An Automated Guided Vehicle for Flexible and Interactive Task Execution in Hospital Scenarios

Riccardo Caccavale and Alberto Finzi

Università di Napoli "Federico II", DIETI, via Claudio 21, 80125 Napoli, Italy
{riccardo.caccavale,alberto.finzi}@unina.it

Abstract. We present the control architecture of a modular robotic system designed for hospital logistics. The robotics system is an automated guided vehicle that can autonomously perform tasks like carrying and delivering objects, medicines or devices, while interacting with humans in the hospital environment. Specifically, the robotic platform is designed to dock and move passive vehicles (like carts, containers, etc.), which dynamically change the robot shape and function during the task execution. We describe the overall control architecture focusing on the executive and the planning systems. We discuss the system at work in different scenarios considering both autonomous and interactive tasks.

Keywords: Service Robotics · AI and Robotics · Automated Guided Vehicles · Human-Robot Interaction · Robot Healthcare.

1 Introduction

Hospital logistic is an important aspect for the healthcare systems since it allows to optimize costs and to improve the quality of service in hospitals [1]. In particular, medical supply distribution like sterile instruments to operating rooms or food and medicines to patients, are some of the most common processes in hospitals [13]. In this context Automated Guided Vehicles (AGVs) are often deployed [3, 2] to help employees to transport these materials, making them available at the right time and at the right place minimizing errors and efforts. The capability of transporting different supplies for different purposes in a dynamic environment such as an hospital requires a robotic system capable of flexibly adapting behaviors with respect to the environmental and the contextual changes. In this paper, we present a control architecture for hospital logistic AGVs that enables flexible planning and execution of structured tasks and motions in the presence of physical human-robot interaction.

In the following sections we firstly introduce the scenario in which the work is carried out, then we detail the overall control architecture focusing on its principal components and finally we describe case studies of supplies transportation in both simulated and real hospital scenarios.

2 Hospital Logistics

The proposed robotic system is framed in the context of the "RoMoLO - Modular robots for hospital logistics" project. The project proposal aims at creating a mobile and modular robotic system capable of performing different logistic tasks in a hospital scenario. The proposed platform is an omnidirectional mobile robotic base able to hook passive vehicles with different functions: transport of sheets, drug dispensing system, telepresence vision system, etc.. The peculiarity of the system is the adoption of a single type of mobile base, which can then integrate different types of passive vehicles on wheels for multiple usage. Specifically, an automatic coupling system can dock different types of passive vehicles: the mobile robot moves under the passive vehicle, docks it, and carries it through restricted environments, replacing the manual thrust. Therefore, the same mobile robot platform can be exploited for different logistic processes, e.g. to circulate drugs, sheets and waste in the hospital, interacting with staff and patients to receive instructions or communicate information.

These vehicles, compared to the state of the art, should allow greater flexibility while containing costs since a single mobile platform may be adapted to perform several tasks. In summary, the proposed robotic system should support the following functionalities: autonomous or remote navigation, pick-carry-place different passive vehicles, physical human-robot interaction, possibility of manual driving by lightly pushing the vehicles and using the mobile robot as a force amplifier.

3 System Architecture

In this section, we illustrate the overall control architecture of the RoMoLO system (see Figure 1) describing its main components and functionalities. In particular, we first describe the executive system, then we focus on task and motion planning/execution, and finally on human-robot interaction.

Executive System. The robot behavior is managed by the *executive system* that interacts with the robotic system and the human operator. We deploy the framework by [7, 6] that provides the high-level control mechanisms needed to flexibly orchestrate the execution of multiple hierarchically structured tasks. Following a supervisory attentional system and contention scheduling approach [12, 9], this orchestration is obtained not only by enabling or disabling processes at different levels of abstraction, but also through regulations that enhance or reduce the activation of the processes. Specifically, the supervisory system can monitor and execute multiple hierarchically structured tasks exploiting bottom-up (stimuli-oriented) and top-down (task-oriented) influences. This process is managed by a control cycle that continuously updates an internal hierarchical structure, that we call *Working Memory* (WM), and a set of *behaviors* representing the overall processes involved in the execution exploiting schemata specifications represented in the *Long Term Memory* (LTM). The LTM is a repository that collects

