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Airport snow shoveling

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***Abstract*— In this paper, we present results of a feasibility study of airport snow shoveling with multiple formations of autonomous snowplow robots. The main idea of the approach is to form temporary coalitions of vehicles, whose size depends on the width of the roads to be cleaned. We propose to divide the problem of snow shoveling into the subproblems of task allocation and motion coordination. For the task allocation we designed a multi-agent method applicable in the dynamic environment of airports. The motion coordination part focuses on generating trajectories for the vehicle formations based on the output of the task allocation module. Furthermore, we have developed a novel approach of formation stabilization into variable shapes depending on the width of runways. The method using a receding horizon control provides optimal trajectories and inputs for robots' actuators during splitting and coupling of formations. The algorithm can be utilized in arbitrary static and dynamic airport assemblage. All components as well as the complete system have been verified in various simulations and hardware experiments in both indoor and outdoor environments, which are presented in the submitted video.**

I. INTRODUCTION

Today, the tracks of an airport are freed from snow by utilizing a fleet of human driven snowplows. Recent technological advances in the field of mobile robotics enable to set up a multi-vehicle system consisting of groups of autonomous vehicles for this task. Periodicity of the task predestinates the use of autonomous robots.

In the presented movie, we show results obtained by novel approaches developed within the project, in which formations of autonomous plows are employed for the airport snow shoveling. This approach has been motivated by the current strategies used for shoveling of runways by human driven snowplows. Furthermore, by arranging the vehicles in formations and applying coordinated task allocation, the time of interrupted airport traffic can be significantly reduced.

To the best of our knowledge, such a system has not been investigated up to now. Related sweeping approaches lack robustness or rely on simplifications of the problem that make them unusable for the airport sweeping problem [5], [10]. Also the current algorithms of formation stabilization and control [1], [9] turned out to be hardly applicable in the airport snow shoveling application. We have presented a more comprehensive overview of the sweeping methods and the formation driving algorithms in [3], [8].

The remainder of this paper is structured as follow: In section II, a scheme of the proposed system, which has been employed in all of the presented experiments, is described. Section III provides an outline of the submitted video. Final conclusions and future work are presented in section IV.

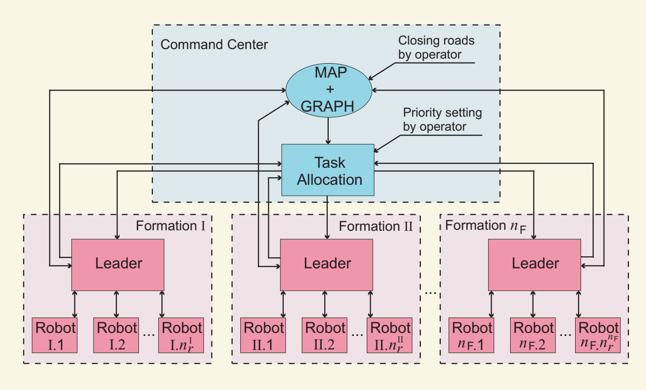

Fig. 1. Scheme of the complete snow shoveling system. The arrows denote communication links between the different modules. $n_{\mathcal{F}}$ is number of formations and n_r^i is number of robots in the i-th formation.

II. SYSTEM OVERVIEW

In this section, we introduce the structure of our system. Due to the space limitation, we can provide only a sketch of the algorithms' description, while a more detailed information together with theoretical studies of their convergence and additional results can be found in our previous publications [7], [6], [2], [3], [8].

In the system design, we decided to rely on a central supervision for the high level coordination. The main reason for this is safety, since a central command center (usually placed on an airport control tower) has a complete overview of the whole system and it is the appropriate place for operator intervention in case of trouble. The single point of failure problem, which rises from a single command center can be dealt with one or two redundant command center units that take over in case of a failure. Another reason for the centralized approach is that the workspace of the robots is well known in size and structure. Therefore, the scalability provided by a decentralized approach with agents exchanging parts of the map etc. is not necessary.

