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Automated Reasoning and Robotics: A Systematic Review

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Abstract

Nowadays, humans are more dependent on machines and specifically robots, due to the technological advancements in this area. When it comes to robots, it's a combination of machine and artificial intelligence programs, which are built on logic and planning. We could define the robotics navigations based on logical representations for the possible allowed movements without any human interactions. Hence, such automated logic\reasoning will help the programs act and produce logical orders to the correspondent part to take any action or answer some questions. However, the task of robots learning involves integrating with many objects such as sensors, cameras for vision, and movements; this process involves understanding how automated reasoning can be applied to robots' computer programs and how it will enhance the robots' responses. Besides, it involves understanding what the used techniques are in automated reasoning which is related to Robotics. This paper will review the different types of knowledge representation used in robotics.

1. Introduction

Information technologies made a significant societal impact across different domains (Abou Samra et al., 2020; Abousamra & Al Ali, 2017; Al-Emran et al., 2015, 2018; Al-Emran & Shaalan, 2017). Robotics advancements are measured in how good they are in replicating humans in activities and responsibilities (Al-Emran, 2015a). One of the robots' tasks is communicating with surroundings from humans and other robots (Al-Emran, 2015b; Alshaafee et al., 2021). Such a task needs some standardization in robots' knowledge representations, which will, in turn, assure efficiency in data transfer and integrations among robotics systems in addition to precisely defining the concepts in standard knowledge representations (Al-Amri et al., 2021; Jnr et al., 2021; Schlenoff et al., 2012). Automated reasoning in the field of study in knowledge representations is the ability to automatically make inferences in computer programs (Portoraro, 2019; Wikipedia, 2021). Robotics is a composition of machine and computer programs; Hence, applying automated reasoning to robotics will ease the way of how robotics can interact and move in the real world, which will lead to more advancement in replicating humans. This review intends to answer the following questions:

- How is knowledge representation implemented in Robotics?
- What are the techniques and languages used to define the knowledge and reasoning in Robotics?

This document is organized as the section **Error! Reference source not found.** will discuss the process followed in writing this study, from search keywords to search study technique. The section Synthesis will discuss the paper contents showing the strengths and used algorithms and technologies. The section **Error! Reference source not found.** will summarize our findings and conclude our future work.

2. LITERATURE SEARCH PROCEDURE AND CRITERIA

Since this is a literature review it's important to outline the literature search criteria and the underlying process involved. The research questions are "How is knowledge representation implemented in Robotics? Are there well-defined Standards for knowledge representations in Robotics? And what are the techniques, languages used to define the knowledge and reasoning in Robotics?"

2.1 Search terms and strategy

We have searched three different databases; Scopus(Elsevier, 2021a), Semantic Scholar(Semantic Scholar, 2021a), and Google Scholar (Google, 2021a). The main search database was Scopus, and the secondary search database was Semantic Scholar and Google Scholar.

We used the following keywords in the search "Automated Reasoning and Robotics", "Knowledge representation and robotics", "Reasoning techniques and robotics". We have used a combination of words, alternative synonyms, and keywords related to knowledge representation and reasoning in Robotics area fields.

2.2 Inclusion and Exclusion criteria for the papers

We have used a set of rules for inclusion criteria:

- Paper documents should be published in the last 6 years.
- Paper documents should be ranked in "https://www.scimagojr.com/ "
- If a paper is published in Journal, it should be ranked as Q1, Q2 in Scimagojr.
- If a paper is published at Conference, the Citation per document fields should be greater than 1 document in the last 2 years as per the scimagojr.com website.
- Publish by will know publishers, i.e., IEEE, Elsevier, and Springer.
- The study should be relevant to the chosen topic.
- The study should be written in English.
- The study should be of high quality.
- The study's full text should be accessible.

We have used a set of rules for exclusion criteria:

- The study is published before the year 2014.
- The study is not related or relevant to the topic.
- The study is not written in English.
- Duplicate and non-quality studies are excluded.
- The study was published by an unknown publisher.

2.3 Data bases analysis and resources

We have searched three different databases; Scopus(Elsevier, 2021b), Semantic Scholar(Semantic Scholar, 2021b) and Google Scholar (google, 2021b). The main search database was Scopus, and semantic Scholar while Google Scholar is considered as a secondary database.

