The Advanced Remote Tower System and Its Validation

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Advanced Remote Tower project

Validation Results

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Executive summary

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Problem area
The Advanced Remote Tower (ART) project studies the operational use of image enhancement, video tracking and the usability of a Pan Tilt Zoom (PTZ) camera in a 360 degrees panoramic remote tower control facility.

Description of work
The Advanced Remote Tower prototyping-project (ART) studies enhancements to an existing LFV facility for a remotely operated tower: projection on a 360 degrees panorama screen, adding synthesized geographic information and meteorological information, video tracking, fusion of video and radar tracks, labelling, visibility enhancement and surveillance operations with a remotely controlled Pan Tilt Zoom camera. The ART functions have been embedded in the existing Swedish test facility for remote tower operations in Malmö airport Sturup observing Ängelholm traffic about 100 km to the North.

Results and conclusions
The ART functions were tuned and validated by 15 tower controllers. Emphasis was on the traffic and situation awareness of tower controllers using remote cameras and projection system for safe

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operational tower control, replacing direct view on the airport and its traffic. The validation results give valuable information for further development and operational application even outside the Remote Tower application area.

Applicability
Besides application in remote controlled visual towers, most of the functions are also applicable to manned towers and present day tower operations.

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Advanced Remote Tower project

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Summary

The Advanced Remote Tower project (ART) studies enhancements to an existing LFV prototype facility for a remotely operated tower: projection on a 360 degrees panorama screen, adding synthesized geographic information and meteorological information, video tracking, fusion of video and radar tracks, labelling, visibility enhancement and surveillance operations with a remotely controlled Pan Tilt Zoom camera. The ART functions have been embedded in the existing Swedish test facility for remote tower operations in Malmö airport Sturup observing Ängelholm traffic about 100 km to the North. They were tuned and validated by 15 tower controllers. Emphasis was on the traffic and situation awareness of tower controllers using remote cameras and projection system for safe operational tower control, replacing direct view on the airport and its traffic. The validation results give valuable information for further development and operational application even outside the Remote Tower application area.

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Abbreviations

AFIS	Aerodrome Flight Information Service
ART	Advanced Remote Tower (project)
ATC	Air Traffic Control
DG-TREN	Directorate General for Transport and Energy
E-OCVM	European Operational Concept Validation Methodology
HMI	Human Machine Interface
IFR	Instrument Flight Rules
LFV	Swedish Air Navigation Service Provider
PIP	Picture In Picture
PTZ	Pan Tilt Zoom (camera)
RNLAF	Royal Netherlands Airforce
ROT	Remotely Operated Tower
TWR	Tower
VET	Visibility Enhancement Technology

1 Introduction

The Advanced Remote Tower (ART) [ART2006] project studied from 2008 to early 2010 the concept of remotely operated Air Traffic Control (ATC) units and supporting technologies in order to enhance regularity during low visibility operations and to substantially decrease the ATC related costs at airports. The ART enhancements are prototype functions with different level of maturity. They are supposed to be good candidates for application in remote tower control.

ART is co-funded by the European Commission (Directorate General for Transport and Energy). Partners in the ART project are: Saab (Project Coordination and system integrator), the Swedish Air navigation Service Provider LFV (Operational input and hosting the ART trials and ART facilities), the National Aerospace Laboratory of the Netherlands NLR (Validation and Safety Assessment), LYYN Sweden (Visibility Enhancement Technology VET) and Equipe Ltd. UK (projection facility).

The purpose of ART is to explore the concept of remotely operated towers and to prototype and validate additional sensors and Human Machine Interface (HMI) that will enhance the air traffic controllers' situational awareness at reduced visibility conditions due to weather and darkness. Promising new technologies, as well as technologies of today, applied and presented in an innovative and more efficient manner, are being explored. The enhanced situational awareness is one of the main prerequisites for enhanced regularity at the aerodrome, which has proven to be one of the bottlenecks in today's Air Traffic Management system (ATM).

A cost benefit analysis [LFV-ROT] regarding remotely operated towers performed by the LFV Group shows substantial economical benefits compared to traditional ATC operations at airports. These benefits for the Air Navigation Service Provider (ANSP) will in turn reduce the cost for airline operators and travellers.

