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Indoor Object Reconstruction Based on Acquisition by Low-Cost Devices

Sergej BONDAR, Borhan SALEM and Josip STJEPANDIĆ[1]
PROSTEP AG, Germany

Abstract. Reverse engineering (RE) is used in the manufacturing industry as a powerful approach to generate the digital twin of a physical object. Hereby, a data acquisition and model reconstruction methodology has been combined to resolve these issues. Such a data set often has to replace the missing original digital model. Subsequently, a model reconstruction plan has to be derived so that an editable CAD model which fulfils process requirements can be generated using standard geometry creation tools. Such a reversed engineered CAD model preferably contains form-feature based design intent and can be easily modified due to new design and manufacturing constraints. In some cases the scanned data are not complete due to the gaps in the acquisition procedure. To repair such meshes mobile low-cost scanner can be taken into account. In this paper the Microsoft HoloLens is used, a mixed reality headset. It scans the environment around and enables the user to place holograms on the real world and interact with it. To permit this experience, the HoloLens scans our environment and reconstructs a spatial mapping 3D mesh of it. So this device is used as in-door scenes 3D scanner to reconstruct a piping system. This approach is proven in reconstruction of piping systems.

Keywords. Reverse Engineering, Indoor Object Acquisition, Piping System Reconstruction, Data Quality

Introduction

The Digital Factory discovers tremendous progress in the past 20 years. The results of a large study conducted in Germany show that over 20% of more than 100 surveyed companies from medium-sized enterprises to large companies have already successfully used the methods and tools of the Digital Factory. Almost 90% of the surveyed companies indicated that they want to deal with the challenge of the Digital Factory in the next future [1]. The essential components of the digital factory are digital models of products, processes and resources which aim the standardization of processes, the increasing of flexibility and shortening of the lead time [2]. In particular, digital models find nowadays many fields of application in manufacturing (e.g. planning of factories, layout-optimization in shop floors, approval processes for modification and fire protection, optimization of production processes) [3][4]. Furthermore, the simulation has become a key element of the digital factory and is becoming increasingly more important through developments in the area of Industry 4.0 [5]. Assuming the all-time measurable gap between the real and the virtual factory, concrete solutions are needed for the continuous synchronization of the planning data

[1] Corresponding Author, Mail: josip.stjepandic@opendesc.com.

and simulation models from the product development, the production planning and the production by using measured values from the real factory [6]. High quality CAD data of all geometrical objects in the factory are the pre-requisite for seamless downstream processes [7].

With fast scans of the production and subsequent object recognition, the production layout (e.g. size and location of the objects) and the production logic (e.g. machine types, transport routes) can be recorded as automated as possible and visualized true to scale in digital models [8][9][10]. The identification of CAD models from a reference database and the transfer of geometry and other object data (e.g. machine types) as modular objects directly from the database significantly reduce the scan times for a first rough "prescan" of the production [12][13]. At the same time, database reconciliation enables the use of simpler and cheaper scanning methods [13][14]. The definition of suitable interfaces enables the transfer of information into a program for material flow simulation and a precisely fitting digital twin of the manufacturing can be generated - almost without manual interventions [15][16].

The remainder of this paper is structured as follows: in Section 1 the background is given, followed by the description of the low-cost device in Section 2. In Section 3 the use case is demonstrated with the related discussion in Section 4. Finally, Section 5 summarizes the conclusions and outlook.

1. Background

The process of digitizing a part and creating a CAD model from a scanned cloud data is feasible if it consumes less time and provides greater accuracy than the manual process by measuring the part and designing the part from scratch in CAD. The typical process from process industry is depicted in Figure 1.

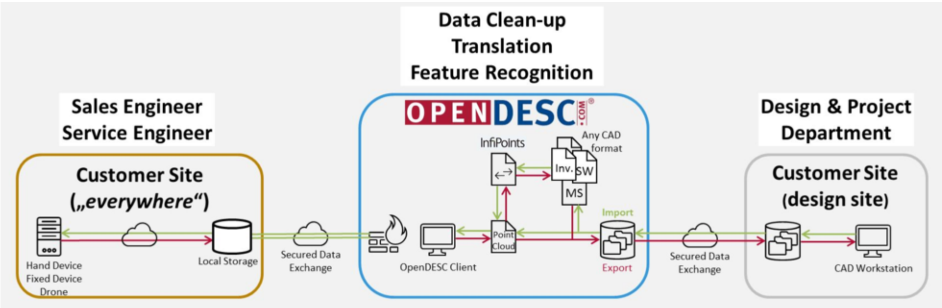

Figure 1. Process chain reverse engineering in the process industry.

