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User Modelling in Adjustable Control System

Thi-Hai-Ha Dang and Adriana Tapus

Robotics and Computer Vision Lab

ENSTA-ParisTech

828 Blvd des Marechaux, 91762, Palaiseau, France

Email: {tdang; adriana.tapus}@ensta-paristech.fr

Abstract—A good adjustable control system is a system that can adapt its behaviors according to the user’s state over time. While most researches in Human-Robot Cooperation focus on making the robotic system more efficient and effective in task accomplishment, we argue that very few works tried to model the human operator. In this paper, we discuss several aspects related to the human operator that we consider important for an efficient Human-Robot Cooperation. Furthermore, we present a tentative architecture of an adjustable control system, where these aspects are emphasized.

I. INTRODUCTION

Adjustable autonomy refers to dynamically adjusting the level of autonomy of an agent depending on the context. For a human-robot team the desired or optimal level of control may vary over time. For example, the human and the autonomous agent can have completely different observations that can lead to inconsistent decisions. In [9], Olsen and Goodrich discussed six interrelated metrics that can be basic to the design of human-robot interaction, especially to evaluate the autonomy of a HRI system [2]. The six metrics are presented in Table I.

TABLE I: SIX METRICS TO EVALUATE THE AUTOMONY OF A HRI SYSTEM [9]

Metrics	Definition
Task Effectiveness	How well a human-robot team accomplishes some task.
Neglect Tolerance	How the robot’s current task effectiveness declines over time when the robot is neglected by the user.
Robot Attention Demand	How much attention that a robot is demanding.
Free Time	The fraction of the task time that the user does not need to pay attention to the robot.
Fan Out	The number of robots that a user can effectively operate at once.
Interaction Effort	How hard the user interacts with the robots during the task realization.

We believe that if the robotic system can adjust its behavior during a cooperative task, task performance can be greatly enhanced and undesired events can be avoided. Some adaptive interaction strategies are mentioned in [13]. Hence, to make a Human-Robot interaction efficient, the robotic system needs to have enough information about the user.

II. USER MODELLING: DETERMINANT FACTORS

An efficient interaction is an interaction that adapts to the user’s current preferences and promotes a good task performance to achieve the goal. Interaction strategy should be consistent with the user’s preference and user’s current internal state. User’s preference may depend on the user’s expertise about the robotic system, and also on his/her personality. In the following sections, we discuss why it is so important to take into account user’s current internal state, user’s expertise about

the robotic system, and user’s personality so as to provide an adaptive interaction with the human peer.

A. Human’s Emotional State Selection For An Appropriate Autonomy

Psychologists had long recognized the undeniable role of emotional process in the adaptability of humans [11], [4]. It is also well known that emotional intelligence greatly relates to the human’s ability to cope adaptively with changing and therefore stressful situations [8], [15]. However, while emotion modelling was well studied in virtual agents and social robotics to simulate human’s emotional process [1], [18], [19], emotion-based interaction seems to have been marginally considered in human-robot cooperative tasks. Most of researches study individual phenomena of human’s emotional process (e.g., attention tunneling [13], anxiety [7]).

Yerkes and Dodson, in [14], discussed the effect of human’s arousal level on task performance. Later on, Hebb’s theory [20] was just an adaptation of the Yerkes-Dodson law, and stated that “human beings seek out an optimal level of arousal”. In Fig 1 the relationship between human’s arousal level and task performance is represented as an inverted-U curve. This means that until a certain threshold, increase in arousal level has a positive influence on task performance. When the arousal level exceeds this threshold, task performance starts to decrease.

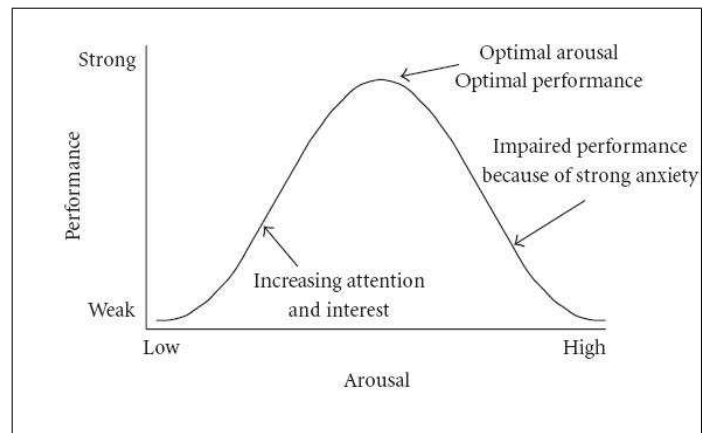


Figure. 1: Hebbian version of the Yerkes Dodson curve [17].