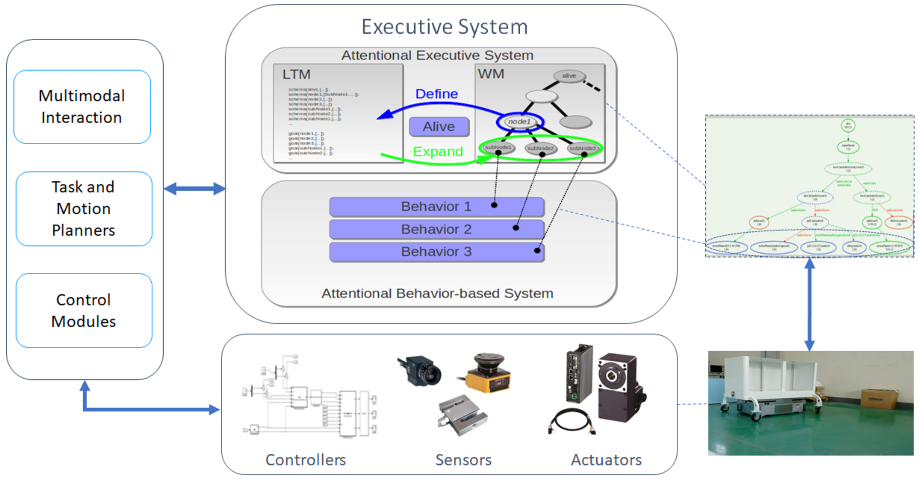

Fig. 1. The system architecture of RoMoLO. The executive control system orchestrates hierarchically decomposed tasks. It implements an supervisory attentional system that regulates the execution of multiple tasks allocated as hierarchical behaviors. Specialized modules are deployed to enable human-robot interaction, task and motion planning, low-level control.

the declarative representations of all the possible behaviors and tasks available to the robot, including collaborative activities. The WM represents the executive state of the system as an annotated tree structure, whose nodes represent processes/behaviors allocated and available for the execution, while the edges represent parental relations among sub-processes/sub-behaviors. Each node is annotated with preconditions, effects, and an activation level. It is worth noticing that, not only multiple tasks can be allocated in the WM, but also multiple methods for the same tasks may compete for the actual execution. The orchestration of multiple tasks/activities, possibly in conflicts, is obtained by exploiting attention regulations affecting the activation of the behaviors. Specifically, the most active behavior is selected following a winner-take-all approach. Additional details can be found in [7, 6, 8].

Task and motion planning and execution. The supervisory system can also invoke task and motion planning processes during the execution of the tasks. Different task and motion planning methods can be available to the system and can be associated to different contexts. The planning and execution process starts from the executive system, where high level tasks are hierarchically decomposed into sub-tasks at different levels of abstraction. The task decomposition process can allocate path and motion planning processes. For instance, Figure 2 depicts task and motion planning during the execution of simple cart-taking activity. Here, the hospital map is provided, a Dijkstra-based path planning is deployed to find a feasible sequence of waypoints, while the navigation between waypoints is performed using an RRT-based planner. In this case, task, path, and motion

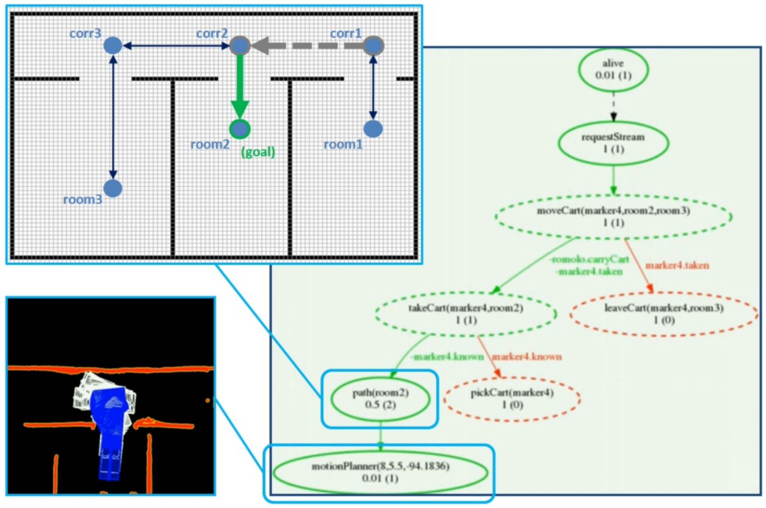

Fig. 2. A hierarchical task that invokes path and motion planning processes. Combined task, path, and motion planning can be also invoked.