Database name	Research Paper Count	Classification
Scopus	2088	Main Source
Semantic Scholar	1888	Main Source
Google Scholar	16900	Secondary Source*

Table 1. DATABASE ANALYSIS WITHOUT APPLYING INCLUSION \ EXCLUSION CRITERIA

Secondary source databases were mainly used for cross-checking the citations, and availability of documents in some cases. Table 1 represents the search results per each database without applying inclusion and exclusion criteria.

2.4 PRISMA Flow diagram

We followed the guidelines provided in previous reviews (Al-Maroof & Al-Emran, 2021; Al-Qaysi et al., 2020; Al-Saedi et al., 2019). Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA is used as evidence for a systematic review to assure the highest possible quality in identifying and choosing the right papers. Figure 1 is used in the process of identifying the choosing the research papers for this review. The detailed analyses are illustrated in Appendix B.

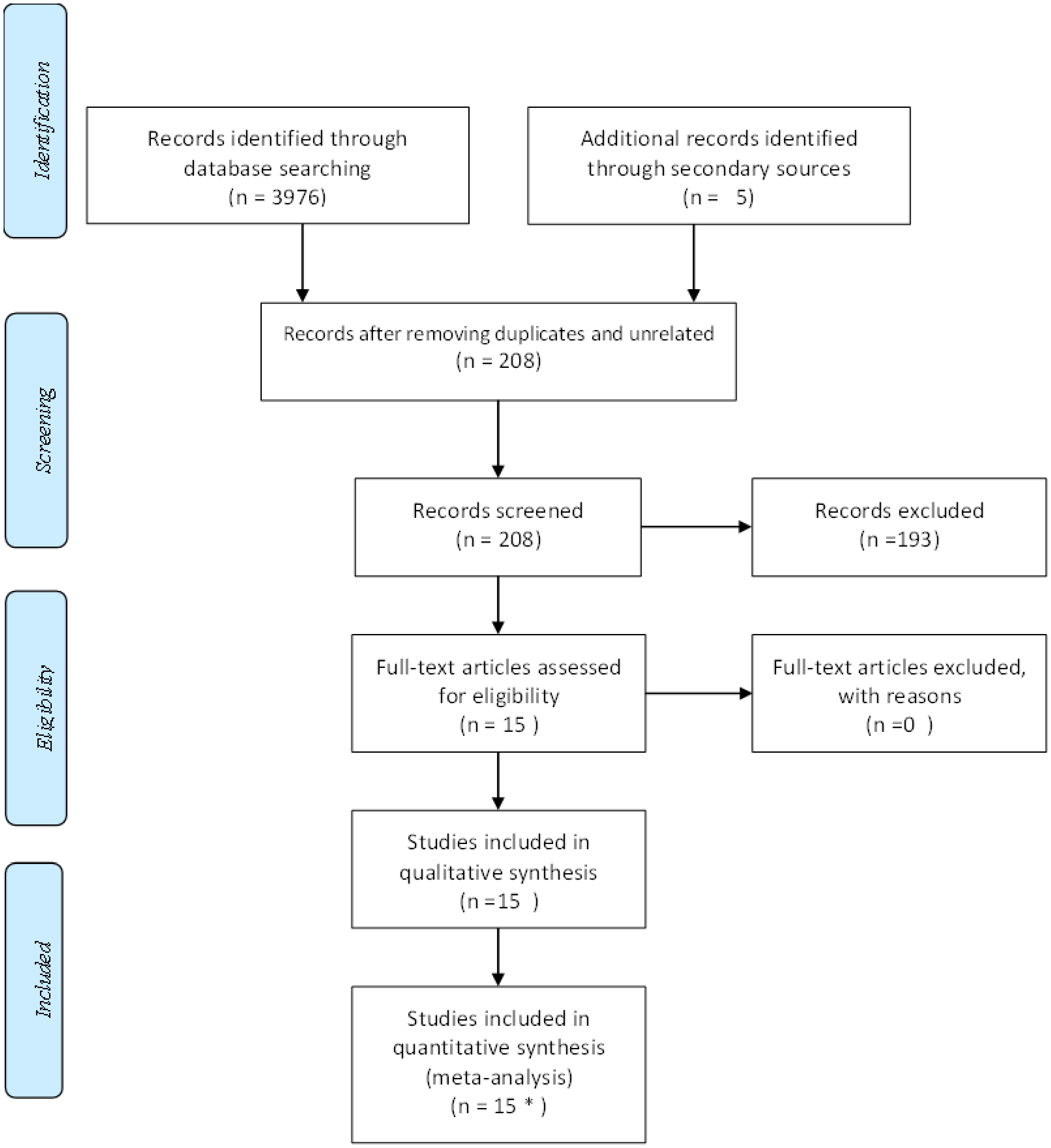

Figure 1. PRISMA flow diagram in choosing the papers

3. SYNTHESIS

In this section, we will discuss the findings and the results of this systematic review. Besides, it will be summarized in (*Table II. Paper Content Analysis*).