Put it differently, the arousal level can be divided into three emotional states as shown in Table II. When arousal level is still under boredom threshold, human can be considered as being bored by the task. When the arousal level surpasses the boredom threshold and stays under the Stress/Anxiety threshold, human can be considered as motivated in performing

the task. When task performance is optimal, the arousal level is called baseline threshold, which is recommended for the best task performance. When the arousal level exceeds the Stress/Anxiety threshold, human is stressed and his/her task performance would decrease drastically.

TABLE II: EMOTIONAL STATES IN TERMS OF AROUSAL LEVEL

Emotional State	Condition
Bored	if $ArousalLevel < BoredomThreshold$
Motivated	if $BaselineThreshold \leq ArousalLevel \leq Stress/AnxietyThreshold$
Stressed/Anxious	if $ArousalLevel > Stress/AnxietyThreshold$

Moreover, it was shown that task performance is strongly dependent on user's skill level, personality, trait anxiety, and task complexity [22], [23], [24].

Therefore, it is important to take into account the emotional states of the human partner during human-machine cooperation, so that the machine (e.g. robotic systems) can interact in such a way that allows the user to remain in his/her motivated state. This means that the robotic system should be able to monitor the user's emotional state, and to motivate the user whenever he/she is bored, and to ease his/her stress during the cooperation.

Several researchers in adjustable autonomy already considered this element in their work and two examples are presented below. In [13], when discussing some problems of Human-Machine cooperation, specially attention tunneling and perseveration behaviors of the human operator, the authors suggested various solutions to solve these problems, mainly involving adaptive interaction of the robotic system according to the human operator's internal states.

Moreover, the authors in [7] designed a robotic-based basketball game that adapted the game difficulty level in terms of the player's anxiety level. Their experiment shows that by adapting robot's behavior to the anxiety level of participants, task performance was enhanced for most participants.

In this context, we argue that human's internal state is a very important information required by the robotic system during the interaction/cooperation with the human peer. We posit that by applying some knowledge from psychology about human's emotional state, we can customize/adapt the robotic system to fit the user's internal state and thus contribute to a more appropriate human-robot interaction in a cooperative task.

B. User's Proficiency About The Robotic System

In [26] a relation between social-demography and user acceptance towards assistive technology is depicted, and it is clearly shown that user acceptance towards assistive systems is superior when the user has higher education and/or technological experience. User acceptance also shows to be positively correlated with the felt ease of use that user has towards the machine.

Some research works in HRI can be cited as examples of how important human's knowledge about the robotic system's capabilities is for an efficient Human-Robot cooperation. In [3], the authors discuss about Human-Robot Team performance

under stress, and they notice that when human operator doesn't know what, how, and why the robot is doing what it is doing, he/she will not accept to cooperate with the robot and the Human-Robot collaboration will just fail. Moreover, the main challenges in human-robot cooperation are presented in [13]. One of the main challenge, in such systems, is to avoid situations where the operator and the decision algorithm "do not understand each other".

To design a better system, we suggest that user's understanding of the system should be added as a parameter so that the control of the system can be adjusted to his/her level. We also believe that an effective adjustable autonomy minimizes the necessity for human interaction, but also maximizes the capability for humans to interact at whatever level of control is most appropriate for any situation at any time.

