Trust-Based Symbolic Robot Motion Planning with Human-in-the-Loop

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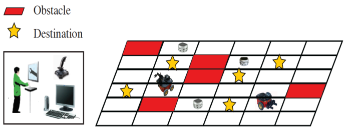
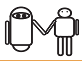
Overview

Runtime Verification (RV):
- Considering safety and efficiency of a system at the same time by monitoring and verifying the system execution results. RV techniques check whether or not a system under scrutiny can satisfy a set of given specifications, which is undoubtedly necessary for systems with high level of complexities.

Scalable Multi-Robot Systems:
- Compositional reasoning to reduce computational requirements



Robots:
- Pros:
  - Decrease physical and cognitive workload of operators
  - Good for repetitive tasks
  - Immune from mistake in simple tasks
- Cons:
  - Limited sensing ability
  - Limited flexibility
  - Not as intelligent as human
  - Poor decision-making ability



Human-Robot Interaction (HRI):
- Take into account the strengths of both autonomy and human operation
- Increase task performance

Humans:
- Pros:
  - Intelligent
  - High cognition ability
- Cons:
  - Prone to mistake
  - Becomes fatigue
  - Unpredictable
  - High complexity
  - Hard to quantify behaviors

Methods

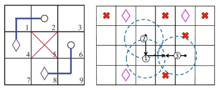
Approach: Trust-Based Runtime Verification (RV)

Framework
- Motion Planner
- Controller
- Monitor
  - Filter: Extracts info., sends info. to event recognizer
  - Event Recognizer: detects events, informs the checker module of the detected events
- Runtime Checker
- Decision Maker
  - Determines control
  - Trust-based decision-making

Modes
- Advanced Manual Subsystem
  - Human-in-the-loop
  - Higher performance but not guaranteed safety
- Baseline Autonomous Subsystem
  - Guaranteed correctness but inefficient

Approach: Compositional Reasoning for Multi-Robot Systems

$$\frac{\langle \varphi_2 \rangle R_1 \langle \varphi_1 \rangle \quad \langle \varphi_1 \rangle R_2 \langle \varphi_2 \rangle}{\langle true \rangle R_1 \| R_2 \langle \varphi_1 \wedge \varphi_2 \rangle}$$

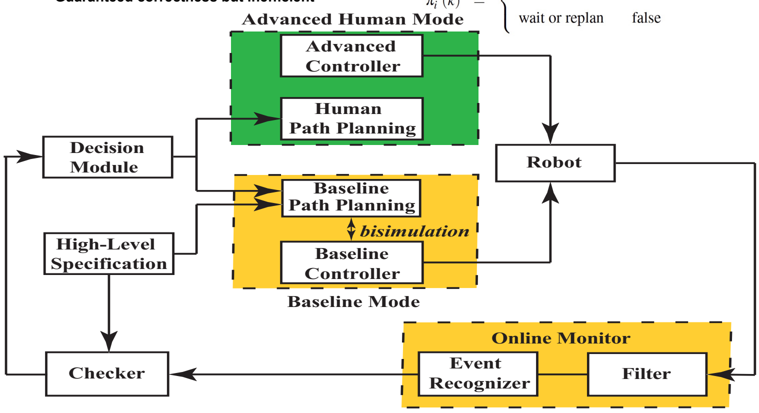


1. Communication Atomic Proposition
2. Observation Atomic Proposition
3. Control Atomic Proposition

$$\pi_i^c(k) = \begin{cases} \|x_i(k) - x_j(k)\| \le \rho_i & \text{true} \\ \|x_i(k) - x_j(k)\| > \rho_i & \text{false} \end{cases}$$

$$\pi_i^o(k) = \begin{cases} Collision\ is\ observed & true \\ No\ collision\ is\ observed & false \end{cases}$$

$$\pi_i^u(k) = \begin{cases} \text{LQR} & \text{true} \\ \text{wait or replan} & \text{false} \end{cases}$$



Trust Model

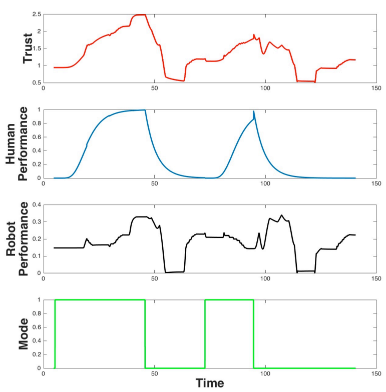
- Environmental Characteristics
- Robot Performance
- Human Performance

$$T(k) = AT(k-1) + B_1 P_R(k) - B_2 P_R(k-1) + C_1 P_H(k) - C_2 P_H(k-1)$$

$$P_R(k) = \left(\frac{1}{\pi}\arctan(\Lambda(D_O(k) - \Theta) + 0.5)\right)^{\frac{D_G(k)}{D_G(k-1)}}$$

