

virtual vehicle

Accelerating Innovation

# Comparing the Predictive Event Handling Algorithm LookAhead to Rollback and Early Return


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# About Me

- **Felix Tischer, 31**
- **Industrial Engineering, Technical College Bulme, Graz**
  - Graduated 2014
- **Astrophysics (MSc) Karl Franzens University, Graz**
  - Graduated 2021
- **Researcher, Virtual Vehicle Research as of 2022**
- **Doctorand, TU Graz from March 2023 onwards**
  - In cooperation with Virtual Vehicle



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# Work & Research

## Co-simulation & Software Group

- Developing solutions for co-simulation problems
- Digital twins
- Traffic orchestration
- Implementation of features on our own co-simulation platform ICOS

## PhD Topics

- Focus on non-iterative and hybrid co-simulation
- Event-handling in co-simulation
- Prediction of state events

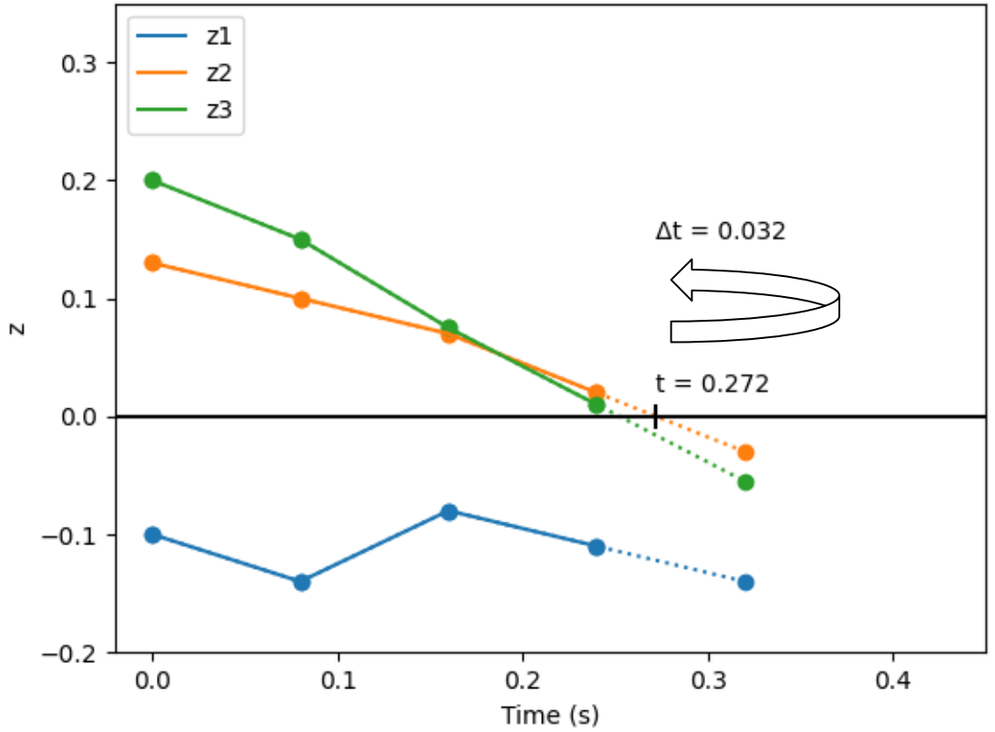
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# Previous Work on LookAhead

