Enhancing Task Planning in Proactive Human-Robot Collaboration

2023 I-RIM Conference
October 20-22, Rome, Italy
ISBN: 978-88-945805-4-9
10.5281/zenodo.10722564

Enhancing Task Planning in Proactive Human-Robot Collaboration

Samuele Sandrini, Nicola Pedrocchi
STIIMA
National Research Council of Italy
Milan, Italy
name.surname@stiima.cnr.it

Marco Faroni
DEIB
Politecnico di Milano
Milan, Italy
marco.faroni@polimi.it

Andrea Orlandini
ISTC
National Research Council of Italy
Rome, Italy
andrea.orlandini@istc.cnr.it

***Abstract*—Poor coordination in human-robot collaboration can lead to inefficiencies and, more critically, to risky situations for human operators. Such coordination issues often stem from task planning that overlooks the presence of humans, who impact the duration of the robot's actions due to safety measures, *e.g.*, if they have to access the same area simultaneously.**

This paper proposes an approach that leverages information from past process executions to estimate the coupling effect between actions performed concurrently by humans and robots. We introduce a synergy coefficient for each human-robot task that quantifies how human actions affect the duration of robotic actions. We implement the proposed method in a simulated scenario where agents share a collaborative workspace. We show that our approach can learn such bad couplings, enabling the enhancement of a task planner with this information, fostering a proactive agent interaction.

***Index Terms*—Task and Motion Planning, Task Allocation and Scheduling, Autonomous Agents, Quality of Interaction**

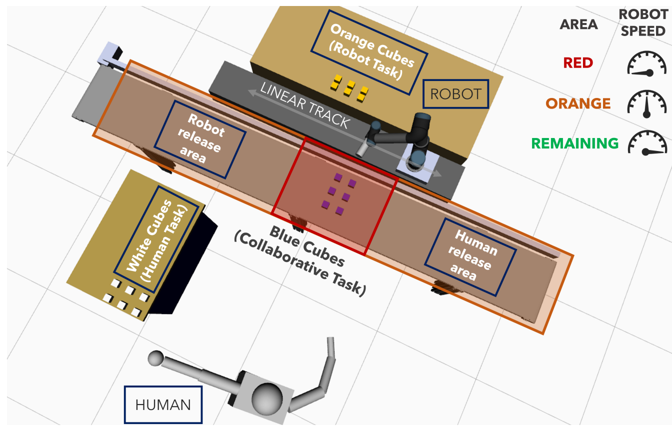


Fig. 1: Simulated human-robot collaborative workcell

I. Introduction

Human-robot collaboration is the challenge of modern semi-autonomous robotic cells, *e.g.*, for assembly/disassembly of complex parts where the coexistence of agents with different skills increases flexibility. In this scenario, ensuring the operator's safety working in a shared workspace with the robot is critical [1]. ISO/TS 15066 addresses these issues by introducing safety requirements for risk reduction in HRC. One of the collaborative methods provided by the technical specification is the concept of *Speed and Separation Monitoring* (SSM), which allows collaborative robots to operate within shared workspaces without the need for physical fencing. However, a control system must be in place to prevent collisions by adapting the robot's velocity to ensure safety.

A classic approach to *Task Planning* in robotics involves *Task Allocation and Scheduling*, defining who and when to execute tasks to accomplish a process goal. A vanilla task planner that does not proactively consider the human presence may assign to agents tasks temporally and spatially close, potentially leading to risky situations and inefficiencies.

In this paper, we propose a method to estimate from the experience of past process execution *synergy coefficients* between human-robot task pairs that represent the effect of one task over the other. The resulting synergy coefficients can be exploited in task planning and allocation methods to select advantageous task couplings.

