Comparison of AI-based task planning approaches for simulating human-robot collaboration

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Abstract. Today, increased demands for personalized products are making human-robot collaborative tasks a focus of research mainly for improving production cycle time, precision, and accuracy. It is also required to simplify how human-robot tasks and motions are generated. A graphical flow control-based programming can be one of such methods. This work investigates whether the graphical approaches (e.g., using RAFCON) yield a better real-time simulation or not compared to agent approaches (e.g., using MOSIM-AJAN). This work may support the agility of the digital manufacturing process by enhancing the efficiency of human-robot collaboration.

Keywords: task planning, graphical human-robot programming, virtual manufacturing, shared autonomy

1 Introduction

Today, increased demands for personalized products are making human-robot collaborative tasks a focus of research. Predictable human behavior would help robots to adapt tasks for assisting human workers dynamically. In particular, time-dependent process flow requires agile and intuitive high-level planning that may include graphical representation. Analysis of time dependency, e.g., in the assembly process, is crucial for reducing cost and improving efficiency. Moreover, harmonizing how humans and robots interact in collaborative planning plays a crucial role for efficiency of smart workplaces. Whether it is a sequential operation or simultaneous activities, the reasoning and semantic interpretations of motions and actions may cause time delay. Robots may assist the worker with tedious tasks such as inserting pins for assembling handle rods into the car body if an assembly of a pedal car in a hybrid working place is considered. This could improve the production time by saving some time for the worker to execute the next operation. In this regard, semantic or agent-based task planning approaches have been considered for distributing tasks between humans and robots. Existing and open source frameworks such as AJAN (Accessible Java Agent Nucleus) and RAFCON (RMC advanced flow control) can be mentioned as artificial intelligence (AI)-based and graphically supported task planners. AJAN applies a web-based behavior modeling, whereas RAFCON generates a state machine-based sequence of operations. Comparing the two approaches or investigating ways to combine both approaches could help exploit the combination's best performance. However, it is not easy to select a better fitting approach for simulating collaborative tasks.

2 Related works

The approaches presented in state of the art are analyzed as simplified programming approaches for task planning and control for abstracted high-level actions. The existing approaches are discussed in the category of task planning for human-robot collaboration (HRC) in section 2.1, and methods for action representation in section 2.2.

2.1 Automated planning approaches for HRC

Pre-allocation of roles has been defined using humans' and robots' cognitive capabilities and reasoning skills in simulation environments. The process of defining problems for generating a sequence of actions that aims to achieve the desired goal is called planning (cf.[11]). If we consider difficult tasks, it is hard to find a generalized solution. Instead, other representations by decomposing into sub-level tasks should be considered using AND/OR graphs, heuristic visualization of behavior trees, or state machines. An AND/OR graphs help to quickly implement transition states with fewer nodes [9]. AI-based planners such as fast forward/downward planning system [7, 5, 8] are implemented using Planning Domain Definition Language (PDDL) semantic descriptions for progressive planning using hierarchical decomposition, including robots and human tasks.

PDDL is among the multiple expressive syntax's that define an AI Planning by decomposing tasks into sub-levels to find a solution. There are various versions of PDDL, e.g., PDDL 2.1, PDDL 2.2, and PDDL 3. Problems in PDDL comprise a domain and problem file. [11] created a web planner that solves the planning problems and visualizes the heuristic graphs. Similarly, it has been implemented in the task planning plugin of RAFCON. RAFCON[1] is a graphical planning and programming approach developed to improve the usability and acceptability of robot programming. It has an intuitive graphical interface that can be interfaced into a robot operating system (ROS). This is advantageous for planning collaborative tasks and sharing autonomy between human and robot operator [3, 14, 2].

Web-supported agent-based behavior planner so-called AJAN (Accessible Java Agent Nucleus) has been presented in [1]. According to [1], AJAN[2] is an

[1] https://github.com/DLR-RM/RAFCON
[2] https://github.com/aantakli/AJAN-editor

agent system that comprises graphical behavior modeling for interacting with linked data domains.

Behavior tree (BT) and state machines-based task plannings can be distinguished based on modularity, state transition, and transparency. In this regard, the state can be described with high-level tasks, and internal sub-tasks represent basic actions that define robots or humans' behavior in hybrid production environments. BTs are increasingly gaining more acceptance e.g., for designing games for non-player characters [6, 13]. Their scalability and ease of implementation give them a priority over hierarchical state machines. Notably, it is advantageous for certain tasks that provide success or fail output. Moreover, a hybrid approach that combines both state machine and behavior helps achieve better performance than either of the two methods. In this case, humans and robots comprise multi behavior trees and state machines in which the currently running behavior tree can be represented as state machines for detecting events and creating smooth transitions.

