Towards a model for situation-aware navigation tasks*

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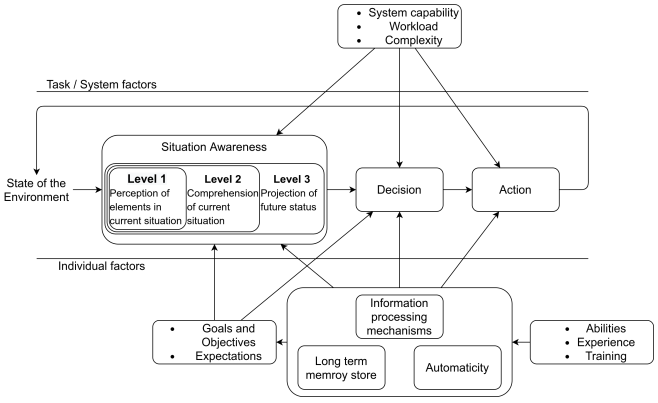

Fig. 1. The situation awareness model, its' position in the perception-decision-action loop, and factors that are affecting it. Adapted from [1].

I. Introduction

Navigation is an essential task for any autonomous mobile robot. It allows the robot to move between places, enabling it to accomplish other tasks. However, to successfully perform its' navigation tasks, the robot must have an understanding of the surrounding environment and its' dynamics. This understanding is referred to as *Situation Awareness* (SAW) and has been extensively studied in the field of human factors. In general, SAW studies how understanding a situation affects the performance of tasks executed by humans [1]. Specifically, it focuses on understanding which elements of the environment a human perceives given a task at hand, what relations the human forms to create higher-order understanding, and how the state of the elements is projected in the future. In addition, it studies the effects of various limitations of human cognition, and coping mechanisms that help overcome those limitations. SAW is used then by humans to make decisions and take actions that will help accomplish their tasks. A graphical representation of SAW and how it fits in the decision making and action execution cycle is shown in figure 1.

Drawing parallels to task execution by humans, autonomous robots, navigating in the real world also need a form of SAW. For example, this SAW would include features detected by sensors, used to localise in a given map, or the positions of potential obstacles along with their relative velocities etc. In most cases, all the pieces of information required to perform the navigation task, along with how they should be interpreted and used, are defined in an ad-hoc way by an expert application developer. In addition, all the needed information pieces, their relations and the algorithms that use them to navigate autonomously are hard-coded in the robot. This practice makes it harder to integrate new algorithms and sensors into the robot, as it requires reprogramming from an expert to be able to use them.

This work makes an initial attempt to overcome these shortcomings by introducing situation awareness in navigation tasks. It does so by introducing models that describe the navigation task in terms of goals the robot has to achieve, and by linking those goals to sensors and algorithms the robot can use to achieve those goals. Representing these models using a property graph, the robot can use graph traversals to autonomously find out which sensors, algorithms, and parameters to use. Moreover, such a representation is robot agnostic and can be used to perform any navigation task if the robot has specific capabilities.

II. Relevant work

In the robotics literature, situation awareness is mainly studied in the context of human-robot interaction. The main concern of such works is the state of situation awareness of the human related to the robot. For example, in [2] the process of a human acquiring SAW from a remote robot in search and rescue scenarios. In [3] a study is conducted to define which interfaces give higher situation awareness to squad members accompanied by an autonomous robot. The work described in [4] studies the effects of communication of the intent of an autonomous agent to the shared situation awareness and trust with humans. In [5] the work focuses on measuring the operator SAW using eye-tracking mechanisms in a supervisory control task of multiple robots.