C. Why Personality Is Needed In Adjustable Control System?

In behavioral psychology, personality refers to the patterns of thoughts, feelings, social adjustments, and behaviors consistently exhibited by an individual over time that strongly influence their expectations, self-perceptions, values and attitudes, and predicts their reactions to people, problems and stress. Lots of researches in psychology have been carried out to study the effect of personality in team performance. Works presented in [28], [29] suggest that team performance in creative tasks can be maximized if members' personality (evaluated in terms of Big Five Personality Traits [25]) meet the optimal pattern consisting of moderate levels of Extraversion, high levels of Openness to Experience, and high levels of Conscientiousness. Moreover, the authors in [27] have studied the effect of group's personality pattern in cooperative task and found that each dimension of Big Five personality has a different effect on group's performance in cooperative task, such as Extraversion influences tasks that do not enforce very short time constraints, Openness to Experience has impact on search tasks, while Agreeableness was important for tasks where tight collaboration was required.

Several reseraches in social robots, found that personality is an important factor in HRI. AIBO robot with personality has been perceived as more intelligent and attractive by human with complementary personality to the personality of the robot during an interaction-for-fun session [5]. Assistive robot ActivePioneer with personality has been considered as more effective by people with the same personality to the personality of the robot during rehabilitation sessions [12]. Human beings find the interaction more interesting and more engaging when interacting with a robot system that is not only technically robust, but also socially adapted in terms of interaction. When people are to interact/control/use tools, with time they establish some sort of connection with these and begin attributing personality traits to them [10].

Therefore, we consider that the personality plays an important role and should be part of the system.

Based on all the discussed issues, we posit that a formal model on the reasoning and the representations of the human's intentions, goals, emotional states, personality, and knowledge is needed. In this context, the human operator needs to be included in the control loop and this can be done by integrating a model of the human at a lower level of the system.

In the following section, we present our attempt to design a generic adjustable control system, which takes into account the three aspects of the user in its adaptive action strategies.

III. JARVIS SYSTEM ARCHITECTURE

This section describes our system called Jarvis - an adjustable control system, that can also provide social interaction with the user in order to make him/her engaged in the task and more productive at the same time. Its main feature is to enable the system to adapt its autonomy accordingly during the mission and to engage human in the task in case of disengagement. Jarvis remains a system serving human as a tool to accomplish a task or a mission (e.g., a car driving system, search and rescue system, etc.).

In order to cooperate with human in a mission, Jarvis should be able to manage several kinds of information, for example: information about the mission, the current situation, and its human partner. For example, a driver assistive system should have information about the destination, its current position, the states of the vehicle (e.g., fuel, motor's performance, speed), the environmental external factors (e.g., weather, pedestrians), and the state of the driver. A search and rescue system, on the other hand, should also have information about the object/subject to search, its current position and states (e.g., power, components' states), current environment, and the state of its human operator. Figure 2 presents general architecture of Jarvis taking into account this kind of information.

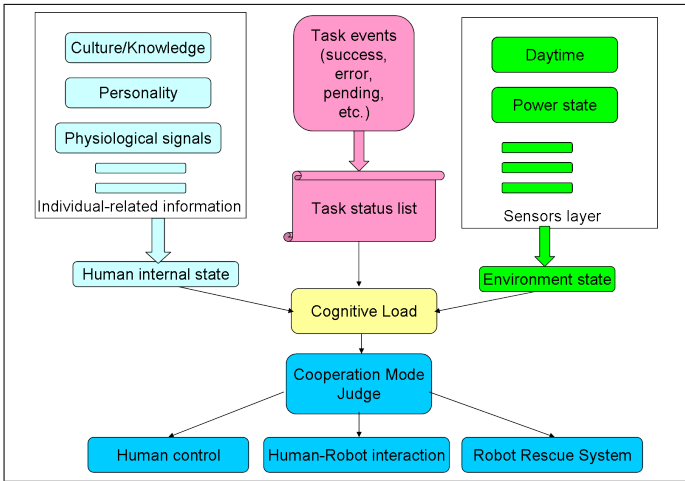


Figure 2: Jarvis' architecture.

In a normal condition, human operation is supposed to control the robotic system in order to execute the task at hand and thus accomplish the mission. The adaptation of system's autonomy happens when human operator is not in the condition to carry on the task or is overloaded. In order to detect when adaptation is needed, Jarvis has to continuously check the human's emotional state and/or human's Cognitive Load (i.e., workload). In the next sections, we will discuss on how Jarvis obtains these informations and on its adaptive strategies.

