \\ -\sin\theta & \cos\theta & 1 \end{pmatrix}$$

$$\nabla U = \begin{pmatrix} \frac{\partial U}{\partial x} & \frac{\partial U}{\partial y} & 0 \end{pmatrix}, U = U_a + U_r$$

(x, y) is the robot position and θ is the orientation of robot. k_1 and k_2 are positive constants. U_a denotes the attractive potential toward the goal and U_r is the repulsive potential which exerts force to avoid the obstacles. Two different potentials are defined as [29]:

$$U_a = \frac{1}{2} k_a [(x - x_g)^2 + (y - y_g)^2]$$

$$U_r = \begin{cases} \frac{1}{2} k_r (\frac{1}{\rho} - \frac{1}{\rho_0})^2 & \text{if } \rho \leq \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases}$$

where (x_g, y_g) is the intermediate goal that is computed by switching strategy in table I. ρ_0 is a constant, defined as the radius of influence from the obstcle, ρ is the minium distance between obstacle and robot. k_a and k_r are constants.

The force feedback haptic device mounted on the robot has two different functions. The subject can give a velocity input to the robot and get a force guidance from the joystick. The "assist-as-needed" idea with force tunnel is implemented to decide the direction and amount of the guided force. "Assist-as-needed" paradigm is widely used in training studies and has shown positive results with adults and children [20], [30], [31]. As the subject's hand goes further from the desired direction, it is guided with larger force towards the desired direction.

The linear and rotational input velocity from the subject

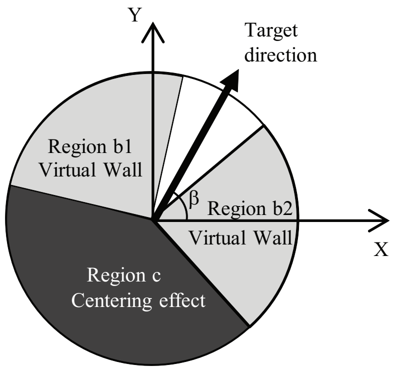

Fig. 2. The effect of the joystick force feedback with the target direction seen from above

is mapped on the x-y plane of the joystick. If the driver moves the joystick towards the front or back along the y axis (Fig. 2), the joystick gives a pure translational command to the robot. However, if the joystick is moved along the x axis, pure rotational movement is given to the robot. The force feedback has three different effects depending on the direction of the joystick. Before discussing these three regions, the targeted tunnel direction toward the intermediate goal should be defined with the velocity given from the potential field controller [21]. The targeted direction angle β yields

$$\beta = \arctan\left(\frac{v}{v_{max}} / \frac{w}{w_{max}}\right) \tag{1}$$

The first region (Region a) is a cone including the targeted direction where there is no force guidance. If the child pushes the joystick into this region, the child can move towards the intermediate goal. Next region (Region b1 and b2) corresponds to the force tunnel wall where the joystick pushes the hand of the child toward the targeted direction. The last Region c applies a restoring force on the childs hand to bring the joystick back to the center [20].

Fig. 3. The robot driver chasing the moving caregiver during the training trial

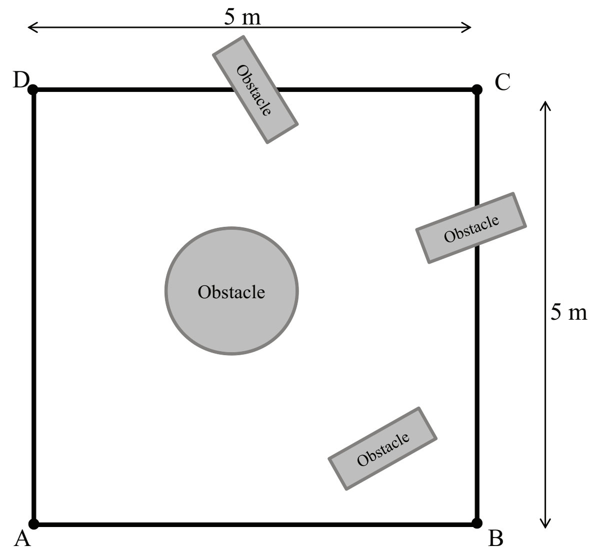

Fig. 4. The task area with the obstacles

III. Protocol

Designing an experiment with children as subjects needs more care than adults. The age of the child should be appropriately chosen so that they can understand the given task. Additionally, the attention time for a task differs largely based on the age. Three additional factors are considered: First, intermittent verbal instruction should be given to encourage the child to focus on the experiment. Fun is an important factor that prevents the child from relinquishing the experiment. Gaming factor of the experiment makes the children enjoy it and also motivates other subjects to participate in the experiment. Rewards between the experiment trials are set up to increase the motivation of the child. Verbal reinforcement and positive feedback were used to increase intrinsic motivation [32], since material reinforcers such as candy, token and small toy are able to distract children from concentration on the task [33].

