Concept of Autonomous UUV/USV Operations for Harbor Surveys

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SUMMARY

Harbors and ports are constrained environments especially for harbor and port surveys due to heavy marine traffic, constructions and cargo operations. Survey time is restricted by working hours of the crew, the tide, marine traffic, occupied berths, and dredging operations. All these influencing factors have to be considered for survey planning and execution. To increase the flexibility of hydrographic surveys an autonomous approach seems promising as the application of autonomous survey platforms has strongly progressed in recent years. Their utilization has been extended to various uses like military, oil and gas, scientific research, and offshore renewables. So far they are not deployed for everyday harbor surveys. This article deals with the requirements and demands of hydrographic harbor surveys based on questionnaires completed by port authorities. The challenges of the application of autonomous vehicles for the hydrographic data acquisition in this field are pointed out before proposing a concept of a semi-autonomous solution which could be realized in the near future.

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1. INTRODUCTION

Harbors play a significant role for the economic trade as over 90% of the global trade is carried by the international shipping industry by over 50,000 merchant ships (ICS, 2015). Harbors are characterized by dense infrastructure, high volume of traffic, and shallow water. Furthermore, their seabed can be subject to dynamic changes caused by strong tides and currents for example. For such a constrained environment the aspect of safety plays a very important role.

Port authorities are responsible for the maintenance and the development of the port infrastructure as well as controlling the maritime traffic. The main task of a survey division of a port authority is the determination and monitoring of water depth to ensure the accounted under-keel clearance for ships in their areas of responsibility. Furthermore, they support dredging operations and examine shoreline installations (e.g., quay walls) to detect possible damages underneath the water surface. In order to certify the safety of navigation and to maintain maritime safety, frequent and repetitive full-coverage surveys are conducted. Such surveys are currently done by survey vessels equipped with echo sounders, auxiliary necessary sensors and personnel for planning and monitoring the data acquisition.

Over the last years the deployment of unmanned underwater vehicles (UUVs) like ROVs (Remotely Operated Vehicle) and AUVs (Autonomous Underwater Vehicle) and unmanned surface vehicles (USVs) which also include ASVs (Autonomous Surface Vehicle) has increased. Like indicated by the name, UUVs operate underneath the water surface whereas USVs float on the water surface. Some of the systems are hybrids which can operate on and underneath the water surface. UUVs and USVs can have different degrees of autonomy. ROVs for instance are usually linked to a ship by cable or tether which provides communication and power. The operator can control and navigate the vehicle and monitor the data acquisition of installed sensors. In contrary AUVs/ASVs operate completely autonomously (i.e. without external control).

This article deals with the usability of UUVs/USVs for the automation of hydrographic harbor surveys. The demands and specifications of them are pointed out, a comparison of these to state-of-the-art UUVs/USVs, and properties of an optimal vehicle used for autonomous harbor surveys is discussed. To investigate the needs of harbor surveys a questionnaire was completed by international survey divisions of port authorities. These requirements are opposed to the properties of UUVs/USVs available on the market, before discussing the feasibility of their usability in this area of application by pointing out the discrepancy between the demands for harbor surveys and the technical specifications of autonomous UUVs/USVs.

2. STATE OF THE ART

2.1 Harbor surveys

For investigating the tasks, requirements, and challenges of harbor surveys a questionnaire was answered by the survey divisions of three European port authorities. This chapter summarizes the results of the returned questionnaires as well as the content of *FIG Publication No. 56 Hydrographic Surveys in Ports and Harbors* (FIG, 2010).

The main task of the hydrographic surveys in a harbor is to verify the locally defined target depth to ensure the under keel clearance. Further areas of responsibility include the monitoring of dredging operations (Figure 1) and slopes for the detection of instabilities. Also infrastructural monitoring (e.g. locks) for the detection of potholes is done. The area of jurisdiction varies with the size of the harbor and reaches up to a few thousand hectares. The area surveyed daily varies strongly according to the available resources (e.g. vessels) and circumstances (e.g. weather, transit time) and can reach up a few hundred hectares per day. Harbors are usually characterized by shallow water depths compared to the open sea. In the investigated ports the water depths range from 0m up to 45m. Consequently, the local target depths vary according to the area as the size and therefore draught of ships differs.

