Changes to User Learning Behaviour of powered wheelchair drivers depending on the level of sensor support

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Abstract — **This paper describes early results in ongoing work to evaluate the effect of intelligent sensor support while a user learns and develops the skill to drive a powered wheelchair. Dependence on training procedures was measured during situations when different levels of support were provided by sensor systems. Results from experiments are presented and some insights are made concerning user learning behaviour during wheelchair driving.**

I. INTRODUCTION

Research into powered wheelchairs is attempting to improve safety and performance and the distribution of tasks and control between human users and powered wheelchair systems is a key issue to be considered [1],[2]. The appropriate level of control and automation is influenced by a variety of factors: level of ability and expertise, mental workload; effectiveness and reliability of the automation; and the users' trust in the automation [3]. It has been reported that the burdens associated with managing automation can sometimes outweigh the potential benefit of the automation to improve system performance. For example, Kirlik studied the interaction between human users and automated systems to investigate why aids might sometimes go unused [4]. Situation Adaptive Autonomy was proposed in which the importance of a change in the level of automation according to dynamically changing situations has been emphasized [5]. It was reported that the time taken to complete a task with a wheelchair partly depends on how the human user interacts with the powered-wheelchair [6],[7]. Other recent work reported that users tend to rely heavily on visual feedback if it is available [3][8],[9] and that the amount of sensor support should be varied depending on circumstances [10],[11].

In the research presented in this paper, the way that users adapted their behaviour in the face of different levels of support is examined. The results are used to evaluate the effect of providing intelligent support during teaching as the users learn and develop their skills. The appropriate level of automation and assistance depends on the complex interaction of several factors and this work investigated how powered wheelchair users should be trained if different levels of support were available. Recent work had shown that in some circumstances, a skilled user who was trained without any sensor support could sometimes perform even better by using a sensor system to assist them [6]-[11]. The question addressed in this paper was, could a powered wheelchair user trained to achieve tasks with a sensor system to assist them handle a situation without a sensor system? The adaptation behaviour of the users when provided with different levels of support was investigated and it was found that they behaved differently when they encountered different working conditions.

In conventional studies to examine the use of different levels of support, experts with developed skills were taken as examples. The process of acquiring skill has usually been neglected [1]. The task of driving a powered wheelchair was selected as a practical example of human computer interaction and two sets of experiments are described. Similar experiments using remote industrial robot manipulators can be found in the literature [12],[13].

II. THE POWERED WHEELCHAIR SYSTEM

The apparatus consisted of a dedicated controller with analogue interfacing, DC servo-amplifiers and joystick, and a BobCat II powered wheelchair was modified to include exra control and sensor systems. Two driven wheels were at the front over each driving wheel and two trailing castors at the back. Ultrasonic sensor pairs were mounted over each driving wheel. Altering the differential of rotational speed of the driving wheels affected steering and direction of movement.

Sonar sensors have been widely used for powered-wheelchairs and mobile robots [14],[15] and ultrasonic ranging was selected, as it was simple, cost effective and robust. Ultrasonic transmitter and receiver pairs were mounted at the front of the powered-wheelchair. With suitable processing the ultrasonic signals were converted to a simple representation of the environment ahead of the wheelchair. An integral function was used with the joystick signals so that the tendency to turn when approaching an object could be over-ruled by the user, for example to reach a light switch on a wall.

Software algorithms to intelligently mix the inputs to the powered wheelchair (joystick and sensors) were described in [16]–[20] and the wheelchair was driven under computer control by "fly-by-wire". The direct link between the powered wheelchair and joystick was severed and a computer processed control information. Sensors were activated and interrogated by the computer and the computer was programmed to modify the powered-wheelchair path. Alternatively, joystick control data

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could be processed and sent to the wheelchair controller without modification. In this case the powered-wheelchair responded to joystick inputs as if it was an unmodified wheelchair system. Software systems were constructed using methods discussed in [21]-[23]. Systems had three main levels: supervisory, strategic and servo control. These were similar to the levels and sensor systems described or used in [24]-[26].

Algorithms applied the following rules: (1) The user remained in overall control. (2) Systems only modified the trajectory of the powered-wheelchair when necessary. (3) Movements of the wheelchair were smooth and controlled.

III. EXPERIMENTS

Three levels of support were given to the powered wheelchair drivers:

- Level 0: The ultrasonic sensor system was switched off. The user could steer the manipulator without any disturbance from the automated systems. The user had the most freedom of action in this case but risk of collision was the highest.

- Level 1: The sensor system was switched on and a repulsive force was provided when the powered wheelchair was driven close to obstacles. The magnitude of the repulsive force was inversely proportional to the distance between the obstacle and a sensor.

- Level 2: The sensor system was switched on and the system automatically steered the powered wheelchair away from obstacles. If the driver tried to move the powered wheelchair towards an obstacle, the system automatically steered the powered wheelchair away from the obstacle.

