SEMANTIC ENVIRONMENT FORMALIZATION FOR MOBILE ROBOTS NAVIGATION

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Abstract

In this work is presented an environment formalization for the generic description of mobile robot environments, by offering a common semantic frame to suit almost every possible scenery. It is also designed to be used by heterogeneous groups of robots with different capabilities in terms of perception or mobility between others. In order to achieve this goal is defined a hierarchy of environment elements, that ranges from the more simple objects till the whole map specification. Furthermore, it must be able to manage 2D, 2.5D and 3D geometric representation, to deal with both, static and dynamic elements, and to describe navigation landmarks. The application of areas of interest, defined as a subsection of the full map, will optimize the environment management costs enhancing the system execution. Finally, this formalization is used to define an experimental environment in order to show the advantages of this proposal.

Key words: environment modelling; mobile robots; autonomous robots; robot navigation

1 INTRODUCTION

Mobile robots usually requires a high degree of interaction with the environment in order to execute certain tasks just as the sensorization, the manipulation, the navigation or even the coordination. For this reason the proper definition of the environment and its objects is critical for performing all this tasks [1].

For that reason, the present work aims to establish a generic formalization of the environment and its elements. The main objective of this formalization is to have a common representation which can be managed by any robot independently of its sensorial capabilities. The definition of the environment must also describe all the scene elements and discriminate between different type of objects, that may be managed as obstacles, as interaction objects, or as navigation landmarks. In addition, objects must also be defined as static or dynamic element in the scenery.

The main advantage of this formalization is the capability of developing robot applications without the need of redefining the description of the environment in order to satisfy new requirements. According to this, there are established the following objectives:

- To formalize a generic definition of the scenery, the environment objects and the landmarks, giving special relevance to the semantic information.
- To enhance the system by adding optimization mechanisms that narrows the computational costs when dealing with large map descriptions.

This article is organized as follows: in Section 2 main environment modelling and characterization techniques are discussed. Along Section 3 a formalized and generic definition for the scenery and environmental elements is established. In Section 4 the formalized proposal is carefully analyzed and verified through an example scene and several tests. Finally in Section 5 conclusions are presented, and the future work is detailed in Section 6.

2 ENVIRONMENT MODEL

In order to allow mobile robots to perform autonomously, a minimum knowledge of the environment is required [9]. That way, since early autonomous developments in the 80s [2], the representation of the robot surrounding has been continuously evolving. In firsts works environments are modelled by using occupancy grids [3], and progressively has been upgraded to more complex representation of the scene and its objects by using 3D models [11] [12].

Many 3D environment models are defined by describing its elements as a set of geometric cuboids of different characteristics. That is the case introduced in [15] which employs a representation based in Octrees [14], or the one presented in [6], that proposes a Rtrees [4] topology formed by using a set of rectangular cuboids. In both cases

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objects can be modelled by using different levels of resolutions, allowing to represent objects from a rough surrounded geometry, till an almost exact model. Thus, environment can be specified in many different levels fitting the robot capabilities and requirements.

Despite of the quality obtained by using a 3D representation, the associated computational cost could be excessive for some applications which do not require this level of accuracy, being more efficient to use a 2D or a 2.5D representation [8]. In order to improve the flexibility of the system some proposals provide a mixed representation of 2D, 2.5D, and 3D models [7].

Nevertheless, geometric information is not the only way to characterize the environment and its elements. Humans recognize its surrounding in terms of semantics, where characteristics like the object meaning, or the interaction capabilities are evaluated rather than its numeric parameters. The use of semantic descriptions is also an extended tool in autonomous robots. Sensor classification mechanisms allows to extract semantic information from raw data [13]. In order to perform object recognition classified data can be matched with the elements definitions, that usually are compiled in data structures like tables [16]. As a result, a more human like procedure is obtained, offering a natural specification of the robot surrounding.

As has been introduced, map modelling techniques are an active topic that have been approached in a wide range of works. Although the number of researches, can not be found any solution which fits all the requirements for reaching an autonomous performance in every possible scenery. For that reason, some of this techniques will be combined, taking profit of their advantages, in order to provide a generic solution, that could fit any situation independently of the characteristics of the robot and the environment, by ensuring that in each case some minimum requirements are gathered.

