Vision-based Runtime Monitoring for Human-Construction Robot Systems

Apala Pramanik, Kyungki Kim, Dung Hoang Tran

University of Nebraska Lincoln

Introduction & Challenges

Vision Based Runtime Monitoring

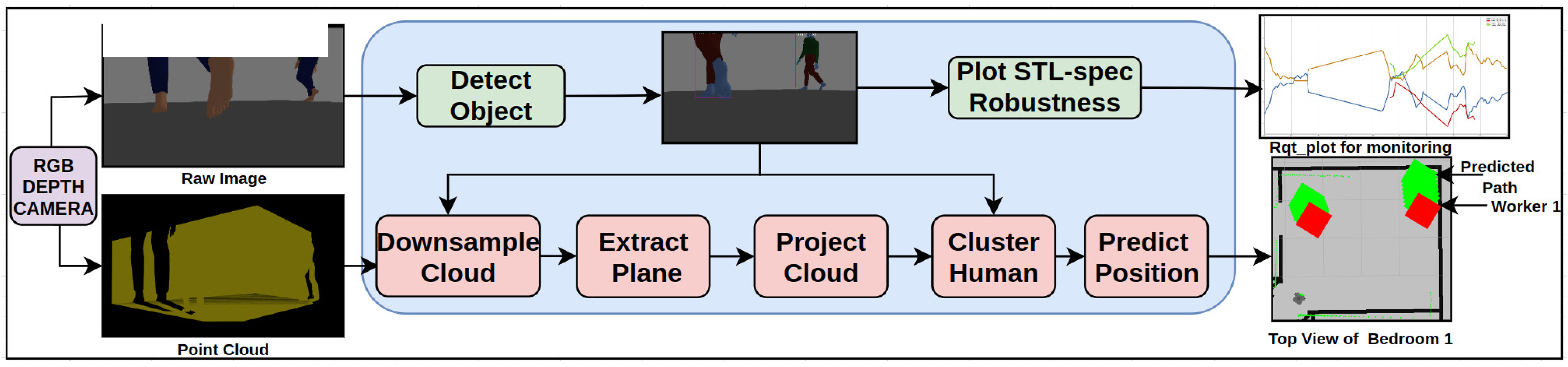
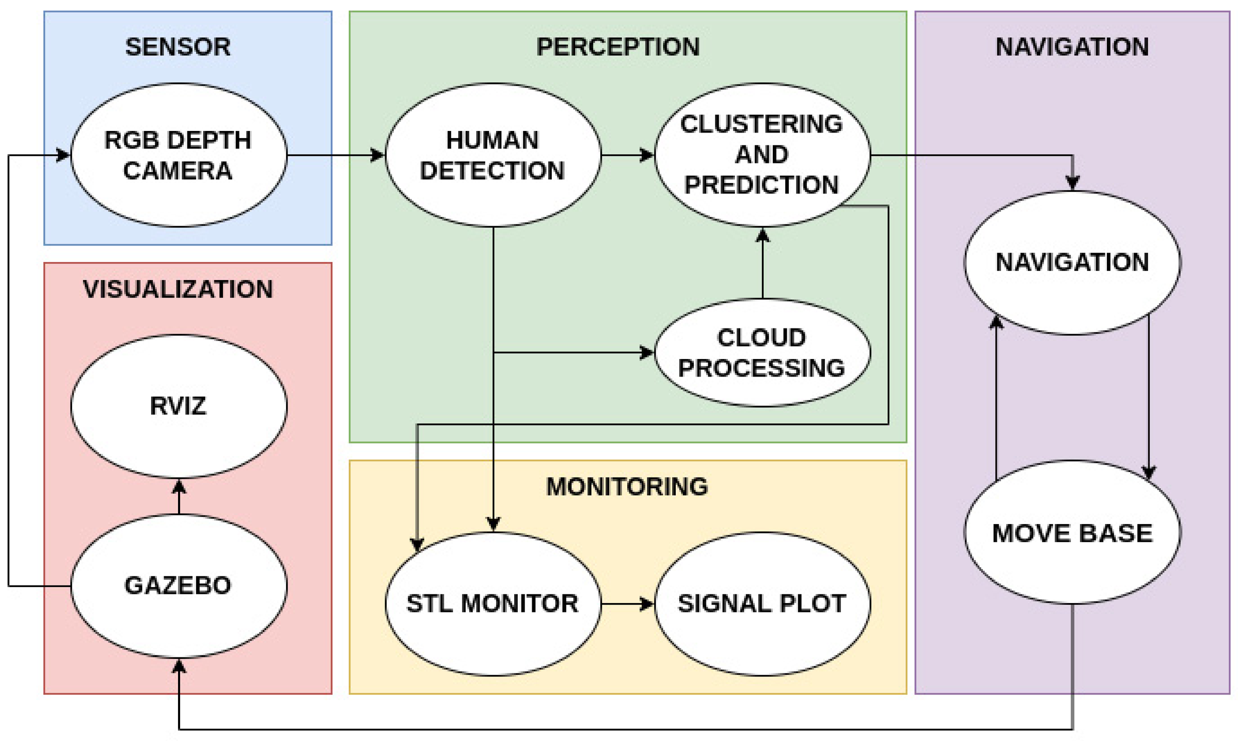


