CONFIGURABLE MODULAR SYSTEM FOR TESTING ALL TYPES OF ELECTRO-OPTICAL SYSTEMS

OECD CONFERENCE CENTER, PARIS, FRANCE / 2–4 FEBRUARY 2016

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KEYWORDS: night vision, metrology

ABSTRACT:

A long series (over 40 test systems) of test systems in many different versions is offered by Inframet for testing all types of EO imaging&laser systems. However, practically all these test systems can be treated a single configurable modular system shaped into many versions optimized for different applications. This configurable test system is built from a series of basic blocks: collimators, blackbodies, light sources, rotary wheels, targets, laser viewing devices, and meters. In this paper these basic blocks of systems for testing imaging and laser systems are discussed. Technical challenges to design these blocks are emphasized.

1 INTRODUCTION

Electro-optical surveillance technology covers a wide range of systems: thermal imagers, VIS-NIR cameras, SWIR cameras, UV cameras, night vision devices, laser range finders/ designators/illuminators/pointers), multi-sensor surveillance systems, and fused imaging systems. These different EO systems have been developed by separate communities that typically specialize in one type of EO system. Next, EO imaging and laser systems are offered on market in myriad of different versions.

The same trend can be noted in area metrological equipment for testing electro-optical systems. Most test systems are optimized to testing one type of EO systems. Great majority of test systems is offered in form of a series of versions of different design and different test capabilities.

2 INFRAMET UNIQUE MARKET POSITION

Inframet is one of manufacturers of equipment for testing electro-optical imaging and laser systems. However, ultra wide offer puts Inframet on an unique position comparing to other manufacturers. Inframet basically can deliver systems for testing all types of electro-optical imaging and laser systems and modules of these systems: thermal imagers, night vision devices, VIS-NIR cameras, SWIR cameras, UV cameras, laser range finders, laser designators, laser trackers, laser pointers, multi-sensor systems, fused imaging systems, image intensifier tubes, IR FPAs, VIS-SWIR sensors and optical systems.

A long series of test systems offered in many different versions is offered by Inframet for testing earlier mentioned types of imaging&laser systems. In detail, over 40 systems is offered, and almost every system is offered in 3-10 versions. That gives high number of potential test systems that can be delivered by Inframet. However, practically all these test systems can be treated a single configurable modular system that can be built in many versions optimized for different applications. This configurable test system is built from a series of basic blocks: collimators, blackbodies, light sources, rotary wheels, targets, laser viewing devices, and meters. In this paper these basic blocks of test systems are presented. Technical challenges to design these blocks are emphasized.

3 COLLIMATORS

Collimators are optical systems used to imitate standard targets placed in "optical infinity" (very long distance). The collimators are used for projection of image of reference targets into direction of tested imagers. According to type of optical elements used in design, collimators are divided into two groups: reflective collimators and refractive collimators. Reflective collimators due to their wide spectral range are almost exclusively used in systems for testing thermal imagers and are also preferable in systems testing VIS-NIR cameras, SWIR imagers, laser systems and multi-sensor surveillance systems. Refractive collimators are mostly used in systems for testing night vision devices or VIS-NIR cameras working in visible/ near infrared range.

From optical designer view, the reflective collimators are inverted telescopes. Therefore it can be claimed that there are many types of reflective collimators depending on mirrors configurations (Newton, Cassegrain, Schwarzschild, Maksutov, etc). However, practically the reflective collimators are typically built using Newton design (big parabolic primary, collimating mirror and smaller secondary flat mirror).

Next, the reflective collimators are further divided into two types: on-axis collimators and off axis collimators. The first collimators have a dead area in center of their optical aperture due to presence of a non transmitting, secondary mirror. This feature limits significantly applications of on axis collimators in systems for testing imagers. There is a risk that the dead area of the on-axis collimator can distort measurement results when only a part of aperture of optics of tested imager is used to create image.

Off axis collimators offers un-obstructed aperture because the secondary mirror is located outside collimator aperture (Fig. 1). However, off axis reflective collimators are also much more costly than reflective on axis collimators.