3 ENVIRONMENT FORMALIZATION METHOD

Here is described the purposed formalization method for environment characterization, ranging from the the most simple element to the most complex one. It has been also introduced an hierarchy between this elements, in order to structure the different levels of the information.

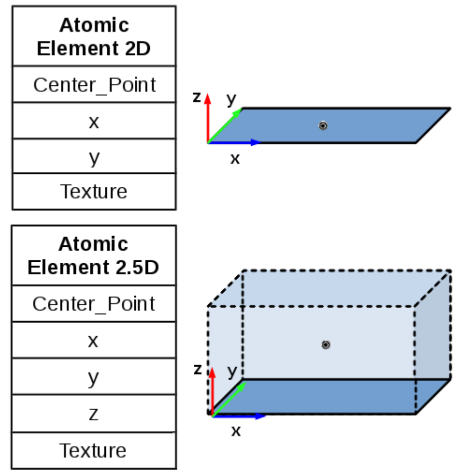

Figure 1: Atomic Element.

3.1 ATOMIC ELEMENTS

Atomic elements are the simplest structure in the environment, offering basic geometric and texture definition. In this case, atomic elements aims not to define a whole object, but bounding a basic feature of the scene. Geometric information is defined as a 2D rectangular section, such as the Rtrees [4]. This 2D representation can be extended to represent a 2.5D cuboid on those cases when features belongs to 3D objects. In both cases atomic elements offers information about its texture, which can be also defined as a plain color. As can be observed on Fig. 1 atomic elements are defined by its center point, expressed in the global space coordinates, its dimensions in x, y and z (in case of 2.5D), and its texture.

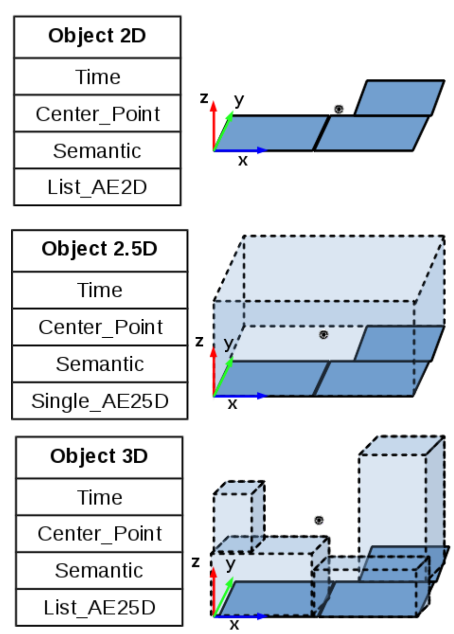

Figure 2: Environment Object.

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3.2 ENVIRONMENT OBJECTS

Object definition and management is one of the most important factors in order to provide a detailed and complete information of the environment. This is even more critical for autonomous robots which in most cases have to interact with its surroundings.

As is described on Fig. 2 object definition is designed to work with all 2D, 2.5D and 3D object representations. Each type is defined by the set of atomic elements that compose the object. 2D objects can be set by a single 2D atomic element or a combination of several ones. 2.5D objects can only be defined by a single 2.5 atomic element, which bounds the whole real object. Finally, 3D objects are composed by one or several 2.5D atomic elements.

The definition of any type of object includes a Semantic Tag, that refers to an entry in the semantic meanings table. In this table is gathered all the information about the semantic of every object in a more human like way. By using the semantic tag can be extracted all the object properties, such as the localization information, the dynamic, its possible interaction capabilities, etc. The information compiled into the semantic table will also depend on the characteristics of the described scenario.

The last parameter is the time stamp, that offers temporal information about the related object. This is especially critical for the management of dynamic objects which can modify its position as time advances. But time stamp can also be used in many other purposes, like information sharing, or detecting inconsistencies in the navigation system.

