Task planning for Human-Robot Interaction

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Abstract— **Human-robot interaction requires explicit reasoning on the human environment and on the robot capacities to achieve its tasks in a collaborative way with a human partner.**

This paper focuses on organization of the robot decisional abilities and more particularly on the management of human interaction as an integral part of the robot control architecture. Such an architecture should be the framework that will allow the robot to accomplish its tasks but also produce behaviors that support its engagement vis-a-vis its human partner and interpret similar behaviors from him.

Together and in coherence with this framework, we intend to develop and experiment various task planners and interaction schemes. that will allow the robot to select and perform its tasks while taking into account explicitly the constraints imposed by the presence of humans, their needs and preferences.

We have considered a scheme where the robot plans for itself and for the human in order not only (1) to assess the feasibility of the task (at a certain level) before performing it, but also (2) to share the load between the robot and the human and (3) to explain/illustrate a possible course of action.

I. INTRODUCTION

The introduction of robots in our daily life raises a key issue that is “added” to the “standard challenge” of autonomous robots: the presence of humans in its environment and the necessity to interact with them. Clearly, the human should be taken explicitly into account in all steps of the robot design.

We are conducting research on robot decisional abilities taking into account explicit reasoning on the human environment and on the robot capacities to achieve its tasks in such a context.

This paper focuses on organization of the robot decisional abilities and more particularly on the management of human interaction as an integral part of the robot control architecture. Such an architecture should be the framework that will allow the robot to accomplish its tasks but also produce behaviors that support its engagement vis-a-vis its human partner and interpret similar behaviors from him.

Together and in coherence with this framework, we intend to develop and experiment various task planners and interaction schemes that will allow the robot to select and perform its tasks while taking into account explicitly the constraints imposed by the presence of humans, their needs and preferences.

Section II discusses briefly related work. Section III draws a general view of the framework that we propose. In section IV and V we discuss new human-interaction related issues in symbolic action planning as well as in motion planning. The last section presents an application that will serve as an implementation and validation testbed.

II. RELATED WORK

A number of contributions in Human-Robot Interaction (HRI) involve a human operator who controls the robot from a distant place [17], [15], [1]. Besides tele-operation issues, the main issues that are treated in this context are mixed initiative, shared decision and adjustable autonomy. Indeed, in such context the human intervenes essentially at interpretation and decision level.

In our context the human is physically present in the vicinity of the robot, is sensed by the robot and may even participate to the task performance. In such applications, HRI takes place at different levels [14]: verbal, visual, physical, decisional, etc…

Only a limited number of papers consider the robot and the human as agents who can cooperate to achieve common goals. The current paper focuses on this particular issue. One major point is that the robot must act in a way judged as “acceptable” by humans.

In relation with this, a number of recent contributions about close interaction deal with the notion of physical and mental safety [22] or the introduction of emotions and/or cognitive models in robotic structures [6], [21].

Very often, HRI is merged into the task performance. This tends to reduce HRI to a (sometimes very sophisticated) human interface.

Our aim is to endow the robot with an explicit consideration of humans and with the ability to manage its interactions with them. This must be considered at different levels: at the architecture level as well as at the task planning and motion planning levels.

Our first source of inspiration is the Joint Intention theory (see [11], [19], [12]). It is based on the notion of commitment for team members and defines for a team the concept of Joint Persistent Goal. These definitions constitute a basis for the elaboration of cooperation schemes between heterogeneous agents (see [16] for an example). However these definitions are very general and we have tried to adapt them to our context.

One problem in the design of an architecture for HRI is the representation of humans. In fact, the attitude of a human depends on a great number of factors more or less controllable. A good idea is the representation of an agent with a proxy. This approach has been explored and implemented in STEAM and more recently in Machinetta (see [28], [24], [25]).

Our robot is controlled by a three layer architecture (see [2]). We discuss here below the design of the decisional level in which we introduce what we call InterAction Agents (IAAs). They are similar to proxies but are directly implemented on the robot side as a representative of a human agent. To make the interaction more explicit we have defined a complete process of establishing a common goal, achieving it and verifying commitment of all agents involved. Besides, relevant IAA models should be devised and used in the robot planning activities. Such models will range from high-level specifications of the human abilities and preferences to geometric attributes such as position, posture or visibility regions.

