Sold!: Auction Methods for Multirobot Coordination

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March 27, 2003

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IEEE Transactions on Robotics and Automation, Vol. 18, No. 5
October 2002

Available Online:

http://robotics.usc.edu/~gerkey/research/final_papers/tra01.pdf

The Problem

- Need an efficient method for dynamically allocating incoming tasks to a physically embodied team of agents

- General assumptions for physical robots:
  - system composed of physically embodied robots
  - robots heterogeneous
  - communication, but messages sometimes lost
  - robots honest & cooperative
  - part, or all, of a robot may fail at anytime
  - a robot may not recognize its own failure

The Problem

- Assumptions specific to this model:
  - robots are multipurpose, rather than task specific
  - no model to describe the sequence in which tasks are generated
  - if a robot is to oversee a task, it can determine the progress and completion of the task
- The goal is to minimize:
  - resource usage
  - task completion time
  - communication overhead

Approach

- Anonymous communication via broadcast
  - saves bandwidth when sending messages to multiple recipients
  - allows robots to move in and out of range
- Hierarchical task structure
  - each task is a tree containing other tasks
  - flexible enough to handle a wide variety of tasks
- Auctions
  - scalable
  - cheap to broadcast and compute (only one round of bidding)
  - allow modularization
  - similar to CNP negotiation scheme, but without centralized broker

MURDOCH

- Publish/Subscribe messaging
  - *subject-based addressing*: messages addressed by content rather than by destination
  - a data-producer tags a message with a particular subject
  - only data-consumers interested in the specified subject will receive the message
  - subjects represent a robot's resources
  - resources can be:
    - physical devices (e.g., **`camera`**, **`gripper`**)
    - high-level capabilities (e.g., **`mobile`**, **`tracking`**)
    - abstracted notions of current state (e.g., **`idle`**, **`pushing-box`**)
  - for example, to send a message to all robots capable of retrieving a red can, a subject such as {**`mobile`**, **`camera`**, **`gripper`**, **`idle`**} would be appropriate

MURDOCH

- Auction Protocol
  - a task can be introduced to the system by a human, an automated task generator, a higher level task already in progress, or many other ways
  - each new task triggers a 5-step auction:
    1) task announcement - an agent acts as “auctioneer”, publishing an **`announcement`** containing the details of the task and with an appropriate subject
    2) metric evaluation - the **`announcement`** contains metric(s) to determine task fitness
    3) bid submission - each candidate robot calculates and publishes its “score” as a **`bid`**
    4) close of auction - the auctioneer processes the **`bids`** and sends a **`close`** message, the winner receives a time-limited contract to execute the task
    5) progress monitoring/contract renewal - the auctioneer monitors task progress and continues to send **`renewal`** messages to the winner as long as progress is satisfactory, the winner replies to each **`renewal`** with an **`acknowledge`** message

MURDOCH

- time-limited contracts provide fault tolerance
- tasks are always assigned to the most capable robot, thus MURDOCH is an instantaneous greedy task scheduler
- compared to a centralized task allocation system:
  - PRO: tasks may be randomly input at anytime
  - CON: use of resources can not be optimized by analyzing concurrent tasks

Testing

- Closed indoor environment
- Pioneer 2-DX mobile robots
  - sensors(each robot has one or two): camera, laser range finder, tactile bumper
- Wireless ethernet with shared bandwidth of ~1.9 Mb/s, allowing robots to communicate freely with one another at all times

Testing

- Loosely coupled task allocation
  - long-term autonomy
  - randomly generated sequence of tasks
  - overhead-camera attached to desktop PC used as the sole auctioneer
- Results
  - system ran successfully over a period of about 3 hours
  - resources allocated efficiently, i.e., the most capable robot available was always assigned the new task
  - bandwidth usage was very small, implying good scalability

Testing

- Box pushing
  - requires tightly coupled cooperation
  - system composed of “watchers” and “pushers”
  - the box is moved via the **`pusher-watcher`** approach:
    - watcher stays in front of box and measures angular error between box and goal
    - pushers move forward in such a way that angular error is reduced
  - a watcher task is auctioned by the system whenever a box must be moved
  - this watcher auctions two pusher tasks based on angular error
  - the side of the box lagging behind gets the first pusher, thus if only one pusher is available it will continually switch sides as one falls behind the other

Testing

An example of one pusher failing, then recovering

recover_push_hi.avi

Testing

- Results
  - out of 40 trial runs, task completed successfully 90% of the time
  - partial pusher failure much more time-consuming than total pusher failure because the watcher had to recognize lack of progress, rather than simply lack of acknowledgement or resources
  - allowing a failed pusher to rejoin proved time-saving
  - the box was kept along a near-ideal trajectory
- More clips and info available at:
  - http://robotics.usc.edu/~gerkey/research/murdoch.html

Related Work

- Unembodied task allocation
  - CNP, Open Agent Architecture, RETSINA: all use central broker
  - *Condor* : executes background jobs on idle workstations
  - *Challenger* : much like MURDOCH, but just recently moved to physical robots
- Embodied task allocation
  - ALLIANCE: all robots monitor each other’s progress
  - BLE: distributed form of subsumption, more minimalist
  - both methods rely on behavior-based control
- Box-pushing
  - pushing control system similar to pusher-steerer and master-slave systems, but neither of these implement fault tolerance
- MURDOCH’s results not directly compared to any other work

Summary of MURDOCH

- fully distributed method of task allocation
- anonymous, resource-centric communication
- hierarchial task structure
- each new task auctioned to the most capable agent available
- extremely reactive to environmental changes such as robot failure and randomly introduced new tasks
- empirically demonstrated on physical robots in situations involving both tightly coupled cooperation and long-term loosely coupled cooperation
- more work is being done to exploit MURDOCH in other domains

Questions?