In each case, a driver could move the powered wheelchair against the applied force if they made more effort. The average time to complete a task (T) and the number of collisions (C) during that task were used as measures of performance.

A. *The first set of experiments*

A first set of experiments made a comparison between learning in Level 0 (with the ultrasonic sensor system switched off) and Level 2 (with the sensor system switched on and the system automatically steering the powered wheelchair away from obstacles). A second set of experiments compared learning in Level 0, Level 1 and Level 2 when the environment changed.

In each of four experiments, volunteers were tasked with driving a Bobcat II Powered wheelchair [7], [10] through one of four different courses. The first route was a simple route from a start line between some double doors, along a corridor avoiding three obstacles and then turning a corner to a finish line.

The four courses were of various lengths and different numbers of obstacles were located within the path of the powered wheelchair. Volunteers were instructed to drive the powered wheelchair through each course and to avoid hitting the obstacles. The powered wheelchair drivers used a joystick connected to the powered wheelchair.

For the tests at Level 2, resistive force became stronger if the driver moved the powered wheelchair closer to obstacles. Thus the support was more restrictive compared with Level 1.

Volunteers were sixty University students (without any previous experience). They were divided into two groups (Group A and Group B). Group A and Group B were then divided between the four different courses used for the experiments; roughly eight volunteers in each sub-group (A1, A2, A3, A4, B1, B2, B3, B4). Tests for each of the courses (one to four) took place on different days.

Volunteers were shown their route for the powered wheelchair and the obstacles along the route. Subjects in Group A and Group B performed the task ten times with and without the sensor systems to assist them respectively. Then, subjects in Group A and Group B performed the task with different support conditions. The purpose of second set of experiments was to examine performance when an user encountered new support conditions after they had already developed some skill in driving the powered wheelchair. A simple questionnaire was used to collect subjective information about preferences. Questions asked were: (1) “Which do you prefer Level 0 support or Level 2 support? “ and (2) “Which do you think easier to drive; Level 0 support or Level 2 support?”

Responses are shown in Table 1.

B. *Results from the first set of experiments*

Figs 1 and 2 show the average time T of each of Group A and Group B for each attempt at driving along the four different courses. Trial numbers 1 to 10 correspond to the first half (Group A with Level 2 support and Group B with Level 0 support) and 11 to 20 correspond to the second half of the experiments (Group A with Level 0 support and Group B with Level 2 support).

In the first half, subjects in Group A reached the learning equilibrium earlier and more stably than subjects in Group B. This result suggests a positive effect of using Level 2 support during the earlier stages of learning and skill development. Better performance was also observed for Group A during the second half of the trials, when subjects performed the task with Level 0 support. Skill acquisition was accelerated using Level 2 support and subjects may have acquired the general skills which can be applied to the conditions without any support. On the contrary, the performance of subjects in Group B in the second half of the trials did not show any significant improvement in terms of average time and stability even if the Level 2 support was applied.

TABLE I. RESPONSES FROM QUESTIONNAIRES

	Strongly prefer 0	Prefer Level 0	Un-decided	Prefer Level 2	Strongly prefer 2
Preference	13	15	17	12	3
How easy?	14	17	8	15	6

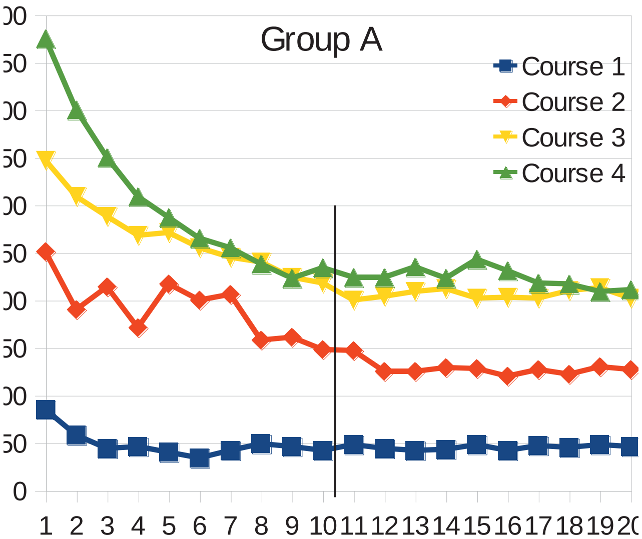

Figure 1. Average time T for Group A to complete four different courses. Level 2 support first, then Level 0

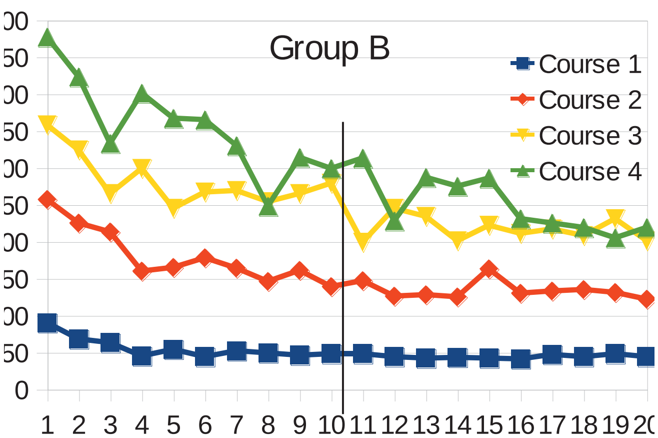

Figure 2. Average time T for Group Group B to complete four different courses. Level 0 support first then Level 2