Fig. 2: Overview of the proposed vision-based runtime monitoring approach.



ROS rqt_graph

"The paper proposes a new perception logic-based approach for monitoring safety in human-construction robot systems, overcoming challenges related to robots' limited local view in real-world construction applications"

1. Robotics in construction has the potential to replace 47% of US construction jobs by handling repetitive, risky, and physically challenging tasks.[2]

2. Academic studies and industrial applications have explored robotization approaches in construction, including excavation, rebar tying, and bricklaying.

3. Integrating autonomous robots into construction sites presents safety challenges due to dynamic and congested environments with human workers earby.

4. To address safety concerns, various safety measures have been implemented, but safety instructions for robots often lack specificity.

Case Study

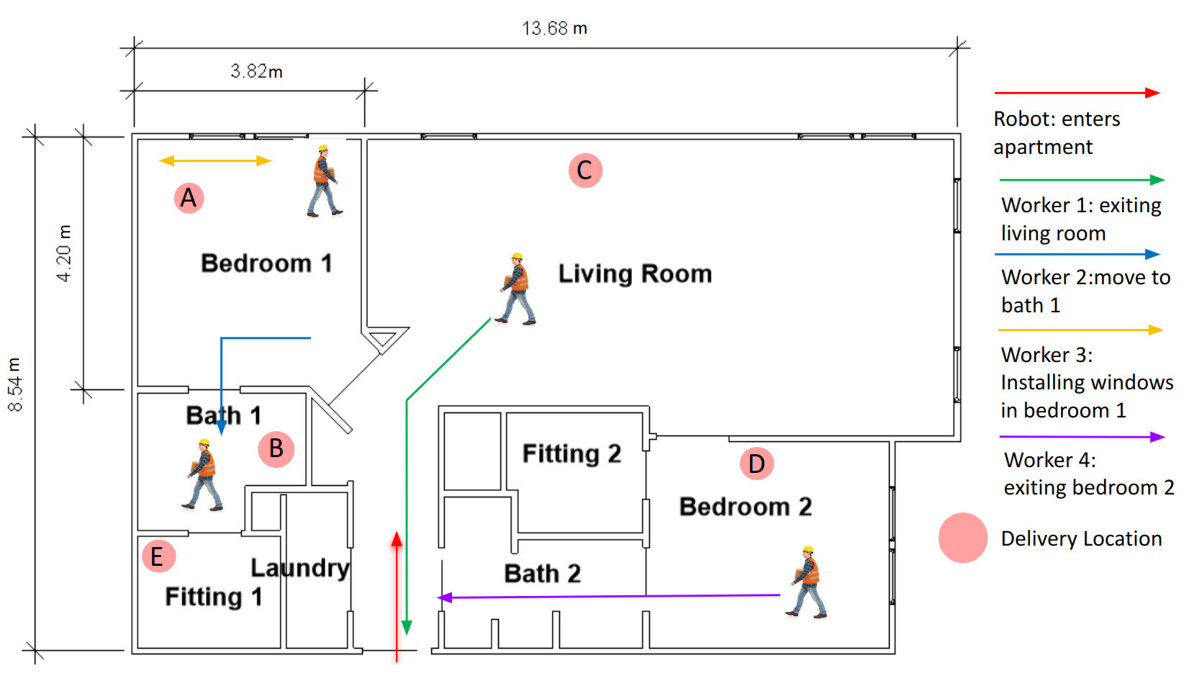


Fig. 3: Case study: robot navigating from apartment entrance (red arrow) to various locations (red dots) detecting and maintaining a safe distance from workers during navigation