In the first step (left), the data acquisition of a object is conducted at customer site, which could be everywhere, by fixed or portable scanner and data are sent to a data management center which provides the data clean-up, the translation of point cloud to CAD objects (surface, solid, feature) and object upgrade by feature recognition. Finally, the design and project department needs such data set to make new design or design change in a retrofit of the existing product.

Such a process can be extended to Reverse Innovative Design (RID) [17] which comprises digitizing, modelling with shape and product definition parameters, CAE analysis-based product optimization, and rapid prototyping (RP). Figure 2 shows a comparison between the workflows of conventional RE and RID. The core of RID is the feature based parametric solid model constructed from scanned data, for analytically shaped models as well as models with freeform shapes. For analytically shaped models, features with natural definition parameters will be extracted by fitting remaining freeform shapes.

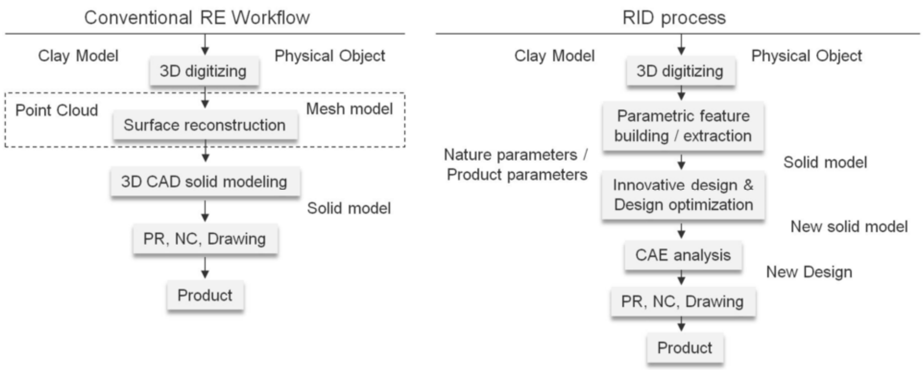

Figure 2. Workflow of conventional RE vs. RID [17].

Despite the tremendous progress of scanning technologies (e.g. driven by the enormous demand of autonomous driving technology), some challenges still remain unresolved [18][19]. Scanning order and procedure can become critical for the speed and the productivity, in particular when the built space incorporates many different objects which overlap each other [20][21][22]. In such cases, the application of a two-step procedure (main and detail acquisition) could be a solution. For the main acquisition, a fast fixed acquisition device can be useful. For acquisition of gaps or hidden details in previous steps, the use of portable or mobile low-cost devices could be meaningful [23]. Thus, the main purpose of this research is the question wheter low-cost devices used in the area of mixed reality are an alternative to support the process of reverse engineering of indoor objects as practised in the data exchange service www.OpenDESC.com [7].

2. HoloLens as Low-cost Scanner

2.1. *Low-cost device: Microsoft HoloLens*

Microsoft HoloLens is one of the first mixed reality headsets [24]. It enables to place and interact with holograms in the real word. It scans our environment and reconstructs a 3D model of it in real time. The user can interact with content and information using eye gaze, hand gestures and voice commands. It doesn't require a computer or a phone. This device is a self-contained, wireless, holographic computer with the operating system Windows 10.

The HoloLens uses sensors [25], four environment understanding cameras (two on each side) scan the environment on a view field of 120 by 120 degrees. A depth camera estimates the depth of the scanned environment using the time of flight technology. The HoloLens has also an ambient Light Sensor and a 2MP Photo and HD video camera. The collected information is combined to reconstruct a 3D model of the real world environment and to detect the user hand gestures. The created 3D model and detected gestures are then used to place and interact with holograms in the real world.

The HoloLens has an internal measurement unit (IMU) with an accelerometer, a magnetometer and a gyroscope to track the head movement speed, position and orientation. This is used to estimate the eye gaze and to show or hide the holograms on the real world. These holograms are integrated into the real world by projecting them into the See-through holographic lenses through the 2 HD 16:9 light engines.