III. DECISIONAL SYSTEM FRAMEWORK

We envision HRI in a context where two agents (a human and a robot) share a common space and exchange information through various modalities[10].

Interaction happens as a consequence of an explicit request of the human to satisfy a goal or because the robot finds itself in a situation where it is useful if not mandatory.

In both cases, the robot has a goal to satisfy. An important issue is the notion of engagement, a process in which the robot will have to establish, maintain and end a connection with a human partner. Besides conversation, such a process will provide a framework for robots performing tasks in a human context.

This will cover goal establishment, selection of an incremental refinement of the task that is intended to achieve it. The establishment of a connection between the human and the robot will serve to the robot follow human task performance and to monitor his/her commitment to the common goal, and even to influence it.

In order to deal with the various aspects that the decisional kernel of the robot has to do, we have designed a decisional framework which consists of several entities, having each a specific role. The global view is illustrated by Fig. 1.

The HRI we consider in this paper is the common achievement of tasks by two agents - a robot and a human - in order to satisfy a joint goal.

The Agenda: Several goals may be sought at a given time, involving possibly several persons. At any moment, there may be several active, inactive and suspended goals. The Agenda manages the current set of robot goals. It ensures the consistency between active goals, and determines their priorities, and their causal links. Based on data provided by the Supervision Kernel, the Agenda determines the relevance of goals and decides to create, suspend, resume or abandon a goal. When a goal is created, it may be associated to the robot alone or to a "team" of agents.

The IAA Manager: The humans encountered by the robot are represented by entities called "InterAction Agents" (IAAs). An IAA is created dynamically and maintained by the "IAA Manager".

The Task Delegates: The set of active goals entails the incremental execution of a set of tasks in interaction with humans. Each task corresponding to an active or a suspended goal is represented by an entity called "Task Delegate" that is in charge of monitoring the progress towards the goals of both the robot and the IAA and to assess the level of commitment of the associated person. To do so, it controls a set of "Observers" (OBs).

The Robot Supervision Kernel: The Robot Supervision Kernel is responsible of all tasks selection, refinement and execution. It maintains an integrated view of all robot activities and ensures a global coherence of robot behavior. It is the only entity that can send execution requests to the functional level.

For each new active goal the Robot Supervision Kernel creates a Task Delegate, selects or elaborates a plan and allocates the roles of each team member. Notice that the creation of the Task Delegate is combined with the creation of an OB for each human involved in the task performance.

For all the other active goals, the Robot Supervision Kernel has already a plan and is in charge of the execution of the robot part. Whenever an elementary action is performed, the Robot Supervision Kernel forwards this information to all active Tasks Delegates.

Depending on the context, the planning process can be more or less elaborated. Indeed, the presence of humans in the environment raises new issues in the classic motion, manipulation and task planning. We are developing, in coherence with the architecture presented here, a motion planner [27], [23] that can be used not only to plan safe robot paths, but also to plan good, socially acceptable and legible paths and a high-level task planner [20], [10] that is able to deal with constraints imposed by the presence of humans, their needs and preferences.

IV. HIGH-LEVEL SYMBOLIC PLANNING

Context: The main point here is how high level robot planning skills should be developed in order to allow it to act as a companion.

In such a scheme, the robot plans for itself and for the human in order:

- not only, to assess the feasibility of the task (at a certain level) before performing it
- but also, to share the load between itself and the human
- and also, to explain/illustrate a possible course of actions.

We concentrated on a planner that is able to take into account "social constraints" and to synthesize plans compatible with human preferences, acceptable by humans and easily legible in terms of intention.

Representing social constraints: We have elaborated a formalization where both the robot and the human are represented in terms of actions they can perform. In a first tentative, we have limited our representation to STRIPS-like domains.

