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# MESSRS: A model-based 3D system for of recognition, semantic annotation and calculating the spatial relationships of a factory's digital facilities

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ABSTRACT

Obtaining a detailed, orderly and valued relationship of elements belonging to a factory, that is, making an inventory, can be a complex task; this is because it is necessary to consider both general aspects, such as the characteristics of the factory and specific aspects such as elements to be inventoried. Automatic recognition, semantic rules and calculation of spatial relationships can help in the description of elements in digital mockups. The traditional geometric primitives recognition algorithms can recognize primitives, but the real elements can be large and complex because they are composed of several geometric primitives. Therefore, it is necessary to improve the traditional approach by incorporating semantics in order to identify and characterize recognized geometric primitives, along with rules for composing real objects. With this in mind, this paper presents MESSRS, a novel and conceptual model for semantic representation of digital mockups. MESSRS applies 3D recognition techniques, topology mechanisms and semantic rules to identify and tag elements of a factory in order to make a complete inventory. The proposed model serves as a basis for the exchange of logical, physical and semantic information obtained from real objects in a factory. In addition, an evaluation of a real use case of this model is also presented as proof of the concept.



## 1. Introduction

An inventory is a detailed, orderly and valued relationship between elements that make up the assets of a company or person at a given time [6]. It is detailed because the characteristics of each of the elements that integrate the patrimony are specified; it is considered orderly because it groups elements in their respective accounts; and it is valued because the value of each asset is expressed in units.

Therefore, making an inventory in an industrial environment requires effort. Especially when an inventory of the facilities of a factory is required, and the elements are in a large plant, or the facilities are diverse and numerous. The task requires several visits to the plant in order to identify and check the elements. In this way, the use of digital mockups, reverse engineering and semantic technologies can improve the process.

Reverse engineering was defined by Chikofsky and Cross [3] as the process of analyzing a system in order to, 1) identify its components and their interrelationships and 2) create representations of said system in other ways, or at higher levels of abstraction. In this sense, in the industrial field, reverse engineering plays a substantial role in the area of creating inventories; especially in the upgrade of existing planes of factories, which lack updated information about real objects. These planes could be represented by 3D reconstruction techniques.

This paper presents a reverse engineering method, which recognizes, classifies and performs semantic annotations, and calculates spatial relationships by the semantic rules of geometric primitives from scanned 3D point clouds; furthermore, it creates a conceptual model for semantic representation of digital mockups from real objects. In this case, and as proof of concept, a point cloud

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of a factory is presented, thereby creating a higher level of abstraction and semantic meaning of the real facilities within it.

The traditional geometric primitives recognition algorithms recognize and segment geometric primitives, but elements in the real world can be large and complex because they are composed of several geometric primitives or their elements are larger than the segments provided by the algorithms. Therefore, it is necessary to improve the traditional approach by 1) incorporating semantics to identify and characterize recognized geometric primitives and 2) creating rules for composing real objects. The main features that should have an inventory are covered by this model, where the relationships between elements are detailed semantically; it is kept orderly by the calculation of spatial relationships and finally it is valued and stored in a database.

As proof of concept, the model is applied to the 3D point cloud of a medium-large sized industrial facility, obtaining a digital mockup and its linked semantic and spatial representation as a result. The proposed use case is based on a real problem, due to the fact that an inventory of installed items inside a factory, for example gas or steam pipelines, is constantly changing by replacing components of the pipe, because of a breakdown or remodeling and the planes are not always updated. Therefore, the lack of updated information complicates the inventory process. Using the proposed model, this factory would be able to find out detailed information about their pipes.

A brief description of recent advances in the state of the art of 3D object recognition, semantic models and the calculation of spatial relationships are presented in Section 2. In addition, a further description of the presented model can be found in Section 3 of this paper; a real use case of the proposed method is described in Section 4 and finally, the concluding remarks are presented.