The HoloLens has 4 microphones which enable voice commands that facilitate the interaction with holograms. Using build-in speakers, the HoloLens creates a spatial sound that make the mixed reality experience more authentic.

To scan the real world environment, place and interact with holograms the HoloLens has a custom-built Microsoft Holographic Processing Unit (HPU 1.0). This device is a self-contained holographic computer with 64 GB flash, 2 GB ram memory and an Intel Atom processor. The HoloLens operates wireless using a 16,500 mWh battery with 2 to 3 hours battery life.

2.2. *HoloLens as 3D indoor Scene Scanner*

Using a build-in system, the HoloLens can act as a 3d in-door scene scanner. It scans indoor scenes and creates a 3D Mesh of it on real time. We use the Mixed Reality Toolkit for Unity3d to implement an application that scans the environment around the user and saves it on the HoloLens [26]. Using the sensors mentioned in the previous section the HoloLens scans the environment around you and processes the collected information using the HPU unit in real time to reconstruct a 3D model of it. This mesh is used to place holograms in the real world. This build-in system to scan user's environment is called Spatial Mapping.

The HoloLens can be connected to a windows 10 computer over Wi-Fi or over micro-USB cable. Using the Windows Device Portal [27], we can view or download the Spatial mapping mesh as Wavefront (.obj) [28] file.

2.3. *Spatial Mapping Application*

Using Unity3d and the Mixed Reality Toolkit, an application for HoloLens in the programming language c# was implemented. Using this app, a room can be scanned and the spatial mapping mesh of it can be saved with different qualities.

The environment was scanned using the prefab SpatialMapping [29]. When the app starts, the quality of the scan must be chosen. By clicking a button with the number 500 to 4500, the variable ''triangles per cubic meter'' on the spatial Mapping Observer will be set to its value. This is the unique option to change the quality of the spatial mapping mesh. Another option to get a better 3d model is the use of the Spatial Understanding [30] prefab. This prefab tries to understand the spatial mapping mesh to find the floor, walls and ceiling.

Using the Mesh Saver script [31], the created meshes can be saved on the HoloLens. The mesh saved on the device portal of the HoloLens by the file explorer can be downloaded. We have scanned our office space with different quality and exported the spatial Mapping meshes.

The following Table 1 presents the number of all created triangles pro mesh and the average edge length per triangle in meter.

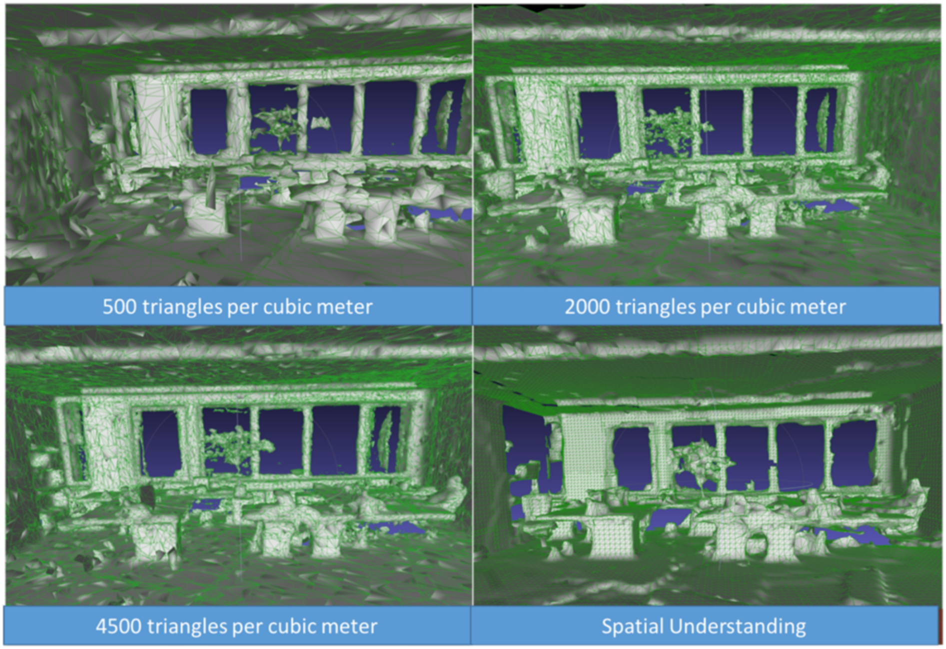

Figure 3. Spatial Mapping Meshes of Office Space with Different Quality.