Probabilistic graphics models have been recently deployed in many types of research to create tasks like navigation which takes care of controlling and monitoring of robot, planning where and when to move to fulfil the mission, sensing, and interaction with other objects surrounding the robot itself. These tasks may not be working probably well with common-sense knowledge. Mobile robots used many algorithms that were supported by logic programming classic planning. These algorithms typically need a substantial amount of prior knowledge of the domain, the agent's abilities, and the preconditions and results of the actions. Many of these algorithms are founded on first-order logic methods and do not support abilities such as default reasoning, non-monotonic logical reasoning, unreliable information with the current beliefs in a knowledge base (Sridharan et al., 2019b).

Answer Set Prolog (ASP) was developed by the international research community with many fields in non-robotics domains and cognitive robotics. For example, ASP has been utilized for planning and diagnostics by a team of simulated, heterogeneous, or physical machine robots working as housekeepers or in toy workshop settings. Also, it has been utilized to interact with people by learning natural language processing (NLP). ASP-based have also been used for the control of autopilot planes in dynamic indoor environments. A more recent investigation has detached the need to solve ASP programs when the problem description changes. As a result, new info can enlarge existing old programs, and ground rules and conflict information can be used again to support interactive theory exploration. Moreover, ASP does not support any of the probabilistic models of uncertainty. Meanwhile, a lot of information available to robots is represented probabilistically to quantitatively model the uncertainty in sensor input processing and actuation (Diab et al., 2019b; Erdem et al., 2016b; Sridharan et al., 2019a).

In papers (Akbari et al., 2019b; Diab et al., 2019a), the authors show many ways for reasoning actions and change in robotic position based on action language. Syntax of action language and its intuitive semantics are simpler for system creators to understand than other languages which are based on declarative language such as Prolog, ASP. Even creators without any previous experience in action language are capable of learning their usage without any familiarity with the semantics. Many various action languages such as PDDL, ALM, BC, and STRIPS, which have been used in various fields, recursive state constraints, non-deterministic causal laws, and non-Boolean fluents are usually used to represent and reason in many robotics applications. Recently, many works have been done by using a three-layered group of knowledge (default, diagnostic, and instance), lower levels are modifying by knowledge in the higher level, also three-layered architecture (belief layer, competence layer, and deliberative layer) are modifying by knowledge in the higher level, path planning in mobile robot devices are used a combination of declarative programming and continuous-time planners.

Recently, a lot of works were done by combining extension of ASP (Answer Set Prolog) with POMDPS Partially observable Markov decision process for probabilistic planning in the human-robot dialog and common sense knowledge, whereas determining some model specifications of POMDPs has utilized a probabilistic extension of ASP, and united logic programming with relational reinforcement learning to progressively and interactively discover domain affordances and axioms. One of the fundamental problems in AI is combining probabilistic reasoning and logic, and many processes have been developed to address this problem. For example, a Markov logic network integrate first-order logic and probabilistic graphical.

Models allocate weights to logic methods. Bayesian Logic reduces the constraint of FOB languages to support a compact representation of distributions over different groups of objects. Other instances contain independent choice logic, first-order relational POMDPs, PRISM, probabilistic first-order logic, and Plog that allocate probabilities where ASP programs were represented by many possible worlds (Akbari et al., 2019a; Bidot et al., 2017b; Erdem et al., 2016a; Hammood et al., 2020). The bellow table (Table II Papers content analysis) will discuss in details the algorithms, applications and focus for each paper in addition to our main finding.