The concept and technology are tested in low-density areas in order to explore the applicability in medium and high-density traffic areas. The ART concept will in turn be one of the bricks in the future concept of highly automated ATM at airports.
The concept of ART will also have spin-off effects in the area of training and investigation after incidents and accidents. ART explores the possibility to not only use recorded voice communication but to reproduce the course of events with audio and video of the controllers' situation.

Major deliverables are ART concept of operations, system design, incorporation and adaptation of sensors and an ART demonstrator on a low-density airport in Sweden with the possibility to explore the concept at any low to medium density airport.

The following steps have been made to achieve these objectives: Design and construction of a remote tower cab, evaluation by end-users of controller workload and situational awareness, evaluation of operational benefits with new possibilities to present information, identification of vital parameters for remote airport operations and evaluation of technical and operational safety issues.

Remote tower concepts are rather unexplored. Brinton and Atkins [Brinton 2006], provide a requirements analysis approach for remote airport traffic services. The German Aerospace Institute DLR performs remote airport tower operation research [Fürstenau 2007] in a national program. US activity can be found in [Ellis 2006].

Next sections explain the ART functions, the test and validation program, the results and the analysis and recommendations.

2 ART Functions

The ART project prototyped the following enhancements for Remote Tower Control:

2.1 360 degree circular panorama display

Nine video cameras are mounted on top of the real tower to observe the total airport and control zone. Images are projected on a circular projection screen (9 times 42 degrees including overlap between projected images, 6 m diameter, 1360x1024 pixel resolution per projected camera image, 20-30 frames per second, Fig. 2-1).

Fig. 2-1 Part of the panorama screen and one of the video cameras

2.2 Visibility Enhancement Technology

A sizeable part of a projected image can be improved by a digital real time Visibility Enhancement Technology (VET), see Fig. 2.2.

Fig. 2-2 Visibility enhancement for a part if the image

2.3 Presentation of airport and geographic information

Synthetic contour lines can be activated enhancing the runway and taxiway edges in low visibility conditions, see Fig. 2.3.

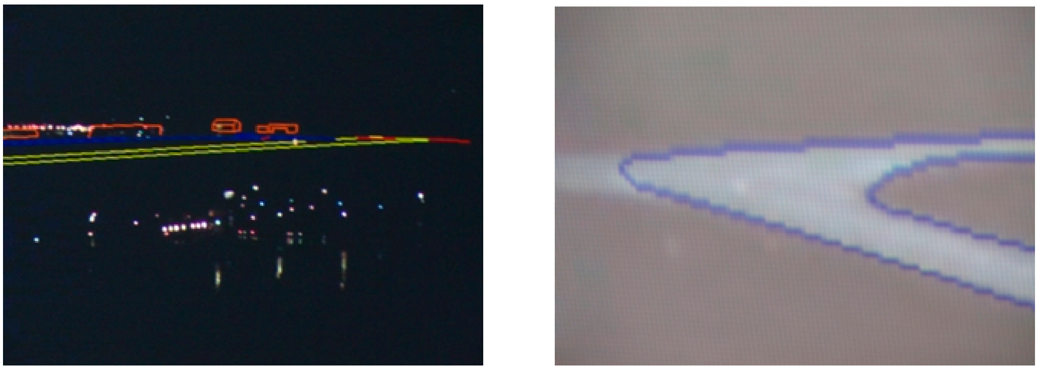

Fig. 2-3 Overlaid geographic information

2.4 Presentation of weather information

Actual weather information is projected on the circular panoramic screen on places without covering traffic, see Fig. 2.4. Actual wind direction and speed are displayed including 2 minute average and minimum and maximum values. Runway Visual Ranges were displayed in the lowest part of the panorama screen.

Fig. 2-4 Meteorological overlay with actual wind speed, direction , 2-minute average and minimum – maximum values

2.5 Sensor data fusion

Objects observed by the video cameras are tracked in the central tracking unit. Radar tracks from the Approach Radar are merged with the video tracks; see Fig. 2-5 right part.