Table 1. The Number Triangles pro Mesh and the Average Edge Length in Meter.

Quality	Number of Triangles	Average Edge Length
500	39497	0,195904927
1000	71043	0,147744834
1500	123857	0,113693221
2000	144686	0,106401108
2500	150358	0,104920048
4000	154124	0,103603904
SU	113381	0,109241124

Using a small number of triangles per cubic meter results on a low mesh quality with large edge length. From 2000 triangles per cubic meter there is no significant improvement in mesh quality. All the triangles of the spatial understanding mesh have the same dimension. It tries to create cube faces with 8cm length.

3. Use Case: Piping System Reconstruction

We try to reconstruct the piping system of a heating room. To scan the room, we use the HoloLens spatial mapping application mentioned in the previous section. We have scanned und exported the spatial mesh of the piping system with different quality. To reconstruct the piping system, we have used the algorithm proposed [26]. In this section we present the used algorithm and apply it to an ideal mesh, that we have created, and to the different exported spatial mapping meshes.

Figure 4. The Heating Room.

3.1. *Algorithm*

This is a normal-based region growing algorithm applied to a laser-scanned 3D point clouds. The normal vector of all points is estimated first. Based on its value the points are divided in different regions with similar normal and within a predefined radius. The obtained region can be a part of the piping system (straight pipe, elbows or junction) or a planar surface

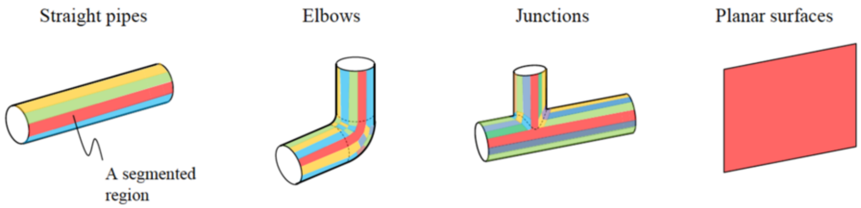

Figure 5. Different Regions with a Similar Normal [32].

For each region an oriented bounding box is calculated and several dividing planes are placed at a regular interval as shown in the following figure. According to the median value of the range of points projected on the dividing planes and a predefined threshold, the regions are classified as a part of the piping system or as a planar surface.

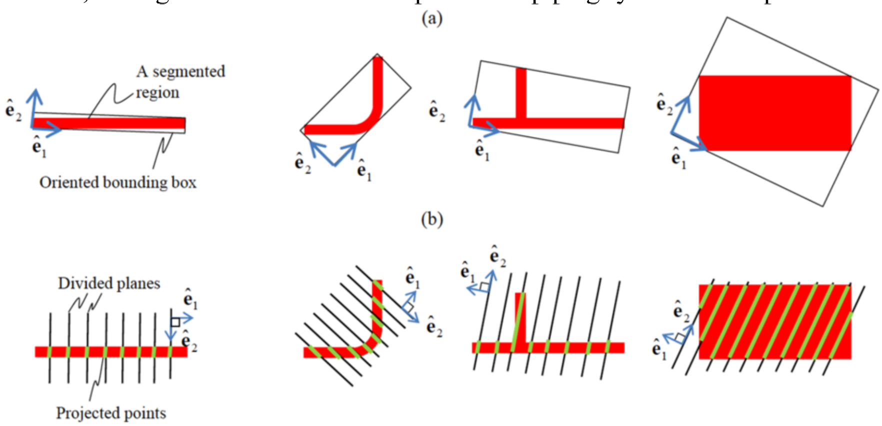

Figure 6. Oriented Bounding Box of Different Regions and Dividing Planes [33].

After having extracted the points of the piping system, a region-growing is applied to group the regions on a pipe segments. Finally, the axe and radius of the pipe segments and the elements of the piping system are estimated.