Paper	Algorithms	Focus	Study Type	Applications	Findings
P1(Rajan & Saffiotti, 2017b)	Classical planning, deep learning.	Uncertainty, Gaps in knowledge, Hybrid reasoning.	Research	Intelligent robots, cognitive robotics, Embodied AI, Integrated systems.	This paper focus on challenges that are important for robotic systems.
P2(Muhayyuddin et	grid-based methods, potential field, k-PMP.	Kino-dynamic planning,	Research	Robotic manipulation, Robot navigation.	This paper discussed important issues in terms of motion planning in robotics, also
P3(Paulius & Sun, 2019b)	Classical Machine Learning, Neural Network Deep Learning.	Markov Networks, Bayesian Networks, Neural Networks.	Survey	Domestic Robots, Task Planning, Service Robotics, Robot Learning.	Summary of using many methods like machine learning and deep learning to teach a robot many skills that could be used for task planning purposes.
P4(Ramirez-Amaro et al., 2017)	multi-step hierarchical clustering, subspace analysis, color-based algorithm.	Activity recognition, Human understanding, Skill transfer, Semantic representation.	Research	Inferring human activities, recognizing complex human activities, extracting visual features	This paper focused on using semantic representations to infers human activities. Also, main issues of moving tasks and skills to human robot.
P5(Gemignani et al.,	multi-layer semantic mapping, The segmentation algorithm,	Human Robot Interaction, Semantic Mapping.	Research	Human-Robot, Domestic Robots.	This paper shown a new method for collecting and representing the
P6(Bidot et al., 2017a)	Task planning, Action planning, Path planning, Motion planning, forward-chaining,	Combined task and motion planning, Geometric backtracking, Robot manipulation, Hybrid reasoning.	Research	robotic systems	The main outcome of this paper is using an approach to hybrid planning for complex robotic platforms. In addition to that, illustrating the issue of geometric backtracking.
P7(Akbari et al., 2019a)	Rapidly Exploring Random Tree, backward search, TAMP. approach,	Combined task and motion planning, Robot manipulation, Geometric reasoning	Research	Yumi robot, Bi-manual Robots.	This study focus on solve manipulation issues for bi-manual robots. Also, it explained the main challenge that supplying low level geometric info for
P8(Sridharan et al.,	semi-supervised, Particle Filter algorithm, SLAM.	Action Language with non-boolean fluents and non-	Research	robotic systems	This study showed a KRR architecture that integrate probabilistic graphical
P9(Feyzabadi & Carpin, 2014)	Probabilistic Roadmaps, Rapidly Exploring Random Trees.	Motion Planning, Path planning, Dynamic Environment, Collision Avoidance.	Research	robotic systems	This paper focused on initial efforts to improve a knowledge base and common representation in dynamic environments for motion planning.
P10(Diab et al.,	Perceptual algorithms, feature extraction.	perception knowledge, knowledge-based	Research	indoor service robots.	This research showed Perception and Manipulation Knowledge (PMK) involve

Table 2 . Papers content analysis.

Paper	Algorithms	Focus	Study Type	Applications	Findings
P11(Zhang et al., 2015)	Robot operating system (ROS), POMDP planner.	Answer Set Prolog (ASP), Hierarchical Planning,	Research	Intelligent robots, Wheeled robot.	This study showed an architecture that mixes probabilistic graphical models and the complementary strengths of declarative programming for knowledge representation and reasoning in robotics.
P12(Erdem et al., 2016a)	Robot Operating System (ROS),	Applications of ASP to Computational Biology and Bioinformatics, Industrial ASP Applications.	Research	Multiple Robots Collaboratively Working in a Cognitive Factory, A Mobile Service Robot.	This paper covered Answer set Prolog (ASP) that utilized in many applications like knowledge representation and reasoning, bioinformatics, robotics, computational biology as well as industrial application.
P13(Lemaignan et al., 2017)	clarification and discrimination algorithms, spark algorithms.	human-robot interaction, cognitive robotics, perspective taking.	Research	Social robots.	The paper focused on human–robot collaborative task that supported by situated communication and multi-modal, also focusing on robot' s capabilities like recognizing.
P14(Niekum et al., n.d.)	Learning from unstructured demonstrations, Incremental semantically, LFD algorithm,	Learning from demonstration, Bayesian nonparametrics, time-series analysis.	Research	Robots.	This study summarizes two primary methods that extend the generalization capabilities of LfD algorithms in complex robotic tasks.
P15(Gayathri & Uma, 2018)	path planning algorithms, c++, Java, Matlab, ROS.	Path planning; Knowledge representation; Reasoning; Ontology; Spatial; Temporal.	Research	Robot path planning, robot systems, Control of autonomous Vehicles.	This paper focus on many approaches that is important for allowing the robot to access objects and execute actions more effectively and accurately with minimal computational. complexity.
P16(Miyazawa et al., 2019)	alpha algorithm, Chemical detector, Autonomous detector	State machines, Formal semantics, Process algebra, Timed properties, language for robotics.	Research	robotic systems.	This paper concentrates on RoboChart including the notions of robotic platform, machines and parallel controllers, as well as synchronous and asynchronous communications.