When it comes to the situation awareness of autonomous robots, the amount of works is rather limited. In [6] a semantic knowledge representation is used to improve the autonomy of an autonomous underwater vehicle. The core focus was on fault-tolerant adaptive mission planning, where faults are detected and mitigated using knowledge stored in an ontology. The situation awareness is provided by a status monitor application ontology, which monitors various variables and specific patterns that are formed and connects them to events. The system designer defines the monitored information in this ontology, and there is no means for the robot to autonomously decide which of those should be monitored dynamically depending on the specific needs of the mission. Unfortunately, not much information is provided

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on the situation awareness and how is it achieved. The work of [7] presents a method for minimising operator intervention during the operation of an autonomous robot. It aims to detect situations blocking the robot from performing manipulation or navigation tasks and recovering from them. It uses an ontology-based representation for perceiving and comprehending the environment. Once comprehension is achieved, a situation similarity check is performed to decide if a new plan is needed or if an already computed one can be reused. However, the provided representation is limited to the specific blocking of navigation or manipulation goals and does not provide information on how the goals are described and what information is needed to achieve each of them.

In [8] a mental model is used to predict future state transitions of other agents in the environment. These predictions are formulated as Gaussian probability density functions and provide a method for making decisions under uncertainty. As already mentioned, that is just part of the whole situation awareness. The work presented in [9] provides a definition of the terminology of situation awareness and situation assessment. In addition, it provides a method to estimate the level of acquired SAW of the autonomous robot based on a surprise based metric. In [10] a learning approach is presented where the robot learns the correlation of perceived elements in the environment with a negative or positive ?emotion?. This allows the robot to react to similar situations encountered in the future quickly. The ”emotional” reaction is similar to automaticity that is presented in the human SAW literature. In this work no information is provided for the situation assessment or what is required to perform it. In [11] an architecture for automated planning and situation awareness for robotic surgery is presented. The presented situation awareness module has a twofold purpose. On the one hand, it is responsible for providing online high-level descriptions of the environment so that the human operator can verify the system's decisions and intervene. On the other hand, it acts as an intermediate layer between the task and motion planning components. The presented approach is tightly coupled with the task and robot at hand, having predefined pieces of information and algorithms to be used, while presenting no explicit model of SAW. Unfortunately, to the best of our knowledge, no work that addresses the problem of situation awareness for navigation tasks has been presented.

III. Proposed approach

Given that SAW is only relevant to the specific task that is executed [1] as it is described by its' goals, a method to define those goals and relate it to ways to achieve them is required. Such a modelling method has been proposed in [15], and is called *Goal-Directed Task Analysis* (GDTA). It aims at identifying the goals of humans operating in a specific role, the decisions they need to make, and what information and relations are needed to achieve that decision. GDTA is performed by a human expert, who defines the goals, sub-goals, and any related information needs. GDTA is used here to define the goals of the navigation task. A graphical representation of the identified high-level goals can be seen in figure 2.

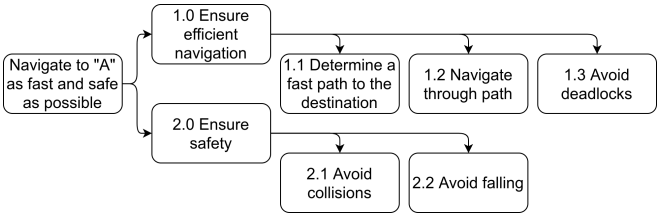

Fig. 2. GDTA results for an autonomous robot performing navigation tasks.

These goals can be further decomposed into decisions and information needs as defined by the GDTA theory. An example decomposition of a sub-goal to sub-sub-goals, decisions, and information needs can be seen in figure 3.

To model the defined goals, decisions, and information needs, a meta-model was designed as a set of SHACL shapes [16] that represent the constraints of the modelled entities (goals, decisions, information needs) in terms of allowed properties and relations to other entities. An example shape representing a goal and its' allowed relations to other entities can be seen in listing 1, which shows a shape representation in Turtle.

