## Today's Themes (AI-Generated)

• Developing adaptive robot hardware and algorithms to enhance mobility over uneven and dynamic terrain  
• Optimizing coordination of multi-agent robotic systems under constraints like obstacles and external disturbances   
• Applying model-based and learning-based control methods to improve autonomous operation of aerial and ground vehicles  
• Designing intuitive human-robot interaction systems leveraging augmented reality to command and monitor robot teams  
• Analyzing challenges and best practices in utilizing robot assistants effectively in real-world applications like manufacturing

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## Summaries

[Why Change Your Controller When You Can Change Your Planner: Drag-Aware Trajectory Generation for Quadrotor Systems](http://arxiv.org/abs/2401.04960) [[PDF](http://arxiv.org/pdf/2401.04960)]

by Hanli Zhang, Anusha Srikanthan, Spencer Folk, Vijay Kumar, Nikolai Matni

Motivated by the increasing use of quadrotors for payload delivery, we consider a joint trajectory generation and feedback control design problem for a quadrotor experiencing aerodynamic wrenches. Unmodeled aerodynamic drag forces from carried payloads can lead to catastrophic outcomes. Prior work model aerodynamic effects as residual dynamics or external disturbances in the control problem leading to a reactive policy that could be catastrophic. Moreover, redesigning controllers and tuning control gains on hardware platforms is a laborious effort. In this paper, we argue that adapting the trajectory generation component keeping the controller fixed can improve trajectory tracking for quadrotor systems experiencing drag forces. To achieve this, we formulate a drag-aware planning problem by applying a suitable relaxation to an optimal quadrotor control problem, introducing a tracking cost function which measures the ability of a controller to follow a reference trajectory. This tracking cost function acts as a regularizer in trajectory generation and is learned from data obtained from simulation. Our experiments in both simulation and on the Crazyflie hardware platform show that changing the planner reduces tracking error by as much as 83%. Evaluation on hardware demonstrates that our planned path, as opposed to a baseline, avoids controller saturation and catastrophic outcomes during aggressive maneuvers.

[A Universal Cooperative Decision-Making Framework for Connected Autonomous Vehicles with Generic Road Topologies](http://arxiv.org/abs/2401.04968) [[PDF](http://arxiv.org/pdf/2401.04968)]

by Zhenmin Huang, Shaojie Shen, Jun Ma

Cooperative decision-making of Connected Autonomous Vehicles (CAVs) presents a longstanding challenge due to its inherent nonlinearity, non-convexity, and discrete characteristics, compounded by the diverse road topologies encountered in real-world traffic scenarios. The majority of current methodologies are only applicable to a single and specific scenario, predicated on scenario-specific assumptions. Consequently, their application in real-world environments is restricted by the innumerable nature of traffic scenarios. In this study, we propose a unified optimization approach that exhibits the potential to address cooperative decision-making problems related to traffic scenarios with generic road topologies. This development is grounded in the premise that the topologies of various traffic scenarios can be universally represented as Directed Acyclic Graphs (DAGs). Particularly, the reference paths and time profiles for all involved CAVs are determined in a fully cooperative manner, taking into account factors such as velocities, accelerations, conflict resolutions, and overall traffic efficiency. The cooperative decision-making of CAVs is approximated as a mixed-integer linear programming (MILP) problem building on the DAGs of road topologies. This favorably facilitates the use of standard numerical solvers and the global optimality can be attained through the optimization. Case studies corresponding to different multi-lane traffic scenarios featuring diverse topologies are scheduled as the test itineraries, and the efficacy of our proposed methodology is corroborated.

[Autonomous Navigation of Tractor-Trailer Vehicles through Roundabout Intersections](http://arxiv.org/abs/2401.04980) [[PDF](http://arxiv.org/pdf/2401.04980)]

by Daniel Attard, Josef Bajada

In recent years, significant advancements have been made in the field of autonomous driving with the aim of increasing safety and efficiency. However, research that focuses on tractor-trailer vehicles is relatively sparse. Due to the physical characteristics and articulated joints, such vehicles require tailored models. While turning, the back wheels of the trailer turn at a tighter radius and the truck often has to deviate from the centre of the lane to accommodate this. Due to the lack of publicly available models, this work develops truck and trailer models using the high-fidelity simulation software CARLA, together with several roundabout scenarios, to establish a baseline dataset for benchmarks. Using a twin-q soft actor-critic algorithm, we train a quasi-end-to-end autonomous driving model which is able to achieve a 73% success rate on different roundabouts.