4. FINDINGS AND CONCLUSION

To conclude our findings by answering the review questions:

- How is knowledge representation implemented in Robotics?
- What are the techniques, languages used to define the knowledge and reasoning in Robotics?

Automated reasoning has been implemented in designing a robotic system and multi-robot cooperation, whereas robots have been widely used in manufacturing, medical education, defense, and other fields. The most autonomous robot getting popularity these days is the self-driving car. These are tremendously hard to develop because of the highly sophisticated uncertain environment of motorized traffic and the strict safety requirements. Most of the research papers were focusing on motion planning and dynamic environment, as well as embedded intelligence that combined reasoning, perception, and actuation. Furthermore, concerted on sensorimotor functions in the aspect of electrical and mechanical engineering. Also, mentioning the main aspects along with the current evaluation of artificial intelligence (Sridharan et al., 2019a).

Some papers outlined improving physics motion planners by implementing a knowledge obtained from a framework called k-PMP based on Kino-dynamic algorithm like Rapidly-Exploring Random Trees (RRT) or KPIECE, and on any dynamic engine, like open dynamic engine (ODE). Also, integration of a reasoning process in the state transition model is done by implementing manipulation knowledge that is derived from abstract knowledge ontology that is written using Web Ontology Language. However, delivering an overview of robot learning and representation for robots, also how important to significant to differentiate representation from learning, Machine learning models, for example, is not enough to be representations alone and are better classified as specialized learning models. This paper tackles the ideologies behind an effective knowledge representation for a robot machine to utilize its whole potential (Erdem et al., 2016a).

Furthermore, paper 4 covered the main challenges for robotics to imitate human activities in a good manner and use a method for taking out the meaning of human activities by gathering objects' properties and hand motion information in human-robot interaction.[10] In research paper 5, was focusing on a modern approach for getting and representing the knowledge about indoor surroundings, so the performances of the robot are reinforced by grounded facts, rather than supported by general world knowledge. In addition to that, provides a solid and expressive representation to manage dialogs about the objects and locations in the surroundings and too complex user instructions denoting spatial locations (Bidot et al., 2017a).

On the other hand, discovering a modern method for hybrid planning in sophisticated robotic platforms, the method is based on the idea of hybrid states, i.e., states that have a geometric component and symbolic component, also centered about the issue of geometric backtracking that appears in motion planning and hybrid task, in order to prepare the geometric preconditions of the current action. Geometric choices should be reconsidered like poses and grasps, that were completed for prior actions (Rajan & Saffiotti, 2017a). Moreover, a compatible set of tasks and motion planning plays a vital role in robotic manipulation problems. Accordingly, a heuristic-based task and motion planning method is suggested, in addition to that, the computation of the heuristic handles a geometrically relaxed problem like grasp poses, reasons for items placements, and inverse kinematics solutions (Muhayyuddin et al., 2018a). finally, described a KRR architecture that integrates the strong point of probabilistic graphical models and declarative programming. The architecture is founded on tightly-coupled transition diagrams that denote the domain knowledge, and the robot's capabilities and goals (Paulius & Sun, 2019a).

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Appendix A

Paper quality control template

Ref	Paper Name	Year	#Citations	Journal Name	Ranking	Publisher
RP1	Towards a science of integrated AI and Robotics	2017	45	Artificial Intelligence	Q1	Elsevier
RP2	Enhancing Physics-based Motion Planners with Knowledge-based Reasoning	2017	6	Journal of Intelligent & Robotic Systems (J Intell Robotic Syst)	Q1	Springer
RP3	A Survey of Knowledge Representation in Service Robotics	2019	39	Robotics and Autonomous Systems	Q1	Elsevier
RP4	Transferring skills to humanoid robots by extracting semantic representations from observations of human activities	2017	84	Artificial Intelligence	Q1	Elsevier
RP5	Living with robots: Interactive environmental knowledge acquisition	2016	28	Robotics and Autonomous Systems	Q1	Elsevier
RP6	Geometric backtracking for combined task and motion planning in robotic systems	2015	53	Artificial Intelligence	Q1	Elsevier
RP7	Combined Heuristic Task and Motion Planning for Bi-manual Robots	2019	12	Autonomous Robots	Q1	Springer Netherlands
RP8	A Refinement-Based Architecture for Knowledge Representation and Reasoning in Robotics	2015	21	Journal of Artificial Intelligence Research	Q1	Morgan Kaufmann Publishers, Inc.
RP9	Knowledge and Data Representation for Motion Planning in Dynamic Environments	2014	2	Advances in Intelligent Systems and Computing	Q3	Springer Verlag
RP10	A Knowledge Processing Framework for Autonomous Robotics Perception and Manipulation	2019	19	sensors	Q1	MDPI Multidisciplinary Digital Publishing Institute
RP11	Mixed Logical Inference and Probabilistic Planning for Robots in Unreliable Worlds	2015	58	IEEE Transactions on Robotics	Q1	IEEE
RP12	Applications of answer set programming	2016	152	AI Magazine	Q2	AI Access Foundation
RP13	Artificial cognition for social human–robot interaction: An implementation	2017	111	Artificial Intelligence	Q1	Elsevier
RP14	Learning grounded finite-state representations from unstructured demonstrations	2015	89	International Journal of Robotics Research	Q1	SAGE Publication Inc
RP15	Ontology based knowledge representation technique, domain modeling languages and planners for robotic path planning: A survey	2018	23	ICT Express	Q1	Korean Institute of Communications Information Sciences
RP16	RoboChart: modelling and verification of the functional behaviour of robotic applications	2019	16	Software and Systems Modeling	Q2	Springer