Furthermore, methods of distributing tasks in hybrid environments may include spatial and multi-criterion analysis. In [12], multi-criteria-based task-sharing assuming a shared working space with multiple resources has been presented. In such methods, humans and robots are considered active resources that are sharing tasks. Further, role adaptation during interaction has been presented, e.g., [10] in which a robot adapts its role based on the interaction forces and yields better performance.

2.2 Action representation for simulation

High-level tasks accomplish the desired job by executing actions that are abstracted by semantic representations. For assembly operations, basic motions such as reach, pick, move, place, insert ad others have been frequently presented. Such motions comprise a set of trajectories and constraints that can be defined by method time measurement (MTM) and robot time measurement (RTM) (for humans and robots, respectively cf.[9]). Data-driven and physics model-based approaches have been used for generating and simulating motions. In data-driven approaches, the representation of motion actions and interface instructions is crucial for simulating in hybrid environments. According to [15], data-driven motion clips have been used to simulate humans and robots. A framework MOSIM has been proposed in [4], in which the motion model interface (MMI) is being used for controlling actions concurrently or hierarchically with task description. Furthermore, combining human and robot actions in hybrid environments has been achieved using ROS frameworks, (see e.g., [1]).

In general, the current work investigates if the semantic and graphical-based human-robot programming is expressive and easily understandable by engineers who have no prior knowledge about RAFCON and AJAN. Various basic human motion simulations such as walk, reach, move, gaze, and release are semantically described for comparison. Furthermore, the current investigation remarks the need for a hybrid approach in future works.

3 Graphical planning and role distribution for Collaborative assembly

As it is highlighted in section 2, this work aims to investigate planning approaches by comparing graphical approaches for automated task planning using simulation tools for improving the process of reasoning and planning a sequence of actions in the context of HRC. Approaches considered in the current investigation include open-source tools that are using state machines and behavior tree models. In this regard, a semantic-based problem description such as Planning Domain Definition Language (PDDL) and SPARQL query are used for defining process plans. The execution of motions that apply models and constraints takes place using a robot operating system (ROS) and MOSIM's MMI. ROS establishes an interface between the high-level task plans and motion model units (MMU).

3.1 Comparison of RAFCON and AJAN features

Parameters for comparing RAFCON's and AJAN's features include expressiveness, productivity, and HRC applicability. Expressiveness shows how syntax is engaging to understand the described actions. In this context, a questionnaire consisting a syntax of an action (e.g., Listing 1.1, 1.2) is used for survey. Participants have to choose the right action from lists of ten actions. Productivity measures how accurately the user can apply the concept from a demonstrative example to define missing parameters. Applicability is the suitability of the respective lists of actions for humans and robots. These parameters are evaluated using survey questionnaires. Five basic actions such as move, gaze, reach, insert and release are used in the evaluation. The semantic definition of these motions are;

- Gaze: Focusing eyesight and movement of the head
- Insert: Physics-based translation/rotation by applying pressure
- Reach: Hand movement towards an object
- Move: Move from current location to destination (without need for locomotion)
- Release: Detach object from hand(s), palm animation

3.2 Use case description and evaluation of RAFCON and AJAN

Assuming a hybrid assembly environment for pedal car assembly, we are interested in distributing tasks between robots and human workers using semantic reasoning and automated planners. A virtual assembly environment has been implemented to simulate the scenario using existing motion interfaces that are mentioned in the earlier sections. Initially, the robot is at the assembly workplace, and the human worker is at an arbitrary position inside the room. Then, the worker is supposed to pick a tool from a resource center, carry and move it to the assembly workplace, insert it at the desired pose by applying force. Finally, the robot is proposed to insert a pin to locate the part into position. This problem is described in the RAFCON task planner and AJAN behavior tree.

Problem definition using PDDL in RAFCON - Graphical process flow control provides ways to model complicated robotic tasks. The task is often executed in small steps (blocks), and each block has predefined sets of objectives to accomplish. It provides a graphical user interface (GUI) to perform a hierarchical state machine's visual programming using the Python programming language. The visualization of a hierarchical state machine with various debugging tools provides easy and fast development of robotics tasks without deep programming skills. A PDDL based task domain and a problem description are defined in RAFCON. The task descriptions are the semantic representation for the basic motions (e.g., see Listing 1.1).

Listing 1.1. PDDL Assembly operation (e.g. Insert MMU).

```
(define (domain hrc-domain)
        (:predicates
                (hand ?h) (target ?t) (at ?h ?t)
                (force ?f) (torque ?tr) (on ?f ?t))
        (:action applyPressure
                :parameters (?target ?hand ?force ?torque)
                :precondition (and (hand ?hand)
                        (torque ?torque)
                        (force ?force)
                        (target ?target))
                :effect (hand ?target)
        )
```

Problem definition using SPARQL-BT in AJAN - In the MOSIM project [3], pedal car assembly use case has been demonstrated with AJAN behavior control. An example of Insert MMU is given in Listing 1.2.