Low cost symmetric parabolic mirrors are used to design on-axis reflective collimators. Non symmetric mirrors (parts of a bigger mother symmetric mirror) are needed in case of off axis collimators. Next, aligning of off-axis collimators is much more difficult than in case of typical on axis collimators.

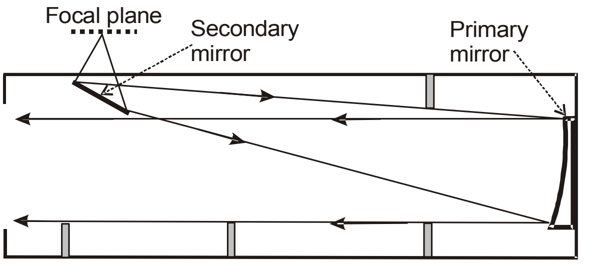

Fig. 1. Block diagram of off-axis reflective collimator (CDT series)

Fig. 2.Photo of several CDT off axis reflective collimators

Inframet manufactures a long series of CDT off axis reflective collimators that are used as blocks of Inframet test systems or as independent optical modules.

Off axis parabolic mirror is the main block of off axis reflective collimator. Present technology level enables mass manufacturing of off axis parabolic mirrors of modest accuracy (L/1.5 at 630 nm P-V) from metal blanks [1]. Next, only mirrors of aperture not higher than about 100mm can be manufactured. Further on, the metal mirrors are characterized by relatively high roughness (up to 17.5 nm RMS). These features makes off axis metal mirrors not suitable for typical off axis reflective collimators due to too small apertures, too low surface accuracy and to high surface roughness. Manufacturing of big, high accuracy off axis mirrors from optical glass is still a domain of optical artists that must manually tune surface of the mirror to desired accuracy.

Inframet posses a team of highly skilled optical technologists capable to manufacture off-axis parabolic mirrors of aperture up to 330mm (option 500 mm) with surface accuracy up to $\lambda/16$ P-V at λ=630nm.

Inframet is also capable to manufacture simpler on axis reflective collimators and refractive collimators.

Fig. 3.Photo of several CVT refractive collimators

4 BLACKBODIES

Blackbodies are devices that work as near perfect emitters of thermal radiation in range from visible to microwaves. There are many blackbodies available on international market [2,3].

Inframet specializes in high-tech blackbodies optimized for narrow market of high requirements [4]. Almost all blackbodies offered by Inframet are characterized by some special features.

TCB series blackbodies are one of very few low temperature (max temperature below about 180ºC) blackbodies that can be controlled with 1 mK temperature resolution and with 2 mK temperature stability. These blackbodies are optimized for use in systems for testing thermal imagers.

Fig. 4. A series of TCB blackbodies

MTB blackbodies are the only medium temperature (max temperature below about 600ºC) blackbodies that can be controlled with 10 mK temperature resolution and with 50 mK temperature stability. These blackbodies are optimized for use in systems for testing SWIR imagers or as reference standards.

Fig. 5. A series of MTB blackbodies

MAB blackbodies are the first commercially available large area blackbodies of high emissivity in THz and short microwave range offered at international market. These blackbodies have been developed after several years of experiments carried out by Inframet research team. Design of these blackbodies is based on a special castable absorber coating optimized for THz/short microwave range, large thermally uniform emitter plate and ultra precision control electronics. High emissivity over 0.95 have been achieved in a wide range from 0.1 mm to 30 mm.

Due to ultra large area, high emissivity, wide spectral range and ultra precision temperature regulation MAB blackbody significantly exceeds performance of other microwave blackbodies known from specialist literature [5].

Fig. 6. MAB-16D blackbody

Testing infrared systems to be sent into space missions is typically done using blackbodies located in cooled vacuum chambers that simulate space conditions. VSB blackbodies are a new type of blackbodies offered by Inframet to meet demands of space laboratories. This blackbody is designed to enable simulation of targets at temperatures from -10°C to +200°C located at cooled vacuum chambers.