Fig. 2-5 Left: *Aircraft tracked only by the Terminal Approach Radar (labels with call sign or SSR code and altitude in hundreds of feet);* Middle: *aircraft tracked by the video camera only (label with track number);* Right: *aircraft tracked by both radar and video*

2.6 Presentation of aircraft and vehicles

Aircraft and vehicles get a rectangle around their observed shape and a track number when observed by the video tracker (Fig. 2.5 middle section). The track number (ID1234) can be changed into flight identity by manual label input or by the automatic merge with the radar track. They get a radar label if detected by the radar (Fig. 2.5 left section) and when inside the airspace with specified range and altitude from the field. Aircraft both tracked by video and radar carry a rectangle-diamond contour and a radar label.

2.7 Pan-Tilt-Zoom (PTZ) camera

The PTZ camera can be remotely controlled from its HMI, see Fig. 2-6 left. It has 768 x 576 pixel resolution and a zoom factor of 36 (1.7 degree minimum view angle). The PTZ camera will sweep 180 degrees in 2 seconds in order to catch an object quickly. The PTZ monitor (Fig. 2-6 left) provides presets for hot spots on the field (tiles around the PTZ image). Manual steering is done by the mouse either on the PTZ monitor or on the panorama screen. The actual heading and zoom is indicated with on a compass rose in the right top corner. The PTZ camera can be slaved to a track and its image is also displayed on the panorama screen as a Picture-in-Picture (PIP) (Fig. 2-6).

Fig. 2-6   Pan Tilt Zoom camera Human Machine Interface (left) and Picture in Picture (right)

3   Test and Validation Program

The requirements for the ART functions have been derived from problem driven operational concept procedures for remote tower control, having in mind that solutions shall be acceptable for remote tower controllers and cost beneficial. Emphasis was on safety and situational awareness. Both shall be at least equal or better as compared to real tower operations. A preliminary safety assessment is part of the ART project. It will be updated with the validation results and published elsewhere.

Early implementations of the ART functions were evaluated by controllers and further developed in at least two cycles before entering the evaluation and validation program. During the validation 15 air traffic controllers participated, each spending two days in the remote cabin in groups of two to three controllers. The controllers came from the Swedish field Ängelholm that was remotely displayed (7), from other Swedish airfields (7) and from a Dutch military airport (1). Their average age is 45, ranging from 28 to 58 and they have an average experience of 20 years, varying from 1 to 32 years.

Due to safety restrictions only passive shadow mode was possible, meaning that actual control of traffic was done from the Ängelholm real tower, while controllers in the remote position judged their function as if they were in full control.

The European Operational Concept validation Methodology [E-OCVM] was applied to define objectives and hypotheses. After verification of the proper functioning of the ART functions, the validation was conducted by real time observation of traffic at the Swedish Ängelholm airport. Recordings were used to evaluate less frequently occurring visibility conditions. E-OCVM is a strict validation methodology leading to definition of objectives and hypotheses to be validated. For the ART functions about 70 have been defined and worked out in to questionnaires with about 138 statements ranking 1 for complete disagreement to 6 for full compliance with the statement. Data were collected via debriefings, questionnaires for, during and after the test runs, and observations. Observations were carried out by Subject Matter Experts and Human Factors specialists.

The validation program consisted of a familiarisation and training phase during which the controllers can make themselves familiar with the proper operation of the ART functions. The ART functions were validated incrementally and in combinations:
Part A - Validation of: Panorama Display, Weather Presentation and Geographic Information display;
Part B - Traffic Presentation (Labelling) and PTZ functions
Part C - Pan Tilt Zoom Camera and Tracking functions;
Part D - Validation of the Visual Enhancement Technology;
Part E - Validation of the combination of all previous mentioned ART functions;
Part F - Expert Judgement Workshop.
The Expert Judgement Workshop covered all validation aspects that could not be answered but by management and policy makers.

Ängelholm airport is an airport in southern Sweden with one runway, taxiways on both sides of the runway and an apron with passenger terminal on the opposite side of the runway about 1500 m from the tower. The distance of the 30 meter tall tower to the runway is 700 m shortest and about 1400 meter to the thresholds.