A "team" composed of two "actors" (the robot and a human) can be represented as: $(A_{human}, C_{human}^{ctxt})$ and $(A_{robot}, C_{robot}^{ctxt})$ where A_i are sets of actions and C_i^{ctxt} are their context-dependent associated costs. The costs

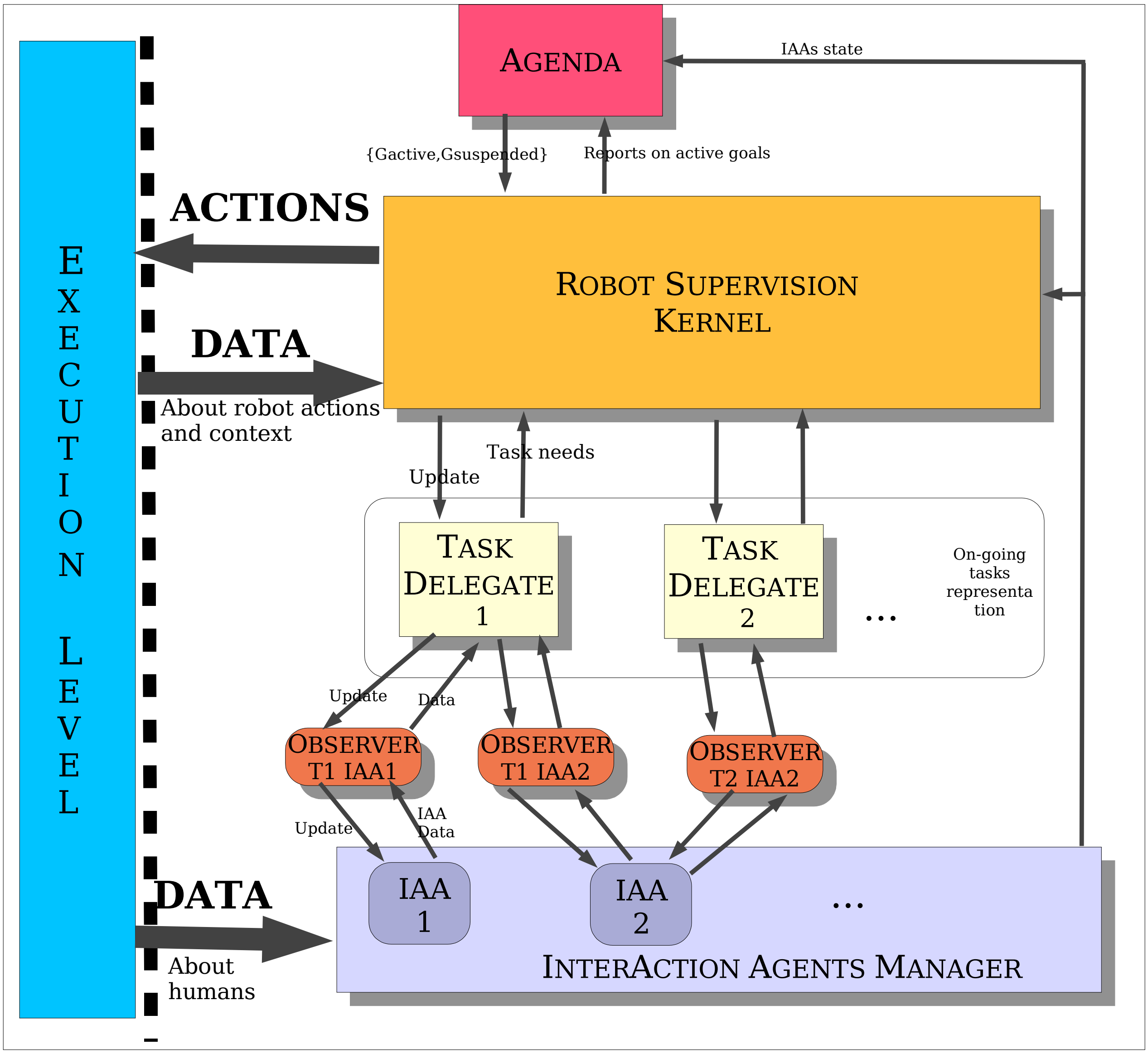

Fig. 1. Decisional framework for a HRI-enabled robot

represent the difficulty and the pleasure an actor has in an action realization.

Besides, in order to take into account issues linked to the acceptability of a plan by a human, we associate a cost to certain situations and to certain actions sequences in order to model states and action courses that might be unacceptable or inconvenient for the human.

Preliminary tests have been conducted based on a HTN (Hierarchical Task Networks) planner SHOP2[1] mainly because it permits to specify costs for each action and it can produce plans with the least total cost.