Fig. 7. VSB blackbody

UHT blackbodies are ultra high temperature, cavity blackbodies of temperature range up to 1600°C. Due to a special design of the cavity, UHT blackbody offers high emissivity in exceptionally wide spectral band from about 1 μm to over 3000 μm. This ultra wide spectral band makes possible to use UHT blackbody as a standard radiation source in both infrared band and THz band. The blackbody is also characterized by a relatively large aperture of 38 mm of the emitting cavity (apertures of typical high temperature blackbodies are rarely bigger than 15 mm).

Fig. 8. Photo of UHT 38D-1500 blackbody

Each of earlier mentioned blackbodies represent technical challenge for designers due to different reasons.

Ultra precision, low noise electronics is the crux in design of TCB/MTB blackbodies.

Special, ultra large emitter of ultra high emissivity in a broadband range from infrared to short microwave is the main obstacle in design of MAB blackbodies.

A similar situation is in case of UHT blackbodies where the main technical challenge is design of cavity emitter of ultra high emissivity capable to withstand ultra high temperatures.

VSB blackbodies can be treated as a special case of TCB blackbodies. The requirements on electronics are multiplied. The electronics must enable not only control of blackbody with 1 mK temperature resolution and 2 mK temperature stability but additionally the electronics is expected to work in vacuum and in extreme temperatures -173ºC to -33ºC.

5 LIGHT SOURCES

There are many low cost artificial light sources used for illumination or for industrial applications: tungsten or halogen bulbs, fluorescent lamps, LED lamps etc. Some of these sources have regulated intensity of emitted light. However, there very few calibrated light sources of precisely known parameters. A light source can be considered as calibrated when its user can precisely regulate its photometric/radiometric parameters like luminance (or illuminance), radiance (or irradiance) at defined spectrum of interest. Such light sources are needed in many applications – among them, in systems for testing night vision devices, VIS-NIR cameras and SWIR imagers.

Inframet offers a series of calibrated light sources that can be divides into three groups [6]:

1. Multi-channel halogen/LED light sources,
2. Single channel halogen light sources,

3. Large emitter light sources.

The light sources from the first group are optimized to be used in Inframet systems for testing VIS-NIR cameras and SWIR cameras. These sources are expected to simulate illuminance conditions met in real life scenarios: from dark nights in Afghanistan mountains to ultra bright days in Arabian deserts.

Such realistic simulation is possible only using light sources of following features:

1. Ultra high dynamic (ratio of maximal luminance to minimal luminance) of light source at level over 10^9 (needed to simulate both bright days and dark nights),
2. Variable light spectrum in VIS-NIR range (needed to simulate variation of spectrum of incoming light and variation of reflecting properties of targets under surveillance),
3. Ability to emit high intensity UV light (needed to simulate conditions met at coastal areas or high altitude mountains with high UV light that are potentially damaging for some imaging sensors).

Two light sources codes as DAL/SAL belong to the first group. These light sources work by combining light from several channels: halogen bulb of 2856K color temperature spectrum and several LED sources. Intensity of the halogen bulb is regulated using an opto-mechanical attenuator that changes light intensity but does not change light color temperature. Intensity of the LED sources is regulated electronically using advanced electronic regulation/stabilization system. Intensity of UV LED is not regulated. Spectrum of emitted light can be regulated by switching light channels or by mixing light from halogen channel with LED channels. Regulation of spectrum of emitted light is additionally supported by a set of external spectral filters.

DAL/SAL light sources look externally the same but there are some design differences: different coating of integrating sphere, slightly different halogen source and different LED sources. DAL is optimized for testing VIS-NIR cameras sensitive up to about 1000 nm; SAL – for testing SWIR imagers sensitive up to about 1700 nm.

Fig. 9. Photo of DAL/SAL light source

DAL/SAL multichannel light sources due to extremely wide range of regulated luminance, ultra high maximal luminance, ability to vary light spectrum of simulated scenery, PC control, and compact design significantly exceed simpler, single channel halogen light sources offered at international market [7].