planning are separated processes. In other cases, in the presence of more complex activities involving multiple carts movement with different shapes in cluttered environments, the system can also deploy combined task and motion planning engines that take into account both logical and kinematic constraints (see e.g. [10]). In this respect, we are currently investigating a RRT-based [11] combined task and motion planning. Additional details will be provided in the simulated case study.

Physical human-robot interaction system. The proposed platform should also support the human guidance (performed by hospital employees) as normal passive carts, hence physical human-robot interaction has to be taken into account. To this end the robotic system is endowed with seven load cells, which are directly integrated in the lifting system as shown in Figure 3. Four of the seven cells are positioned on the corners of the lifter allowing the robot to estimate the weight and the center of mass of the cart (purple arrows), while the other three are along the x and y and around the z axis of the lifter in order to estimate the torque and the forces applied by the cart (blue, red and green arrows). This mechanism allows the HRI module to estimate the forces due to the natural cart shifting and to isolate only the external ones (provided by the human). When relevant external forces are detected, a HRI behavior acquires the control of the robot actuators in order to make the robot compliant with respect to the human guidance. Notice that robot compliance here is needed at different levels of abstraction, not only for the robot motion, but also at the path and task level. In this respect, we are investigating how to adapt methods similar to the ones

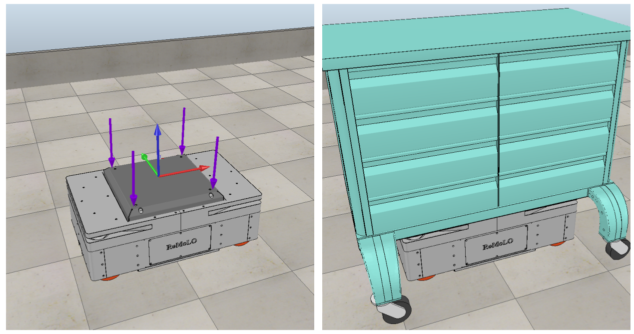

Fig. 3. Mobile robot carrying (right) and not carrying (left) a cart. Arrows represent the load cells used to weigh the cart (purple arrows) and to estimate external torque (around blue arrow) and forces (red and green arrows).

proposed in [4] for collaborative manipulation tasks along with mechanisms for mixed-initiative control with haptic feedback as in [5].

4 Case Studies

In this section, we describe the RoMoLO system at work in hospital scenarios. In particular, the aim is to illustrate the following features: structured task orchestration, task and motion planning, and human-robot interaction. The testing environment is a 15x10m closed space composed by a corridor connecting 3 rooms through 3 openings of 1.2m width (Figure 2). The AGV has four independent mecanum wheels, 4 LIDARs (one for each of the robot corner) for the obstacle avoidance and a frontal camera for carts recognition using ARtags.

Flexible Task Execution. The first case study consists of an autonomous cart transportation from a room to another. The operation is performed by providing the robot with high level commands. For instance, in Figure 4 (top right) the high level task $moveCart(marker4, room2, room3)$ is decomposed into two subtasks, $takeCart$ and $leaveCart$, which in turn are decomposed by the system till the primitive actions (Figure 4 (top left)).