3.2. *Application on Ideal Mesh*

The exported spatial meshes form the HoloLens application are 3D models in the Wavefront format and not a point cloud [34]. To apply the algorithm mentioned in the last section, we have to adapt it to be applied 3D model. Instead of dividing points, we have to divide faces on different regions. Each face (Triangle) is composed of three points (vertices). For each point the normal vector is already calculated. We consider the normal vector of a face as the average value of the three vertices normal vectors. The faces are then divided into different regions and classified to a part of a piping system or not.

To test this algorithm, we have created an ideal, simple model of the heating room without noises und have tried to recognize the piping system on it. Using the normal-based region growing algorithm we are able to extract the piping system faces with an accuracy of 95,75%.

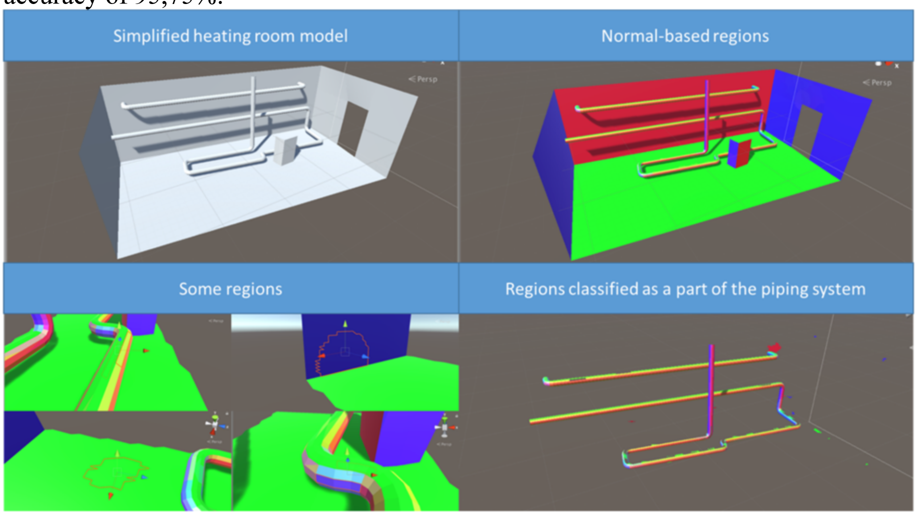

Figure 7. The ideal Mesh and The normal-based Regions.

The previous figure shows the created model and the different normal-based regions. On the right bottom, it shows the faces classified as a part of the piping system.

3.3. *Application on Spatial Mapping Mesh*

We have scanned the heating room and exported the spatial mapping meshes with different quality.

With regard to Table 1, the best reached average edge length using the different quality is 11cm. The pipe system has the diameter of 25cm and cannot be recognized using the normal-based region growing algorithm. The piping system on the spatial mapping meshes is created using a small number of faces and has less details and bad quality. This is due to the limited number of maximal 2000 triangles per cubic meter. If we use a greater number, there is no significant improvement in quality. As a result of the bad quality of the mesh we haven't become a good result applying the normal-based region as on the ideal mesh that we have created. The following graphs show the difference between the ideal and the spatial mesh using 2000 triangles per meter cube.