II. Methodology

Given a set of task $\mathcal{T} = \{\tau_1, \cdots, \tau_m\}$ and a set of agents $\mathcal{A} = \{\mathcal{H}, \mathcal{R}\}$, *i.e.*, the *robot* and the *human* operator, the solution of the task planning problem is a plan π that for each task $\tau_i \in \mathcal{T}$ defines the start time and the assignment of that task i to one agent k with a binary variable (a_i^k) for each agent. For each task pair (τ_i, τ_j), a synergy term, denoted as $s_{i,j}^R$, is introduced for the robot agent. The synergy coefficient denotes the increment of the robot duration execution of task τ_i while the human performs task τ_j. We define this coefficient as:

$$s_{i,j}^R = \frac{d_{i,j}^R}{\hat{d}_i^R} \tag{1}$$

where $d_{i,j}^R$ is the expected duration of robot task τ_i^R when the human executes τ_j^H and $\hat{d}_i^R$ is the expected value of the duration of τ_i^R for all concurrent tasks τ_j^H.

We estimate both task duration and synergy coefficients from experience. Given n executions of a task τ_i, we approximate its duration with its expected value: $\hat{d}_i^R \approx \mathbb{E}[d_i^R|_{k\in[1,n]}]$ for the robot and $\hat{d}_i^H \approx \mathbb{E}[d_i^H|_{k\in[1,n]}]$ for the human operator.

Task synergy coefficients can be estimated by solving a least-square regression problem; for each collected sample k:

$$d_j^H|_k = \sum_{i=1}^{m} \delta_{i,j}^R\Big|_k s_{i,j}^R \hat{d}_i^R + T_{\text{idle}}\Big|_k \tag{2}$$

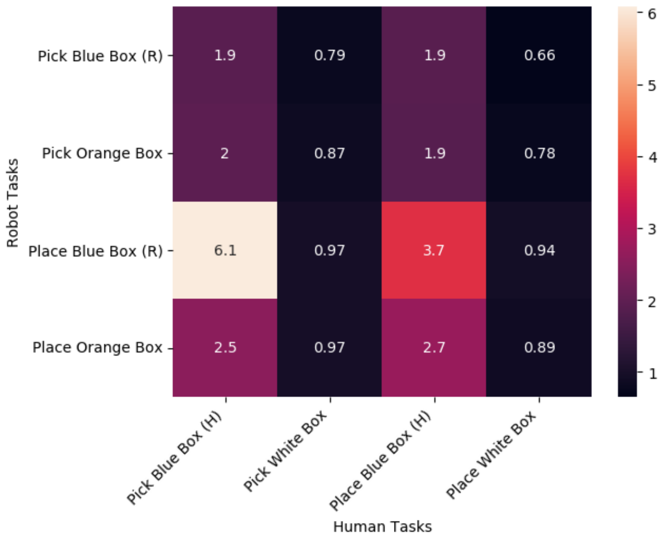
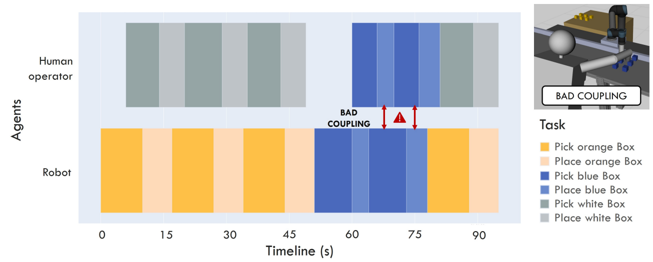
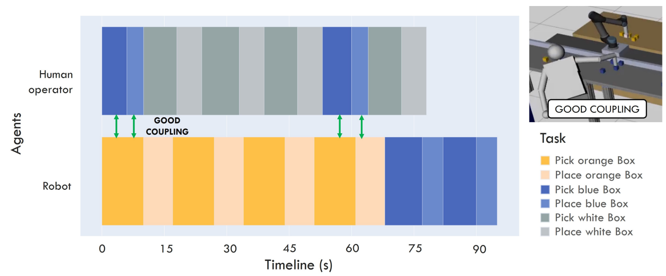


Fig. 2: Robot task Synergy Matrix



(a) Example of bad coupling: H-R Blue Boxes Pick-Place in parallel



(b) Example of nice coupling: H-R Blue Boxes Pick-Place not in parallel

Fig. 3: Comparison of task plans

where T_{idle} is the time when the robot is not assigned to any task during τ_i^H, $\delta_{i,j}^R$ is the measured ratio of task τ_i that is in parallel with τ_j respect its average duration and $m = |\mathcal{T}^R|$.