Examples involved domestic like situations where the robot essentially performs fetch-and-carry and cleaning tasks in interaction with a human. This study have confirmed [20], for us, the relevance of this level and of the types of considerations that should be taken into account when building robot plans in this context. This should be the basis for task planning but also, as we mentioned, role allocation, dialogue about plans, human-robot 'negotiation',

V. HUMAN-AWARE MOTION PLANNING

The presence of humans in the environment raises also new issues to the classic motion-manipulation-task planning [8], [23].

We claim that a human-aware motion planner must not only elaborate safe robot paths, but also plan good, socially acceptable and legible paths. Our aim is to build a planner that takes explicitly into account the human partner by reasoning about his accessibility, his vision field and potential shared motions.

While several contributions take into account safety criteria (distance, inertia), very few papers, in our knowledge,

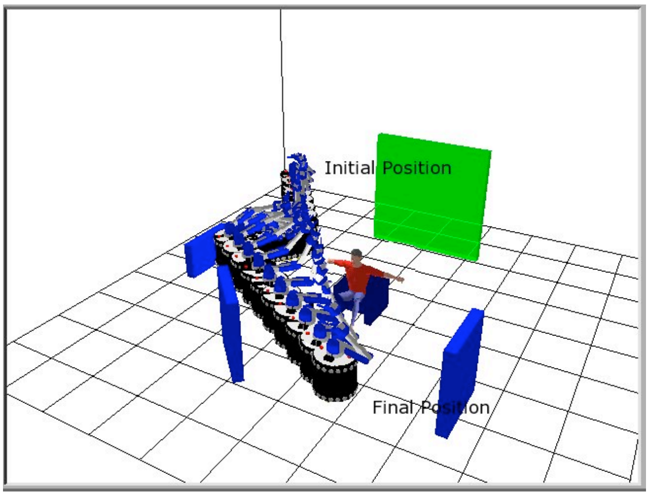

Fig. 2. A path produced by a conventional planner

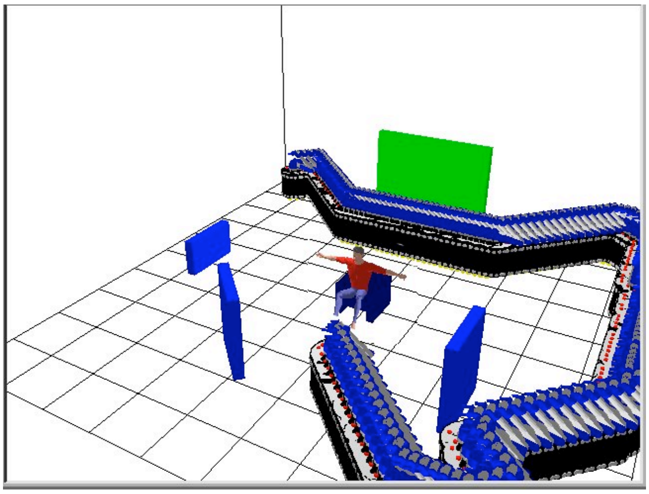

Fig. 3. A path that takes explicitly into account the human presence and preferences. The algorithm conducts the robot to approach the human in face to face situation.

deal with comfort and legibility issues and often in an ad hoc manner. We believe that our approach can be more generic. We introduce two criteria to the motion planning stage to ensure safety and comfort. The robot must take into account these two criteria at the planning stage along with the more common aspects of path planning, i.e. obstacle avoidance and shortest path finding. The first criterion, called security criterion, mainly focuses on ensuring the safety by controlling the distance between robot and human. The robot, if possible, must avoid approaching too much to humans, and in some cases a certain perimeter around humans must not be allowed to pass through. The sudden appearance of the robot from behind an obstacle may cause fear and surprise especially if the obstacle is close to the human.

Another criterion, called visibility criterion, takes into account the human's field of view and robot's relative position relatively to it. Humans tend to feel safer and more comfortable when the robot is in their sight. It is preferable that the robot chooses a path as visible as possible to ensure this criterion. The visible and invisible zones can be ranked proportionally to the minimum angular deviation from the human's gaze. Indeed, we can consider this visibility criterion that is proportional to the "human's effort to keep the robot in his sight by turning the head or the body".

