PHD title

Coopération multi-robot en espaces partagés par vision et jumeau numérique

Multi-robot cooperation in shared spaces by vision and digital twin

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Subject :

- Scientific context

Today, industrial robotics is mainly limited by safety notions, aiming at strictly limiting potential collisions with the environment. Therefore, when an active element has to interact on a common area with an industrial robot, a strict temporal and/or spatial separation is established. Multiple robots collaborating in the same space is extensively studied in the field of fleet control of mobile robots (Zajac et al., 2021), which is basically a 2-dimension problem with low dynamics, but not for industrial robots, where a 3D problem with high dynamics is involved.

It is established for a long time that basing the collision avoidance on the knowledge of the planned behaviors of each robot (Mendelson et al., 2002) is performing well. New sensor technologies (Yasin et al., 2021) allow to limit the risks during an actual cooperation between mobile robots and humans, or between robots, and are more and more applied together with deep learning (Long et al., 2018).

In parallel, digital twins of manufacturing systems (DT) and cyber-physical production systems (CPPS) concepts recent developments exhibit the potential of online evaluation and coordination of entities behaviors, enabling a rapid behavior-based collision avoidance mechanism. CPPS are considered as an interesting way to improve robustness, flexibility and efficiency of the control of manufacturing systems (Cardin, 2019), enabled by the cooperation of autonomous entities in the cyber layer (Putnik et al., 2019). DT is seen here as a virtual representation of the physical part of a CPPS, synchronized in real-time through the data flow coming from the physical part (Semeraro et al., 2021).

The scientific challenge of this thesis is therefore to propose an innovative approach to real-time control of these robots where avoidance trajectories would be computed in the cyber part of a dedicated CPPS, based on simulations of potential robot trajectories in response to the requested task performed in the DT. The definition of the tasks is meant to be based on an observation of the working space by computer vision in the physical part of the CPPS, allowing to identify the different possible positions of objects taking. Multiple simulations are then executed within the DT of each robot from these geometrical data, in order to propose a potential performance of each robot. A negotiation is then set up between the different agents representing the robots to determine the best collaborative response to the requested tasks, implemented as a multi-agent system in the cyber part of the CPPS.

The LS2N laboratory has already obtained results in the three main deadlocks that will be addressed in this thesis:

- Analysis of the position of the part: this task is based on the work of computer vision carried out by the IPI team (Langlois et al., 2018, Langlois et al., 2019). In this work, a vision module has been developed consisting of a camera and the pose estimation program with neural networks to determine the coordinates (x, y and z) and orientation angles (φ, θ and ψ) of the object to be captured.
- Coordinate processing by the DT of each robot: this task is based on the robotic path

simulation work of the ROMAS team. A simulation of the path and the final pose of the robot for gripping on ROS will allow each robot twin to determine a set of performance criteria for the gripping operation: efforts involved, obstacle management, operating time, etc. (Baklouti et al., 2021; Subrin et al., 2018)

- Decision making on the robot able to perform the operation: this task is based on the work of the CPS3 team in production systems control (Cardin, 2021). From the performance indicators reported by the twins, a negotiation is set up between the agents representing each robot in order to determine which robot actually performs the operation. The execution order is then sent to the corresponding robot with the trajectory calculated on ROS.

- Problematics

The dynamic aspect of the cooperation between several robots in the same workspace proposes a set of important scientific challenges compared to the existing state of the art. The thesis will have to answer the following questions:

- In the perception phase:
  - How to evaluate the main difficulty which resides in the potential complexity of the scene, potentially several objects of the same type or not, with partial overlaps of objects?
  - How to choose the right semantic segmentation strategy of the image, not very sensitive to the overlap of identical objects?
  - How to choose the acquisition modality to find the right compromise between speed of acquisition and processing in accordance with the accuracy of the result?
  - How to integrate depth data (estimated by calculation or measured) in pose estimation algorithms?
- In the performance evaluation phase:
  - How to dynamically simulate the trajectories of a robot from final grip coordinates?
  - How to transfer the details of the simulated trajectories to multi-agent systems for decision making and then to the real robot for execution?
  - How to integrate all these elements into a robot Digital Twin?
- In the decision-making phase:
  - How to detect potential collisions between planned and proposed trajectories by the twins?
  - How to sequence trajectory executions in order to exclude the potentiality of collisions between robots?

- Workplan

The objective of this thesis is to develop digital twins of pragmatic robots whose performance on the "computer vision" and "DT" sides would allow for a highly optimized task execution. A first step of the thesis will focus on the state of the art to identify promising avenues for the implementation of DT in an industrial context. A second step will enable the integration of trajectory simulations in the DT, including one then several robots. Finally, a last step will enable integrate the full integration of the architecture, integration computer vision developments and negotiation patterns. The computer developments associated with the development of the platform will allow, through performance indicators, to follow the overall progress of the thesis.

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