Poster: Property Specification Patterns for Robotic Missions

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ABSTRACT

Engineering dependable software for mobile robots is becoming increasingly important. A core asset in engineering mobile robots is the *mission specification*—a formal description of the goals that mobile robots shall achieve. Such mission specifications are used, among others, to synthesize, verify, simulate, or guide the engineering of robot software. Development of precise mission specifications is challenging. Engineers need to translate the mission requirements into specification structures expressed in a logical language—a laborious and error-prone task.

To mitigate this problem, we present a catalog of mission specification patterns for mobile robots. Our focus is on robot movement, one of the most prominent and recurrent specification problems for mobile robots. Our catalog maps common mission specification problems to recurrent solutions, which we provide as templates that can be used by engineers. The patterns are the result of analyzing missions extracted from the literature. For each pattern, we describe usage intent, known uses, relationships to other patterns, and—most importantly—a template representing the solution as a logical formula in temporal logic.

Our specification patterns constitute reusable building blocks that can be used by engineers to create complex mission specifications while reducing specification mistakes. We believe that our patterns support researchers working on tool support and techniques to synthesize and verify mission specifications, and language designers creating rich domain-specific languages for mobile robots, incorporating our patterns as language concepts.

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Mobile robots are complex cyber-physical systems that are increasingly used in complex environments, such as houses, hospitals or plants. Mobile robots aim at intelligently realizing missions, such as exploring rooms, delivering goods, or following certain paths for surveillance. Creating a so-called mission specification is one of the main steps when designing mobile-robot software [1, 4, 8, 9]. A mission specification describes the intended behavior of a robot, including movement, vision, motion, communication, navigation, or collaboration behavior, among others. In the initial design phase, the robot mission is typically described in natural language or in informal models. Refining such descriptions into a formal model allows using automated engineering techniques, such as code generation or software synthesis, while avoiding ambiguities that might exist in the informal representations. Unfortunately, refining an informal mission description—a *mission requirement*—into a formal mission specification is an arduous and error-prone task [4].

Even though specifying the mission is a key part of engineering software for correctly behaving robots, it requires deep expert knowledge and experience to transform the intended behavior into a model expressed in a formal language, such as Linear Time Temporal logic (LTL). Rather than conceiving such properties recurrently in an ad hoc way and with the risk of introducing mistakes, ideally engineers could focus on high-level problems and re-use validated solutions to existing specification requirements retrieved from a catalog.

The challenge of defining behavioral properties in logical languages, such as LTL, is well recognized. While precise behavioral specifications in logical languages enable reasoning about behavioral properties [7], their specification is challenging. Practitioners are often unfamiliar with the specification process as well as with the intricate syntax and semantics of logical languages [3]. Specification patterns have become a popular solution to this challenge. Dwyer et al. [3] introduced the first catalog of patterns, which was later extended by Konrad and Cheng [6] and by Grunske [5] to address real-time and probabilistic properties, respectively. Autili et al. [2] consolidated and organized these patterns into a comprehensive catalog. However, none of these pattern systems focuses on the robotic domain and to the mission specification problem.

We address this gap by presenting a specification pattern system for missions of mobile robots. Our scope is on robot movement—e.g., to patrol areas or to avoid obstacles—as a highly important concern for specifying mobile-robot missions. We synthesized these patterns from real mission requirements that we systematically collected from publications in top robotics and software engineering venues over the last four years.

To identify specification patterns for robotic missions, we first reviewed the relevant literature to collect mission requirements. Subsequently, we considered the mission requirement description, from which we extracted mission concerns inherent in it. Such mission specification concerns, capturing key mission aspects, led to the identification of certain recurrent problems. We considered

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Name: Patrolling

Intent: A robot must patrol a set of areas or points, but not in a particular order.

Template: The following formula encodes the mission in LTL for two locations or points of interest and a robot r:

$$\mathcal{G}(\mathcal{F}(r \; in \; l1) \wedge \mathcal{F}(r \; in \; l2))$$

where r *in* $l1$ and r *in* $l2$ are expressions that indicate that a robot r is in a specific area or at a given point.

Variations: If a relational notion of space is used, propositions have the form r *in* l where *in* indicates that the robot r is inside location l and l identifies the desired location. If an absolute notion of space is used, propositions have the form r *at* (x, y, z) where *at* indicates that the robot r is in a specific point and (x, y, z) indicates a precise position in space.

Examples and Known Uses: This pattern also appears in the literature as surveillance. It is used to encode infinite executions of the robot, such as surveillance, persistent monitoring, and pickup-delivery missions. Consider the areas $l1$, $l2$, $l3$, and $l4$ and a set of areas $\{l1, l2, l3\}$ to be all surveilled. If a robot keeps entering the areas following the order $l1$, $l4$, $l3$, $l1$, $l4$, and $l2$, the mission is achieved. Vice versa, if the robot keep visiting the areas as follows $l1$, $l4$, $l3$, $l1$, and $l4$ the mission is not achieved since $l2$ is not surveilled.