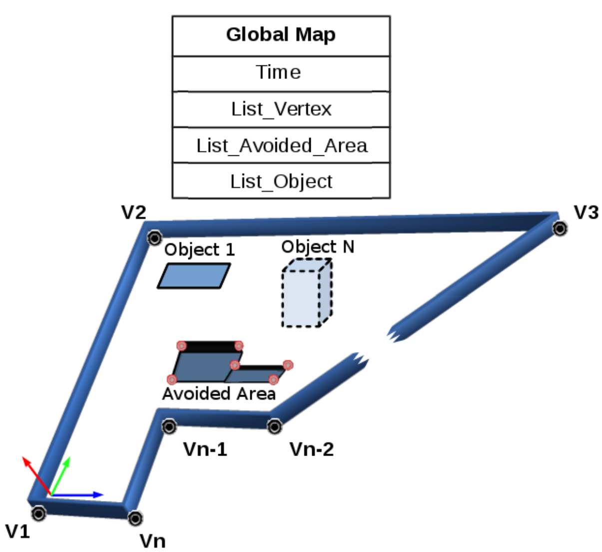

Figure 3: Global Map.

3.3 GLOBAL MAP

Global Map representation is the highest layer in the hierarchy of the environment definition, and consequently is strictly dependent of the characteristics of both, the atomic elements, and the environment objects. New information added into the environment topology is related with the geometric characteristics of the map. It is also defines the avoided map areas, as those regions bounded in the map that can not be physically accessed, such as columns, walls, etc. That way, global map definition describes the geometric bounds of the scene, in addition to the avoided areas enclosed in the whole scene. Both of them, map bounds and avoided areas, are characterized by a list of vertex which are sequentially connected between them. This specification frames the environment in its most simple way, and also encourages the application of point-in-polygon [5] algorithms, in order to found elements located inside of any avoided area, or out of the map bounds.

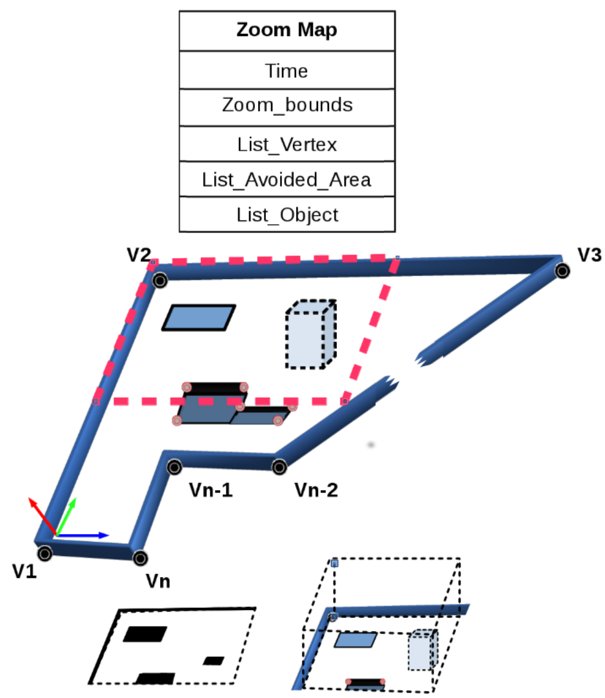

Figure 4: Zoom Map.

As is show on Fig. 3 global map is defined by a time stamp, a list of vertex, that bounds the map area, a list of avoided areas (that are characterized by their own list of vertex), and finally a list of objects enclosed in the scene. The objects in the list can be stored by using either its 2D, 2.5D, or 3D representation, according to the requirements. That way simple 2D objects can be represented without forbid a complex 3D representation of any other object. By allowing the coexistence of different types of representation, and the adaptation

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to the simplest functional geometry in each case, the efficiency of the system is improved.

3.4 ZOOM MAP: AREA OF INTEREST

Although the definition of the global map offers a simple representation of the environment, complexity grows as the size of the scene and the number of the objects are increased. For that reason is proposed the implementation of a new structure which only manages the information framed into a region of interest, defined as a subsection of the global map. That way, cost are narrowed by reducing the number of managed elements. Furthermore, a constant size of the area of interest allows to know the worst case execution time. This size can be specified according to many different parameters such as the range of the available sensors, or the characteristics of the environment. Nevertheless, the development of a dynamic size area of interest will be considered in the future work.

