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cBDI-based Collaborative Control for a Robotic Wheelchair

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Abstract

In this paper we present a collaborative control architecture for a robotic wheelchair with the aim of providing "assistance as required". The architecture is based on cBDI - an extension to the Belief-Desire-Intention model to support human-machine collaboration. We present results of an evaluation of the architecture in a simulated environment and conclude that collaborative control could ensure "feeling in control" even under assistance.

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Keywords: Human-Agent Collaboration; Collaborative Control; BDI systems; Rehabilitation Robotics; ROS-USARSim.

1. Introduction

Intelligent Wheelchair (IW) is presented as a solution to the lack of independence suffered by mobility impaired individuals. The term *robotic wheelchair* is used synonymously with IW. Several prototypes have been developed; control algorithms proposed[?]. However, more often than not, the user is relegated to being a *rider* rather than taking advantage of user's potential. Nevertheless, there are brain-computer-interface (BCI) driven systems taking user mental states to consideration for driving IWs[?]. For retention of residual skills, IWs need to provide "assistance as required"[?]. Most of the current approaches for control of IWs[?] ignore the basic evidence that human act independently (of the system) and are often satisfied with a good solution (which may not be optimal), a phenomenon that is called satisficing[?]. It is important that the system should not only automatically adapt the level of assistance but also perform in a way so as that the user is unable to realize that he is getting help! Could there be a way to create cognitively capable machines that given a human team-mate affect peer-to-peer interaction and collaboration? An *agent* can serve as the basis for such machines[?]. Within agent literature Belief-Desire-Intention (BDI) paradigm is widely used to achieve human-like intelligence. The BDI architecture needs to be extended to enable collaboration[?]. To that end we present cBDI - an extension to the BDI model to support human-machine collaboration. The cBDI agent is the core for a collaborative control architecture supporting "assistance as required". The control architecture: a. facilitate human-centric "decision capabilities" of the machine and b. facilitate "negotiation" in control.

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We are interested in understanding whether a collaborative control architecture could give the sense of “feeling in control”[? ?] even under assistance. We present results of an evaluation of the architecture in ROS-USARSim. The proposed collaborative controller could ensure “feeling in control”.

2. Collaborative Control Architecture

The proposed architecture is three layered (see Figure 1). User Interface facilitates communication with the human user. Superior Control Layer (SCL) built around a cBDI agent provides human-centric decision capabilities including a negotiator, making collaboration possible. Local Control Layer takes care of the low level control of the hardware.

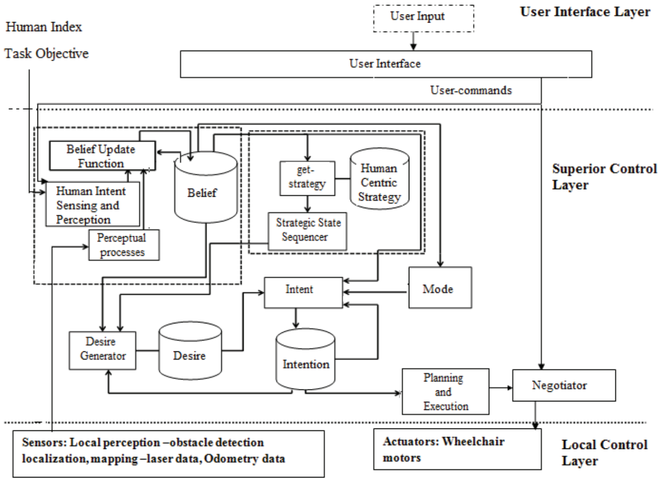

Fig. 1. Collaborative Control Architecture.

