Search and Pursuit/Evasion in the Physical World: Efficiency, Scalability, and Guarantees

International Conference on Robotics and Automation Workshop
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Workshop Organizers:

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Workshop abstract

This workshop will bring together researchers in all areas of pursuit/evasion and search. This includes (but is not limited to) geometric approaches, probabilistic optimization, graph theoretic search, decision theoretic planning, and adversarial search. The primary focus will be on single-robot and multi-robot search, which includes unmanned ground (UGVs), aerial (UAVs), surface (USVs), and underwater (UUVs) vehicles, as well as heterogeneous search teams in both outdoor and indoor environments. Various sensors, including cameras and laser scanners, will be examined, and search for both adversarial and non-adversarial targets will be considered. The theme of this workshop is to unify various formulations of the search problem and move towards a common theoretical and applied framework for search with autonomous robots. This workshop also will be of interest to those working in the general areas of multi-agent systems, distributed computation, and approximation algorithms.

Invited talk abstracts

1) **Interactive Multi-Robot Planning and Multi-Agent Simulation** by Dinesh Manocha
2) **Motion Planning for People Tracking in Uncertain and Dynamic Environments** by David Hsu
3) **Bio-inspired Risk Avoidance and Dynamic Coverage Control for Autonomous Agent Teams** by Karl Hedrick and Shih-Yuan Liu
4) **Algorithms and Complexity Results for Pursuit-Evasion Problems** by Richard Borie, Kenny Daniel, Sven Koenig and Craig Tovey
5) **Solving Pursuit-evasion Problem with Graph-Clear: an Overview** by Andreas Kolling and Stefano Carpin
6) **Belief-driven Cooperative Search and Tracking** by Tomonari Furukawa

Contributed poster abstracts

1) **Demonstration of Multi-Robot Search and Secure** by Fotios Katsilieris, Magnus Lindhé, Dimos V. Dimarogonas, Petter Ögren and Karl H. Johansson
2) **Multi-Robot Teamwork in Multistatic Sonar** by Frank Ehlers

3) **Optimal Strategies to Evade Jamming in Heterogeneous Mobile Networks** by Sourabh Bhattacharya and Tamer Başar
4) **A Decision-Theoretic Framework to Select Effective Observation Locations in Robotic Search and Rescue Scenarios** by Francesco Amigoni and Nicola Basilico
5) **Intelligent Pursuit & Evasion in Unknown Environments against Human Players** by Jonathan Annas and Jing Xiao
6) **Online Probabilistic Pursuit of Adversarial Evaders** by Johannes Strom, Ryan Morton, Kevin Reilly and Edwin Olson
7) **Visibility-Based Strategies for Searching and Tracking Unpredictable Coherent Targets Among Known Obstacles** by Christopher Vo and Jyh-Ming Lien
8) **Solving Pursuit-Evasion Problems on Height Maps** by Andreas Kolling, Alexander Kleiner, Michael Lewis and Katia Sycara
9) **Fault-Tolerant Multi-Robot Area Coverage with Limited Visibility** by Pooyan Fazli, Alireza Davoodi, Philippe Pasquier, and Alan K. Mackworth

Invited Talk

Dinesh Manocha

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Title

Interactive Multi-Robot Planning and Multi-Agent Simulation

Abstract

Modeling of multiple agents and crowd-like behaviors has been widely studied in virtual reality, robotics, computer animation, psychology, social sciences, and civil and traffic engineering. Realistic visual simulation of many avatars requires modeling of group behaviors, pedestrian dynamics, motion synthesis, and graphical rendering. In this talk, we give an overview of the work related to multi-agent and crowd simulation at UNC Chapel Hill. This includes new algorithms for local collision avoidance based on reciprocal velocity obstacles, automatic generation of emerging behaviors using composite agents or proxies, directing crowd simulation using navigation functions, data-driven crowd simulation, and new parallel algorithms that can exploit the capabilities of upcoming multi-core and many-core processors and can handle up to 200K agents at interactive rates. We demonstrate their application to evacuation planning, urban simulations, traffic engineering and online virtual worlds such as SecondLife.

Joint work with Ming C. Lin, Jur van den Berg, Sachin Patil, Sean Curtis, Russ Gayle, Jamie Snape, Stephen Guy, Jatin Chuggani, and Pradeep Dubey

Relevant papers:
http://gamma.cs.unc.edu/CA/ (two papers)
http://gamma.cs.unc.edu/RCAP/ (one paper)

Invited Talk

David Hsu

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Title

Motion Planning for People Tracking in Uncertain and Dynamic Environments

Abstract

Target tracking is an important capability for autonomous robots. Effective motion strategies enable a robot to handle visual and mobility obstruction due to obstacles and maneuver effectively to track a mobile target in an uncertain and dynamic environment.