**Event: discrete, instantaneous change of state**

**State event: event triggered by the system entering a certain state**

**Shared event: event that happens in multiple subsystems simultaneously**



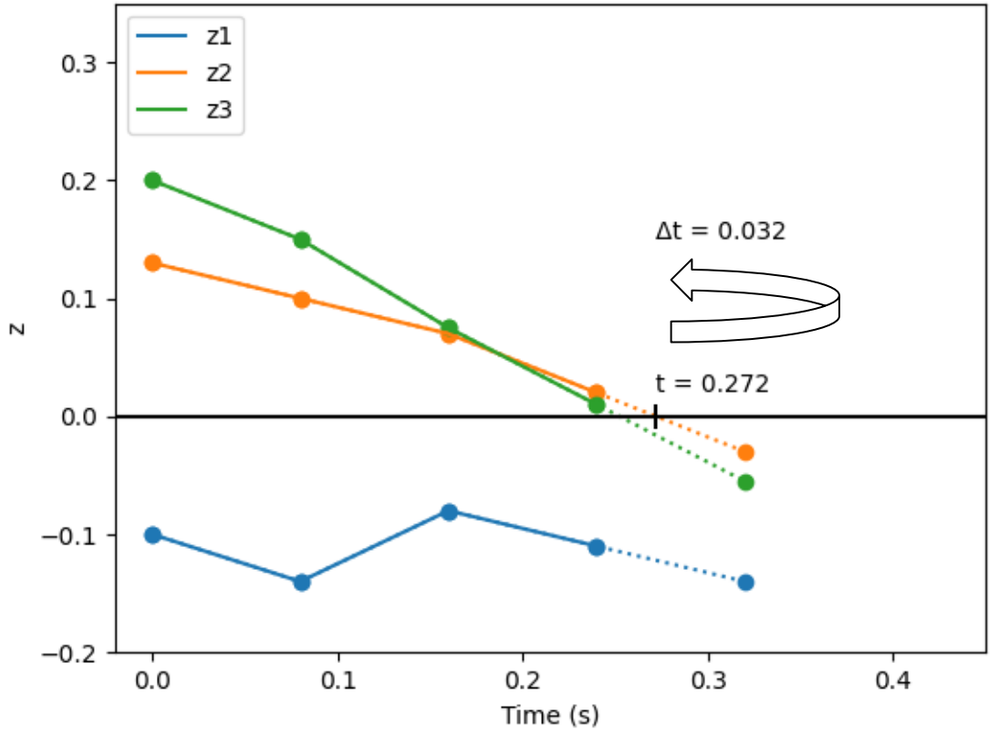

- **Problem: Shared events can be hard to simulate**
- **Idea: Predict events and adapt time step**
- **Solution: Formulate and extrapolate event conditions**

**The result is an algorithm that can improve simulation quality of events without needing event handling support from the subsystems**

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# LookAhead

- **Enhances co-simulation accuracy for systems lacking advanced event handling**
- **Function**
  - Define event conditions dependent on subsystem inputs, outputs, and parameters
  - Zero-crossings indicate events
  - Extrapolate event conditions a number of simulation steps ahead
  - Adapt step size when approaching a zero-crossing
- **Advantages**
  - No internal access to subsystems required
  - No additional event handling capabilities necessary
  - Additional computational cost only tied to event complexity
- **Limitations**
  - Sufficient knowledge of event conditions required
  - Conditions must be modelable without variables that are only available internally




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# Rollback

- **Reset a system’s state to a previous simulation point**
- **Function**
  - State is saved externally by the importer at regular intervals (can be on each communication step or less often)
  - If the step succeeds, the save is overwritten
  - If the step fails, both FMUs are reset to the last saved state
- **Advantages**
  - Errors can be corrected in hindsight
  - Errors can be made as small as desired with enough iterations
- **Limitations**
  - Additional computational cost tied to overall system complexity
  - Saving states of large models can take a long time

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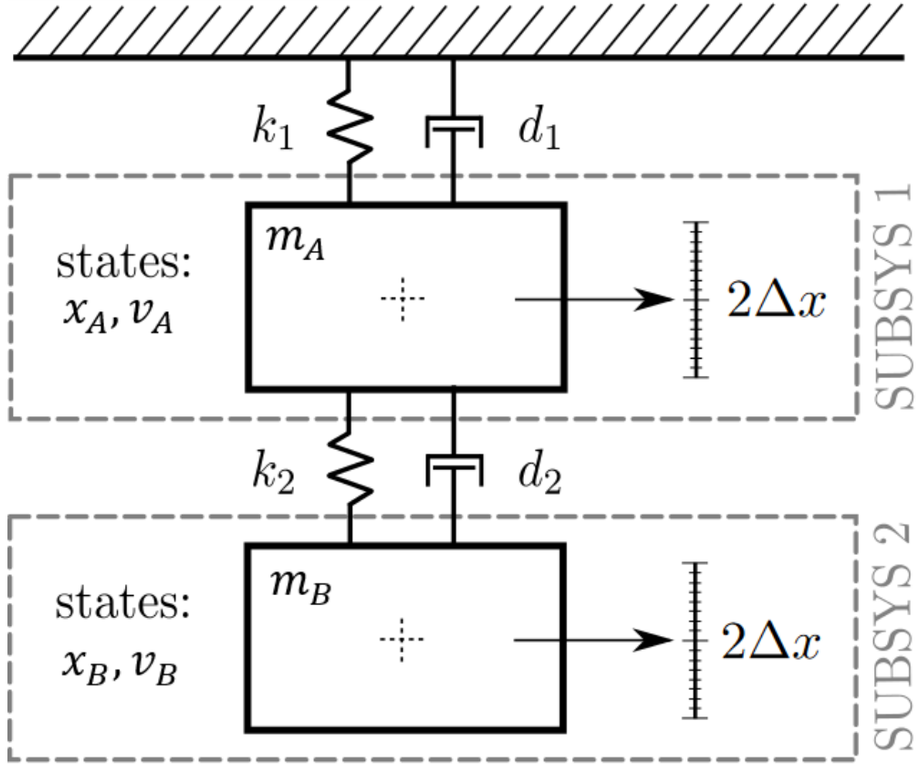
# Early Return