Listing 1. SHACL example of a meta-model

```
sa:GoalShape
  a sh:NodeShape ;
  sh:nodeKind sh:IRI ;
  sh:targetClass sa:Goal ;
  sh:property :HasSubGoal ;
  sh:property :HasDecision ;
  sh:sparql :NoHasGoalCycle .

:HasSubGoal sh:path sa:hasSubGoal ;
  sh:nodeKind sh:IRI ;
  sh:class sa:Goal .

:HasDecision sh:path sa:hasDecision ;
  sh:nodeKind sh:IRI ;
  sh:class sa:Decision .
```

Using this meta-model one can model the navigation goals, decisions, and information needs. For that, this work proposes the use of JSON-LD [17]. These models can be verified using the proposed meta-model, and be used to instantiate a property graph where queries can be made. An

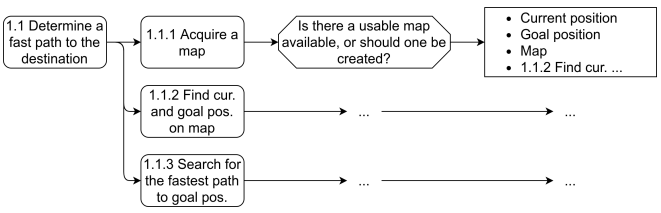

Fig. 3. Decision about how to achieve a goal and relevant information needs.

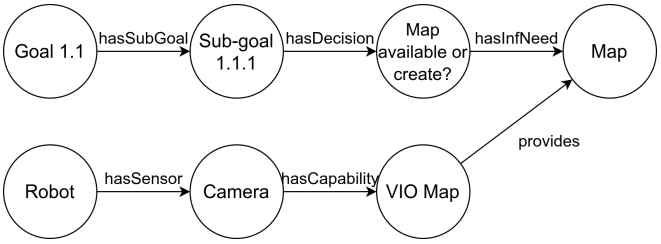

Fig. 4. Situation awareness generic information need and its' relation to robot specific sensors and technologies.

example of the modelled goals of figure 3 can be seen in listing 2.

Listing 2. JSON-LD example of a model

```
{
  "@context":{
    "mech": "https://mech.kuleuven.be/en/",
    "ram": "mech:ram/",
    "sa": "ram:situation_awareness/",
    "nav": "ram:navigation/",
    "sa:hasSubGoal": {"@type":"@id"}
  },
  "@graph":[
    {
      "@id": "nav:goal_1.1",
      "@type": ["sa:Goal"],
      "sa:hasSubGoal": "nav:goal_1.1.1"
    },
    {
      "@id": "nav:goal_1.1.1",
      "@type": ["sa:Goal"]
    }
  ]
}
```

Such JSON-LD models can be inserted in a property graph, where traversals can be made to find the relevant pieces of information, sensor settings, and algorithms that can be used to achieve the goals of the robot. One such graph example can be seen in figure 4. There a graph representation is used to link the robot agnostic goals, decisions, and information needs, with robot specific information. In this example, a need for a robot to have a map is provided by a visual-inertial map constructed using a camera and an IMU on the robot.

Listing 3. Example traversal using Apache Gremlin

```
g.V(goal_1.1).repeat(out())
 .until(has("Map"))
 .in("provides")
```

An example traversal for finding which map the robot can use to achieve its' goal can be see in listing 3. It is using the *Apache Gremlin* graph traversal language. This traversal starts from the node with ID "Goal 1.1" in the top left of figure 4, and gives as a result the node with ID "VIO Map". This can be used to load an existing map, or create a new map by configuring the correct algorithm and sensors responsible for creating it.

IV. Conclusions and future work

This work presented an initial attempt to bring situation awareness for navigation tasks executed by autonomous mobile robots. It relies on a semantic representation of the goals required to achieve the navigation task, along with the information needs required by those goals. These graph-based semantic representations can be then used to automatically find which sensors and algorithms to use, and how to configure them.

Given the rather early stage of research in this topic there are multiple directions for future research. A first line of research would be to devise a generic way to select the active goals based on the current situation automatically. This is because not all goals are active all the time [1]. This can help reduce the computational load as less sensors or running algorithms will be used in those particular moments. In the case of navigation, for example, the goal for finding a path to the goal would only be active in the beginning of the task, or whenever the current path could not be followed.

Another, more generic, line of research would involve creating models for automatic configuration of sensors and algorithms. This would require the generation of generic APIs based on specific models and their usage in the process of situation assessment, SAW-based decision making, and SAW-based acting.

