Spatio-Temporal Memory System for Robots: Enabling Long-Term Contextual Reasoning

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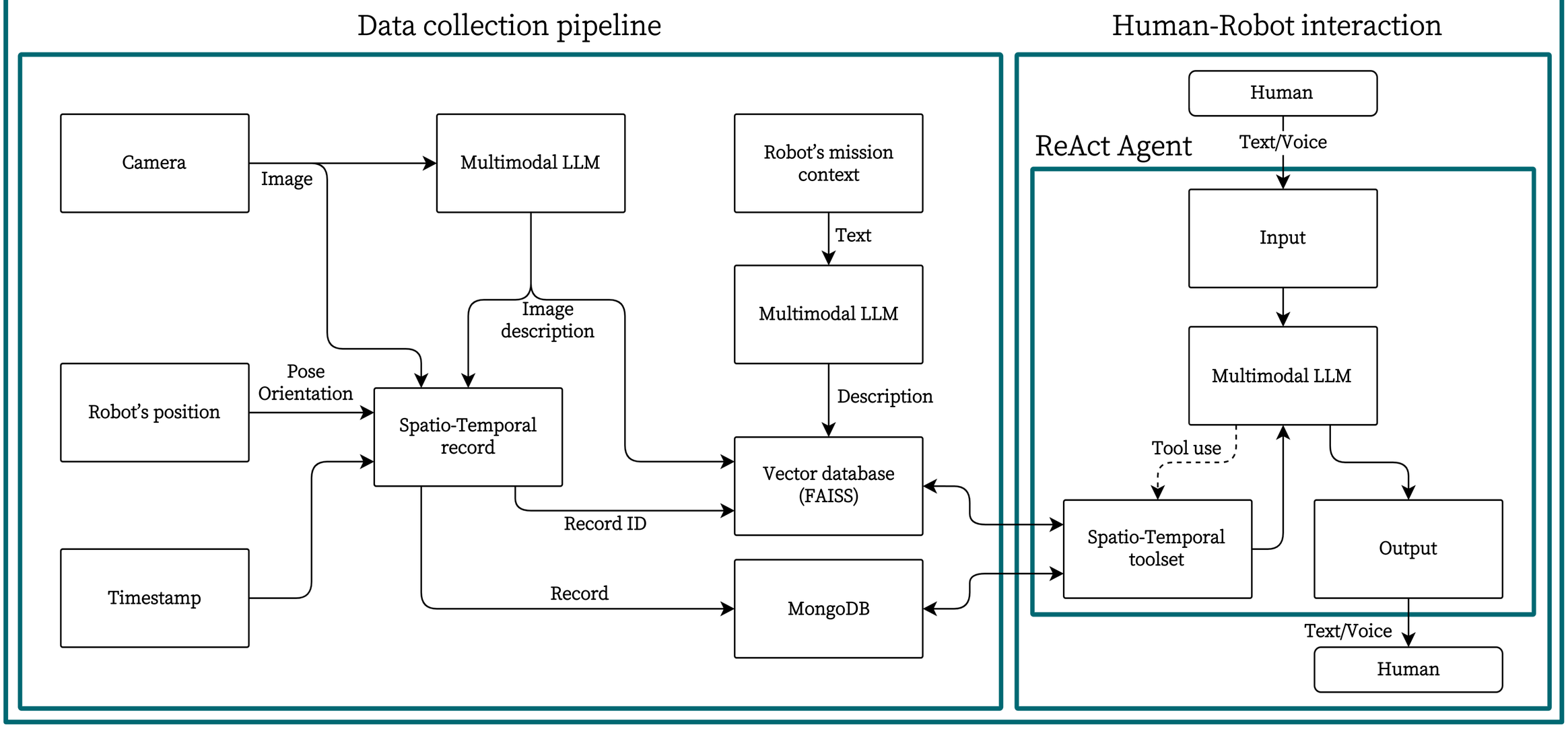
Introduction

Problem
Robots operating over long periods in dynamic environments struggle with remembering past actions, observations, and locations. Standard LLMs are limited by context size and scalability issues.
Goal
To enable long-term contextual reasoning in autonomous robots through a Spatio-Temporal Memory System integrated into the RAI framework.
Key insight
Instead of relying solely on fixed-length LLM memory, we use structured and semantic data storage with retrieval tools to make experience queryable, scalable, and actionable.

Conclusion

Scalable Long-Term Memory
System allows robots to recall spatial, temporal, and semantic data across long timeframes, supporting autonomy in evolving environments.
Retrieval-Based Reasoning
Combining structured and vector databases enables accurate, real-time answers to natural language queries.
Validated in Real Settings
Tested on a mobile robot over multiple days, the system supported tasks like item search, navigation, and answering past-event questions.
Open and Extendable
Freely available at github.com/RobotecAI/rai, the system is ready for future research on memory, reasoning and embodied deployment.

Architecture



Testing and evaluation

Real-World Deployment
Tested on a ROSBotXL in an office environment over several days, performing query and delivery tasks.
Memory Accumulation
The robot continuously stored images, positions, and activity context, building a detailed spatio-temporal memory.
LLM Agent in Action
A ReActAgent used the memory to answer long-horizon questions like "Where were you yesterday?" and "Where was the fire extinguisher last seen?"
Improved Reasoning
The system enabled context-aware decisions, adapting to tasks using relevant past experiences.

Limitations

Image Description Accuracy
Occasionally, image descriptions lacked detail or contained inaccuracies, affecting object identification and retrieval.
Noise in Data Retrieval
Irrelevant information in image descriptions sometimes led to noisy data and less relevant query results.
Redundant Tool Use
The agent sometimes invoked external tools for the knowledge available in the current context, reducing efficiency.
Contextual Drift
Stored data could become outdated or irrelevant over time, affecting decision-making.