An Integrated Approach to Represent and Adapt Human-robot Collaborative Tasks

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***Abstract*—Despite recent developments in perception, processing, and actuation, robots are not able to handle many operations fully autonomously. The presence of human operators becomes necessary to recover from failures and to adapt to novelties. In this paper we propose a novel architecture that manages robot planning while giving the possibility to a human operator to intervene to modify the robot plan using kinesthetic teaching.**

***Index Terms*—Kinesthetic Teaching, AND/OR Graphs, Human-Robot Interaction, Human-Robot Cooperation**

I. Introduction

Learning from Demonstration (LfD) has been developed to allow novice users to be able to train robots. The most common teaching modalities for providing these demonstrations in robotics context include (i) teleoperation [7], (ii) perception [8], and (iii) kinesthetic teaching (KT) [1]. While using KT human operators physically guide the robot arm/body to demonstrate and teach new skills. KT is helpful to teach low-level motion actions but to extract an high level from a demonstration it is necessary a further processing that could involve manual annotation, the usage of automatic learning policies [6], or the construction of a symbolic representation through learning algorithms [5]. Furthermore, autonomous robots should be able to manage dynamically their task execution plans to efficiently cooperate with human coworkers. To address these challenges, we propose a framework that adopts AND/OR graphs to represent the task execution plan, and manages the human-robot cooperation [3] and we extended it with the possibility for the human operator to modify specific parts of the plan using KT. To preserve a natural human-robot interaction the system is integrated with a simple gesture recognition mechanism that the human can use to notify the system is intention to alter the task execution plan.

II. Method

An AND/OR graph is a graph that represents problem solving processes [2]. The hierarchical structure of AND/OR Graphs, enables to map a complex task into a tree, by segmenting the task into an array of meaningful sub-tasks with logical relationships among them. This feature allows robots to accomplish task execution by traversing through its representative tree. Therefore, given a structure know in advance, also the KT problem can be modelled into and AND/OR graph. An AND/OR graph G is a directed graph represented by the tuple $G = \langle N, H \rangle$ where, N is a set of nodes and H is a set of hyper-arcs. For a given AND/OR graph G, $H = \{h_1, \ldots, h_m\}$, where h_i is a many-to-one mapping from a set of child nodes to a parent node. The hyper-arc induces a mapping from the child nodes to the parent node. In that sense, a hyper-arc induces a logical *AND* relationship between the child nodes/states, i.e., all the child states should be satisfied simultaneously to achieve the parent state. Similarly, a single parent node can be in common for different hyper-arcs h_i. These hyper-arcs are in logical *OR* with the parent node. Comprehensive details of AND/OR graphs can be found in [4]. To model a robot task, we break the overall process to many equally structured sub-processes, where every sub-process is mapped into an AND/OR graph.All the graphs are added in a single tree and solved online. In our case the considered task consist in picking an object, inspecting it looking for defects and place it in the appropriate box. This scenario, for a single object, is described by the *Normal Graph* in Figure 1. In the presented scenario the human can intervene using KT. According to the state in which

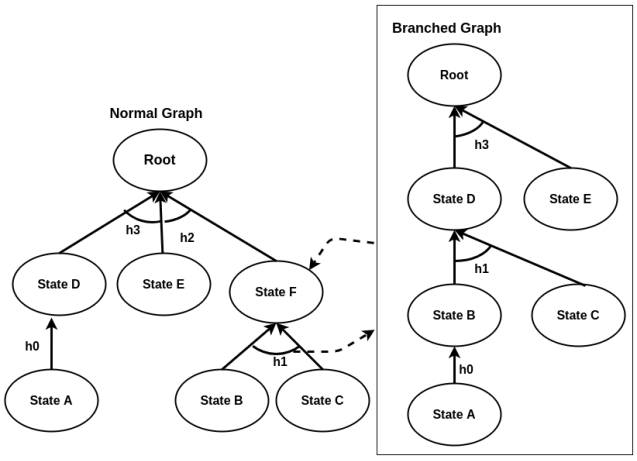

Fig. 1: (left) The normal graph that describes the inspection problem plan, (right) A branched graph that describes the KT procedure.