- **FMU ends a simulation step prematurely, but successfully**
- **Function**
  - Events (or other circumstances) trigger an Early Return in the FMU and stop the simulation step
  - The importer handles events and exchanges additional signals
  - Simulation resumes as normal afterwards
- **Advantages**
  - Versatile in its use
  - No resetting/repeating steps necessary
  - Importer does not need the exact event times
  - Additional computational cost only tied to event complexity
- **Limitations**
  - Importer needs to support Early Return and be able to handle incomplete steps
  - When other subsystems finish the entire steps, sequential execution or rollback might still be necessary after all

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# Comparison Setup

- **Simple spring-damper-mass system**
  - Two masses connected with dampened springs
  - Connected to ceiling at the top
  - Described by system of 4 ODEs, can be solved monolithically
  - Simulation time 20 s
- **Two possible events**
  - Upper mass collides with ceiling (private event) =>
    velocity is reflected downwards
  - Both masses collide (shared event) =>
    elastic collision
- **Subsystems compiled as FMUs**
  - Internal solver step size: 0.001 s
  - For Rollback: canGetAndSetFMUState="true"
  - For Early Return: providesIntermediateUpdate="true", canReturnEarlyAfterIntermediateUpdate="true„



## Simulation via python and fmpy

### 1. Monolithic simulation

- Communication step size = solver step size = 0.001s
- Reference solution for the other simulations

### 2. Standard co-simulation

- Communication step size of 0.08 s
- Simulation without additional event handling methods

### 3. LookAhead

- Base communication step size of 0.08 s, can be decreased for events

### 4. Rollback

- After an event occurs: last simulation step is reset and repeated with a shorter step size such that the event is being hit perfectly

### 5. Early Return

- Subsystems return early right before an event for additional communication points

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# Results & Analysis

- **Two ways of measuring the precision of an event**
  - Position error and its root mean square
  - Correct timing of events
    - not applicable if events are missed or additional events occur