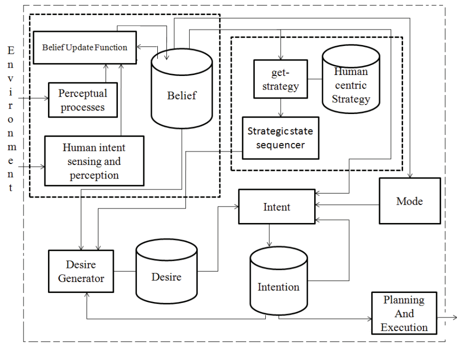

Fig. 2. cBDI Agent Architecture

2.1. cBDI: A Collaborative BDI Agent

cBDI architecture (shown in Figure 2) retains the *Belief*, *Desire* and *Intention* modules. Additional modules include *Human Intent Sensing and Perception* (HISP) and the *Strategic Planner* (SP) together with a *mode* function.
Belief:. Belief describes proprioception-localizing information about self; and the set of executable action of the agent. In cBDI, beliefs have been enhanced to include *human intent* and knowledge of human capacity.
Desire:. Desires D describe the set of goal states that the agent tries to achieve. Desires are obtained through a desire generation function, on the basis of its current beliefs and current intentions.
Intention:. Intention I is the commitment of an agent to a specific action(s) in order to actively follow a desire.
Human Intent Sensing and Perception:. For collaboration the agent should be aware of the intentions, capabilities and actions of the human team-member. The HISP module is a mechanism capable of obtaining the desired information from certain stimuli provided by the environment and translated into agent’s interaction beliefs.
Strategic Planner:. The SP is responsible for maintaining a human-centric strategy and facilitates derivation of a set of “adopted” goals; goals are based on agent’s a priori knowledge of human-centric strategies.
Belief Revision Functions:. There are three belief update functions: a. belief revision function through perception including proprioception ($self$-*aware*); b. *Interaction* and c. human-intent sensing and perception (*Human-intent*).
Desire Generator Function:. Desire generator function described here is similar to the one in classical BDI agent.
Intent Function:. The *Intent* function described here is similar with the one in classical BDI agent; however, here we have added agent’s behaviour state *value*. *value* reflects the agent’s mode.
Mode:. Mode function generates agent behaviour state based on the human capacity.
Plan Function:. The plan function generates a ordered sequence of actions to satisfy agent’s intention.

2.2. *Collaboration through Negotiation*

The cBDI agent is designed to exhibit three kinds of behaviour: collaborative behaviour, autonomous behaviour and idle/inactive state. Collaboration is activated, when agent recognizes user capability is greater than a threshold. For collaborative behaviour the negotiator provides a means of command arbitration to determine the final steering command. It is based on the user intent and take into account candidate command proposed by the cBDI agent.

3. Navigation Experiments: Performance Evaluation in ROS-USARSim

For assessment of the control architecture, ROS-USARSim is used[?]. Simulations requirements are carefully consider and appropriate models are introduced. This ensures simulation results to closely reflect reality[?]. As detailed in[?] choice of USARSim is because of its unique combination of features. USARSim is used to create an indoor environment and ROS is used to define the control architecture. P3AT robot is treated as IW and imbibes our control architecture. The 3D environment created in USARSim is seen as a 2D map using `rviz` - the ROS visualization tool.

3.1. *Experimental Set-up*

Participants were tasked with navigating to a pre-defined goal location from a start point, as shown in Figure 3. Generally accepted principles were followed for our experimental design. Prior to starting the task, participants were given a demonstration of the controls. None of the subjects were aware of the experiment's goal.

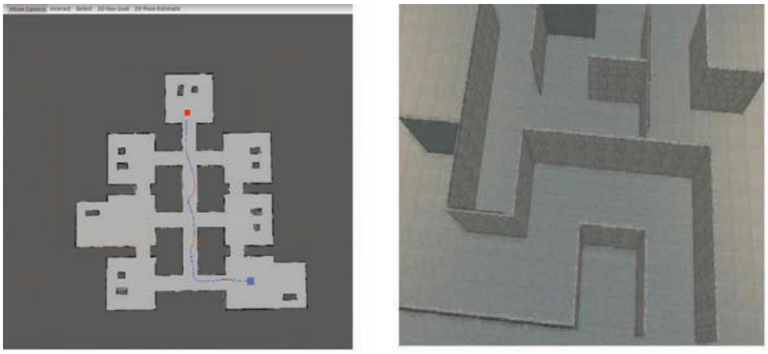

Fig. 3. Figure shows the 2D-map of the environment including a sample path. Here blue box is start and red box is the goal. Blue lines indicate path where user controls the IW; red coloured lines is where the agent initiated control. Also shown is the 3-D Indoor environment created in USARSim.

A questionnaire (inspired from MMSE[?] and IADL[?]) was prepared to estimate the cognitive score of each participant. Participants were grouped into two different categories: a. Low Cognitive Score (LCS) Group and b. High Cognitive Score (HCS) Group. Participants drive the wheelchair (P3AT robot) using arrow keys. Unbeknown to the user, control of the wheelchair was under two different methods:

I. *No assistance*: Participant controls the wheelchair movement. The user would not get any assistance from the wheelchair.

II. *Assistance*: Participant control the wheelchair movement through collaboration. Unbeknown to the user, the wheelchair through the collaborative control architecture provides assistance to the user.

Performance Metrics and Questionnaires:. Following metrics (inspired from[?]) are used to compare the effectiveness of the controller in supporting 'assistance as required':

a. *Finish Time*: Total driving time to reach the goal location is used to evaluate ease of driving the wheelchair. A lower value indicates better overall performance.

b. *Safe Margin Time*: Total time a participant crosses a *minimum safe margin* (moving too near to the obstacles) is used to evaluate wheelchair behaviour "help when required" scenarios. A high score indicates participant was unable to drive as expected. Accordingly a lower value implicates better overall performance.