In the proposed formalization, the region of interest is defined by the Zoom Map structure, which is detailed in Fig 4. Zoom Map can be specified either in 2D or in 2.5D. On one way, a 2D area of interest is focused only on a 2D projection of all the objects into the ground level, giving basic information for an optimum performance of those tasks which only requires to avoid obstacles. On the other way, 2.5D deals with all the objects (in 2D, 2.5D or 3D) enclosed into the bounding box defined as the area of interest. The Zoom Map have to update the location of the area of interest in two different situations. The first one takes place when the robot has reached a threshold distance from the center of the area. The second one is triggered by a time out that indicates the need to update the area. In both cases the conditions can be parameterized according with factors like the dynamic of the robot, the dynamic of the environment, etc.

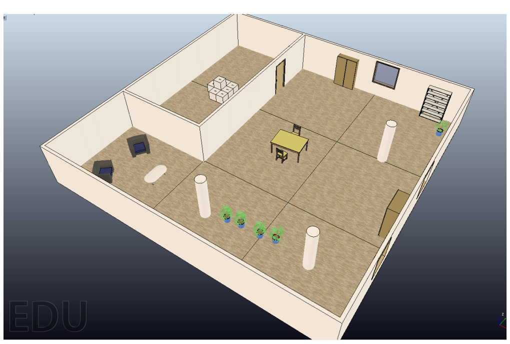

Figure 5: Environment example.

4 USE CASE AND RESULTS

In order to verify this proposal, a typical scenario is formalized using all the previously defined structures. This scenario is modelled in the V-Rep simulator [10] in order to represent a real world environment, just as can be observed in Fig. 5.

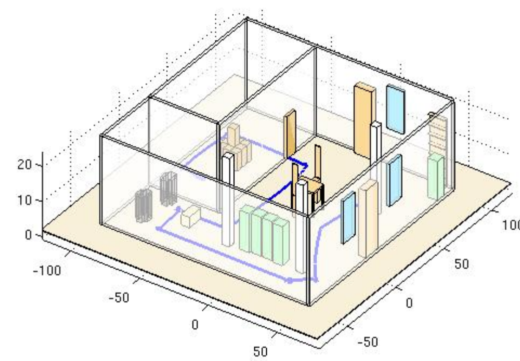

Figure 6: Graphic representation of the formalized environment.

That way, geometrical and semantic characteristic of the environment and its objects are formalized and compiled in a description file. In this definition, objects are represented in 2.5D, for the most simple geometries such as the boxes, the small table or the cupboards, or in 3D, for more complex geometries like the chairs, the shelves or the big table. Because of not being physically accessible, and due to its lack of semantic meaning, all the columns and walls have been formalized as avoided areas. The Zoom Map size and its actualization triggers are also parameterized. The graphical representation of the formalized environment can be checked in Fig. 6.

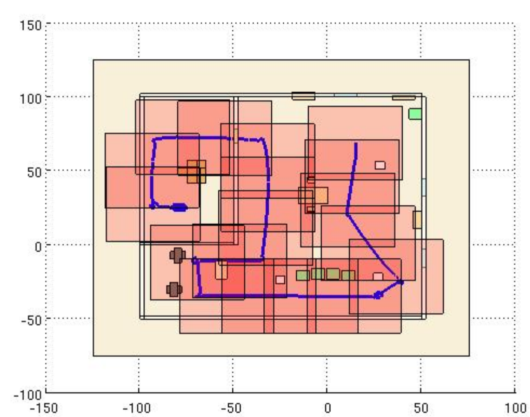

Figure 7: Evolution of zoom map areas.

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In order to test the advantages of managing the Zoom Map instead of the whole map is performed the following experiment. A small wheeled robot is configured to follow a predefined trajectory all around the scenery, which can be identified as the blue line showed in Fig. 6. During this trajectory the area of interest will be updated according to its progression. Due of the dimensions of the map (15mx15m) the size of the region of interest is set to 5mx5m which represents approximately the 10 % of the whole area. Furthermore the actualization process will be triggered each time that the robot reaches a position located 3m (a 40 % of the zoom size) away from the center of the area, and generating a new area centered in the current position. According to this parameterization,the evolution of the zoomed areas can be checked in Fig. 7.