Figur 1: Hamburg harbor. (www.hamburg-port-authority.de)

The number of survey vessels utilized by the respondents varies between 1 and 4. Usually a survey vessel is at least manned with one captain and one surveyor. Besides the field staff, engineers and technicians are also employed in the back office for data processing and generation of final data products. The ratio of field and office staff is varying strongly for the different authorities so that no general statement can be drawn. Also the repetition rate of surveys for a specific area is varying a lot as time intervals range from weekly to 4 years. These intervals depend on the importance of the area for shipping, the local siltation, and scouring.

For depth measurements multi beam echo sounders and the necessary auxiliary systems for navigation and attitude determinations (GNSS, IMU – (inertial measurement unit) or INS (inertial navigation system)), and sound velocity profilers are employed. Further utilized acoustic sensors for particular tasks are density measurement probes and single beam echo sounders.

Regarding the requirements of harbor surveys the highest standards are used as the under-keel clearance is most likely crucial due to shallow water depths and large ships. The requirements regarding the accuracy of soundings are adopted from the *Standard for Hydrographic Surveys – Special Publication S-44* by the IHO (International Hydrographic Society). Harbors usually fall into the category of *Special Order*. The maximum allowable THU (total horizontal uncertainty) must not exceed 2m and the maximum allowable TVU (total vertical uncertainty) must not exceed 0.3m/0.4m for 20m/40m water depths (at 95% confidence level). According to IHO S-44 *Special Order* cubic features of at least 1m have to be detected and a full sea floor search is required. Some further individual restrictions regarding the accuracy are done by some of the respondents, setting the THU to less than 0.1m and the TVU to less than 0.15m. To ensure such high data quality regular calibrations (patch test) of the multi beam echo sounders are carried out (every 3-4 moths at least). Besides that the data quality is monitored carefully by a surveyor during acquisition.

However, to formulate general statements and statistics of hydrographic surveys for harbors is hardly possible, as the environment and therefore the demands for surveys are very diverse. This does not only account for the different characteristics when comparing harbors among each other but also within one harbor the local circumstances like currents, siltation, or marine traffic can vary strongly and therefore the effect on the demands for hydrographic surveys.

2.2 UUVs/USVs

UUVs/USVs are utilized nowadays as multi sensor systems in a broad field of hydrography like research, fishery and aquaculture, military, oil and gas industry, or offshore constructions (inspection, repair, and maintenance). Their size, number of installed sensors, tools, and degree of autonomy varies depending on the application (Figure 2 and 3). Very often they are custom-build to fit the specific needs for a specialized application. Unmanned vehicles have the advantage of being able to work in not easily accessible areas for survey vessels or divers. Furthermore, underwater vehicles can dive into deep water areas and investigate the seabed from a closer distance than having the same sensors installed on a vessel. This way higher survey accuracy can be achieved and close range sensors like cameras can be deployed for gathering additional information.

Figur 2: Unmmaned surface vehicles of different sizes. From left to right: SONOBOT from EvoLogics (www.evologics.de), C-Worker 6 from ASV (www.asvglobal.com), Mariner from Maritim Robotics (www.maritimerobotics.com).

Figure 3: Unmanned underwater (or hybrid) vehicles. From left to right: HUGIN from Kongsberg (www.kongsberg.com), Bluefin-9 from Bluefin Robotics (www.bluefinrobotics.com).

Autonomous vehicles are not connected by tether, cable, or radio communication to a ship or other control station. As a result an autonomous vehicle navigates on its own, whereby waypoints for the mission's path planning can be defined beforehand or the vehicle is launched without prior information and navigates on its own (e.g. by pipeline tracking). The autonomous navigation of such vehicle includes algorithms for decision making when unexpected circumstances occur (e.g. obstacle avoidance). As there is no connection to an external control the power supply is also completely taken care of by the vehicle itself. (DHyG, 2015)

3. REQUIREMENTS FOR AUTONOMOUS UUVs/USVs OPERATIONS FOR HARBOR SURVEYS AND THEIR APPLICATION VIABILITY

So far autonomous unmanned vehicles have not been utilized professionally for surveys in such constrained environments like harbors by port authorities but would be of large interest.
The utilization of autonomous vehicles would decrease the costs due to personnel reduction and operational and maintenance savings. Furthermore, the flexibility would be improved as the application of autonomous vehicles in not bound to working hours. They can approach underwater constructions very close hen diving. Their small size results in a small draught which allows them to reach very shallow areas which might not be accessible by vessels. Furthermore, this fact also decreases the tide dependent factor in survey planning.