Equation (2) can be written in matrix form as:

$$\mathbf{D_j^H} = \mathbf{R^R S_j^R} + \mathbf{T}_{\text{idle}} \tag{3}$$

where $\mathbf{D_j^H} \in \mathbb{R}^{n\times 1}$ contains the human execution task durations $d_j^H|_k$, $\mathbf{R^R} \in \mathbb{R}^{n\times m}$ is the regression matrix, $\mathbf{T}_{\text{idle}} \in \mathbb{R}^{n\times 1}$ contains the robot idle times $T_{\text{idle}}\big|_k$ and $\mathbf{S_j^R} \in \mathbb{R}^{m\times 1}$ contains the synergy coefficients between to be estimated:

$$\mathbf{S_j^R} = \begin{bmatrix} s_{1,j}^R & s_{2,j}^R & \cdots & s_{m,j}^R \end{bmatrix}^T \tag{4}$$

In conclusion, the solution of the regression problem in (3) is obtained from the following:

$$\mathbf{S_j^R} = \left(\mathbf{R^R}^T \mathbf{R^R}\right)^{-1} \mathbf{R^R}^T \left[\mathbf{D_j^H} - \mathbf{T}_{\text{idle}}\right]. \tag{5}$$

III. Experimental Results

We tested our approach in a simulated case study of a collaborative workcell composed of a collaborative robot and a human operator for a mosaic composition. The robot can manipulate only the orange and blue boxes, while the person can only handle the white and blue boxes. Each agent has a dedicated object release area, as Figure 1 illustrates. The process goal is for each agent to compose a mosaic of four proprietary cubes and two shared blue boxes in its own release area. The simulation involves the planning and execution of 50 random plans with the same task-level goal, precedence constraints between pick and place tasks, and objective function (makespan minimization). The simulations were run using the ROS-based framework[1] that the authors described in [2].

After the offline phase, we estimate the synergy terms described in Section II and the results are shown as a heatmap in Figure 2. The robot tasks are placed in the heatmap rows, and on the columns are the human tasks. An $s_{i,j}^R$ element of the heatmap reports the amplification factor of the τ_i robot's average task duration when it is simultaneous to the human task τ_j. We compare the 50 pre-computed plans using the adapted makespan d_π, that is the nominal plan duration plus the additional term ($\tilde{d}_\pi$) given by coupling effects:

$$\tilde{d}_\pi = \sum_i \hat{d}_i^R a_i^R \sum_j s_{i,j}^R \delta_{i,j}^R a_j^H \tag{6}$$

Figure 3 qualitatively compares two plan solutions corresponding to the minimum ($d_\pi = 110.3\,\text{s}$) and maximum ($d_\pi = 145.2\,\text{s}$) adapted makespan defined in Equation (6).

IV. Conclusion and Future Work

We defined a synergy term that encodes the coupling effects between agent tasks. To validate our approach, we conducted simulations in an HRC application, where the positive and negative effects between tasks were easily recognisable. Results show that the proposed method can effectively learn the expected beneficial or detrimental synergy between pairs of tasks. Future work will focus on integrating the estimated synergy term into task planning.

References

[1] R. Awad, M. Fechter, and J. van Heerden, "Integrated risk assessment and safety consideration during design of hrc workplaces," in *2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, 2017, pp. 1–10.

[2] S. Sandrini, M. Faroni, and N. Pedrocchi, "Learning action duration and synergy in task planning for human-robot collaboration," in *2022 IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, 2022, pp. 1–6.

[1]Code available online: https://github.com/JRL-CARI-CNR-UNIBS/task_planner_interface