Relationships: The Patrolling pattern generalizes the Visit pattern by requiring to keep visiting a set of areas.

Figure 1: The pattern Patrolling

these recurrent problems and identified solutions in a pattern catalog, providing model solutions for the identified problems. Specifically, we extracted 208 mission requirements and subsequently analyzed them, identifying recurrent problems they tackle. For each of these problems, we analyzed mission specifications proposed in the literature, we categorized them, and we defined a set of patterns. Each pattern consists of a name, a usage intent, known uses, as well as relationships of the pattern to others. Most importantly, a template formula expressed in LTL, a widely used logical language for specifying behavior, provides a model solution to the problem the pattern identifies. For example, the *Patrolling pattern*, which allows the specification of the requirement "the robot must patrol a set of areas or points, but not in a particular order", is presented in Figure 1.

The pattern hierarchy is obtained from relations of mission concerns; a fragment is illustrated in Figure 2. Leaves of the pattern hierarchy identify concerns, are marked with a grey background and represent actual patterns. Others are mission concerns that facilitate browsing of the hierarchy and are intended to aid decision making and pattern selection. Major mission concerns include (i) *Core movement patterns*, expressing fundamentally how robots should move within an environment; (ii) *Avoidance patterns*, constraining movement in order to avoid occurrence of some behaviour; and (iii) *Trigger patterns*, reflecting reactive behaviour based on stimuli, or expressing inaction until a stimulus occurs.

We evaluated our patterns in three different dimensions. We analyzed (i) the effectiveness of our specification pattern system in capturing mission specification problems, (ii) the applicability of each pattern in mission specifications by calculating the frequency of usage of each pattern in the set of mission requirements, and (iii) how the granularity of the pattern system helps in mission specification, by investigating the usage of pattern combinations.

Based on our evaluation results, our specification pattern system exhibits adequate coverage of mission requirements as encountered in the literature. We have seen a prevalence on the usage of the *Visit* and *Global Avoidance* patterns, since they can be considered rather fundamental, while other are less used. Certain combinations of patterns such as *Global Avoidance* with *Visit* and *Future Avoidance* with

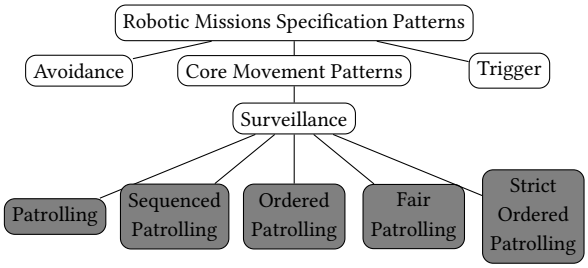

Figure 2: Surveillance specification patterns within the movement patterns hierarchy (fragment).

Patrolling appear more often. Therefore, they maybe considered as meta-patterns by themselves.

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REFERENCES

[1] Ronald C. Arkin and Tucker Balch. 1998. Artificial Intelligence and Mobile Robots. MIT Press, Chapter Cooperative Multiagent Robotic Systems, 277–296.

[2] Marco Autili, Lars Grunske, Markus Lumpe, Patrizio Pelliccione, and Antony Tang. 2015. Aligning qualitative, real-time, and probabilistic property specification patterns using a structured english grammar. *Transactions on Software Engineering* 41, 7 (2015), 620–638.

[3] Matthew B Dwyer, George S Avrunin, and James C Corbett. 1999. Patterns in property specifications for finite-state verification. In *International Conference on Software Engineering*. IEEE, 411–420.

[4] Yoichiro Endo, Douglas C MacKenzie, and Ronald C Arkin. 2004. Usability evaluation of high-level user assistance for robot mission specification. *Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 34, 2 (2004), 168–180.

[5] Lars Grunske. 2008. Specification patterns for probabilistic quality properties. In *International Conference on Software Engineering*. IEEE, 31–40.

[6] Sascha Konrad and Betty HC Cheng. 2005. Real-time specification patterns. In *International conference on Software engineering*. IEEE, 372–381.

[7] H. Kress-Gazit, G. E. Fainekos, and G. J. Pappas. 2009. Temporal-Logic-Based Reactive Mission and Motion Planning. *IEEE Transactions on Robotics* 25, 6 (2009), 1370–1381.

[8] Douglas C MacKenzie, Ronald C Arkin, and Jonathan M Cameron. 1997. Multiagent mission specification and execution. In *Robot colonies*. Springer, 29–52.

[9] Douglas C MacKenzie, Jonathan M Cameron, and Ronald C Arkin. 1995. Specification and execution of multiagent missions. In *International Conference on Intelligent Robots and Systems*. IEEE, 51–58.