Cooperative Frameworks for Multiple Mobile Robots

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1. Introduction

In this paper, we investigate the design, analysis and implementation of a flexible, scalable system of multiple mobile robots, that are individually autonomous and can team up to cooperatively transport large objects and to perform tasks that simply cannot be performed by a single mobile platform. Such frameworks for remotely controlled or remotely supervised cooperation of multiple autonomous mobile robots with their unique non-odometric dead-reckoning accuracy and active reconfigurability have many applications from uneven terrain exploration to material handling on the shop floor.

Our system derives its name from **A**utonomous mobile **R**obot **N**avigation with **O**dometric and **L**ink-based **D**ead-reckoning (i.e. **ARNOLD**). In its current implementation, each individual module comprises of a wheeled mobile robot with 2 planar two-d.o.f arms attached to the sides of the platform as shown in Figure 1. An effective articulated physical coupling between modules is formed when the arms come in contact with a common object.

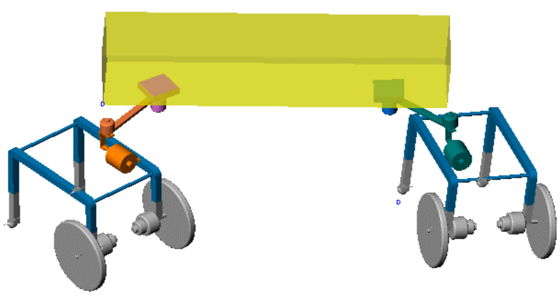

Figure 1. Conceptual Model of ARNOLD

The resulting composite systems share many features with the class of Multi-Degree-of-Freedom (MDOF) Vehicles as well as the class of Wheeled Actively Articulated Vehicles [1]. While several researchers have investigated the creation of omnidirectional robots with special wheels [2], we will restrict our attention to systems with nonholonomically constrained disk wheels. The presence of these nonholonomic constraints requires the introduction of articulations between the individual wheels. Examples of such systems includes HERMIES-III which was designed and built at the Oak Ridge National Laboratory [3,4], has two powered disk wheels that are also individually steered.

Similarly, the CLAPPER [5], employs a dual system of differentially-driven mobile robots attached to each other by a compliant link to form an MDOF platform. Such MDOF systems have been found to display exceptional maneuverability in tight quarters in comparison to conventional 2-DOF mobility systems, but have been found to be difficult to control due to their over constrained nature and the commensurately increased wheel slippage and thus reduced odometric accuracy.

2. Research Issues

Hence, it is useful to examine the potential for further relaxing the rigid body constraints between the various axles by introducing further articulations. In our system, each differentially driven mobile base possesses a single rigid axle between two fixed disk wheels with the usual complement of non-holonomic constraints. The presence of a common object supported by planar, 2-DOF arms between adjacent modules, creates an effective linkage between the two modules. These articulations (with at least 3 degrees-of-freedom) now permit us to relax the requirement for a common "Center of Rotation" between the multiple axles. However, while the velocity-level kinematic constraints for the system are eliminated, other holonomic constraints are introduced between the relative motions of the bases.

The resulting articulations endow the composite vehicle with: (i) ability to accommodate changes in the relative configuration; (ii) redundant sensing for localizing the modules; and (iii) redundant actuation method for moving the common object to compensate for disturbances in the motions of the base. Hence, the design and control of the intermediate linkage, thus formed, becomes critical. The important design parameters include the various link lengths and the configuration of the linkage, at any instant of time. Further the existence of the holonomic (loop-closure) constraints limit the degrees of freedom. Hence not all degrees of freedom need to be actuated. The selection of location of the active and passive joints also plays an important role in determining the overall manipulability of the transported object.

As mentioned earlier, wheel-slippage and reduced-odometric accuracy are important problems with such MDOF systems. We are currently working on developing a system with proprioceptive feedback control in which the link-mounted joint encoders will be employed to localize the individual modules relative to each other, permitting us to augment/correct the odometric-based dead-reckoning.