$$e_{pos} = |x_1 - \hat{x}_1| + |x_2 - \hat{x}_2|$$

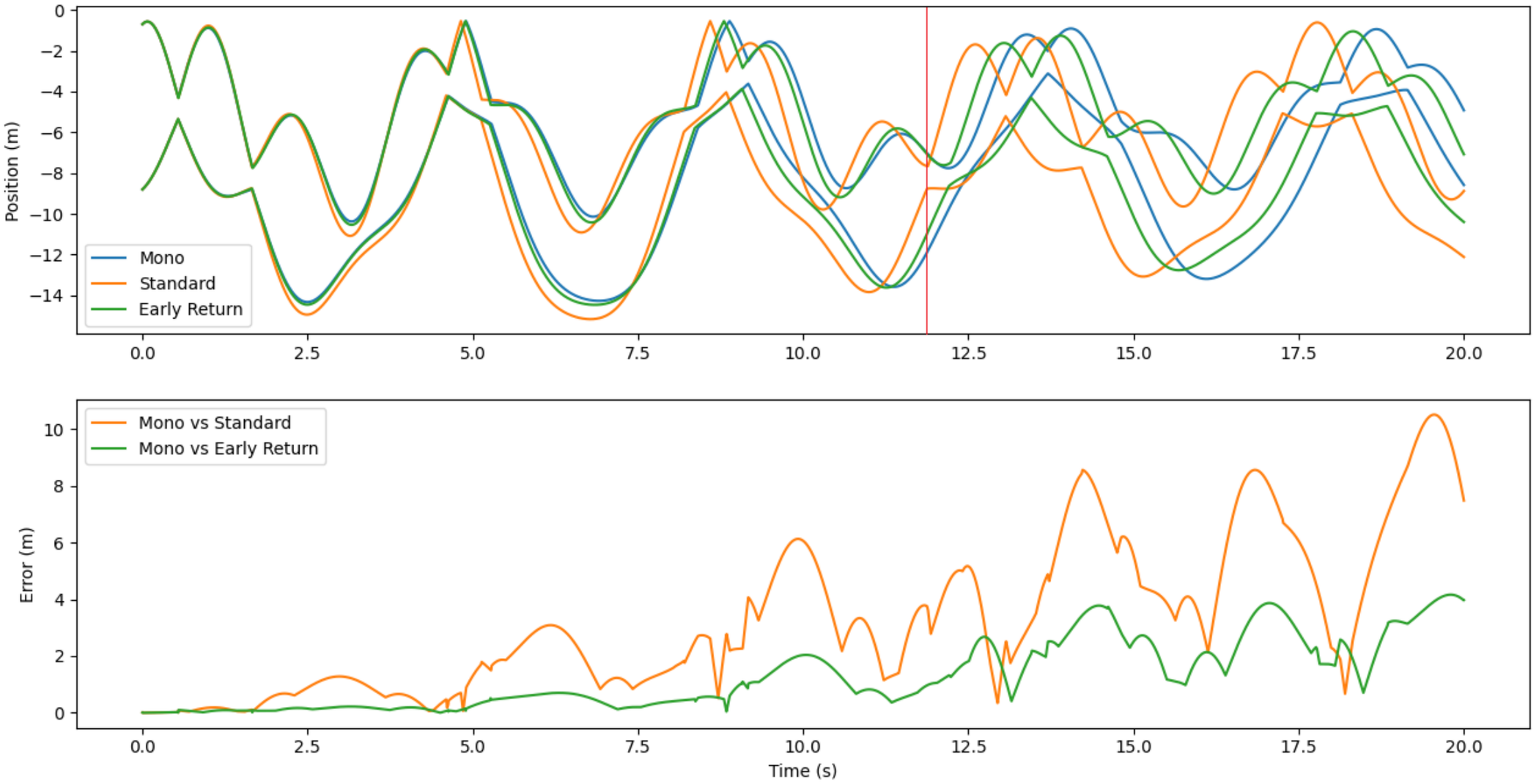
$$e_{time} = \sum_{i}^{n} |t_i - \hat{t}_i|$$

| Method | Position error RMS (m) @ 5s | Position error RMS (m) @ 10s | Position error RMS (m) @ 20s |
|---|---|---|---|
| Standard | 1.309 | 6.060 | 4.575 |
| LookAhead | 0.172 | 0.100 | 0.128 |
| Rollback | 0.148 | 0.180 | 0.156 |
| Early Return | 0.250 | 2.035 | 1.937 |

| Method | Private/shared event accuracy (s) @ 5s | Private/shared event accuracy (s) @ 10s | Private/shared event accuracy (s) @ 20s |
|---|---|---|---|
| Standard | 0.079/0.013 | 0.186/0.122 | 0.186/∞ |
| LookAhead | 0.005/0.008 | 0.006/0.009 | 0.006/0.007 |
| Rollback | 0.003/0.008 | 0.002/0.008 | 0.002/0.008 |
| Early Return | 0.010/0.004 | 0.047/0.028 | 0.047/∞ |

