A Distributed Laguerre-based Model Predictive Control Scheme for Path Planning and Obstacle Avoidance with Resilience to Security-related Events

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Model Predictive Control

**Key Part:** Uses a Model of the System to Predict and Optimise the Future Performance

**Some Applications:**
- Path Planning/Obstacle Avoidance
- Optimising Energy Usage/Generate
- Distributed/Decentralised Control
- Robust/Stochastic Control (Handling Uncertainty)
- Adaptive and Fault Tolerant Control

**Advantages:**
- Ability to Anticipate Future Events
- Non-reactive control -> Smoother Control Actions
- Handling Time-Delays, Nonlinear Dynamics and Constraints

**Disadvantages/Challenges:**
- Requires a relatively accurate model of the system
- Computational burden -> Impacts real-time capabilities

Path Planning and Obstacle Avoidance for Autonomous Vehicles

**Two Common Methods:**
- Potential Fields (Preferred)
- Nonlinear Constraints

**Advantages of Potential Field:**
- Smoothness
- Reduced Computational Burden
- Scalability

**Nonlinear Constraints:**
- Suboptimal w.r.t. Nonlinear Constraints

**Other Applications to Path Planning:**
- Secure Communications via Physical-layer

Distributed Model Predictive Control

**Advantages vs Centralised:**
- Reduced computational burden
- Resilient to local failures, inc. communications
- Scalability
- Modularity
- Reconfigurability

**Disadvantages vs Centralised:**
- Suboptimal
- Relies on communication

Parametric Curves / Trajectory Parameterisation

**Key Part:** Rather than using single waypoints, use a “compressed” smooth representation of the planned trajectory

**Advantages:**
- Reduced computational burden
- Smooth trajectories with competitive performance if appropriately tuned
- Capture a large plan with few variables
- Less bandwidth requirements
- Less information to encrypt/decrypt

**Disadvantages:**
- Can be slightly suboptimal
- Less flexible due to limited options

Legible Control Systems (Player/Observer)

**Key Questions for Player:**
- Can an external observer infer my intentions?
- How can we design our control systems for our actions/plans to be legible by external observers?

**Key Questions for Observer:**
- Can I infer other vehicles’ intentions?
- How can this affect my confidence to navigate around or close them?
- Should this have a separate state?

Example application:
- Overtaking manoeuvre in highway taken from [1]: The vehicle announces the intention by leaning to the left side of the lane before actually executing manoeuvre.

Simulation Results

**Case Study:** Large-scale obstacle avoidance/deconfliction of 50 Multi-rotor UAVs within a cylindrical airspace of 15 meters radius with a height of 10 meters.

**Simulation Assumptions/Specifications:**
- The UAVs have a unified mass damper model with force/accelerations as inputs, commonly used for path planning.
- Each UAV is targeting a randomly generated waypoint which passes close to the centre of the cylinder and changes approximately every 3 seconds or when the waypoint is reached, and are required to maintain a minimum distance of 1 meter to each other.
- Laguerre-based Distributed MPC. Each UAV has its own control system which takes into account the parameterised paths from all the nearby UAVs.
- There exist constant communication between all UAVs.

Future Work

**1st Stage:**
- Develop efficient autogeneration algorithms for its implementation.
- Include legibility considerations in the control design for external diagnosis of UAVs state in the presence of various cyber-physical attacks such as communication failures, as well as GPS/Positioning spoofing and jamming.
- Increase the model accuracy to couple with inner UAV dynamics and control systems, as well as to model noise in the system.
- Develop an indoor experimental validation of the proposed approach using the VICON system with at least 5 UAVs.

**2nd Stage:**
- Increase the level of uncertainty from the environment including common GPS positioning errors such as drift, scales or bias, as well as other positioning errors obtained from other sensors such as cameras.
- Extend the indoor experimental validation of the proposed approach relying only on GPS data.
- Generalise the model to work on any path planning for highway autonomous driving.

References

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