Other critical issues such as: avoidance of singularities of articulations; cooperative task performance; and robustness to platform positioning errors arise for the motion planning and control for the individual modules are being addressed.

3. Implementation

Each individual mobile robot system consists of a small mobile platform with two powered wheels, two unpowered casters. Conventional powered disk-type rear wheels are chosen because of robust physical construction and ease of operation in the presence of bumps, cracks, or any other terrain irregularities. Passive ball casters were preferred over wheel casters to simplify the constraints on maneuverability introduced by the casters. Each mobile base was designed to simplify manufacturing and assembly times and costs. The frame was created using angle plates bolted together to serve as structural members and permitting mounting of the motors, casters, and the electronics.

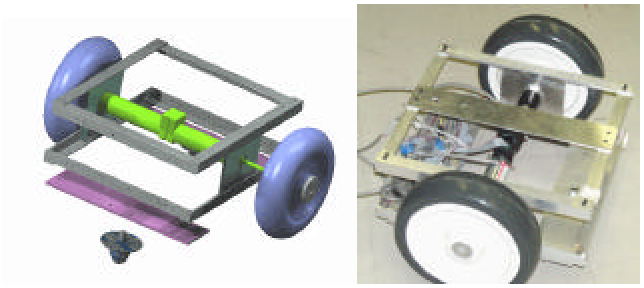

Figure 2. CAD rendering (left), Fabricated module (right).

At the design stage, our goal is to determine the optimal configuration of the linkage (including link-lengths, assembly configuration and the location of the actuated joints) so as to maximize the overall manipulability of the transported object [6,7]. Preliminary results are currently being examined.

In implementing the passive proprioceptive control, each module obtains measurements from the encoders mounted on the arms, to localize itself with respect to the other module, and implements an online trajectory planning algorithm [8], to determine its further motions so as to maintain the optimal configuration.

A dynamic simulation of the 2 mobile robots was created using Working Model and is driven by a MATLAB/Simulink interface implementing the control algorithm. This permits us to evaluate the results of the design optimization and proprioceptive control in a virtual environment prior to testing on the real prototype. Each mobile robot module is controlled by a PC/104 system which has the encoders, and motor driver cards mounted on it. The refined Simulink based control code is then compiled using xPCTarget/Real-Time Workshop and a real-time executable is downloaded to the target computer via an ethernet interface. This process is shown graphically in Figure 3. Thus such a distributed control framework with real-time sensor based planning would be more robust in the presence of unmodeled errors or large numbers of modules.

4. Summary

In this paper, we explored the design, development and implementation of a cooperating system of multiple mobile robots. The system consists of two differentially driven mobile robots, which support a common object using planar 2-DOF manipulators.

The resulting composite vehicle, with instrumented and actuated articulations, possesses: (i) the ability to accommodate changes in the relative configuration; (ii) redundant sensing for localizing the modules; and (iii) redundant actuation method for moving the common object to compensate for disturbances in the motions of the base.

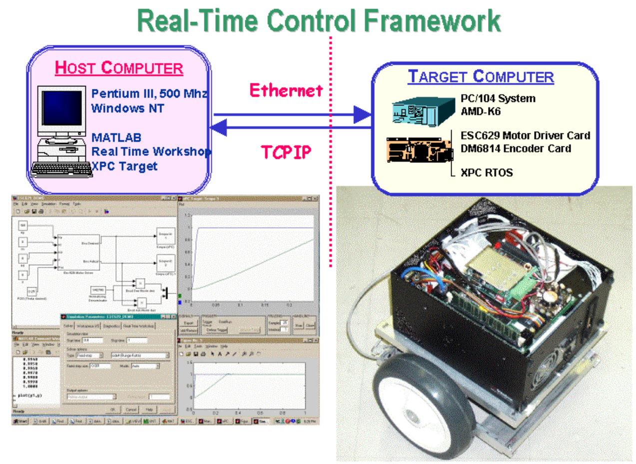

Figure 3. Real-time Control Framework

5. References

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