Note that other aspects should be taken into account like speed (time to contact) and acceleration of the robot (or a part of it) particularly when it is in the close vicinity of the persons.

We are investigating various minimization criteria based on a weighted combination of distance, visibility and comfort for computing a satisfactory path and velocity profile. Preliminary results with a comparison to the conventional planner are shown in Fig. 3.

VI. AN APPLICATION CONTEXT

One application on which we envisage to implement and test the proposed approach is an interactive tour-guide robot called Rackham (Fig. 4). Let us first briefly introduce it.

Rackham: Rackham[9] has been designed as a new tour-guide robot. Besides robustness and efficiency in the robot basic navigation abilities in a dynamic environment, our focus was to develop and test a methodology to integrate HRI abilities in a systematic way.

To test and validate our developments, we have decided to bring it regularly (two weeks every three months) to a museum in Toulouse. Rackham has already been used at the exhibition for hundreds of hours (May 2004, July 2004, February 2005, May 2005), accumulating valuable data and information for future enhancements. The project is conducted so as to incrementally enhance the robot functional and decisional capabilities based on the observation of the interaction between the public and the robot.

A number of features have been installed for HRI:

- the detection of dynamic "obstacles",
- a vision-based face detector[7],
- a 3D animated head with speech synthesis[4],
- displays and inputs from the touch screen,
- control of robots lights.

In its current version, the emphasis has been mainly put on robustness in a dynamic environment. All HRI features currently running on Rackham have been classically encoded as event-driven automata with no explicit management of the interactions and no reasoning on human behavior. The next step is to implement the proposed framework for HRI.

Rackham desired capabilities: Here are some examples of the desired abilities:

- when left alone, Rackham should seek for people to interact with.
- Rackham should be able to detect various types of persons and adapt its behavior to them.
- Rackham should be able to manage two or more interactions in parallel.
- Rackham should be able to measure level of com-

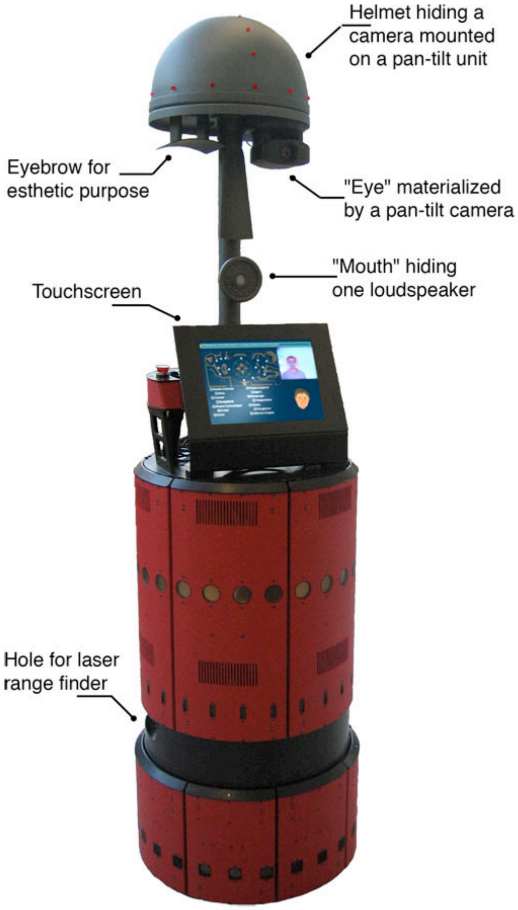

Fig. 4. Rackham: a tour guide robot

mitment of its human interactors and should react accordingly; for instance, detecting that the guided person follows slowly or is no more interested by the tour.

There will be various types of IAA corresponding to the different types of persons that Rackham might encounter: *passer-by*, *visitor*, *operator* will have their specific abilities and preferences. Rackham will behave and interact differently with them.

VII. CONCLUSION AND FUTURE WORK

In this paper we have presented a decisional framework designed for robots operating in a human environment. Our objective was to provide a management of human interaction that can be seen as an integral part of a general robot control architecture. This was done in order to provide a principled way to deal with HRI.

We also intend to use the developed approach as a framework in which we will develop and experiment various task planners and interaction schemes that explicitly consider human abilities and preferences.

The next steps will be a further refinement of the framework proposed here and its implementation on a physical robot.

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