4 Results

The prototype ART functions were validated during typical autumn conditions; rain, low visibility, dispersed showers and low cloud base conditions. Main emphasis was on the controller appreciation of working conditions and their situational and safety awareness. The program spent also several hours with each group of controllers during night time conditions. The traffic for Ängelholm consisted of about 20 to 30 aircraft per day being scheduled flights, training flights and occasionally charters and business flights. Vehicles on the taxiway and runway were surveyed also: runway inspection cars, maintenance vehicles, towing tracks, with and without rotation and flashing lights. Following results originate from answers to the questionnaires and debriefings. In the context of this limited publication only the highlights are given. An extensive version of the ART prototyping results with more quantitative and descriptive details is being published as part of the project documentation.

4.1 Results for the Panorama Display

Visibility in the remote tower was found less than in the real tower. Overall the confidence in the projection system was anyhow high among the controllers. The controllers found the small distortions of the panorama image due to the composition from nine cameras acceptable. The camera - display combination was not performing sufficiently in resolution and in detection capability to survey all objects and movements on and around the airfield, compared to real tower operations. The controllers complained about missing depth of view. It was difficult for them to estimate distance and to judge which aircraft was closer. The controllers found the nine cameras in combination with the panorama display acceptable for ATC operations of single aircraft only. They expressed however to have problems to use this panorama set-up for handling multiple aircraft. The automatic camera adjustments for changing light conditions did not interfere much with the controllers' tasks, but a risk existed that controllers are not fully aware of the real daylight conditions, especially during twilight. Then remote controllers might think that it is daylight condition. Overall the controllers' awareness of the meteorological conditions was less; they have some difficulties to judge the clouds.

4.2 Geographic Information display

There was no consistent opinion among the controllers on the use of geographic overlays. Controllers familiar with Ängelholm said not to need extra synthetic reference information, this in contrast with non-Ängelholm controllers who found assistance by the extra reference lines. The participants slightly agreed that geographical information can be useful during darkness and low visibility though it has to improve. They judged it would not significantly benefit capacity. The overlay may obscure other important information and it is felt slightly cluttering the display.

4.3 Weather Presentation

The controllers slightly agreed that weather information on the display is useful. Controllers preferred to position the weather information at own choice, for instance close to the touch down zones. Overlaid weather information will be helpful to keep eyes on the screen e.g. in gusty conditions. It was not causing more workload and it could eventually cover other important information. The presentation of Runway Visual Range was appropriate and controllers felt confident..

4.4 Results of Traffic Presentation (Labelling and Tracking)

Controllers preferred labels irrespective of the sensor source from which they were derived. Target tracks and labels were considered useful but most during night and low visibility. Their source (radar, video or both) should be indicated in the target symbol. Labels tended to increase controller's situational awareness, but controllers did not judge tracking performance good enough (so far) to increase capacity and to improve safety in low visibility (<2000 m). Workload was judged slightly increased. Labels for aircraft and vehicles were expected to improve the capability of controllers to follow, monitor and control traffic. Controllers considered it a slight risk to obscure important information. When labels overlapped controllers were able to put them apart and make them visible manually, but automatic label de-conflicting would be preferred. Label swops were found a safety risk. Any mismatch between video and radar target should be removed. Adding a label, editing the label content and switching the label appearance was considered easy, which also applied to manual track termination. Display of different target symbols and labels for aircraft and vehicles was found intuitive in respect to the source of the track (video, radar or combined).

4.5 Results of validation of the Visual Enhancement Technology

VET increased the luminance of higher intensity areas a factor 2 and lowers the lower intensity areas also a factor 2, giving more contrast between the high and the low brightness areas. The controller expectations were high (see through fog, make the invisible visible). Controllers wanted the whole picture to be enhanced in contrast and the effect should be larger. VET produces noisy pictures during night. In contrast the PTZ turned out to be much more light-sensitive in the dark than the visibility enhanced panorama cameras. This effect was enlarged due to automatic exposure control of the cameras which was in favour of the PTZ (optimising a zoomed in part) and negative for the panorama cameras (averaging the whole image).
VET did not convince the participating controllers to improve visibility and awareness in the way it was set-up in these validation exercises. This finding was irrespective of visibility and day/night conditions. VET did not allow operating at lower visibility thresholds as compared to standard Low Visibility Procedures. In low visibility, the additional visibility offered by VET enabled not to see all the objects controllers need to see at and around the airfield with sufficient detail neither it enabled for earlier detection.

