# Coverage Path Planning for a Fleet of Industrial Cleaning Robots

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## 1. Introduction

One of the fundamental applications of autonomous robotic platforms is to perform coverage tasks: area inspection, surveillance, creating image mosaics, structural monitoring, mowing, harvesting, planting, mapping, searching, painting, controlling CNC machines, and more. Such problems require that a robot (or – generally – a tool) at some time will visit a certain region of the environment, eventually visiting, or observing, the entire region of interest. Additionally, any obstacles should be avoided. Moreover, other optimization criteria can be incorporated in the process (e.g., minimizing time or energy). In order to do so, a Coverage Path Planning (CPP) algorithm must be employed [1,2]. Generally, it is a difficult problem, especially if realistic, noisy motion models or measurement errors are taken into account (even the classical "lawnmower problem" in its simplest form is NP-hard). A group of cooperating robots can realize the coverage in a faster and more robust way than a single unit. However, the underlying CPP should be designed appropriately.

## 2. Multi-robot CPP

In order to solve CPP, robots must: 1) move through all the points in the target area covering it completely; 2) preferably without an overlapping path; 3) robots must avoid all obstacles; 4) simple motion trajectories; an optimal (in some way) path is desired. Depending on formulation, the CPP is related to the covering salesman problem (a variant of the traveling salesman), the lawnmower problem, the art gallery problem and the watchman route problem – all NP-hard.

CPP algorithms can be divided in various classes, depending on: operating environment (2D, 3D, building, outdoor); algorithm processing (online, offline, centralized, distributed); model-based, non-model-based (no prior knowledge of the structure or environment); map representation (grid based with various possible shapes, triangular, square, hexagon, diamond; cell decomposition; geometric path generation); optimization goal (time, number of robots, energy, maximize monitoring area, multiobjective, etc.).

We propose a practical solution of a CPP for a group of robots whose task is to clean large scale storage facilities (the cleaning radius is much smaller than a warehouse). The algorithm is based on a decomposition of a 2D environment map into a set of polygons. The input to the algorithm is a 2D grid map representing a static environment, i.e. permanent obstacles (walls, elements of infrastructure, etc.) in a factory or a storage facility. Due to a large scale and required resolution, algorithms based on occupancy grid maps are not suitable. Therefore, in the first step the map is decomposed into a set of polygons. Two methods of decomposition can be applied: trapezoidal and boustrophedon. The latter is a generalization of the trapezoidal decomposition, but has more efficient coverage paths consisting of simple back and forth motions. Regarding optimality, the total time of cleaning is to be minimized.

The polygons are represented as a Reeb graph, where nodes have associated time-cost of cleaning and edges represent a single cell to be covered. The graph is further divided so that the workload is evenly distributed among the robots. Finally, a boustrophedon back and forth movement is generated in a way which minimizes total time to cover a given area [3].

## 3. Summary

Fig. 1 depicts a cleaning robot in an underground garage, together with a 2D grid map obtained by means of laser scanning. In addition to testing on real world maps, we have performed a statistically significant number of simulations for realistic virtual maps which show that the cleaning time of the proposed method scales as $t \propto N^{-0.964}$, N being the number of robots ($N_{max}$=5) and, of course, $t \propto N^{-1}$ being the perfect scaling. The real world application is currently being tested by our industrial partner.

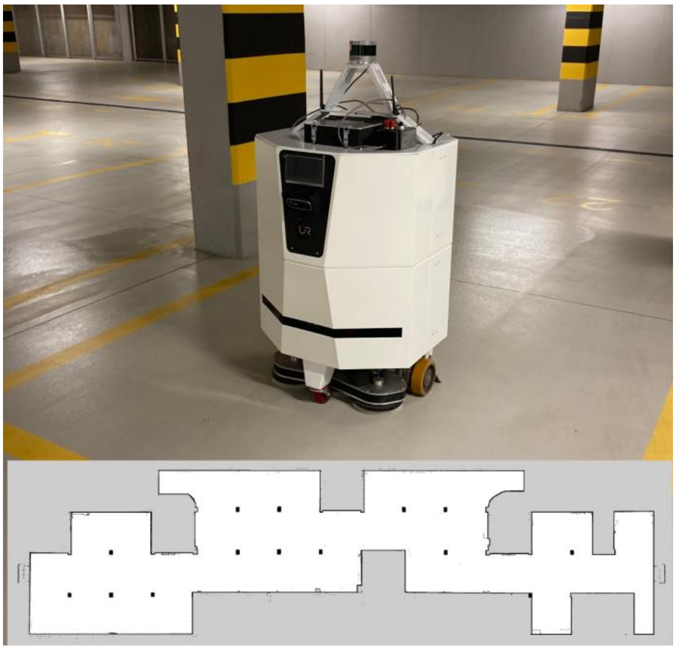

**Figure 1**. The cleaning robot with a 2D static map of a garage to be cleaned.

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## References

[1] **Galceran E., Carreras E.**, A survey on coverage path planning for robotics, Robotics and Autonomous Systems, Vol. 61, Issue 12, 2013.
[2] **Almadhoun, R., Taha, T., Seneviratne, L. et al.** A survey on multi-robot coverage path planning for model reconstruction and mapping. SN Applied Sciences 1, 847, 2019.
[3] **Bähnemann R. et al.**, Revisiting Boustrophedon Coverage Path Planning as a Generalized Traveling Salesman Problem. In: Ishigami G., Yoshida K. (eds) Field and Service Robotics. Springer Proceedings in Advanced Robotics, vol 16. Springer, Singapore, 2021.