A chase game was set up to test the feasibility of this experiment within a 5 x 5 m area, as shown in Fig. 4. The caregiver had an Ubisense IPS tag attached to the body and verbal direction was given to the child to catch the caregiver. A paper stick was given to the child as an extension of the arm to catch the caregiver, since the front of the robot extends beyond the arm length of the child. Four healthy children participated in this experiment with an average age of 2.3 years. Two children were randomly chosen for the experimental group who were trained with the force feedback joystick, and the remaining two children were assigned to the control group. The experimental protocol was approved by the Institutional Review Board of University of Delaware and the consent forms were signed by the parents of the children.

The experiment consists of evalutation and training sessions. First, to measure the effect of the training, the

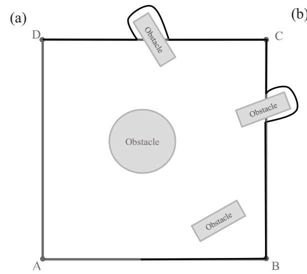

Fig. 5. The task configuration. (a) Pre(post) session: caregiver moves along the rectangle track. (b)Training session: caregiver moves randomly within the rectangular area

evaluation sessions are conducted without enabling the force feedback in the joystick. An evaluation session is conducted before and after the training session: two pre-training and two post-training (Fig. 6). Then, these data from pre- and post-trainings are compared to check the effect of the session. Second, in the training sessions conducted in between the above evaluation trials, the force feedback is provided from the joystick of the robot to the hand of the children in order to guide them towards the caregiver. The training session constitutes four training trials as indicated in Fig. 6. Each trial in the evaluation and training session lasts for 40 seconds and all eight trials are conducted in a single day. In the evaluation session, the caregiver is instructed to move along the pre-determined trajectory with a constant velocity as shown in Fig. 5(a). Unlike the evaluation session, in the training session, the caregiver is instructed to run away randomly from the robot with the child driving it in a real chase game. The following describes further details of the evaluation and training sessions.

- Evaluation session: The caregiver is asked to move along the edge of a 5 x 5 m area (Fig. 5(a)). Before the experiment, the caregiver is trained to move with a constant speed to be consistent in all evaluation trials. The caregiver stands one meter away from the child at the starting point which is switched from point A(D) to D(A) at each trial to evaluate right and left turns equivalently. The child is driving on the robot without the force feedback from the joystick during the session.

- Training session: The caregiver moves randomly between the obstacles in a 5 x 5 m square in order to train the child to chase a randomly moving object. Additionally, the caregiver is instructed to be in the range where the caregiver can make eye-contact with the child and encourage him/her to follow the caregiver. After 40 seconds of the session, the caregiver pretends to be caught by the child. In this session, the force feedback is provided to the child to move the joystick toward the desired direction.

According to Ruff [34], the focused attention of 2.5 year old children lasts for about 16 seconds. However, our experiment lasts for 40 seconds which is nearly three times longer than the typical attention span of the children. In order to keep the attention of the children, rewards are given whenever the child touches the caregiver with the paper stick. As a reward, the caregiver makes a funny face and "high five" with the child for encouragement. Moreover, in the middle of trials, the caregiver gives verbal motivation to the child if he/she is not focused on the training.

For the evaluation, the distance between the robot and caregiver is measured. Also, the input data of the joystick is recorded with respect to x and y coordinates which shows the directional manipulation ability of the children.

IV. Result

Fig. 7 shows the average distance between the robot and caregiver for each child in control and experimental group. The distance is averaged for 40 seconds and two evaluation trials for each pre and post-training are also averaged to observe the overall trends. The average distance presents how well the child is able to chase the caregiver with directional manipulation of the joystick. Two children in the experimental group show more than 35 % decrease of the distance between pre and post training sessions.

Session		Evaluation		Training				Evaluation	
Trial		1	2	3	4	5	6	7	8
Testing set		B	B	T	T	T	T	P	P
Task track		Fixed		Random				Fixed	
Joystick Force Feedback	Experi-mental	x	x	0	0	0	0	x	x
	Control	x	x	x	x	x	x	x	x

B Base line T Training P Post training

Fig. 6. Protocol for the experiment. The experiment consists of evaluation and training sessions. Evaluation session constitutes pre- and post-training trials.