The highest level of the proposed scheme (see Fig. 1) is divided into two types of units. The first one, *Command Center*, is responsible for the central tasks. The second one (blocks denoted as *Formation I* - *Formation $n_{\mathcal{F}}$*) represents the current constellation of vehicles where each unit corresponds to one formation. These units are independent from the *Command Center* most of the time.

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The core of the *Command Center* is the *Task Allocation* module, which is using an agent-technology based method for autonomous design of ad-hoc formations and for planning their tasks. The obtained plan depends on priority setting for each road, on the airport traffic as well as on the snowing intensity. An execution step of the *Task Allocation* module is triggered by snowplows that have just accomplished (or failed) their task and they are waiting for new instructions.

In the *Formation I - Formation* $n_{\mathcal{F}}$ units, the *Leader* module is responsible for generating a reference trajectory at the beginning of each task. This is done with the information received from the *Task Allocation* module and with known map of the airport. The leader is just one designated robot in the formation, usually the one in front of the unit. Besides the snow shoveling the leader acts as a connection between the robots and the *Command Center*. It informs the *Command Center* about detected obstacles, finished or aborted tasks as well as the need of additional robots to compensate failures. The individual control inputs are calculated separately by each follower in order to follow the reference trajectory while maintaining the formation.

III. VIDEO DESCRIPTION

The presented video is structured as follows: in the first part, the task allocation process is demonstrated via a simulation using a satellite map of Frankfurt international airport. The Frankfurt airport has been chosen due to its high complexity, which verifies the utilization of the proposed method in arbitrary big airports. In the simulation, each plow is represented by a circle with a unique non-changing identification number and color. Note that the circular arrangement of groups was chosen due to readability and therefore the nodes are not located at the corresponding vehicles' real positions. The utilized diagonal shape of the formation structure is shown in the second part of the movie, which presents a simulation of runway snow shoveling by 11 plows. The number of robots, width of runway and size of robots' shovels have been configured in agreement with the Frankfurt airport and standard runway sweeper "RS 200". This simulation demonstrates an ability of the formation driving algorithm to avoid dynamic obstacles as well as to automatically change the shape of the formation in the case of roads' necking.

The third part of the video shows an indoor snow shoveling hardware experiment, which was carried out with the G2Bot-Testbed of the Czech Technical University. The G2Bot robotic platform is equipped with odometry and wireless communication, which has been used for distribution of data necessary for the formation stabilization. Control inputs have been computed on-line on robot's internal PC. For the experiments the snow was made of small pieces of polystyrene. We used straight bars mounted on the robots as shovels. The experimental scenario consists of two larger runways that have to be swept by two vehicles and four smaller roads for only one plow. The localization of robots in the experiment relies on odometry.

The same experimental setup has been utilized in the second hardware experiment as well. Here, two plows are facing a blind corridor with an aim to turn at the end. This scenario is motivated by a situation on the airport, where the plows detect a blockage of the runway. The plan of robots is then as follows: 1) build a compact formation appropriate for turning, 2) turn 180 degrees and 3) return back to the shoveling formation. We should mention that the transitions between the different formations as well as the turning maneuver are computed automatically using a novel method employing two virtual leaders. Only the positions of the vehicles within the formations (safety distances, required overlapping of shovels etc.) are given by experts before the mission.

The final part of the video has been captured during a hardware experiment in a city park environment. The experiment is part of a feasibility study of real snow shoveling by autonomous robots. We have utilized the P3AT platform equipped with wheels' encoders and camera. The robot has been driving autonomously using a SURF-based localization [4] developed within our group and an information about the position of snow covered paths in the park.

IV. CONCLUSIONS

The introduced video illustrates the ideas of efficient snow removing from airfields using formations of autonomous plows. Presented results, which have been obtained by experiments in indoor as well as outdoor environments, verify functionality of the proposed methods and demonstrate that such a system is realizable. As a future work, we plan to realize a large-scale outdoor hardware experiment in order to demonstrate the overall system applicability in the environment of airports.

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