There are two broad approaches to address dynamic changes and uncertainties in the environment: to react fast or to plan ahead. The choice often depends on the amount of prior information available on the environment and the target behavior. I will an overview of our work on target tracking using these two approaches. For the first approach, I will describe a greedy algorithm. It uses purely local geometric information from the robot's sensor to compute the robot's motion at each time step, and yet carefully balances the robot's ability to track the target in both the current and the future time. The algorithm uses only information from the robot's sensor and requires no prior information on the environment or the target behavior. For the second approach, we use partially observable Markov decision process (POMDP) to build a model of target behavior. As a result, the robot is capable of more sophisticated tracking behavior. For example, it may intentionally allow the target to get out of sight in order to minimize its own movement and save energy, but does not comprise long-term tracking performance.

Invited Talk

Karl Hedrick and Shih-Yuan Liu

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Title

Bio-inspired Risk Avoidance and Dynamic Coverage Control for Autonomous Agent Teams

Abstract

The goal of this paper is to seek inspiration for control of cooperative autonomous agent teams from the complex cooperative behavior of gregarious animals and predator-prey interactions. We focus on the prey part of the interaction for the similarity between foraging and information gathering behavior and between predation risk and risk in an autonomous information gathering mission environment.

A short overview of static and dynamic coverage approaches will be presented for the information gathering aspect. For the risk avoidance aspect, we utilized the domain of danger concept, which has been used to model the predation risk avoidance behavior of prey animals within a group. We will present a way to utilize the domain of danger concept as a risk measurement for an autonomous agent team in a risky environment. Also an approach to integrate the risk avoidance behavior brought by the domain of danger concept into a simple dynamic coverage control algorithm will be discussed.

Invited Talk

Richard Borie[1], Kenny Daniel[2], Sven Koenig[2] and Craig Tovey[3]

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Title

Algorithms and Complexity Results for Pursuit-Evasion Problems

Abstract

We study pursuit-evasion problems where a number of pursuers have to clear a given graph. We study when polynomial-time algorithms exist to determine how many pursuers are needed to clear a given graph and how a given number of pursuers should move on the graph to clear it with minimal cost (either a minimum sum of their travel distances or minimum task-completion time). We generalize prior work to both unit-width arbitrary-length and unit-length arbitrary-width graphs and derive both algorithms and complexity results for a variety of graph topologies. In this context, we describe a polynomial-time algorithm, called CLEARTHETREE, that is much shorter and algorithmically simpler than the state-of-the-art algorithm for the minimum pursuer problem on trees. We also describe a heuristic approach, called ESP, that solves large pursuit-evasion problems on series-parallel (that is, treewidth-2) graphs quickly and with small costs. It exploits the topology of the graphs by performing dynamic programming on their decomposition graphs.

Further information can be found in the following papers:
http://idm-lab.org/bib/abstracts/Koen09l.html
http://idm-lab.org/bib/abstracts/Koen09p.html

Invited Talk

Andreas Kolling[1] and Stefano Carpin[2]

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Title

Solving Pursuit-evasion Problem with Graph-Clear: an Overview

Abstract

This paper presents an overview of the numerous results we recently published for the problem of multi-robot pursuit evasion. We review the Graph-Clear formalism we introduced, we summarize the variants we studied, and the main results we derived. Finally, we outline directions for future research both in Graph-Clear and for pursuit-evasion and search problems in general.

Paper available at:
http://www.frc.ri.cmu.edu/~gholling/SearchWorkshop/papers/KollingCarpin.pdf