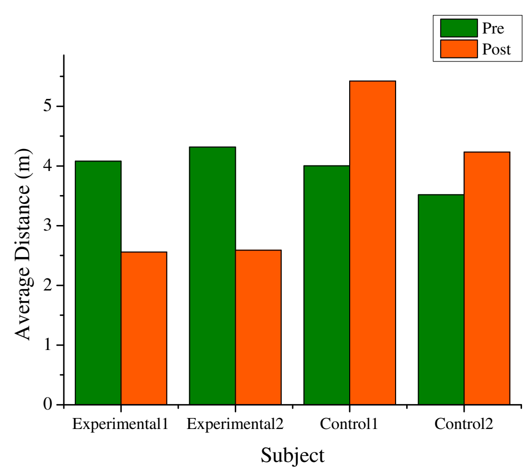

Fig. 7. Average distance between the caregiver and child for children in experimental and control groups

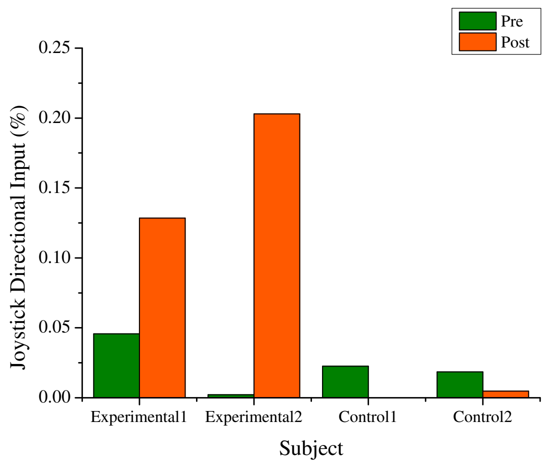

Fig. 8. Joystick rotational input percentage for children in experimental and control groups

However, the children in the control group, without the guidance of the force feedback, were found to show low rate of improvement after the same training time with the children in the experimental group. Instead, the children in the control group were observed to make inefficient forward and backward movements resulting in increase of the distance to the caregiver, which differs clearly from the children in the experimental group with the force feedback. The second graph shows the input data of the joystick for directional manipulation from each child. As described in the session II (hardware set up), x coordinate of the joystick corresponds to the angular motion of the mobile robot. At the start of the experiment (pre-training), the children rarely try to move the joystick to the left or the right. They perceived the joystick of the robot as simple pulling or pushing device to make the robot move, even though the joystick can be controlled in any direction within its 360^o range. After the training sessions with the force feedback, the children in the experimental group learned to perform the rotational movement with the help of the force feedback. This fact is supported by results in Fig. 8 - the joystick input data for the rotational movement of the children in the experiment group showed definite increases compared to that of the control group. The increased value of the joystick input data indicates that the children learned well the directional manipulation of the joystick to the left and the right for rotation of the robot.

Even though the number of subject is small, the resulting trends in Fig. 7 and Fig. 8 are quite striking and provide valuable insights into larger studies in future. As the children in the experiment group have the force feedback during the trial session, they show better performance to track a moving goal with directional changes.

V. Discussion and Conclusion

The driving performance of the children with force feedback showed distinct improvements compared to those with conventional joystick. This can be explained as follows: First, the force feedback informs the children that the joystick can be moved along all directions. At the beginning of the experiment, none of the children tried to move the joystick to the left or the right to get rotational movement. However after experiencing the force feedback, they become more skillful at it. Second, the force feedback guides continuously in which direction they should move. It is supported by the fact that the distance between the caregiver and driver decreases with the help of the force feedback.

Force feedback was also shown in other studies as a powerful tool to enhance skills for manipulating systems, in medical surgery, or in tele-operated robots [35]–[38]. The effects of the force feedback as a rehabilitation tool have been presented for CP, stroke, and other motor impaired patients [39]–[41]. The force feedback is more intuitive and continuous than visual or auditory feedback. As the child holds the joystick, the feedback is sustained during the whole driving period. From our experiments, this haptic sensory feedback shows promise to train children to move towards their peers. This will provide more opportunity to children to interact with others and is a first step towards socialization.

Future work of our study is to extend the experiments to children with special needs. The chase game experiment will foster children with special needs to play with normal children and interact socially with others. Also, we want to evaluate the social skills of the children quantitatively and show the merits of the force feedback in social training. For example, PEDI (Pediatric Evaluation of Disability Inventory) [42] score can be used as a clinical measurement tool, LAQ-CP (Lifestyle Assessment Questionnaire) [43] and PedsQL (Pediatric Quality of Life Inventory) [44] can assess social activity of the children with special needs. Many teachers and care givers put a lot of time and energy to bring special needs and healthy children together in a class room. We believe that this mobile robot with haptic fedback will provide a new paradigm that will allow children to communicate and play together and help caregivers and classroom teachers in a seamless way in the future.

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