A. Calculation Of Human's Emotional State

Taking into account the human's emotional state can be considered as the most important aspect in Jarvis. By knowing

the state of its user, the system can adapt its behavior to fit its user's current state. As presented in Table II, several physiological indicators need to be measured, such as thresholds, current physiological state. Thresholds (including Stress threshold, Anxiety threshold, baseline threshold, boredom threshold) are to be collected and serve as parameters of Jarvis before the effective Human-Jarvis cooperation. Human operator's physiological state is collected in realtime during his/her performance. When undesired state is detected (e.g., the human is bored/stressed/anxious), Jarvis can execute a more engaging Human-Robot Interaction strategy in order to drive the human's emotional state into a desired state (e.g., motivated).

To identify the current emotional state of the human operator, Jarvis needs to calculate his/her current arousal level, as suggested in Table II. Researches interested in processing human's physiological signals already showed that it is possible to calculate arousal level of human user from his/her physiological signals (such as heart rate, skin conductivity, blood volume pulsation), as presented in [30], [31]. So, during the cooperation, the human operator will be wearing sensors that allows to measure and send his/her physiological signals in realtime to the Jarvis system. From these signals, Jarvis calculates user's arousal level and then determines his/her emotional state by comparing the arousal state with the appropriate arousal thresholds (including boredom threshold, baseline threshold, stress/anxiety threshold).

B. Calculation Of Human's Cognitive Load

Jarvis has to manage different kinds of information, including human internal state, on-going tasks execution, and environmental state. From the three sources of information, Jarvis calculates the current Cognitive Load of the user, so as to know if he/she is overloaded in order to propose assistance. Too much simultaneous tasks to process, high stress level, or attention tunneling state are some of the example of overload Cognitive Load.

To calculate Cognitive Load at time t , C_t , Jarvis needs information about (1) $Arousal_t$: human operator's current arousal level, and (2) the list of current tasks T being executed at time t where each task ta_i is associated with a difficulty level D_i .

$$C_t = Arousal_t \times \sum_{i=1}^n (ta_i \times D_i)$$

where n is number of current tasks that the user has to execute at the moment.

The difficulty level of each task is predefined based on the user's experience and is adjusted along the time according to the environmental conditions. When environmental conditions (for example: weather, fuel level, obstacles) become favorable for a task execution, the task difficulty level will be lowered down; if the environmental conditions change in a unfavorable way to the task execution, the task difficulty level will be increased.

C. Adaptable Action Strategies Upon Human Operator's State

Jarvis is equipped with a Cooperation Mode Judge that helps it to decide what to do upon either current Cognitive Load level and/or human's current emotional state. These strategies include Human Control, Human-Robot Interaction, and Robot Rescue.

- The Human Control is selected when there is no problem emerged in the system, and its user can control the whole system (for example, driving the car correctly). In this mode, the user can also ask Jarvis to take control of the system (doing the task) partially or entirely, supposing that he/she can take the control back whenever he/she wants to.
- The Human-Robot Interaction strategy will be executed if Jarvis detects problems in the system, such as a heating system failure, a sudden obstacle on the road, or its user is getting tired (e.g., after driving the car for a long period of time). This strategy is favored when the problems are repairable, i.e. human special attention can solve the problem. This is where Jarvis acts in such a way that fits the social preferences and personal preferences of the user (i.e., his/her personality).
- The Robot Rescue strategy is executed when the situation is critical and endangers the user, for example the human gets too tired and sleepy while driving. When this situation is detected, Jarvis has to execute the Rescue plan, for example, manage to find a solution that puts the user in a safe state.

IV. CONCLUSION

In this paper, we discussed several elements needed to design an adaptive autonomy for robotic systems. We believe that the adaptive autonomy should consider several types of information about the users, from short-term informations to long-term ones. While the user's current internal state can help to adapt the system's behavior to avoid human's error, user's experience can suggest to the robotic system about how often it should report to human operator about its plan. Additionally, the user's personality can help to alter the robotic system in such a way that renders the interaction during the task more enjoyable and more engaging to the user. Based on all the previous elements discussed, in future research we plan on tackling hard issues such as: monitoring and situation awareness; mission criticality; modelling and predicting behavior; reasoning about communication; and prioritized tasking.

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