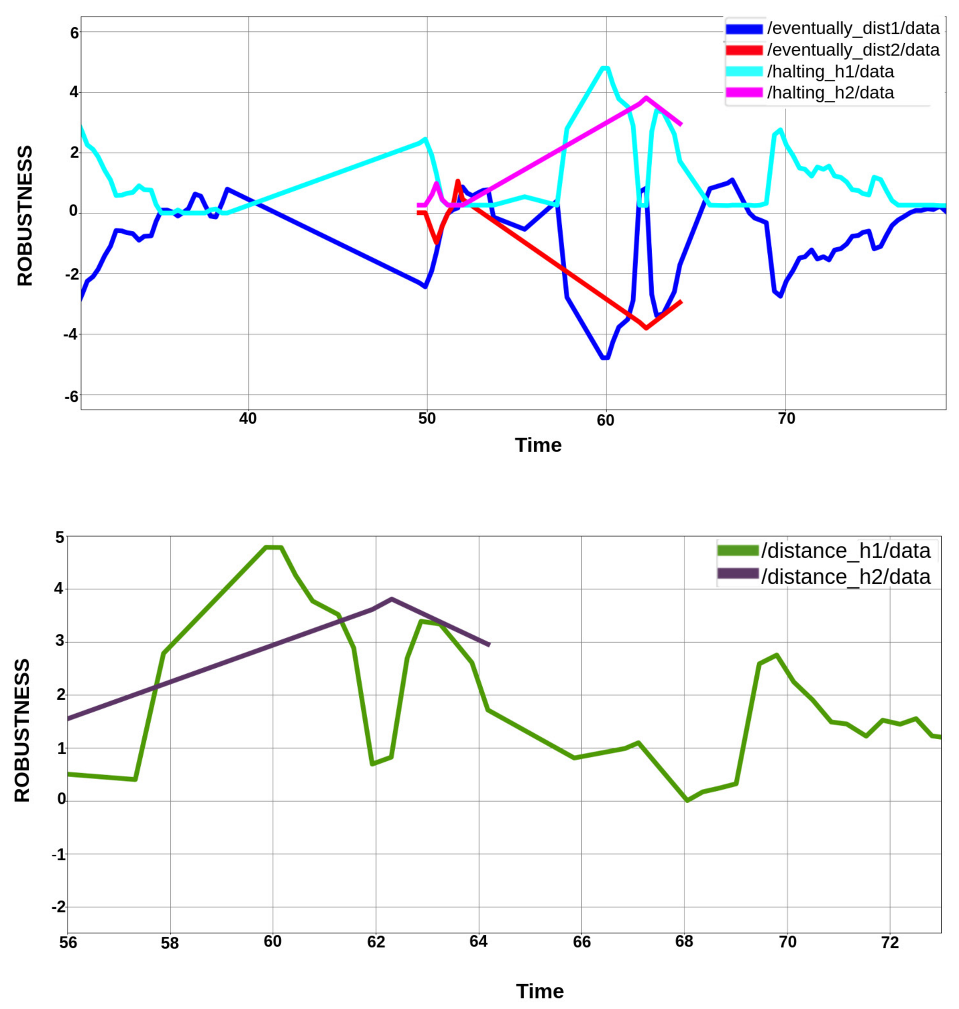


Fig. 4: Quantitative robustness plot for STL specifications in equations 2 and 3 for two human workers at the same time.

- *Localization phase*: process the point cloud received from the depth camera and localize the human in the robot's local view by extracting and clustering the human point cloud.
- Each position is then transformed to the current frame of reference since both the human and the robot are in motion (illustrated in Fig.1).
- *Estimation phase*: the transformed positions are used to estimate human motion using an appropriate Kalman filter.
- *Monitoring phase*: uses the predictions of human positions to calculate the robustness of user-specified STL-based [1] safety specifications over a period of time in the future