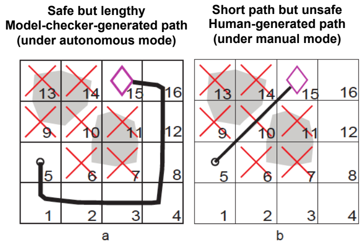
$$P_H(k) = \gamma(k)^{S_O+1}$$

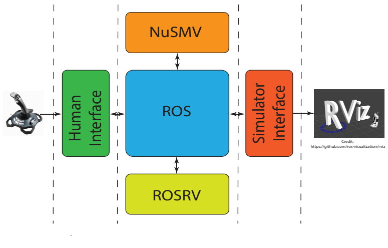
$$\gamma(k) = \frac{1 + (\tau - 1)\gamma(k-1)}{\tau}$$



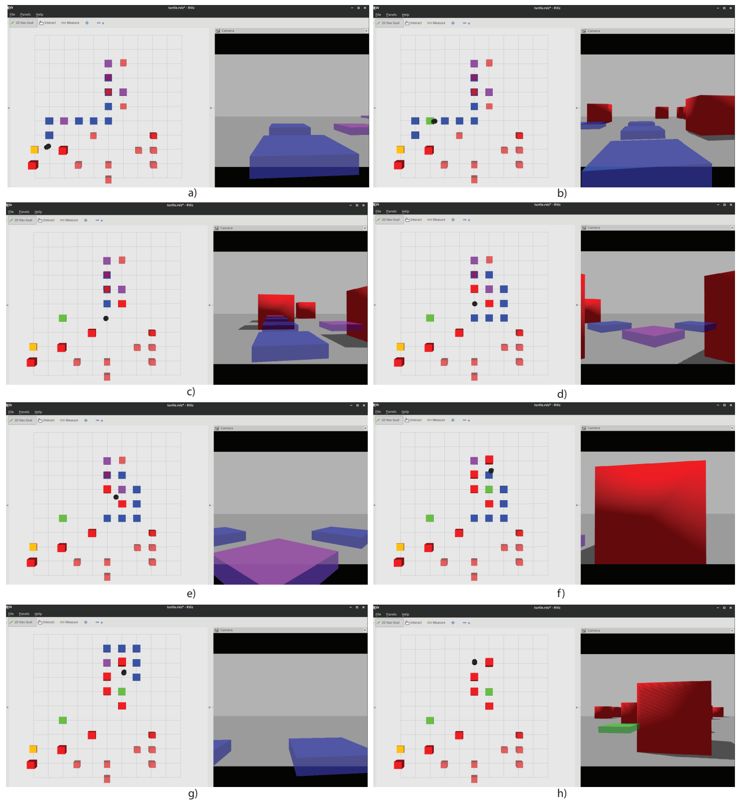
Case Study & Results

Software Implementations:
- Simulation by ROS
- Model Checking by NuSMV
- Runtime Verification by ROSRV

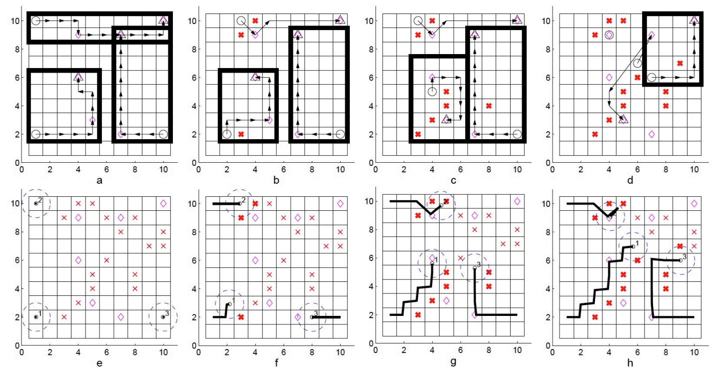




High-level overview of simulation components



The figure above highlights scenes of different steps of the simulation using our proposed trust-based runtime verification algorithm with human-in-the-loop. The right portion of each figure shows how the operator sees the environment from the robot onboard camera. In Fig. (d), the operator decides to take over the motion planning since he/she observes a shorter path between two obstacles and Fig. (e) shows that the robot passes through the obstacles under the manual mode. Fig. (f) shows that a collision is about to happen so the system automatically switches back to autonomous mode and generates a path towards the last goal.



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