## 2. Motivating scenario and related work

Currently there are diverse efforts to create digital models of scenes in different contexts: all of them aim to describe, in detail, the elements that comprise it. Scenes of industrial facilities, outdoor scenes, or even generation of object models with great detail, are examples of digital models in the industrial sector. The generation of these models themselves is a significant advance, which is especially relevant in cases where planes and prototypes are non-existent, incomplete and/or outdated.

The challenge is to describe the environment we see in a virtual scene in such a way that its physical and semantic properties are detailed, and the elements that comprise it are labeled semantically and express their spatial relationships. Due to the nature of this research, the state of the art has been divided into 3 sections in order to describe the contexts: Object recognition, semantic on object recognition and finally, the spatial relations of objects.

### 2.1. Object recognition

Previous work on reconstruction and recognition of objects in 3D scenes has been developed in order to resolve the question: **What objects are present in the scanned scene?** Each of these projects has special features according to its domain. An example is a system for recognizing objects in 3D point clouds of urban environments which was presented by Golovinskiy et al. [7]; this system recognizes small objects in city scans in four sections: location, segmentation, characterization and cluster classification. Another example is a system for building object maps of indoor household environments which was developed by Rusu and Blodow [20] and which uses techniques for statistical analysis, feature extraction, resampling and segmentation from partial views of the environment scanned by robots. While all these studies can identify elements within scanned scenes, they do not provide a semantic meaning to the segments; consequently, they are not able to make any inference between elements or additional relevant information. On the other hand, MESSRS aims to provide the detail of the physical, semantic features and the spatial relationship of elements within a scene scanned in an industrial context.

### 2.2. Semantics in context

As previously mentioned, MESSRS aims to extend the recognition process to enrich the data obtained semantically, in order to ease the inventory process in factories. In this way, the most relevant work reported in the literature, within the scope of semantic technologies applied to 3D recognition, seeks to resolve the question **What kind of elements does the scene have and what are its characteristics?** It is described below.

A knowledge-based detection approach of 3D objects using the OWL ontology language known as WiDOP was presented by Hmida et al. [10]. WiDOP uses VRML language to define the ontology of an indexed scene. This scene is created by a set of 3D point clouds. WiDOP has the ability to detect objects but does not recognize them. Instead, MESSRS recognizes and classifies each element that belongs to the scene. A feedback algorithm based on supervised feature extraction techniques was presented by Leifman et al. [12]. This algorithm has a web search engine that uses the relevant feedback to retrieve semantically-similar objects. The authors also propose a new signature: a sphere projection, which attempts to capture the global characteristics of a 3D model. The authors have presented semantically, an annotation by tags in the models in a database. Instead, MESSRS not only makes annotations to objects by tags, but provides them with a semantic meaning and description of the main features according to their class. A dataset called IAIR-CarPed was introduced by Wu et al. [22]; which is the first fine-grained and layered object recognition dataset with human annotations. This dataset works with two representative categories: cars and pedestrians. In this study, the authors attempt to demonstrate how humans tend to have fine-grained categorizations, within-category interpretations of objects, instead of a simple categorizations. Each image in IAIR-CarPed belongs to at least one instance of a car or a pedestrian. There are two types of annotations: semantic labels and geometric labels. The semantic labels are logical nodes, while the geometric labels are the bounding boxes of the objects and their key parts. Although IAIR-carped presents a great contribution to the classification of pedestrians and cars, semantically, they are only element associated tags. In contrast MESSRS has the ability to link its semantically defined elements with other sources of information based on ontologies, in order to enrich the scene.

### 2.3. Spatial relations

Topological maps try to localize objects within a space and the relationships between them; they are an extension of combinatorial maps designed to represent 3D scenes [4,23]. This presents a significant problem because there are different ways to represent the same object within the space. To resolve this problem, some properties can be added to topological maps in order to ensure the uniqueness of the representation. Bearing this in mind, the most salient studies into this approach are briefly described with a view to trying to answer the question **Where are the elements physically and what are their relationships?**

A visual system that analyzes a real world 3D image used by a robot was presented by Hois et al. [11]; aiming to identify objects