We also collected subjective metric through questionnaires to ascertain if participants sense difference in the two methods of control.Our questionnaire is very close to Parikh *et al.*[?] ; they studied human behaviour during navigation through a wheelchair.

3.2. Results

12 people (seven female and five male) aged between 25 years and 47 years (Mean Age = 32.09, S.D = 8.63) completed the experiment. Participants were naive to the purpose of the experiment.

Assessment of Trajectory:. Trajectories give a scope for user behaviour evaluation. Figure 4 shows a sample trajectory taken by a participant with LCS. Unbeknown to him the agent was providing assistance. Blue coloured path is where the participant is controlling the wheelchair. The red coloured lines are where the agent initiated control. Participant showed erratic driving; yet this was within acceptable limits and the agent did not intervene. The yellow circles represent the part of trajectory where quality of driving dropped below acceptable limits as 'safe margin' exceeds a threshold defined a priori; agent eventually take over control of the chair. This was until the user could give acceptable control commands. Figure 5 shows the case where the agent did not show any initiative action, even though the control was under 'assistance'. This is because participant was able to successfully control the wheelchair.

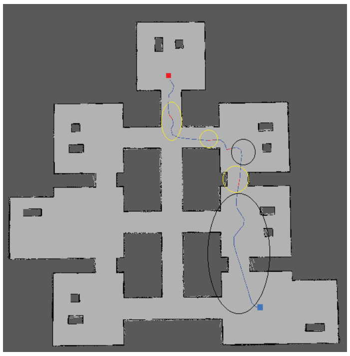

Fig. 4. Trajectory taken by a participant with low cognitive score during 'assistance' control.

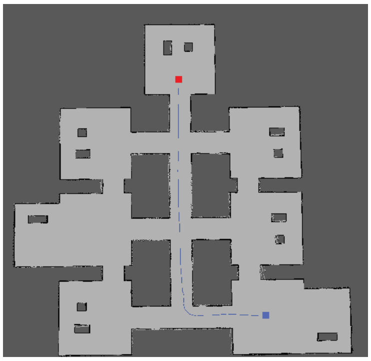

Fig. 5. Trajectory taken by a participant with high cognitive score during 'assistance' control.

Assessment of User Performance:. Table 1 provides descriptive statistics for "finish time" and "safe margin". For participants with LCS, "finish time" in two control methods is different. This was found to be statistically significant. $F(1,9) = 13.022, p = .007$. Under "assistance" control, interaction between groups and finish time is not significant, $F(1,11) = 0.833, p = .383$. There is no difference of finish time under "assistance" for the two groups of users. However, finish time under 'no assistance' for the two groups of users is different. This was found to be statistically significant, $F(1,11) = 16.77, p = .002$. There is a difference in safe margin time for the two groups of participants in "assistance" control. This was found to be statistically significant $F(1,11) = 5.342$, p <.05.

Table 1. Mean and Standard deviation for 'finish time' and 'safe margin' in seconds.

Control Method	Finish Time (in secs)		Safe Margin (in secs)	
	LCS Group	HCS Group	LCS Group	HCS Group
No assistance	153.48(32.42)	89.65(21.89)	47.60(12.81)	23.14(15.45)
Assistance	78.68(33.12	66.67(8.30)	13.4(11.26)	3.42(2.49)

Assessment of participant feedback:. 83.33 % of users reported no difference in driving the wheelchair (under two control methods). Participants with LCS could not make out difference of driving in the two control methods. Five out of seven participants with HCS reported driving the wheelchair in two control method as same. The Wilcoxon signed rank test shows that groups and their assessment of robot control is significant ($z = -3.153, p < .05$).

3.3. Discussion

Users with LCS and HCS had very similar “finish time” for “assistance” control. This was expected as the architecture was designed to take-over whenever the user performances fall below a threshold. The control architecture ensured that users finish around the same time; with the architecture requiring more interventions for users with LCS. Even though there exist a difference in safe margin time in “assistance”control for two group of participants, LCS user performed nearly same as to HCS user. Interestingly, participants do not sense difference between “assistance” control and “no assistance” control. Architecture was able to give the sense of “feeling in control”.

4. Conclusions and Future Work

We have proposed and evaluated a collaborative control architecture for an IW. The architecture is based on an extension to the BDI model to support human-machine collaboration. The collaborative control architecture ensured “assistance as required” and “feeling in control”, enabling people with LCS to drive the wheelchair safely. We have found that even a person with HCS gained from the collaborative control architecture. As far as we are aware, this is the only BDI based collaborative control architecture ensuring “feeling in control”. The architecture holds promise in applications where the user’s commands are prone to errors. The architecture would prevent the agent from acting erroneously. This is particularly true for BCI, where low information rate makes it difficult to control a powered wheelchair efficiently. Embedding the control architecture in a BCI driven wheelchair is part of ongoing research.

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