Listing 1.2. SPRQL-QUERY Assembly operation (e.g. Insert MMU).

```
PREFIX mosim: <http://mosim.eu/vocabs/mosim-ns#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
SELECT ?hand ?target ?force ?torque
WHERE {
        ?task rdf:type mosim:Task .
        ?task mosim:part ?target .
        ?task mosim:tool ?hand .
        ?task mosim:operation ?applyPressure .
} LIMIT 1
```

[3] https://mosim.eu/

4 Result and discussion

The overall task description in the current work is that the worker looks at the part (e.g., frame). Then tries to reach the part, and moves the part to the hybrid assembly station, and applies pressure on the target object. Finally, the worker releases the part after insertion. Five basic motions such as gaze, reach, move, insert, and release are selected (see Fig. 1). The actions are described using AJAN and RAFCON tools for comparison. ROS framework offers possibilities for interfacing various packages and libraries that can be re-used for developing complicated human and robotics tasks. Also, it has a function that bridges communication between different tools, either on the same or remote network (cf.[1]). In the current work, ROS is used as a bridge for communication between graphical process flow control software (RAFCON) and Unity3D (i.e., MOSIM) scene environment. In this regard, human-robot models' action and their ability to complete a given task can be evaluated and tested in simulation without the risk of hurting human operators.

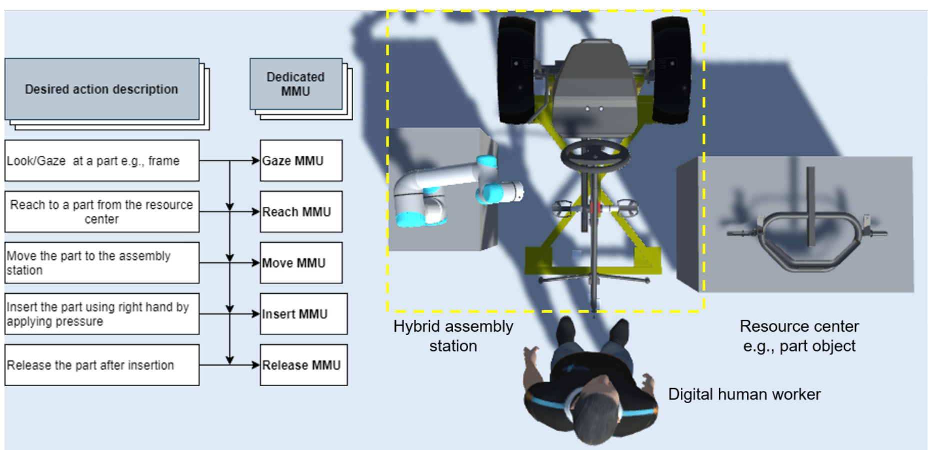

Fig. 1. Pedal car hybrid assembly virtual environment

To analyze if such tools are expressive, productive and easily applicable, survey questionnaires are given to twelve master's degree students in the Mechatronics Engineering field. All participants have responded as they have no prior experience in RAFCON, AJAN, SPARQL, and PDDL tools or languages. Based on the task and motion description applied in MOSIM, they are requested to choose from the lists of AJAN and RAFCON programming for the five basic motions described in Fig. 1. According to the result analysis, more than half of the participants able to correctly respond to PDDL based problem descriptions. In the same manner, quarter of the participants correctly answered the action lists described using SPARQL. To be more specific, more than half of the participants vote for PDDL based task descriptions for expressiveness, productivity and applicability than SPARQL based action descriptions. This may reflect that PPDL based action descriptions are more expressive and easily understandable for engineers with basic programming knowledge. In smart and hybrid manufacturing, semantically represented action descriptions may help to improve engineers' involvement in automated reasoning and task planning. However, both of the investigated approaches have shown pose applicability issues for engineers with mechanical and industrial engineering background.

5 Conclusion

To conclude, a graphical approach has been used to create intelligent and automated task/action planning in virtual HRC environments. Graphical approaches may be considered easy and reliable for HRC tasks focusing on step-wise objective completion. Moreover, it may allow planners in the context of HRC to quickly implement AI-based reasoning and planning models. Ultimately, it may also simplify how humans and robots dynamically share tasks and roles with little knowledge of programming. This may make planners to concentrate more on a solution to a problem rather than programming hurdles. In the future, it is necessary to develop a hybrid approach that enables people with no experience to perform better.

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