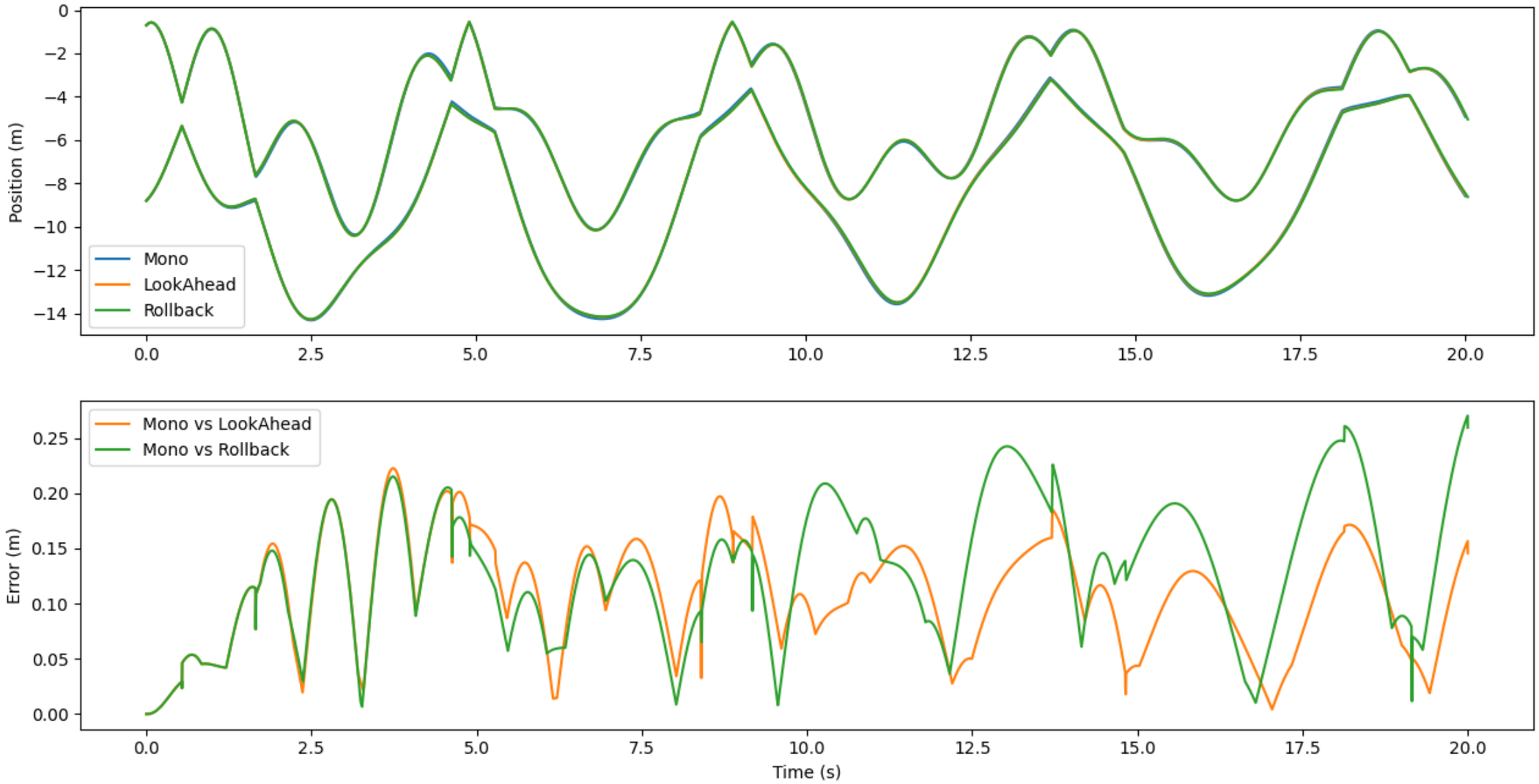
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# Results & Analysis