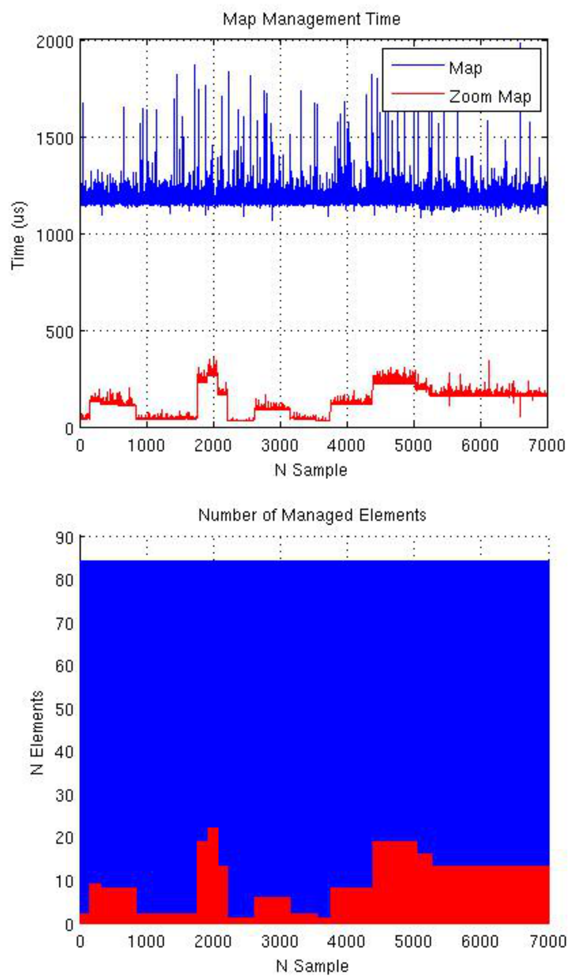

Figure 8: Management time for map and zoom map during the proposed test.

In order to quantify the improvements, during this test have been stored the temporal costs of dealing with the full specification of the Map, and the costs of managing only the Zoom Map. In this second case it also have been included all the costs related with the check of the actualization triggers, and the actualization itself. Obtained times are compared in the first graphic of Fig.8. As can be observed, in comparison when using the Zoom Map is obtained a 75 % time reduction in the worst case, and up to 90 % in the best one. Focusing on the evolution of the Zoom Map costs, updates in the area of interest can be easily noticed as square shaped regions which represents each new zoom in the map. In the case of the full Map, the computed time is always constant due of the lack of variations in the number of elements managed. The number of managed elements can be checked in the second graphic of Fig.8.

5 CONCLUSIONS

As conclusion can be highlighted the description of a formalization process which offers the capability of describe and characterize any possible environment. This provides a common representation which promotes the interaction between the robot and its surrounding. This interaction gives a strong importance to semantic meaning by adding a semantic, offering a more human friendly frame. Furthermore, system allows to discriminate different types of objects, like landmarks or dynamic elements, and manage them.

It is also introduced the Zoom Map, implemented as an interest area which provides significant improvements by selecting a subsection of the scenery according to the requirements of the performed tasks. The parameterization and update of the area of interest is a decisive factor for avoiding system malfunction and suiting the robot dynamic.

Both objectives, the generalized formalization method and the computational improvement, has been tested and verified in the result section. It has been showed a real application on a small wheeled robot, which has been configured to manage the formalized representation of a real world environment, and also to compare the time consumption when managing the whole map and the areas of interest using the Zoom Map structure.

6 FUTURE WORK

The introduced development opens several lines for future work. Some of them are focused on the improvements of the contribution itself, some others will be focused on taking profit of the optimizations mechanisms here described.