4.6 Results for the P TZ Camera and Object Tracking

The controllers found the PTZ rather useful for searching and detecting aircraft and vehicles, for manual and automatic runway inspection and for inspection of aircraft and vehicles, most of all during daylight and good visibility. The PTZ Picture in Picture should be moveable to any position on the panorama screen. The response of the PTZ camera was considered good enough and residual time delays were acceptable. The automatic tracking capability of the PTZ depended on the choice made for central video tracking and thus its performance. Controllers did not expect to handle more traffic with PTZ. The availability of the PTZ picture-in-picture camera favoured to keep a better focus on the panoramic display, but there was a risk to stay too long with the PTZ. Controllers found the PTZ operating procedures easy to use and Controllers felt confident using the PTZ camera.

4.7 Results of validation of the combination of all ART functions

The controllers could not stay ahead of traffic with the ART functions as tested in these live trials, compared to real manned tower operations. They had a slight tendency to focus too much and too long on the new ART functions. Controllers expressed a thought that in an ART environment (=more synthetic), there is a risk of forgetting something important since you don't have all "real" visual inputs in the same way. They also expressed a feeling of not being able to plan and organise tower control in the same manner as in the real tower. Despite the ART functions, controllers searched for information that is easier to find in the real tower. The ART functions therefore need more development and better integration before being accepted. Using just one mouse integrated for all ART TWR operations/systems, as tested in these trials, was somewhat complicated. The mouse has to be positioned on the right screen before the desired effect is obtained. On one hand controllers expected to learn quickly how to use these tools, on the other hand they said to need a lot of training. The ART facility was judged moderately realistic in reproducing the Ängelholm airport.

Some controllers experienced too much workload overall in the ART cabin. Fatigue was said to be caused by sitting in the cab with tempered light and noise from the cooling fans in the projectors.

4.8 Results from the Expert Judgement Workshop

About 25 subject matter experts participated in the Expert Judgement Workshop to share their opinion on matters not directly related to hands-on air traffic control. They worked out their opinions in three ART related discussion blocks: (1) Implementation of remote tower functions, (2) Costs / benefits as expected for remote tower applications and (3) Opportunities as seen for ART.

The experts found that the implementation of ART functions can be broadened to non-remote applications at large airports (extra surveillance and contingency applications) and remote applications in areas with an extreme climate as there are for example airports in Polar Regions. Airports with Flight Information Service (AFIS) only can be enhanced in service with a selection of ART functions, giving better flight information remotely. The experts agreed on better resolution and detection capability in next maturity level of ART. ART procedures need to be further developed and special airspace for remote tower operations is given a thought. More elaborated safety and human factor cases are on the wish list, as are the development and implementation of ART regulations and licensing.
The experts expected a reduction in cost of tower operations on small and mediums size airports. Also more opening hours were expected in low visibility giving a better business case and probably attracting more customers. ART functions can benefit safety and thus save lives and avoid the costs of accidents and incidents. The ART technology can also benefit airport and aviation security. The ART realisation can bring more uniformity in training and operations. However, working remote increases the gap between the remote controllers and local personnel / knowledge of the field.
Remotely operated airports can be specific for hosting of emergency openings, the geographical location: closely connected grouped airport (similar weather and traffic conditions), airports with similar infrastructure and unfavourable locations.
Next steps for ART as suggested by the expert group are: better performance (resolution, depth of view, visibility enhancement, tracking, better positions for the cameras, better working conditions). Cooperation with other air navigation service providers was promoted. Study is needed to apply ART on more than one airport at a time and to introduce ART in active control. The PTZ was most preferred for application of ART functions on manned towers.

5 Analysis and Recommendations

5.1 5.1 Observations

The ART validation program was executed with live trials in passive shadow mode. Live trials with a more active control were not possible because of time constrains and safety reasons.
The statistical analysis of the responses showed high standard deviations in the answers of the controllers on 100 of the 138 statements. Possible explanations for the large standard deviation are: insufficient exposure to the scenario needed for testing the hypothesis, not sufficient familiarisation and training, system immaturity or misunderstanding of the questions. Further analysis showed a bias between controllers from Ängelholm and the other controllers. The local controllers were on average less positive on the ART functions.