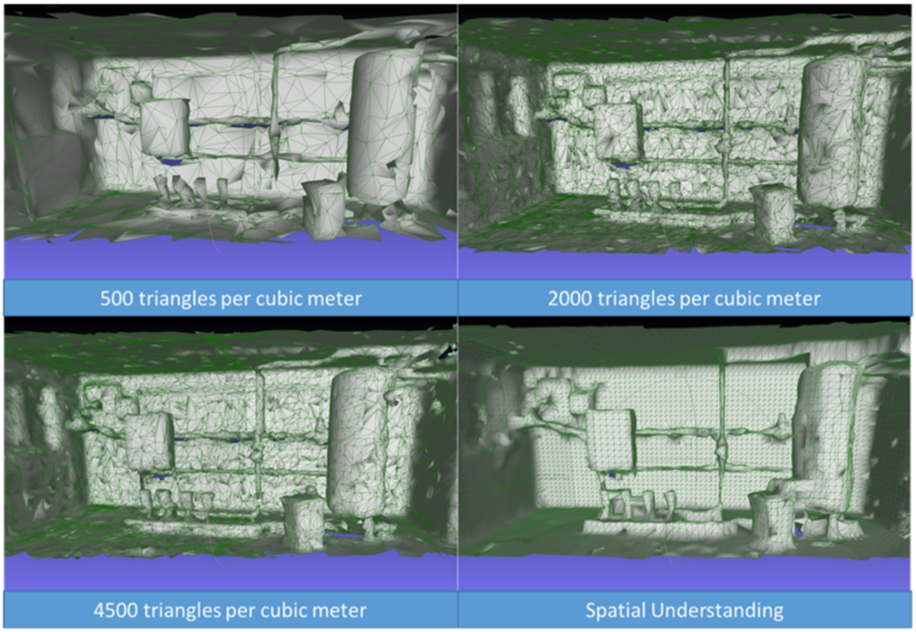

Figure 8. Spatial Mapping Meshes of Heating Room with Different Quality.

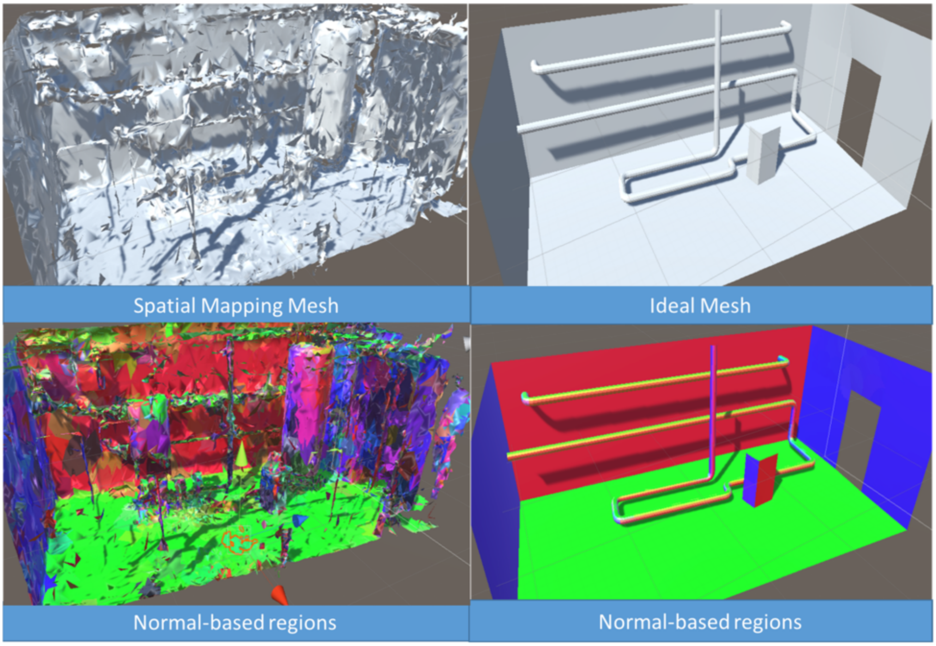

Figure 9. Comparison between the Spatial Mapping and the Ideal Mesh.

4. Discussion

The scanning of the heating room was quite a bit fast (took less than 5 minutes). The resulting spatial mapping mesh makes a lot of noise but it describes the room geometry roughly. The right side of the hot water storage tank wasn't properly scanned as shown in Figure 8. This is due to the small distance between it and the wall and the minimal scanning distance of 0.8 meter of the HoloLens. The pipes aren't properly scanned because, compared to the hot water tank, they have a smaller diameter of 25 centimeters. The part of the pipes near to the wall, floor and roof wasn't scanned because it's difficult to gaze it using the HoloLens camera. The same problems occur for the top and bottom parts of the water tank. There was no dark or reflective surface on the heating room, all the visible surfaces were scanned.

5. Conclusions and Outlook

Using the HoloLens, indoor scenes can be scanned and exported as a 3D model. The exported spatial mapping meshes have a much lower quality thana laser scanned 3D model. But it describes roughly the scene and can be used to accurately place holograms on the real world and offer an exciting mixed reality experience. We can use it to detect planar surface such as floor, celling or roof using the spatial undressing [34] capability on the HoloLens. But it is not suitable for recognizing piping systems or round surfaces generally. At this time, the resulting spatial mapping mesh makes a lot of noise and doesn't capture small objects properly. It gives us a rough description of the scene, so that the holograms can be placed accurately. This may be changed, if Microsoft publishes a new API, that allow us to get access to the sensor row data.

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