DAL/SAL light source are designed to cooperate with collimators in Inframet test systems. The image projectors (collimators) require from the light source Lambertian emission of light only in narrow angle (typically below 10°). Therefore DAL/SAL light source behave like a fully Lambertian source at emission angles up to 15°). This limited Lambertian performance is not acceptable in applications where the light source is used as an independent block. Next, there are applications when aperture of light emitter of DAL/SAL sources (40 mm) is too small. Therefore Inframet offers also H40 light source, L150 light source and H150 light source.

H40 is a single channel source halogen light source that emit light of 2856K spectrum. Technically it can be treated as a simplified DAL light source without LED channels and with modified light emitter. Diameter of light emitter in H40 sources is the same as in DAL/Sal sources (40 mm) but there are two important changes: a) Lambertian source at emission at angles up to 60°, b)ability to cooperate with bright collimators of low F-number (ratio of focal length to aperture can be as low as one).

The second change means that by using additional bright collimator an apparent aperture of the light source can be increased (typically up to 200mm) while still keeping sufficient emission angle. Practically it means that H40 light source cooperating with a series of bright CRAD refractive collimators makes possible calibration of VIS-NIR cameras or SWIR cameras with optics as big as 200mm.

Fig. 10. Photo of H40 light source

Ability to calibrate VIS-NIR cameras and SWIR cameras of big optics can be also directly obtained by using light sources of big emitter. Two such light sources are offered: L150 and H150.

Fig. 11. Photo of H40 light source integrated with CRAD collimator

L150 is a single channel, ultra compact (thin design) LED source that emits light using emitter of 150mm diameter. Emission in different spectral bands is possible: visible, NIR or in SWIR.

H150 a single channel, halogen source that emits light using emitter of 150mm diameter. The source emits polychromatic light of 2856K spectrum in VIS-SWIR range.

Fig. 12. Photo of L150 large area light source

Fig. 13. Photo of H150 large area light source

The series of earlier presented light sources can fit for virtually all applications when reference light source is needed.

6 ROTARY WHEELS

Rotary wheels are one of basic blocks of systems for testing imaging EO systems. They are needed to enable motorized exchange of active target at collimator focal plane. There are usually 8 holes in the wheel for targets (other numbers are also possible). Wheels are covered with a black high emissivity coating (emissivity at least 0.97).

Design of rotary wheels look apparently simple but practical manufacturing is no so easy. Ultra precision positioning (high repeatability) of the wheel is the main design challenge. Positioning uncertainty of the rotary wheel at level below 0.1 mm is expected in case of systems for testing imagers used for automatic target recognition.

Fig. 14. Photo of MRW-8 rotary wheel with attached TCB-2D blackbody blackbody

7 TARGETS

Targets are modules needed to generate images of reference patterns. INFRAMET divides test targets according to intended main application into two main groups: A) <u>IR targets,</u> B)v<u>isible targets,</u>

Targets from group A are developed to support mostly testing infrared imaging systems understood as thermal imagers. These targets can be used also in testing visible/near infrared cameras or SWIR cameras but such application is not optimal.

Targets from group B are developed to support mostly visible/NIR systems. These targets can be also optionally used for testing most SWIR imagers.

a) b)

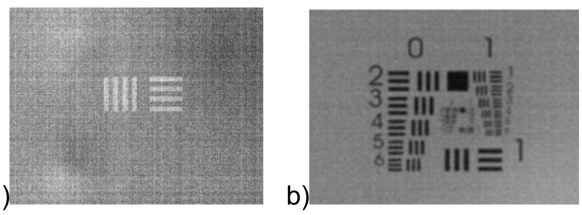

Fig. 15. Images of test targets generated by tested imagers a)image of 4-bar IR target, b) image of visible USAF 1951 target

IR targets for testing infrared imaging systems (thermal imagers) are manufactured by creating precision holes in metal sheets of different shapes. When a blackbody is put behind such a target, the tested thermal camera sees a "target" of shape determined by the holes on an uniform background. The apparent temperature of this "target" is equal to blackbody temperature.