The initial configuration of the task is the one depicted in Figure 4 (top left). Initially, the robot is heading towards the $room2$ and it is reaching the Landmark $corr2$ first (middle and bottom, first left). Then a sequence of four subtasks (blue ovals in Figure 4 (top right)) is executed. The robot moves towards $room2$ (sutask 2). When the cart is detected by the robot (marker $marker4$), $pickCart$ is enabled (subtask 3) to reach an approach point, move the robot under the cart and lift it. Once lifted the cart, $takeCart$ is completed and $leaveCart$ (in $room3$) is enabled. When the robot carries a cart, the robot's footprint in the motionPlanner tasks is appropriately increased. Therefore, the task affects not only logic constraints, but also the kinematic ones. Figure 4 (bottom) shows

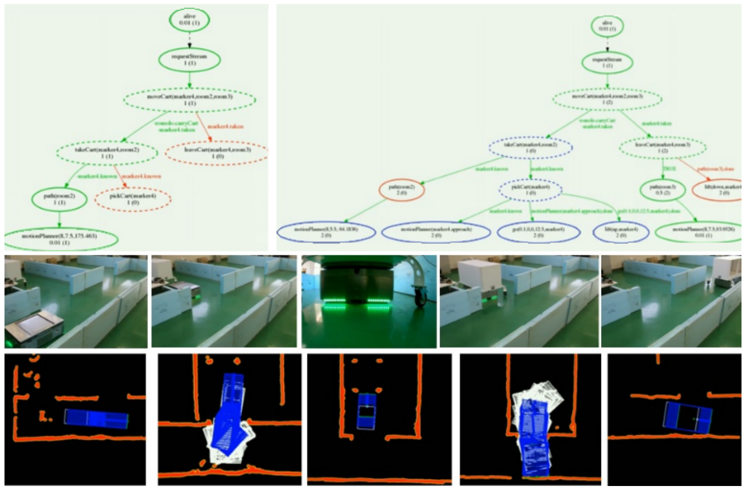

Fig. 4. *moveCart* task execution (from left to right) showing the state of the executive system on start and after the execution of four subtasks accomplished (upper right). The robot executes five subtasks (middle), while planning and mapping (lower).

Fig. 5. Cart hand guidance and compliant robot behavior.

how the robots size is updated when the cart is carried (third and fourth, bottom). Notice also that multiple tasks can be allocated and flexibly orchestrated by the executive system. For instance, during navigation additional deliveries may be on-line requested and opportunistically executed. Notice also that the WM provides an explicit representation of the activities which are planned, executed, enabled, disabled, etc., therefore it also supports task-level explainability. The robot executive status can be inspected at different levels of abstraction, while a human operator can also disable or enable activities at run-time. We are currently investigation adaptive human-machine interfaces suitable for this scenario.

Manual carriage. In a different case study, manual carriage transport was simulated using the estimate of external forces through the load cells of the lifting system. Figure 5 shows the manual transport of the trolley from room *room*3 to room *room*2. The force impressed by the human to move the trolley is between 1 and 2 kg. During the hand guidance, the robot and the human activities are supervised and regulated by executive system, this way the robot can follow the human guidance, while maintaining a compliant behavior. A specific HRI be-

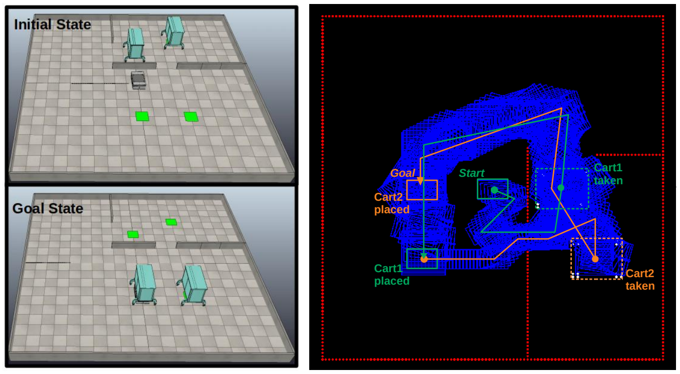

Fig. 6. Integrated task and motion planning for a two cart scenario: the robot is to move both carts (top left) outside the room (bottom left). In the generated plan (right) blue rectangles represent samples of the robot plan.

havior is activated to manage this interaction, but we are currently developing and testing more complex interactions as in [4].