That behaviour can be attributed to the fact that skill developed during Level 0 support did not transfer so easily to the skills required in a different support condition. The results of the subjective evaluation obtained by questionnaire are shown in Table 1. Subjects suggested that they thought it was easier to drive without support (Level 0) which contradicted the objective results shown above. The subjective evaluations also implied that constraint-based support was disliked.

C. *Discussion of the first set of experiments*

Results from the first set of experiments suggested that a driver who had been trained with a sensor system supporting them could still handle situations when the systems were removed. The support from the sensor systems during the training phase also had a positive effect on performance without any support. It should be noted though that subjects may have become accustomed to maneuvering the powered wheelchair through the same path during the sequence of trials. Further experiments will be required to confirm that the developed skill can be transferred to different working conditions without the support function. The results agree with those suggested by Chikura [1] but the behaviour of subjects facing different types of task needs to be examined if results are to be confirmed and generalized.

Results suggested that a driver trained without the support of the sensor systems could not perform better using the support of the sensor systems. This may be because the task needed motor skill. Results indicate that subjects trained without support did not show steady learning compared with subjects who started without any previous experience. This suggests that skill gained when driving without any assistance had a negative effect on the performance with the support function. This is important when considering a training procedure. Informal interviews with subjects revealed that this was partly because of a feeling that freedom of movement was being constrained. This inconsistency between the performance results and the subjective evaluation indicated that selecting options based on human preference could lead to inferior performance.

D. *Second set of experiments*

A second set of experiments is now being conducted to investigate adaptive behaviour when working conditions were changed and volunteers were using different levels of support. A new route is being used in the second set of experiments that is longer and more complicated. That is allowing obstacles to be moved to create three different (but similar) courses along the same route. Progress so far is described.

The purpose of the experiments in phase two was to investigate whether there were any differences in subjects' behaviour for different levels of support when they encountered different working conditions. First, the route was completed six times. Then the route was modified by moving the obstacles for both the second set and then the third set of six attempts to create two new different courses.

Each driver performed each task with the same support conditions throughout the three sets of six attempts over each of the three courses. Ten university students without previous experience (they had not participated in the first set of experiments), were divided into three groups (Groups X, Y and Z). Subjects in Group X performed the task with level 0 support (manual control) and Group Y with level 1 support (sensor system providing a repulsive force) and Group Z with Level 2 support (sensor system automatically steering the powered wheelchair away from obstacles). Task completion time T and number of collisions C were recorded.

E. *Results from the second set of experiments*

The resultant T for the second set of experiments for Groups X, Y and Z respectively and the number of collisions with obstacles for each subject are being recorded. So far, it appears that Level 2 support results in the lowest number of collisions. Contrary to this positive effect thoogh, the performance in terms of T degraded compared with Level 0 support. To examine the net effect of each support Level, the differences in T when the configuration of obstacles changed was evaluated. T tended to increase in cases of Level 1 and 2 support, while T did not show any significant change in case of Level 0 support. This result indicates that skills acquired without any support may be more general compared with skills obtained with support.

F. Discussion of the second set of experiments

There do appear to be differences in adaptation and behaviour for different levels of support when drivers encounter a new and different working condition. T is showing different behaviour for each support level when the configuration of the obstacles was changed.

IV. OVERALL DISCUSSION AND CONCLUSIONS

Adaptation behaviour to different levels of support was examined to evaluate the effect of using systems to assist during teaching and learning and skill development. The positive effect of learning to operate the powered wheelchair using the sensor systems to assist was demonstrated in the results of these experiments. The negative effect of learning while driving manually and then using sensor systems to support driving was also shown. In the second set of experiments, it was shown that Level 2 support reduced the number of collisions for various obstacle configurations.

Results would have benefited from a larger number of volunteers for the second set of experiments that is ongoing. In addition, results obtained during the second set of experiments are not consistent with some of those obtained during the first set of experiments. In the first set of experiments, it was suggested that support had a positive effect during learning and skill development compared with driving manually. This was not observed in the second set fo experiments. Although further experiments focusing on user performance are needed to obtain a more general result, the work presented here has provided an insight concerning the behaviour of powered wheelchair users as they learn under different conditions and with different levels of support provided to them.

It should be noted that although this research has suggested that using the sensor systems during training is efficient, other research has suggested that once a user has become proficient at driving a powered wheelchair then users perform better in unrestricted environments without the sensor systems [23],[27]. The sensor systems become more useful as the environment becomes more complicated.

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