Optimization Based Coordinated UGV-MAV Exploration for 2D Augmented Mapping

(Extended Abstract)

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ABSTRACT

This paper presents a novel optimization formulation for coordinated exploration between unmanned ground vehicles (UGV) and micro-aerial vehicles (MAV). The exploration is posed as an Integer Programming (IP) problem and the allotment of these vehicles(agents) to frontier locations is specified as an integer constraint. The optimization provides a one shot solution for the allotment of all such active agents to possible frontier locations thereby guaranteeing substantial performance gain over previous approaches where the allotment proceeds in an incremental fashion. We also show a practical realization of such an exploration where an UGV-MAV team efficiently builds a map of an indoor environment.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed artificial intelligence— *multiagent systems*

Keywords

Robot coordination; Robot teams; multi-robot systems

1. INTRODUCTION

Herein we present a novel collaborative exploration strategy modeled as an Integer Programming (IP) optimization problem. The allotment of agents to frontiers is computed in one shot by the framework as the allocation is modeled using binary variables. Along with it several other constraints, that arise in heterogeneous exploration involving agents of different sensing and motion capabilities, are also introduced as constraint equations in the formulation.

We present several comparative results in simulations that highlights the advantages of our approach. Finally we show experimental results of real-time runs on a UGV/MAV combine for mapping a lab space using the proposed method.

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2. PROBLEM AND SYSTEM DESCRIPTION

Given a workspace U consisting of floor area and obstacles the objective is to find an efficient exploration strategy to explore U through a combination of UGV and MAV.

2.1 Agent Mapping

The UGV's and MAV's share a global map and this is updated by each robot independently to build a 2D occupancy grid map. This map is processed in each iteration to identify points at the boundary of unoccupied and unknown regions called frontiers.Such centralized systems for multi robotic exploration have been used at various times in past as well [2, 5].

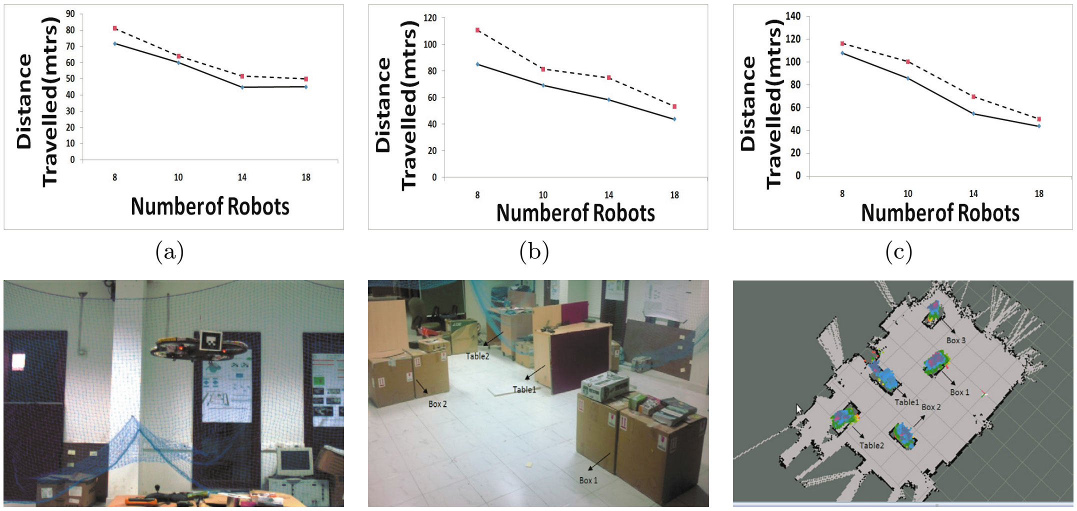
A MAV begins by "passively" following a UGV. Sensor data is processed to detect frontiers mappable by the MAV but not the UGV. A transition to this frontiers makes the MAV "active" as it begins contributing to the map with its camera/3D sensor.