Invited Talk

Tomonari Furukawa

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Title

Belief-driven Cooperative Search and Tracking

Abstract

The talk will present the work of the speaker in the last 10 years on the belief-driven control and system integration for cooperative unmanned vehicles from theoretical developments to experimental demonstrations. The belief-driven control is formulated based on the theory of information and communication similarly to other Bayesian control schemes but shows its theoretical uniqueness by the further incorporation of the theory of search, which enables the unmanned vehicles to search for and track partially known targets while maintaining their belief, as well as by the development of robust recursive Bayesian estimators. The dynamic control of belief space in addition to the belief itself also makes the proposed control most solid, general and efficient, exhibiting its applicability to real-time, real-world environments. As a result, the proposed control allows the cooperative control of not only autonomous unmanned vehicles but also teleoperated unmanned vehicles. The system integration work ranges from the enhancement of hardware systems for real-world sensing and real-time control to the enhancement of software systems for operator-in-the-loop and platform-in-the-loop simulation. The enhancement of hardware systems includes the use of graphics processing units for grid computing while the enhancement of software systems includes the implementation of different communication protocols and the development of server-client systems. Successful demonstrations of the proposed cooperative control for heterogeneous real-size systems carried out to date will also be reported. These will include the decentralized data fusion of unmanned air and ground vehicles, manned ground vehicles and humans, the cooperative control of autonomous air vehicles for static targets, and the most recent cooperative control of unmanned ground vehicles for moving targets.

Contributed Poster

Fotios Katsilieris[1], Magnus Lindhé[1], Dimos V. Dimarogonas[2], Petter Ögren[3] and Karl H. Johansson[1]

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Title

Demonstration of Multi-Robot Search and Secure

Abstract

We consider the search and secure problem, where intruders are to be detected in a bounded area without allowing them to escape. The problem is tackled by representing the area to be searched as a traversability graph, which is reduced to a tree graph by placing stationary robots to remove loops. The search of the remaining tree is performed using two strategies that represent different trade-offs between the needed search time and the number of robots. Proof of correctness is provided for these two strategies. The proposed algorithm was implemented and demonstrated as part of an outfield experiment involving a team of Rotundus spherical robots.

Contributed Poster

Frank Ehlers

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Title

Multi-Robot Teamwork in Multistatic Sonar

Abstract

In this paper we present a novel and relevant application for multi-robot systems which is to implement autonomy for Multistatic Sonar. Multistatic Sonar is used in Antisubmarine Warfare and exploits multiple aspects on the target generated by multiple acoustic sources and receivers. We propose to use a team of unmanned underwater vehicles starting with search operations as covert receivers and then switching to pursuit operations as actively communicating multistatic receivers. With the help of a simulation setup and data from recent experiments at sea, we explain what are the specific challenges related to the Multistatic Sonar setup. These challenges are mainly related to the measurement model and to communication constraints. We then briefly outline a potential "baseline" solution, presented as a survey, for the overall system architecture capable to face these challenges.

Contributed Poster

Sourabh Bhattacharya and Tamer Başar

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Title

Optimal Strategies to Evade Jamming in Heterogeneous Mobile Networks

Abstract

In this paper, we consider a scenario in which a mobile intruder jams the communication network in a vehicular formation. We formulate the problem as a zero-sum pursuit-evasion game with players possessing heterogeneous dynamics. We use Isaacs' approach to derive the necessary conditions to arrive at the equations governing the saddle-point strategies of the team of players.

Contributed Poster

Jonathan Annas and Jing Xiao

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Title

Intelligent Pursuit & Evasion in Unknown Environments against Human Players

Abstract

We will present and evaluate the results of testing our adaptive pursuit and evasion robotic agents in simulation against human opponents in complex unknown environments cluttered with obstacles of arbitrary shapes and sizes. This work tests our previously published real-time adaptive motion planner for pursuit-evasion agents against human players in order to further validate our system, and to gain insight into which aspects of human strategy should be incorporated into future robotic agents for pursuit-evasion. Our approach introduces a real-time adaptive motion planner that can be independently employed by either a pursuer agent or an evader agent for its purposes. The pursuer agent aims to catch the evader agent without knowing the latter's motions and destination. The evader agent aims to reach its destination as quickly as possible while avoiding being caught by the purser. Both agents move in the initially unknown environment. Each is also unaware of the other's motion strategies. Each agent relies on its line-of-sight sensing capability to discover the environment and the other agent. Our real-time planner enables simultaneous planning and execution of an agent's motion based on a continuously improved map model of the environment via sensing. Starting from an empty map model, the agent goes through cycles of sensing and map improvement, motion planning, and movements. Each planning cycle searches multiple paths from the agent's current configuration based on evolutionary computation to meet one or more optimization objectives. The optimization objectives can be dynamically changed based on an agent's need, such as escaping, goal-seeking, or hiding for the evader, and chasing based on recent sighting or exploring possible evader locations for the pursuer.