Appendix B

The bellow table shows the detailed analysis on **Scopus Database**

<table>
<tr><th>Search Criteria</th><th>Papers #</th><th>Inclusion\ Exclusion Filter</th><th>Papers # after filter</th><th>Paper # after screening</th><th>Final papers</th></tr>
<tr><td>Knowledge representation and robotics</td><td rowspan="3">2088</td><td rowspan="3">((TITLE-ABS-KEY (Knowledge representation and robotics) OR TITLE-ABS-KEY (Automated Reasoning and robotics) OR TITLE-ABS-KEY (Reasoning techniques and robotics))) AND (automated reasoning) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (OA,"all")) AND (LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR,2015) OR LIMIT-TO (PUBYEAR,2014)) AND (LIMIT-TO (SUBJAREA,"COMP")) AND (LIMIT-TO (EXACTKEYWORD,"Robotics") OR LIMIT-TO (EXACTKEYWORD,"Knowledge Representation") OR LIMIT-TO (EXACTKEYWORD,"Robots")) AND (LIMIT-TO (LANGUAGE,"English"))</td><td rowspan="3">42</td><td rowspan="3">6</td><td rowspan="3">1-Artificial cognition for social human–robot interaction: An implementation
2- Learning grounded finite-state representations from unstructured demonstrations
3- Ontology based knowledge representation technique, domain modeling languages and planners for robotic path planning: A survey
4- RoboChart: modelling and verification of the functional behaviour of robotic applications
5-Knowledge and Data Representation for Motion Planning in Dynamic Environments
6- A Knowledge Processing Framework for Autonomous Robotics Perception and Manipulation</td></tr>
<tr><td>Automated Reasoning and robotics</td></tr>
<tr><td>Reasoning techniques and robotics</td></tr>
</table>

- The bellow table shows the detailed analysis of **Semantic Scholar Database**

Search Criteria	Papers #	Inclusion\ Exclusion Filter	Papers # after filter	Paper # after screening	Final papers
Knowledge representation and robotics	107	URL 1*	8	4	1-Applications of answer set programming 2- Mixed Logical Inference and Probabilistic Planning for Robots in Unreliable Worlds 3- A Refinement-Based Architecture for Knowledge Representation and Reasoning in Robotics 4- A Survey of Knowledge Representation in Service Robotics
Automated Reasoning and robotics	581	URL 2*	66	0	
Reasoning techniques and robotics	1200	URL 3*	92	0	

- The bellow table shows the detailed analysis on **Google Scholar Database**

Search Criteria	Papers #	Inclusion\ Exclusion Filter	Papers # after filter	Paper # after screening	Final papers
Knowledge representation and robotics	16900	URL1*	5**	5	1- Towards a science of integrated AI and Robotics 2- Enhancing Physics-based Motion Planners with Knowledge-based Reasoning 3- Transferring skills to humanoid robots by extracting semantic representations from observations of human activities 4- Living with robots: Interactive environmental knowledge acquisition 5- Geometric backtracking for combined task and motion planning in robotic systems Combined Heuristic Task and Motion Planning for Bi-manual Robots
Automated Reasoning and robotics					
Reasoning techniques and robotics					

** Search was random based on the related content to the review, taking in the point the paper quality.