Within the questionnaire the respondents were asked to formulate the requirements for an application of autonomous vehicles from their point of view. These can be grouped related to the demands on performance of the survey data quality, survey platform, technical infrastructure, and autonomy. They are listed in table 1 as well as their availability based on exemplary case studies (for autonomous UUVs and USVs) are given where these requirements were met. Indicators marked with "v" represent requirements which are met by available systems. Availabilities marked with "(v)" indicate some partial or not complete fulfillment of the requirement to the demanded extent.

Requirements for autonomous harbor surveys		Availability	
		UUV	USV
Survey data quality	Accuracy of sounding data (THU < 0.1m, TVU <0.15m)	(v)	v
	High positioning accuracy (within a few centimeters)	(v)	v
Survey platform	Same sensor payload as vessels	v	v
	Survey duration / battery capacity	v	v
	Speed of up to 4 m/s	v	v
	Operation at strong swell	v	(v)
Infrastructure	Data handling / data transfer	v	v
	Fast recharge of batteries	(v)	(v)
Autonomy	Autonomous decision-making (e.g. approach of power station)	(v)	(v)

	Collision avoidance	(v)	(v)
	Real time quality monitoring	(v)	(v)

Table 1: Requirements for autonomous UUVs/USVs operations for horbor surveys stated by the port authorities and indicators of where the requirements are met (by systems available on the market).

3.1 Survey data quality

The requirements for autonomous UUV/USV surveys derive first of all from the demanded survey specifications as an autonomous solution should provide the same performance like current vessel-based surveys. This particularly accounts for the accuracy and quality of the survey data which is of highest standards to ensure the safety of navigation. This aspect therefore includes also the demand to equip such a vehicle with the same sensors used generally.

The determination of position and attitude of a sensor carrier platform in a defined reference frame system plays a crucial role as its quality directly influences the accuracy of the senor measurements and therefore the quality of the final product. The interviewed authorities use a combination of GNSS (RTK-real time kinematic) for positioning and INS (inertial navigation systems) for attitude determination and positioning support. An INS determines the change in location and attitude of an object by measuring the acceleration along and angular velocity around the three orthogonal axes. The obtained three dimensional change of position within a certain time can subsequently be applied to the previous known location of the vehicle. The uncertainty of the navigation solution for such an indirect localization technique decreases rapidly over time. Therefore, additional methods of navigation are combined with an INS solution to reduce its drift and improve the positioning accuracy of the platform (Groves, 2013). The utilized integrated navigation solutions achieve accuracies of a few centimeters.

Such integrated navigation solution can directly be employed without any constraints to USVs and are available on the market as for example for the Z-Boat 1800-RP from Teledyne Marine (Teledyne Marine, 2017) to achieve the required accuracy of less than 10cm for THU and 15cm for the TVU. For UUVs a GNSS-based positioning would be no option. The positioning of underwater vehicles is therefore mainly based on INS. To reduce the drift of the dead-reckoning technique over time, a support of the navigation solution is necessary. This could be realized by a stationary network of underwater beacons at known positions, which are detected, recognized, and utilized for localization by the vehicle within a harbor. Further methods to support the inertial localization could include further additional sensors (e.g. Doppler log) as well as information about the surrounding environment obtained by previous surveys for terrain based navigation (TBN). The final positioning accuracy achieved by UUVs depends strongly on the utilized INS aiding techniques and their algorithmic integration. In general, available systems on the market achieve positioning accuracies within the IHO S-44 requirements for Special Order (Kongsberg, 2017).

3.2 Survey platform

The combination of a large payload, a required speed of at least 4m/s, and a desired survey duration of a few hours make a strong propulsion and large battery capacity necessary. UUV and USV systems like the Hugin from Kongsberg (Kongsberg, 2017) or the Z-Boat 1800-RP from Teledyne Marine (Teledyne Marine, 2017) meet such specifications for example.