[OkayPlan: Obstacle Kinematics Augmented Dynamic Real-time Path Planning via Particle Swarm Optimization](http://arxiv.org/abs/2401.05019) [[PDF](http://arxiv.org/pdf/2401.05019)]

by Jinghao Xin, Jinwoo Kim, Shengjia Chu, Ning Li

Existing Global Path Planning (GPP) algorithms predominantly presume planning in a static environment. This assumption immensely limits their applications to Unmanned Surface Vehicles (USVs) that typically navigate in dynamic environments. To address this limitation, we present OkayPlan, a GPP algorithm capable of generating safe and short paths in dynamic scenarios at a real-time executing speed (125 Hz on a desktop-class computer). Specifically, we approach the challenge of dynamic obstacle avoidance by formulating the path planning problem as an obstacle kinematics augmented optimization problem, which can be efficiently resolved through a PSO-based optimizer at a real-time speed. Meanwhile, a Dynamic Prioritized Initialization (DPI) mechanism that adaptively initializes potential solutions for the optimization problem is established to further ameliorate the solution quality. Additionally, a relaxation strategy that facilitates the autonomous tuning of OkayPlan's hyperparameters in dynamic environments is devised. Comparative experiments involving canonical and contemporary GPP algorithms, along with ablation studies, have been conducted to substantiate the efficacy of our approach. Results indicate that OkayPlan outstrips existing methods in terms of path safety, length optimality, and computational efficiency, establishing it as a potent GPP technique for dynamic environments. The video and code associated with this paper are accessible at https://github.com/XinJingHao/OkayPlan.

[BoundMPC: Cartesian Trajectory Planning with Error Bounds based on Model Predictive Control in the Joint Space](http://arxiv.org/abs/2401.05057) [[PDF](http://arxiv.org/pdf/2401.05057)]

by Thies Oelerich, Florian Beck, Christian Hartl-Nesic, Andreas Kugi

This work presents a novel online model-predictive trajectory planner for robotic manipulators called BoundMPC. This planner allows the collision-free following of Cartesian reference paths in the end-effector's position and orientation, including via-points, within desired asymmetric bounds of the orthogonal path error. The path parameter synchronizes the position and orientation reference paths. The decomposition of the path error into the tangential direction, describing the path progress, and the orthogonal direction, which represents the deviation from the path, is well known for the position from the path-following control in the literature. This paper extends this idea to the orientation by utilizing the Lie theory of rotations. Moreover, the orthogonal error plane is further decomposed into basis directions to define asymmetric Cartesian error bounds easily. Using piecewise linear position and orientation reference paths with via-points is computationally very efficient and allows replanning the pose trajectories during the robot's motion. This feature makes it possible to use this planner for dynamically changing environments and varying goals. The flexibility and performance of BoundMPC are experimentally demonstrated by two scenarios on a 7-DoF Kuka LBR iiwa 14 R820 robot. The first scenario shows the transfer of a larger object from a start to a goal pose through a confined space where the object must be tilted. The second scenario deals with grasping an object from a table where the grasping point changes during the robot's motion, and collisions with other obstacles in the scene must be avoided.

[Discrete-Time Stress Matrix-Based Formation Control of General Linear Multi-Agent Systems](http://arxiv.org/abs/2401.05083) [[PDF](http://arxiv.org/pdf/2401.05083)]

by Okechi Onuoha, Suleiman Kurawa, Zezhi Tang, Yi Dong

This paper considers the distributed leader-follower stress-matrix-based affine formation control problem of discrete-time linear multi-agent systems with static and dynamic leaders. In leader-follower multi-agent formation control, the aim is to drive a set of agents comprising leaders and followers to form any desired geometric pattern and simultaneously execute any required manoeuvre by controlling only a few agents denoted as leaders. Existing works in literature are mostly limited to the cases where the agents' inter-agent communications are either in the continuous-time settings or the sampled-data cases where the leaders are constrained to constant (or zero) velocities or accelerations. Here, we relax these constraints and study the discrete-time cases where the leaders can have stationary or time-varying velocities. We propose control laws in the study of different situations and provide some sufficient conditions to guarantee the overall system stability. Simulation study is used to demonstrate the efficacy of our proposed control laws.