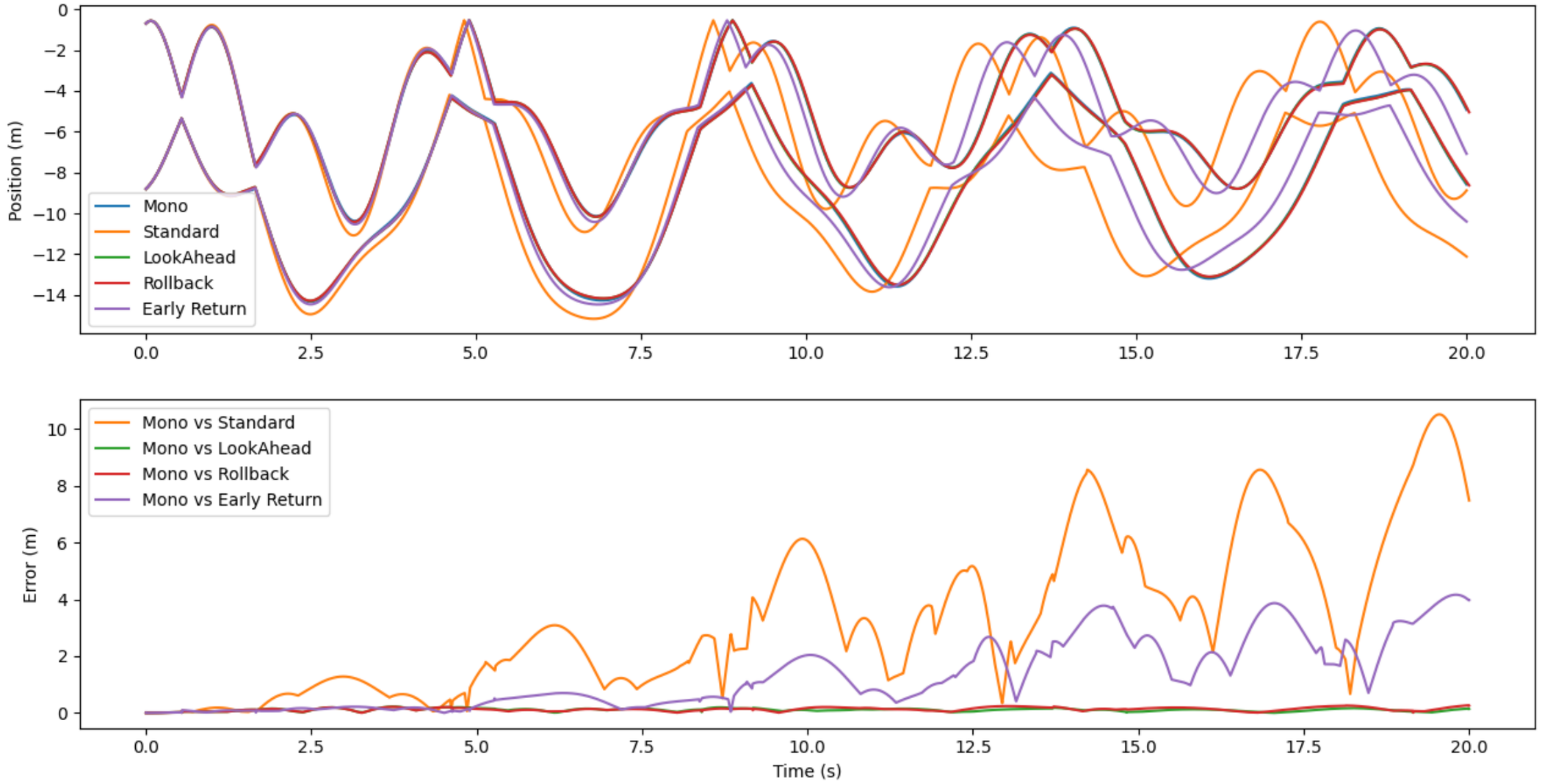

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# Results & Analysis




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# Interpretation

**Standard**

- **Without event handling, a few collisions (unary and binary) are enough to derail the simulation**

**Early Return**

- **Handles private events well**
- **For shared events, a single additional communication step can be too little**

**Rollback**

- **Works well for all events**
- **Iterative method, not always feasible**

**LookAhead**

- **Works well for all events even without event handling support**
- **Constrained by depending on inputs, outputs, and model knowledge**

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# Conclusion

## Summary

- LookAhead performs very well where other methods don‘t
- Can be used with subsystems that do not support rollback, Early Return, or other methods
- Improvement with basically no additional computational cost

## Future Work

- Develop an industrial example
- Right now, only linear algebraic equations are supported for event prediction – expand LookAhead‘s range of applicability by allowing more complex functions (ODEs, integrators)
- Carry out a sensitivity/variance analysis to quantify impact and interaction of LookAhead with other methods

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# COMPARING THE PREDICTIVE EVENT HANDLING ALGORITHM LOOKAHEAD TO ROLLBACK AND EARLY RETURN

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ENABLING **FUTURE VEHICLE** TECHNOLOGIES

## THANK YOU




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