The survey platform should be utilizable also in harsher environments of larger swell caused by bad weather conditions or bow waves of large ships. This does not pose a problem for UUVs as they operate within the water and are therefore less affected by waves. In contrary, such rougher water surface conditions could pose a problem for the utilization of USVs.

As the improvement of battery size and capacity is evolving quickly this might not depict a major problem regarding the demands of survey time as long as the battery change proceeds quickly, autonomously, and the downtime is minimized.

3.3 Technical infrastructure

The rapid development in technologies for autonomous UUVs/USVs is not only restricted to the battery size and capacity but also accounts for the data transfer to the office. Regarding to the respondents an average data volume of about 1 GB is gathered by the port authorities daily and can already transferred to the office by the end of the day by wireless network when surfacing. This would therefore not constitute a challenge for the implementation of autonomous vehicles for harbor surveys.

The time span for recharging batteries should be kept as short as possible to reduce the downtime of the survey platform to a minimum. A long persistence is desirable as the maintenance effort should be minimized and the spontaneous deployment at short notice be possible. Research and trials regarding docking station for UUVs are dating back to more than 10 years (e.g. Hobson et al. 2007) and have shown the usability of underwater docking stations for UUVs (mainly focusing on resistant UUVs in oil and gas applications). To decrease the downtime due to battery recharge an automatic battery exchange could be utilized.

3.4 Autonomy

For taking full advantages of the application of an autonomous survey vehicle for harbor surveys a high level of autonomy would be preferable. Three main factors were mentioned by the port authorities addressed by the port authorities and are listed in Table 1. They are further discussed in the following subchapters.

3.4.1 Autonomous decision making

The aspect of the requirement for an autonomous decision making and subsequent execution of actions is mainly focusing on the demand to keep the human interaction and the maintenance as small as possible. This includes the approach of a power station for recharge but also reporting of dangerous flotsam for example.

3.4.2 Collision avoidance

Harbors are spatially limited regarding the extent of waterways in width and depth. Additionally, influences by tides and marine traffic play a crucial role for the application of autonomous UUVs/USVs as they further challenge their autonomous movement in the harbor area. Therefore, an integrated collision and obstacle avoidance is of large importance. It has to work reliable and precise as failures could result in a risk for safety (Moitie et al., 2000).

Currently, the legislation for the application of unmanned vehicles in harbors is not clear according to the respondents. Usually port authorities act relatively self-sufficient but in reference to the deployment of unmanned crafts within such constrained environments like harbors the Ministry of Transport is challenged. Procedures and protocols defining the interaction of UUVs/UVSs with other maritime traffic have not been developed so far. The consistent functionality of the algorithms implemented in autonomous vehicles has to be ensured by 100 percent to guarantee their reliability. This is still a huge challenge.

The sensors utilized for collision avoidance differ for UUVs and USVs. Underwater vehicles can be equipped with forward looking sonars to detect obstacles in front of or next to them. They have the possibility to evade in three directions (sideways, vertically, and backwards). Surface vehicles in contrary have more possibilities regarding the employed sensors to detect obstacles as AIS (automatic identification system), radar, or acoustic or electromagnetic signals for vertical distance measurements can be employed. In contrary they are limited regarding the directions of evasion.

Some research regarding the improvement and further development of collision and obstacle avoiding algorithms for autonomous USVs is taking the COLREG (International Regulation for Preventing Collisions at Sea) into account as they are focused on the development of autonomous transport of merchandise (e.g. Campbell et al., 2012). The development towards autonomous harbor surveys would strongly benefit from such approaches. A special awareness regarding the evasive manoeuver has to be raised as the harbor is characterized by denser ship traffic than the open oceans.