The formalization of the environment will be used as the source information for the implementation

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of generic localization methods. The generality in this method is reached by dealing with the formalized definition of the elements, which is used by the robot for performing a match between the given map definition and the perceived surrounding. For this goal it is also necessary to perform a previous classification of the sensors raw data to extract the semantic and geometric properties of the spotted elements in the scene. That way, future work will also analyze a proper semantic classification that suits the proposed formalization by offering a generic description of the sensor measures.

The application of the Zoomed Map has promoted a significant compute save, in spite of this improvement new mechanisms must be proposed in order to exploit the optimization capabilities enabled by the Zoom Map. For that reason, a deep study of the parameterization of the area of interest is needed. One of the more decisive factors is the proper selection of the size of this area. The different variables that may be involved in the establishment of this size must be analyzed, including the dynamic of the environment, the speed of the robot, or the goal mission, between others. Furthermore, these variables will be also used for the implementation of a dynamic size Zoom Map, in which the area of interest will be escalated according to the requirements of the active task.

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References

[1] Raja Chatila and Jean-Paul Laumond. Position referencing and consistent world modeling for mobile robots. In *Robotics and Automation. Proceedings. 1985 IEEE International Conference on*, volume 2, pages 138–145. IEEE, 1985.

[2] James L Crowley. Navigation for an intelligent mobile robot. *Robotics and Automation, IEEE Journal of*, 1(1):31–41, 1985.

[3] A Elfes. Using occupancy grids for mobile robot perception and navigation. *Computer*, 22(6):46–57, 1989.

[4] A Guttman. *R-trees: A dynamic index structure for spatial searching.* ACM, 1984.

[5] Eric Haines. Point in polygon strategies. *Graphics gems IV*, 994:24–26, 1994.

[6] S Khan, A Dometios, and C Verginis. RMAP: a rectangular cuboid approximation framework for 3D environment mapping. *Autonomous Robots*, pages 1–17, 2014.

[7] B Lau, C Sprunk, and W Burgard. Incremental updates of configuration space representations for non-circular mobile robots with 2D, 2.5 D, or 3D obstacle models. In *European Conference on Mobile Robots (ECMR)*, pages 49–54, Orebro, Sweden, 2011.

[8] RC Luo and CC Lai. Enriched indoor map construction based on multisensor fusion approach for intelligent service robot. *IEEE Transactions on Industrial Electronics*, 59(8):3135–3145, 2012.

[9] Ren C Luo, M-H Lin, and Ralph S Scherp. Dynamic multi-sensor data fusion system for intelligent robots. *Robotics and Automation, IEEE Journal of*, 4(4):386–396, 1988.

[10] Eric Rohmer, Surya PN Singh, and Marc Freese. V-rep: A versatile and scalable robot simulation framework. In *Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on*, pages 1321–1326. IEEE, 2013.

[11] S Thrun, W Burgard, and D Fox. A real-time algorithm for mobile robot mapping with applications to multi-robot and 3D mapping. In *Robotics and Automation, 2000. Proceedings. ICRA'00. IEEE International Conference on.* IEEE, 2000.

[12] A Torralba, KP Murphy, WT Freeman, and MA Rubin. Context-based vision system for place and object recognition. In *Computer Vision, 2003. Proceedings. Ninth IEEE International Conference on*, pages 273–280. IEEE, 2003.

[13] R Vieux, J Benois-Pineau, JP Domenger, and A Braquelaire. Segmentation-based multi-class semantic object detection. *Multimedia Tools and Applications*, 60(2):305–326, 2012.

[14] J Wilhelms and A Van Gelder. Octrees for faster isosurface generation. *ACM Transactions on Graphics (TOG)*, 11(3):201–227, 1992.

[15] KM Wurm, A Hornung, M Bennewitz, C Stachniss, and W Burgard. OctoMap: A probabilistic, flexible, and compact 3D map representation for robotic systems. In *Proc. of the ICRA 2010 workshop on best practice in 3D perception and modeling for mobile manipulation*, page Vol. 2, 2010.

[16] H Zhao, Y Liu, and X Zhu. Scene understanding in a large dynamic environment through a laser-based sensing. In *Robotics and Automationand Automation (ICRA), 2010 IEEE International Conference*, pages 127–133. IEEE, 2010.

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