Contributed Poster

Johannes Strom, Ryan Morton, Kevin Reilly and Edwin Olson

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Title

Online Probabilistic Pursuit of Adversarial Evaders

Abstract

The pursuit-evasion problem consists of a team of pursuers maneuvering to capture one or more evaders. Solutions to the pursuit-evasion problem help search and rescue teams quickly find survivors, sentries protect against intruders, and law enforcement apprehend suspects. Early work considered the case of adversarial evaders, though these approaches become prohibitively expensive when scaling to large environments and/or multiple pursuers. More recently, probabilistic pursuit methods have yielded computationally efficient approaches, but have sacrificed the ability to deal with adversarial evaders.

We describe a new probabilistic method that solves the adversarial pursuit-evasion problem without the need for costly adversarial searches (e.g., minimax). In particular, we show how a random-walk model of evaders can be transformed into a model that reflects the behavior of an adversarial agent. Our approach allows pursuers to characterize their opponents' cunning, allowing faster capture times in the case of sub-optimal evaders. Finally, we demonstrate our algorithm's performance on a number of benchmark problems, and verify our implementation on a robot.

Contributed Poster

Francesco Amigoni and Nicola Basilico

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Title

A Decision-Theoretic Framework to Select Effective Observation Locations in Robotic Search and Rescue Scenarios

Abstract

In some applications, like mapping and search and rescue, robots are autonomous when they are able to decide where to move next, according to the data collected so far. For this purpose, navigation strategies are used to drive the robots around environments. Most of the navigation strategies proposed in literature are based on the idea of evaluating a number of candidate locations according to an utility function and selecting the best one. Usually, ad hoc utility functions are used to provide a global evaluation of candidates by combining a number of criteria. In this paper, we propose to use a more theoretically-grounded approach, based on Multi Criteria Decision Making (MCDM), to define exploration strategies for robots employed in search and rescue applications. We implemented our MCDM-based exploration strategies within an existing robot controller and we experimentally evaluated their performance in environments used in the RoboCup Rescue Virtual Robots Competition.

Contributed Poster

Christopher Vo and Jyh-Ming Lien

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Title

Visibility-Based Strategies for Searching and Tracking Unpredictable Coherent Targets among Known Obstacles

Abstract

There are many scenarios in the real world and virtual world where it is necessary to find and track groups of coherent targets, whether they are groups of people, swarms of robots, or players in a video game. In such scenarios, some information about the environment may be available, but trajectories of the targets are usually not known in advance. This paper shows that finding unknown coherent targets in a known environment can be done asymptotically more efficiently than finding a single target. In addition, this paper presents several methods for tracking multiple coherent targets with unknown trajectories through environments with known obstacles (such as walls, buildings, etc). We also present variations of our algorithms that incorporate informed search to regain visibility of targets when they escape the camera's view, with promising results.

Contributed Poster

Andreas Kolling[1], Alexander Kleiner[2], Michael Lewis[1] and Katia Sycara[2]

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Title

Solving Pursuit-Evasion Problems on Height Maps

Abstract

In this paper we present an approach for a pursuit-evasion problem that considers a 2.5d environment represented by a height map. Such a representation is particularly suitable for large-scale outdoor pursuit-evasion. By allowing height information we not only capture some aspects of 3d visibility but can also consider target heights. In our approach we construct a graph representation of the environment by sampling points and their detection sets which extend the usual notion of visibility. Once a graph is constructed we compute strategies on this graph using a modification of previous work on graph-searching. This strategy is converted into robot paths that are planned on the height map by classifying the terrain appropriately. In experiments we investigate the performance of our approach and provide examples including a map of a small village with surrounding hills and a sample map with multiple loops and elevation plateaus. Experiments are carried out with varying sensing ranges as well as target and sensor heights. To the best of our knowledge the presented approach is the first viable solution to 2.5d pursuit-evasion with height maps.

Contributed Poster

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Title

Fault-Tolerant Multi-Robot Area Coverage with Limited Visibility

Abstract

We address the problem of multi-robot area coverage and present a new approach in the case where the map of the area and its static obstacles are known and the robots have a limited visibility range. The proposed method starts by locating a set of static guards on the map of the target area and then builds a graph called Reduced-CDT, a new environment representation method based on the Constrained Delaunay Triangulation (CDT). Multi-Prim's is used to decompose the resulted graph into a forest of partial spanning trees (PSTs). Each PST is then modified through a mechanism called Constrained Spanning Tour (CST) to build a cycle which is then assigned to a covering robot. Subsequently, robots start navigating the cycles and consequently cover the whole area. We show that the proposed approach is complete and robust with respect to robot failure.