Task and motion planning with two carts. In this case study, we consider a simulated scenario where two carts are present. As illustrated in Figure 4 (left) the robot has to move both carts outside of the room. Notice that this task can only be performed by moving the left cart (cart1) before the right one (cart2) because the second one is blocking the room opening. In this particular case, decoupled task and motion planning can be ineffective: the executive system may select the wrong cart to be moved first and this fault will be detected during the execution, in so inducing replanning. In order to avoid these situations, we developed an integrated task and motion planner. In particular, in the proposed approach, task and motion constraints are handled by an extended RRT-based planning system, which generates not only the robot movement, but also the tasks the robot is to execute in order to reach the goal state. In the case of the two carts, the result of this combined task and motion planning process is depicted in Figure (right) where the blue rectangles represent samples of the robot plan. In the planned sequence the robot firstly takes $cart1$ from the room leaving it in the right-position, afterwards the $cart2$ can be taken and transported outside to the left-position. The integrated plan can be generated in about 3 sec (3.11 avg and 1.67 std of 30 runs on a platform $Intel\ i5-5200U\ 2.20GHz$, 8Gb ram with a single threaded implementation). We are currently carrying out tests in simulation to assess the performance of the integrated task and motion planner in different contexts.

5 Conclusion

We presented the control architecture of a modular robotic system designed for hospital logistics. We described the overall system that enables flexible execution of multiple complex tasks. We discuss the system at work in different scenarios considering both autonomous and interactive tasks. In this scenario, we are currently investigating: i) human guidance in the presence of complex tasks; ii) human-machine interfaces for the logistic scenario; iii) methods for integrated task and motion planning, where both logical and kinematic constraints are considered.

Acknowledgement. The research leading to these results has been supported by the H2020-ICT-731590 REFILLs, MISE ROMOLO, and MIUR PON ICOSAF.

References

1. Đapić, A., Novaković, Ž., Milenkov, P.: Hospital logistics. In: 2nd Logistics International Conference. Belgrade: LOGIC. pp. 309–314 (2015)
2. Bačík, J., Ďurovský, F., Biroš, M., Kyslan, K., Perduková, D., Padmanaban, S.: Pathfinder–development of automated guided vehicle for hospital logistics. IEEE Access **5**, 26892–26900 (2017)
3. Bloss, R.: Mobile hospital robots cure numerous logistic needs. Industrial Robot: An International Journal **38**(6), 567–571 (2011)
4. Cacace, J., Caccavale, R., Finzi, A., Lippiello, V.: Interactive plan execution during human-robot cooperative manipulation. IFAC-PapersOnLine **51**(22), 500–505 (2018)
5. Cacace, J., Finzi, A., Lippiello, V.: A mixed-initiative control system for an aerial service vehicle supported by force feedback. In: 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems, Chicago, IL, USA, September 14-18, 2014. pp. 1230–1235. IEEE (2014)
6. Caccavale, R., Cacace, J., Fiore, M., Alami, R., Finzi, A.: Attentional supervision of human-robot collaborative plans. In: Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on. pp. 867–873. IEEE (2016)
7. Caccavale, R., Finzi, A.: Flexible task execution and attentional regulations in human-robot interaction. IEEE Transactions on Cognitive and Developmental Systems **9**(1), 68–79 (2017)
8. Caccavale, R., Finzi, A.: Learning attentional regulations for structured tasks execution in robotic cognitive control. Auton. Robots **43**(8), 2229–2243 (2019)
9. Cooper, R., Shallice, T.: Contention scheduling and the control of routine activities. Cognitive Neuropsychology **17**, 297–338 (2000)
10. Kaelbling, L.P., Lozano-Pérez, T.: Hierarchical task and motion planning in the now. In: Proceedings of the 1st AAAI Conference on Bridging the Gap Between Task and Motion Planning. pp. 33–42. AAAIWS'10-01 (2010)
11. LaValle, S.M., Jr., J.J.K.: Randomized kinodynamic planning. In: 1999 IEEE International Conference on Robotics and Automation. pp. 473–479 (1999)
12. Norman, D.A., Shallice, T.: Attention to action: Willed and automatic control of behavior. In: Consciousness and self-regulation: Advances in research and theory, vol. 4, pp. 1–18 (1986)
13. Ozkil, A.G., Fan, Z., Dawids, S., Aanes, H., Kristensen, J.K., Christensen, K.H.: Service robots for hospitals: A case study of transportation tasks in a hospital. In: 2009 IEEE international conference on automation and logistics. pp. 289–294. IEEE (2009)