[Multi S-Graphs: an Efficient Real-time Distributed Semantic-Relational Collaborative SLAM](http://arxiv.org/abs/2401.05152) [[PDF](http://arxiv.org/pdf/2401.05152)]

by Miguel Fernandez-Cortizas, Hriday Bavle, David Perez-Saura, Jose Luis Sanchez-Lopez, Pascual Campoy, Holger Voos

Collaborative Simultaneous Localization and Mapping (CSLAM) is critical to enable multiple robots to operate in complex environments. Most CSLAM techniques rely on raw sensor measurement or low-level features such as keyframe descriptors, which can lead to wrong loop closures due to the lack of deep understanding of the environment. Moreover, the exchange of these measurements and low-level features among the robots requires the transmission of a significant amount of data, which limits the scalability of the system. To overcome these limitations, we present Multi S-Graphs, a decentralized CSLAM system that utilizes high-level semantic-relational information embedded in the four-layered hierarchical and optimizable situational graphs for cooperative map generation and localization while minimizing the information exchanged between the robots. To support this, we present a novel room-based descriptor which, along with its connected walls, is used to perform inter-robot loop closures, addressing the challenges of multi-robot kidnapped problem initialization. Multiple experiments in simulated and real environments validate the improvement in accuracy and robustness of the proposed approach while reducing the amount of data exchanged between robots compared to other state-of-the-art approaches. Software available within a docker image: https://github.com/snt-arg/multi\_s\_graphs\_docker

[Modelling, Positioning, and Deep Reinforcement Learning Path Tracking Control of Scaled Robotic Vehicles: Design and Experimental Validation](http://arxiv.org/abs/2401.05194) [[PDF](http://arxiv.org/pdf/2401.05194)]

by Carmine Caponio, Pietro Stano, Raffaele Carli, Ignazio Olivieri, Daniele Ragone, Aldo Sorniotti, Umberto Montanaro

Mobile robotic systems are becoming increasingly popular. These systems are used in various indoor applications, raging from warehousing and manufacturing to test benches for assessment of advanced control strategies, such as artificial intelligence (AI)-based control solutions, just to name a few. Scaled robotic cars are commonly equipped with a hierarchical control acthiecture that includes tasks dedicated to vehicle state estimation and control. This paper covers both aspects by proposing (i) a federeted extended Kalman filter (FEKF), and (ii) a novel deep reinforcement learning (DRL) path tracking controller trained via an expert demonstrator to expedite the learning phase and increase robustess to the simulation-to-reality gap. The paper also presents the formulation of a vehicle model along with an effective yet simple procedure for identifying tis paramters. The experimentally validated model is used for (i) supporting the design of the FEKF and (ii) serving as a digital twin for training the proposed DRL-based path tracking algorithm. Experimental results confirm the ability of the FEKF to improve the estimate of the mobile robot's position. Furthermore, the effectiveness of the DRL path tracking strateguy is experimentally tested along manoeuvres not considered during training, showing also the ability of the AI-based solution to outpeform model-based control strategies and the demonstrator. The comparison with benchmraking controllers is quantitavely evalueted through a set of key performance indicators.

[CineMPC: A Fully Autonomous Drone Cinematography System Incorporating Zoom, Focus, Pose, and Scene Composition](http://arxiv.org/abs/2401.05272) [[PDF](http://arxiv.org/pdf/2401.05272)]

by Pablo Pueyo, Juan Dendarieta, Eduardo Montijano, Ana C. Murillo, Mac Schwager

We present CineMPC, a complete cinematographic system that autonomously controls a drone to film multiple targets recording user-specified aesthetic objectives. Existing solutions in autonomous cinematography control only the camera extrinsics, namely its position, and orientation. In contrast, CineMPC is the first solution that includes the camera intrinsic parameters in the control loop, which are essential tools for controlling cinematographic effects like focus, depth-of-field, and zoom. The system estimates the relative poses between the targets and the camera from an RGB-D image and optimizes a trajectory for the extrinsic and intrinsic camera parameters to film the artistic and technical requirements specified by the user. The drone and the camera are controlled in a nonlinear Model Predicted Control (MPC) loop by re-optimizing the trajectory at each time step in response to current conditions in the scene. The perception system of CineMPC can track the targets' position and orientation despite the camera effects. Experiments in a photorealistic simulation and with a real platform demonstrate the capabilities of the system to achieve a full array of cinematographic effects that are not possible without the control of the intrinsics of the camera. Code for CineMPC is implemented following a modular architecture in ROS and released to the community.