Despite one needing to perform GDTA once per task, and being able to reuse it with multiple robots, it is still a process that requires a human expert. It would be interesting to see if the goals, sub-goals, and information needs can be derived automatically using approaches from the planning literature.

To take advantage of the situation awareness one would need to connect it to decision making and acting. That would require exploring the possibility of generic decision-making algorithms that would make use of the given task, goals, and situation awareness. Such algorithms should be able to generate or configure controllers and monitors that will be used to realise the decided course of action.

References

[1] M. R. Endsley, "Toward a theory of situation awareness in dynamic systems," *Human Factors*, vol. 37, no. 1, pp. 32–64, 1995.

[2] H. A. Yanco and J. Drury, "" where am i?" acquiring situation awareness using a remote robot platform," in *2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No. 04CH37583)*, IEEE, vol. 3, 2004, pp. 2835–2840.

[3] A. R. Selkowitz, S. G. Lakhmani, and J. Y. Chen, "Using agent transparency to support situation awareness of the autonomous squad member," *Cognitive Systems Research*, vol. 46, pp. 13–25, 2017.

[4] K. E. Schaefer, E. R. Straub, J. Y. Chen, J. Putney, and A. W. Evans III, "Communicating intent to develop shared situation awareness and engender trust in human-agent teams," *Cognitive Systems Research*, vol. 46, pp. 26–39, 2017.

[5] R. M. Ratwani, J. M. McCurry, and J. G. Trafton, "Single operator, multiple robots: An eye movement based theoretic model of operator situation awareness," in *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, IEEE, 2010, pp. 235–242.

[6] E. Miguelanez, P. Patron, K. E. Brown, Y. R. Petillot, and D. M. Lane, "Semantic knowledge-based framework to improve the situation awareness of autonomous underwater vehicles," *IEEE Transactions on Knowledge and Data Engineering*, vol. 23, no. 5, pp. 759–773, 2010.

[7] M. W. B. Ghezala, A. Bouzeghoub, and C. Leroux, "Rsaw: A situation awareness system for autonomous robots," in *2014 13th International Conference on Control Automation Robotics & Vision (ICARCV)*, IEEE, 2014, pp. 450–455.

[8] O. McAree, J. M. Aitken, and S. M. Veres, "Towards artificial situation awareness by autonomous vehicles," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 7038–7043, 2017.

[17] G. Kellogg, P.-A. Champin, and D. Longley, "Json-ld 1.1–a json-based serialization for linked data," PhD thesis, W3C, 2019.

[9] N. Dahn, S. Fuchs, and H.-M. Gross, "Situation awareness for autonomous agents," in *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, IEEE, 2018, pp. 666–671.

[10] C. Rizzi, C. G. Johnson, F. Fabris, and P. A. Vargas, "A situation-aware fear learning (safel) model for robots," *Neurocomputing*, vol. 221, pp. 32–47, 2017.

[11] M. Ginesi, D. Meli, A. Roberti, N. Sansonetto, and P. Fiorini, "Autonomous task planning and situation awareness in robotic surgery," in *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2020, pp. 3144–3150.

[12] C. J. Matheus, M. M. Kokar, and K. Baclawski, "A core ontology for situation awareness," in *Proceedings of the Sixth International Conference on Information Fusion*, vol. 1, 2003, pp. 545–552.

[13] M. M. Kokar, C. J. Matheus, and K. Baclawski, "Ontology-based situation awareness," *Information fusion*, vol. 10, no. 1, pp. 83–98, 2009.

[14] N. Baumgartner, W. Gottesheim, S. Mitsch, W. Retschitzegger, and W. Schwinger, "Beaware!—situation awareness, the ontology-driven way," *Data & Knowledge Engineering*, vol. 69, no. 11, pp. 1181–1193, 2010.

[15] M. R. Endsley, *Designing for situation awareness: An approach to user-centered design*. CRC press, 2016.

[16] *Shapes constraint language (shacl)*. [Online]. Available: `https://www.w3.org/TR/shacl/`.