2.2 Optimization Formulation

The crux of the optimization procedure is to allot frontier locations from the set of frontiers to the set of UGV-MAV agents. We choose a cost function that maximizes visibility gain while minimizing the distance travelled that closely follows [5]. The objective functions is:-

$$\begin{aligned}\max \quad & \textstyle\sum_{\texttt{UGV}\ i} \sum_{\texttt{UGVFrontier}\ j} \left(x_{ij} \times \frac{\texttt{Visibility}(j)}{\texttt{Distance}\,(i,j)} \right) + \\ & \textstyle\sum_{\texttt{ActiveMAV}\ i} \sum_{\texttt{MAVFrontier}\ j} \left(y_{ij} \times \frac{\texttt{Visibility}(j)}{\texttt{Distance}(i,j)} \right) + \\ & \textstyle\sum_{\texttt{PassiveMAV}\ i} \sum_{\texttt{MAVFrontier}\ j} \left(z_{ij} \times \frac{\texttt{Visibility}\ (j)}{\texttt{Distance}(i,j)} \right) + \\ & \textstyle\sum_{\texttt{UGV}\ i} \sum_{\texttt{ActiveMAV}\ j} \left(\frac{ha_{ij}}{\texttt{Time}\ (ji)} \right) \qquad (1)\end{aligned}$$

The optimization attempts to maximize information gain defined as the sum of visibility over distance (V/d) for each allotted frontier. This is expressed in the first three terms of Equation 1 above. The distance to frontier is computed using a planning module. The last term signifies the transition where an MAV goes from an active map builder (Active MAV) to a passive follower (Passive MAV), after map building is complete or due to lack of new reachable frontiers. The



(a) (b) (c)

(d) (e) (f)

Figure 1: (a)-(c)Comparison betweeen incremental frontier allotment(dotted line) and IP(continous lines) on the basis of distance travelled for different number of robots for 3 different maps. (d)UGV tracking UAV marker.(e)Lab area to be mapped.(f)Mapped lab area.

state of the system is captured using 5 sets of binary integer variables.The first three, x_{ij}, y_{ij} and z_{ij} denote that the i^{th} robot is allotted the j^{th} frontier. ha_{ij} denote that i^{th} UGV helps j^{th} Active MAV become passive and hp_{ij} denote that i^{th} UGV helps j^{th} passive MAV become active.

The glpk solver [3] is used to obtain the solution for a Integer program. The solver uses a branch and cut method which is a combination of branch and bound and cutting plane methods.

We model several practical constraints involving visibility, passive to active transitions etc. in the formulation. Only two of most important constraints are discussed below:-

1. Visibility Constraint: The MAV is assisted by the UGV for egomotion estimation.This requires that each MAV be visible to atleast one UGV at the beginning of each time step.

2. Minimum distance between frontiers: To reduce minimum information overlap we introduce a constraint which forces allotted frontiers to be atleast a minimum distance with each other.

For more detail please see the online appendix. `http://researchweb.iiit.ac.in/~ayush.dewan/report.pdf`

2.3 Mapping with Real Agents

The algorithm was implemented on a Pioneer P3DX (UGV) and a Parrot ArDrone(MAV). The MAV is equipped with a downward facing camera and an AR-marker [1], which allows the UGV to track its position accurately. Using the laser on the UGV an accurate map of the ground is created. The data from the MAV camera is input to the Parallel Tracking And Mapping (PTAM)[4] algorithm giving a sparse point cloud over elevated regions. Since MAV's AR-markers are tracked by UGV in world frame the map is accurately scaled.

3. COMPARATIVE RESULTS

The ROS framework was used to model and simulate the ground and aerial robots. The whole formulation was tested on three different maps.

Comparison is shown between our approach and a method that uses incremental allocations, proposed in [2, 5].The comparison is done for distance traversed and computational time. This time includes the time taken for path planning, calculation and allocation of frontiers by optimization/incremental formulation. We observed a significant reduction in average distance traveled by agents due to the current method. Computational time for both methods was comparable.

Figure 1 shows the experimental setup and results.

4. ACKNOWLEDGMENT

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