3.4.3 Real-time quality control of the recorded data

To monitor the data quality (accuracy and density) during acquisition a surveyor utilizes different possibilities which are usually applied simultaneously according to the respondents. During data acquisition online DTMs (digital terrain models) are calculated. These can visualize different data properties like standard deviation or data density. Such depictions are monitored closely to identify systematic errors, blunders, or data gaps. In case of their occurrence the survey profiles are adjusted immediately or other appropriate actions are carried out (e.g. measurement of sound velocity probe). These monitored data quality indicators also include the overlap of the multi beam swaths of neighboring profiles as their width varies according to the water depth. Such an instant adjustment of its path due to data quality issues should also be performed by autonomous vehicles as the time span between the survey and a revisit would be too long. If the data can only read out and checked by a surveyor after the reappearance of the vehicle, morphological structures like sand ripples could have moved up to one meter per day due to tidal influences in the meantime. When re-surveying a location after more than 12 hours to fill in gaps in the dataset, the seabed could have probably changes and result in mismatch of data. If an UUV/USV would reliably check the recorded sensor data in real-time, it could react instantly by adjusting its path accordingly.

Furthermore, the technical parameter settings like gain, swath angle opening, depth filters, or signal strength of the multi beam echo sounder are monitored and adjusted by a surveyor according to the changes in the characteristics of the survey area. This is especially important for surveys related to dredging operations as they not only result in changes of seabed morphology. They whirl up the upper seabed sediments which concurrently makes it hard to detect the soil layer representing the boundary of water and seabed with acoustic sensors for quite a period. As dredging is usually accompanied by surveys before, after, and also sometimes in between the procedure, possible time slots for surveys are quite short. The quality in such areas is strongly depending on the settings of the echo sounders and makes adjustment in the multi beam echo sounder settings necessary. Nowadays such adjustment of most of the technical settings can be done nearly autonomously by most of the echo sounders available on the market which increases possibility of a completely autonomous survey. However, automatic depth filter adjustments in areas of man-made structures like key-walls still have potential for improvement since they still present a challenge for the bottom-detection algorithms of echo sounders (Lurton, 2010).

The third monitoring option for data quality is an alert system which indicates the proper functioning of the individual systems onboard. For example, in case the navigation solution is lost, the survey can be interrupted and resumed when connection is restored. Such a quality control can easily be implemented to an autonomous vehicle and does not represent a big challenge for an autonomous realization of harbor surveys.

4. CONCEPT OF AUTONOMOUS HARBOR SURVEYS

In the previous chapter requirements and their up-to-date availability regarding the needs for harbor surveys were presented. Some of the demands for autonomous harbor surveys are not completely met and therefore represent a challenge for the realization.

Comparing the application of autonomous UUVs and USVs each system has its advantages and disadvantages. The advantages of underwater vehicles can be seen in the diving functionality as they can dive underneath ships and therefore can get closer to specific sites of investigation. They are less affected by waves which results in a more stable attitude. The advantage of surface vehicles is their better visibility for safety reasons and their easier to realize positioning. To achieve positioning accuracies like with RTK-GNSS using UUVs a larger effort regarding aiding sensors and a network of position-aiding beacons would be necessary. Such a network would have to be installed and maintained and would result in large financial and time consuming effort. Furthermore the noisy reverberant conditions within a harbor induced by vessels and various source could lead to problems for an acoustic positioning approach (Christ et al., 2014). An infrastructure independent method would therefore be preferred in harbors.

An unmanned surface vehicle would be the more preferable sensor platform for autonomous harbor surveys of these two as the aspect of safety (visibility and also possibility of mounting different sensors utilized in combination for collision avoidance) and position accuracy plays a major role. If such system would also be able of diving the combination of the advantages of both types of sensor platforms could be combined as a hybrid.

As the requirements regarding the data quality are of very high standards, this factor is of great importance and also depicts the most crucial aspects together with the safety consideration in realization of autonomous surveys in harbors. The amount of human supervisory intervention should be kept at a minimum in general. A various range of surface vehicles can be found on the market for hydrographic surveys in shallow water (Bertram, 2008). Most of them are designed to be operated remotely from the shore or a vessel. A completely autonomous survey cannot be realized for harbors today, but the algorithms and methods for collision avoidance and online data quality checks are already available and with further improvement and their combination the aim could be achieved in the distant future.

The link of intelligent data monitoring and adjustment in path planning is of great importance. These two internal evaluation and decision workflows have to be brought together appropriately to ensure a certain survey data quality is achieved by the end of the mission. A final evaluation and the product creation of a qualified hydrographic surveyor cannot be completely replaced. But the high effort of real time data monitoring could be reduced and the flexibility of surveys could be increased which is the main advantage of autonomous surveys.