[Analysis and Perspectives on the ANA Avatar XPRIZE Competition](http://arxiv.org/abs/2401.05290) [[PDF](http://arxiv.org/pdf/2401.05290)]

by Kris Hauser, Eleanor Watson, Joonbum Bae, Josh Bankston, Sven Behnke, Bill Borgia, Manuel G. Catalano, Stefano Dafarra, Jan B. F. van Erp, Thomas Ferris, Jeremy Fishel, Guy Hoffman, Serena Ivaldi, Fumio Kanehiro, Abderrahmane Kheddar, Gaelle Lannuzel, Jacqueline Ford Morie, Patrick Naughton, Steve NGuyen, Paul Oh, Taskin Padir, Jim Pippine, Jaeheung Park, Daniele Pucci, Jean Vaz, Peter Whitney, Peggy Wu, David Locke

The ANA Avatar XPRIZE was a four-year competition to develop a robotic "avatar" system to allow a human operator to sense, communicate, and act in a remote environment as though physically present. The competition featured a unique requirement that judges would operate the avatars after less than one hour of training on the human-machine interfaces, and avatar systems were judged on both objective and subjective scoring metrics. This paper presents a unified summary and analysis of the competition from technical, judging, and organizational perspectives. We study the use of telerobotics technologies and innovations pursued by the competing teams in their avatar systems, and correlate the use of these technologies with judges' task performance and subjective survey ratings. It also summarizes perspectives from team leads, judges, and organizers about the competition's execution and impact to inform the future development of telerobotics and telepresence.

[Theory of Mind abilities of Large Language Models in Human-Robot Interaction : An Illusion?](http://arxiv.org/abs/2401.05302) [[PDF](http://arxiv.org/pdf/2401.05302)]

by Mudit Verma, Siddhant Bhambri, Subbarao Kambhampati

Large Language Models have shown exceptional generative abilities in various natural language and generation tasks. However, possible anthropomorphization and leniency towards failure cases have propelled discussions on emergent abilities of Large Language Models especially on Theory of Mind (ToM) abilities in Large Language Models. While several false-belief tests exists to verify the ability to infer and maintain mental models of another entity, we study a special application of ToM abilities that has higher stakes and possibly irreversible consequences : Human Robot Interaction. In this work, we explore the task of Perceived Behavior Recognition, where a robot employs a Large Language Model (LLM) to assess the robot's generated behavior in a manner similar to human observer. We focus on four behavior types, namely - explicable, legible, predictable, and obfuscatory behavior which have been extensively used to synthesize interpretable robot behaviors. The LLMs goal is, therefore to be a human proxy to the agent, and to answer how a certain agent behavior would be perceived by the human in the loop, for example "Given a robot's behavior X, would the human observer find it explicable?". We conduct a human subject study to verify that the users are able to correctly answer such a question in the curated situations (robot setting and plan) across five domains. A first analysis of the belief test yields extremely positive results inflating ones expectations of LLMs possessing ToM abilities. We then propose and perform a suite of perturbation tests which breaks this illusion, i.e. Inconsistent Belief, Uninformative Context and Conviction Test. We conclude that, the high score of LLMs on vanilla prompts showcases its potential use in HRI settings, however to possess ToM demands invariance to trivial or irrelevant perturbations in the context which LLMs lack.

[Analytical Model and Experimental Testing of the SoftFoot: an Adaptive Robot Foot for Walking over Obstacles and Irregular Terrains](http://arxiv.org/abs/2401.05318) [[PDF](http://arxiv.org/pdf/2401.05318)]

by Cristina Piazza, Cosimo Della Santina, Manuel G. Catalano, Giorgio Grioli, Antonio Bicchi

Robot feet are crucial for maintaining dynamic stability and propelling the body during walking, especially on uneven terrains. Traditionally, robot feet were mostly designed as flat and stiff pieces of metal, which meets its limitations when the robot is required to step on irregular grounds, e.g. stones. While one could think that adding compliance under such feet would solve the problem, this is not the case. To address this problem, we introduced the SoftFoot, an adaptive foot design that can enhance walking performance over irregular grounds. The proposed design is completely passive and varies its shape and stiffness based on the exerted forces, through a system of pulley, tendons, and springs opportunely placed in the structure. This paper outlines the motivation behind the SoftFoot and describes the theoretical model which led to its final design. The proposed system has been experimentally tested and compared with two analogous conventional feet, a rigid one and a compliant one, with similar footprints and soles. The experimental validation focuses on the analysis of the standing performance, measured in terms of the equivalent support surface extension and the compensatory ankle angle, and the rejection of impulsive forces, which is important in events such as stepping on unforeseen obstacles. Results show that the SoftFoot has the largest equivalent support surface when standing on obstacles, and absorbs impulsive loads in a way almost as good as a compliant foot.