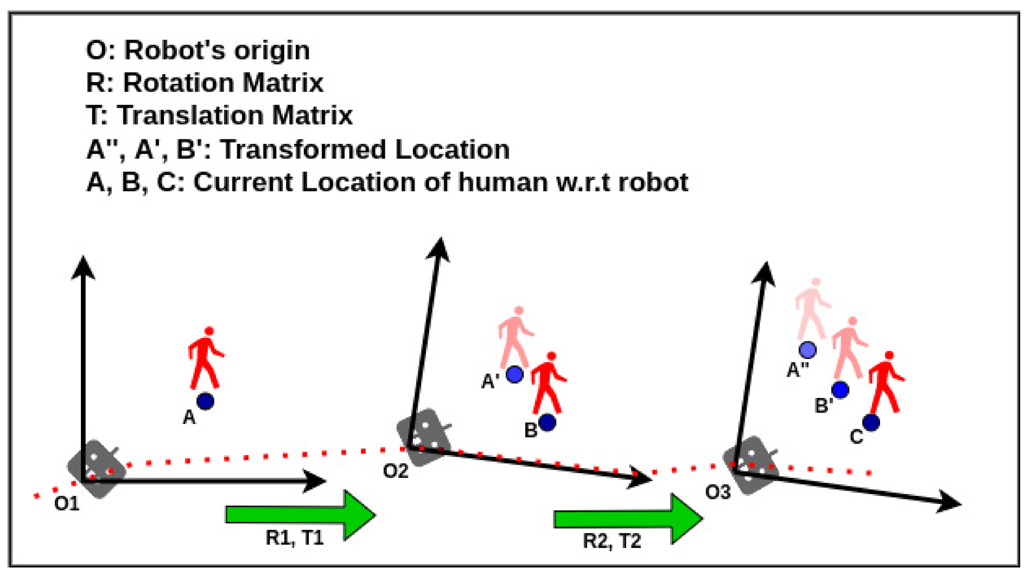


Fig.1.Transformation of a human's location to a new coordinate-system

Results

Goal	(A)Bedroom 1			(B)Bath 1			(C)Living Room			(D)Bedroom 2			(E)Fitting 1		
	$n=1$	$n=2$	$n=3$	$n=1$	$n=2$	$n=3$	$n=1$	$n=2$	$n=3$	$n=1$	$n=2$	$n=3$	$n=1$	$n=2$	$n=3$
Time(sec)	27.65	60.90	107.79	36.84	74.14	—	69.14	80.33	115.87	45.87	90.62	121.31	33.82	94.27	—
$RMSE_{UKF}$(m)	0.1374	0.1027	0.1334	0.0944	0.1578	0.1350	0.1075	0.1217	0.1016	0.0444	0.1162	0.0537	0.1164	0.1065	0.1368
$RMSE_{KF}$(m)	0.2281	0.2367	0.2113	0.2137	0.2737	0.2009	0.2107	0.2187	0.2087	0.2392	0.2338	0.2167	0.2398	0.2071	0.2373
Min $\varphi_{halting}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Min $\varphi_{distance}$	0.0033	0.0030	0.01490	0.0005	0.0003	0.00147	0.0011	0.0396	0.01254	0.0057	0.0060	0.00213	0.0045	0.0011	0.01377

"Proposed approach can efficiently monitor safety across a spectrum of multiple complex scenarios with numerous human encounters simultaneously "

- TABLE shows the proposed monitoring algorithm works well on five scenarios with an increase in the number of human workers from 1 to 3.
- Estimation phase works best with an unscented Kalman filter with an RMSE ranging from 4 to 15 centimeters.
- Fig.4 illustrates positive robustness values over time for both ϕ halting and ϕ distance for scenario A (Bedroom 1) with 2 human workers involved
- This states that the system (i.e., two human workers and the robot) is safe, i.e. no collision detected.
- TABLE shows a significant growth in the time for the robot to complete its task when increasing the number of human workers in the scenes.
- For example, in scenario D (Bedroom 2), the completion time increases from 45.87 seconds (1 worker) to 121.31 seconds (3 workers), i.e., 164.46%.

Future Works

- Research in leveraging runtime monitoring results for safe planning using planning/control/learning.
- Develop modified TEB planner for future costmaps.
- We'll handle varied construction hazards by integrating new safety criteria

Signal Temporal Logic

While navigating to a location, if the distance from a human is less than a safe distance, which is d_safe = 1.25 meters, the robot stops and waits for 2-3 seconds before continuing its navigation.

$$\varphi_{safety} = \Box_{[t,t_{pred}]}(d \geq d_{safe}) \quad (1)$$

$$\varphi_{halting} = \Diamond_{[t,t_{pred}]}(d \leq d_{safe}) \rightarrow (v = 0) \quad (2)$$

$$\varphi_{distance} = (\Box_{[t,t_{pred}]} d \geq d_{safe}) \mathcal{U} (\varphi_{halting}) \quad (3)$$

- Temporal operators used in the quations are "always p", "eventually p", and "q U p" (q until p).
- Colloquially, specification ϕ saf ety in eq(1) requires that "the distance from human is greater than d safe from time t to t pred "
- ϕ halting (eq(2)) requires that "when eventually the human comes closer than d saf e m from time t to t pred implies speed of the robot is zero".
- Eq(3) specifies that ϕ saf ety holds until ϕ halting .

REFERENCES

[1] Maler, O., & Nickovic, D. (2004, September). Monitoring temporal properties of continuous signals. In International Symposium on Formal Techniques in Real-Time and Fault-Tolerant Systems (pp. 152-166). Berlin, Heidelberg: Springer Berlin Heidelberg.

[2] Constructionrobots, "Construction robotics - build smart," 2022, ccessed: 2022-10-25. [Online]. Available: https://www.constructionrobots.com/tybot/

[3] V2A2: https://sites.google.com/view/v2a2/about