The difficulty of reliable collision avoidance according to the legal requirements could result in a semi-autonomous solution. The position and survey of an autonomous vehicle could be monitored and in the event of a potential hazardous situation a human intervention carried out. This could be supported by an alert send from the semi-autonomous vehicle to the observer. Such an human interaction would have further advantages when conducting surveys close to obstacles like quay walls, as an automatic collision avoidance procedure might not allow the vehicle to approach this potential threat for safety as close as required. Even though the human interaction is not completely eliminated during the process of data acquisition this way, the effectiveness would be increased as one person could monitor a number of unmanned vehicles simultaneously.

5. CONCLUSION

The requirements for collision avoidance and data quality monitoring algorithms are very high as well as the demanded reliability. Consequently, a completely autonomous hydrographic data acquisition within harbors will not be realized within the next years. Such implementation in everyday work especially in such constrained environments like harbors is a long process. Furthermore, the legislation is not clearly regulated. Such improvements of algorithms and their reliability as well as the development of official procedures and protocols are a long-term process. Similar evolutions can be seen in autonomous driving cars which technology much further advanced regarding the implementation into everyday use than for water based vehicles.

A semi-autonomous approach seems feasibly in the near future by reducing the human intervention during data acquisition. This article suggests a surface vehicle with autonomous data quality control combined with a reactive autonomy regarding collision avoidance to meet the requirement of autonomous harbor surveys best and could be realized in the near future. Further advancements in technology like power supply, data transfer but especially regarding online data control and consecutively autonomous path adjustments are highly important for further developments towards autonomous data acquisition of harbor surveys.

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REFERENCES

Bertram, V. (2008): Unmanned surface vehicles– A survey. Proceedings of skibsteknisk selskab, Copenhagen, Denmark.

Campbell, S., Naeam, W., Irwin, G.W. (2012): A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance maneuvers. In Annual Reviews in Control, pages 267-283. Elsevier.

Christ, R.D., Wernli Sr, R.L. (2014): The ROV Manual: A User Guide for Observation Class Remotely Operated Vehicles. 2nd Edition, Butterworth-Heinemann.

DHyG – Deutsch Hydrographische Gesellschaft (2015): Hydrographische Nachrichten. No. 102. http://dhyg.de/images/hn_ausgaben/HN102.pdf (accessed September 2016).

FIG – International Federation of Surveyors (2010): Guidelines for Planning, Execution and Management of Hydrographic Surveys in ports and Harbours. FIG Commission 4, Working Group Hydrographic Surveying in Practice, FIG Publication No 56, Copenhagen, Denmark.

Hobson, B.W., McEwen, R.S., Erickson, J.A., Hoover, T., McBride, L., Shane, F., Bellingham, J.G. (2007): The Development of Ocean Testing of an AUV Docking Station for a 21 AUV. Proc, IEEE OCEANS, Vancouver, BC, Canada, Sep. 29-Oct. 4 2007, pp 1-6.

Groves, P.D. (2013): Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems. 2nd Edition, Artech House.

ICS – International Chamber of Shipping (2015): ICS Homepage. www.ics-shipping.org accessed March 2015).

IHO – International Hydrographic Society (2008): IHO Standards for Hydrographic Surveys – Special Publication No 44. 5th Edition, www.iho.int/iho_pubs/standard/S-44_5E.pdf (accessed September 2016).

Kongsberg(2017): Product Leaflet Hugin. https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/A6A2CC361D3B9653C1256D71003E97D5/$file/HUGIN_Family_brochure_r2_lr.pdf?OpenElement (accessed January 2017).

Lurton, X. (2010): An Introduction to Underwater Acoustics. 2nd Edition, Springer, Berlin & Heidelberg.

Moitie, R., Seube, N. (2000): Guidance Algorithms for UUVs Obstacle Avoidance Systems. OCEANS 2000 MTS/IEEE Conference and Exhibition, Volume 3, p. 1853-1860.

Teledyne Marine (2017): Product Leaflet Surface Vehicles. http://www.teledynemarine.com/Lists/Downloads/Autonomous_Surface_Vehicles.pdf (accessed January 2017).

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