[Current Effect-eliminated Optimal Target Assignment and Motion Planning for a Multi-UUV System](http://arxiv.org/abs/2401.05521) [[PDF](http://arxiv.org/pdf/2401.05521)]

by Danjie Zhu, Simon X. Yang

The paper presents an innovative approach (CBNNTAP) that addresses the complexities and challenges introduced by ocean currents when optimizing target assignment and motion planning for a multi-unmanned underwater vehicle (UUV) system. The core of the proposed algorithm involves the integration of several key components. Firstly, it incorporates a bio-inspired neural network-based (BINN) approach which predicts the most efficient paths for individual UUVs while simultaneously ensuring collision avoidance among the vehicles. Secondly, an efficient target assignment component is integrated by considering the path distances determined by the BINN algorithm. In addition, a critical innovation within the CBNNTAP algorithm is its capacity to address the disruptive effects of ocean currents, where an adjustment component is seamlessly integrated to counteract the deviations caused by these currents, which enhances the accuracy of both motion planning and target assignment for the UUVs. The effectiveness of the CBNNTAP algorithm is demonstrated through comprehensive simulation results and the outcomes underscore the superiority of the developed algorithm in nullifying the effects of static and dynamic ocean currents in 2D and 3D scenarios.

[Characterising the take-off dynamics and energy efficiency in spring-driven jumping robots](http://arxiv.org/abs/2401.05554) [[PDF](http://arxiv.org/pdf/2401.05554)]

by John Lo, Ben Parslew

Previous design methodologies for spring-driven jumping robots focused on jump height optimization for specific tasks. In doing so, numerous designs have been proposed including using nonlinear spring-linkages to increase the elastic energy storage and jump height. However, these systems can never achieve their theoretical maximum jump height due to taking off before the spring energy is fully released, resulting in an incomplete transfer of stored elastic energy to gravitational potential energy. This paper presents low-order models aimed at characterising the energy conversion during the acceleration phase of jumping. It also proposes practical solutions for increasing the energy efficiency of jumping robots. A dynamic analysis is conducted on a multibody system comprised of rotational links, which is experimentally validated using a physical demonstrator. The analysis reveals that inefficient energy conversion is attributed to inertial effects caused by rotational and unsprung masses. Since these masses cannot be entirely eliminated from a physical linkage, a practical approach to improving energy efficiency involves structural redesign to reduce structural mass and moments of inertia while maintaining compliance with structural strength and stiffness requirements.

[Making Informed Decisions: Supporting Cobot Integration Considering Business and Worker Preferences](http://arxiv.org/abs/2401.05587) [[PDF](http://arxiv.org/pdf/2401.05587)]

by Dakota Sullivan, Nathan Thomas White, Andrew Schoen, Bilge Mutlu

Robots are ubiquitous in small-to-large-scale manufacturers. While collaborative robots (cobots) have significant potential in these settings due to their flexibility and ease of use, proper integration is critical to realize their full potential. Specifically, cobots need to be integrated in ways that utilize their strengths, improve manufacturing performance, and facilitate use in concert with human workers. Effective integration requires careful consideration and the knowledge of roboticists, manufacturing engineers, and business administrators. We propose an approach involving the stages of planning, analysis, development, and presentation, to inform manufacturers about cobot integration within their facilities prior to the integration process. We contextualize our approach in a case study with an SME collaborator and discuss insights learned.

[Augmented Reality User Interface for Command, Control, and Supervision of Large Multi-Agent Teams](http://arxiv.org/abs/2401.05665) [[PDF](http://arxiv.org/pdf/2401.05665)]

by Frank Regal, Chris Suarez, Fabian Parra, Mitch Pryor

Multi-agent human-robot teaming allows for the potential to gather information about various environments more efficiently by exploiting and combining the strengths of humans and robots. In industries like defense, search and rescue, first-response, and others alike, heterogeneous human-robot teams show promise to accelerate data collection and improve team safety by removing humans from unknown and potentially hazardous situations. This work builds upon AugRE, an Augmented Reality (AR) based scalable human-robot teaming framework. It enables users to localize and communicate with 50+ autonomous agents. Through our efforts, users are able to command, control, and supervise agents in large teams, both line-of-sight and non-line-of-sight, without the need to modify the environment prior and without requiring users to use typical hardware (i.e. joysticks, keyboards, laptops, tablets, etc.) in the field. The demonstrated work shows early indications that combining these AR-HMD-based user interaction modalities for command, control, and supervision will help improve human-robot team collaboration, robustness, and trust.