5.2 System maturity

The ART project tested advanced functions with different maturity. The ART functions are not yet mature enough for operational integration. ART is just a step in the evolutionary process to develop optimal remote tower control facilities and procedures. Most of the ART functions need further development and testing. ART participants were generally positive about the PTZ, and presentation of targets and labels. ART participants were somewhat negative about the current resolution of the panorama display, VET and the tracking performance.

5.3 Operational aspects and recommendations

The ART operational evaluation by 15 active controllers and 25 subject matter experts revealed valuable operational knowledge about the application of remote tower technology. The experiments showed that the ART level of maturity only would so far allow for single VFR and IFR operations.

Resolution (1360 x 1024 pixels per camera) and detection capabilities with ART video cameras need to be improved. Controllers suffered from lack of situation awareness when surveying traffic on the panorama screen. Higher resolution will require extra bandwidth of the data transmission channels. Smart data compression algorithms might be required to fit all data in existing and near future data communication means. This could be more expensive in application.

The optimal positioning of cameras is open for further investigation, mainly in order to keep camera costs low while optimizing the camera output.

With the ART functions as tested, remote tower operations with were perceived less performing than the situation in real manned tower operations. This would be the main subject of investigation during next maturity level of research and development.

The automatic exposure of the surveillance cameras might lead to wrong controller perception of day light conditions. A study could be undertaken to find the right automation in this context.

The overlaid geographic information should be further explored. Controllers were happy with the option to switch it on or leave it off, but they asked for thinner and/ or dashed lines. This might be favoured by eventually higher picture resolutions.

Controllers liked to have weather projected on screen but have no other preference for display of wind and runway visual range information on the panorama screen other than a copy of the existing instruments on their desk in the real tower.

Tracking of video objects and fusion of video with radar data are required to perform to high standards as this is giving the controllers confidence in automatic surveillance. Tracking is safety critical when controllers use it for decision making. High performance tracking is needed for reliable track stability and track identity. In this context the ART video tracking and data fusion should be improved. When it provides a better surveillance performance, controllers will make more use of it and they will get the benefit of improved detection capability as compared to visual surveillance. Installing cameras for video tracking of targets closer to the runways, taxiways and aprons should be investigated.

The track labels should be designed to automatically de-conflict with other labels or other objects. It will reduce the risk to cover important surveillance information.
To increase capacity in low visibility the ART Visibility Enhancement Technology was expected to look through fog. In the few validation occasions of low visibility controllers wanted more effect and to a greater extend, preferably on all images. The VET performed but not to controllers' expectations. The intrinsic noise of video cameras in low light conditions made VET in the current form less useful. Further enhanced trials need to be set up, and other sensors or combination with sensors, like infra red needs to be tried.

The Pan Tilt Zoom camera was the best of class in the ART evaluation. Controllers wanted it for real manned towers also already in its current set-up mode. If supplied with reliable automatic tracking control it will even be more appreciated. Its feature to project a zoomed in enlarged picture on the panorama screen should get more flexibility in choice of position.

The integrated ART tools could be improved by further research and development on the working conditions. The dimmed lighting conditions (in a dark room environment) and the 9 projectors with continuous noise seemed to make controllers tired in comparison to the real environment. It is also possible that the picture frame update rate of 20 frames per second made controllers tired. The mouse operation as central for many ART functions should be further optimised. It should not be needed to drag the mouse so much for activating a function.

The ART type of operations could be applied in other areas: in climate unfriendly areas, as contingency for large airports, possibilities to perform remote aerodrome control simultaneous for more then one small airport for a controller, and to improve the information provision on airports with only flight information service (AFIS).

Additional to earlier detected cost benefits, ART could widen opening hours of airports and attract more users by providing punctuality in services. Also security can benefit from this technology.

It is recommended to continue to develop the remote tower procedures, to investigate multi-airport operations and to expand on safety and human factor cases, on regulations, training and licensing.

It is recommended to investigate in the need of visual information quality in relation to sensor data information for control of aerodrome traffic.

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