Fig. 16. Photo of two 4-bar IR targets

Targets for testing VIS-NIR cameras are typically manufactured by creating non-transparent (or semi-transparent) coating pattern on transparent glass substrate. This method enables development of test patterns with sub-micrometer accuracy.

Fig. 17. Photo of USAF 1951 target of 100% contrast

There are two main technical challenges to manufacture high quality targets needed to test EO imaging systems.
Manufacturing ultra precision holes (rectangles as small as 0.03 mm are needed) in metals sheets coated using high emissivity paint is the main problem for successful manufacturing of IR targets.
Making uniform low contrast resolution patterns on glass substrates is the main difficulty in manufacturing visible targets.

At present Inframet is the only company on international market that offers USAF 1951 resolution targets of contrast as low as 2%. Such targets are needed to evaluate ability of VIS-NIR cameras to detect low contrast camouflaged targets.

8 PULSED LASER VIEWING DEVICES

Visualization of laser spot created by tested laser range finder is one of basic task of a system for testing multi-sensor surveillance systems. Image of laser spot created at focal plane of a collimator is needed to evaluate alignment of laser range finder (LRF) relative to imaging sensors (thermal imagers, VIS-NIR camera, SWIR camera) and to measure divergence angle of LRF.

Sensing cards that can visualize position of laser beam emitted in UV or IR range are known for decades as a low cost solution to view laser spots invisible for human eye [8,9]. The cards are typically built using layer of phosphor or liquid crystal as imaging sensor. The phosphor screen convert directly incoming invisible laser light (UV or IR) into visible light : the spot illuminated by laser starts to emit visible light.

In case of cards based on liquid crystals the conversion of radiation from IR laser to visible light is done indirectly. Radiation from IR laser is absorbed and changes temperature of liquid crystal layer. Change of temperature generated change of color of the card that is visible for human eye.

There are also known more advanced and accurate devices for visualization of invisible laser beams : 2D mechanical scanners and UV/IR cameras [10].
However, all earlier described methods have been developed to visualize beams of CW lasers. They are useless or of limited usefulness in case of pulsed lased used as transmitters in LRFs or laser designators due to a set of different reasons.

Almost all LRF and laser designators operate in range from 905nm to 1570nm. Majority of professional LRFs/designators use transmitters that emits short, high energy pulses at one of wavelengths 1064/1530/1550/1570nm (monopulse LRFs built using laser modules); or emits a series of long, low energy pulses at wavelength about 1550nm (multipulse LRFs built using laser diodes).

Monopulse LRFs will damage earlier described laser sensing cards due to extremely high pulse energy. Next, sensitivity of these cards is too low to visualize laser post created by multipulse LRFs. Further on, mechanical beam scanners are not convenient due to long time needed to generate 2D profile of laser beam. The latter feature eliminates this method in cases of LRFs fixed to gimbal platforms that have never fully fixed angular position.

SWIR cameras can accurately visualize 2D profiles of laser spots created by multipulse LRFs. However, in case of testing monopulse LRF short pulses of ultra high peak power (over 1 mW) generates significant crosstalk between pixels of IR FPA and obtained image of laser spot is significantly blurred.

Burn paper is the only low cost and commonly known method that work relatively well in case of monopulse LRFs/designators. Burn paper is understood as a series of materials that change reflectance (apparent brightness) when irradiated by high power laser pulses [11]. It means that a single laser pulse burns image of laser spot : it can be dark spot on brighter background or inverse). Creation of burn image is not reversible ; the burned spot cannot be later removed.

Photographic paper was a dominant type of burn paper in past. Nowadays there are many low cost materials that can be used as the burn papers. However, there are several disadvantages of burn paper cards.
First, image on burn paper card gives only ap-

proximate information about true 2D profile of laser spot. The image depends on power of incoming pulses and material properties of the card.

Second, burn paper cards create images that are visible only to VIS-NIR cameras. These images are not visible in MWIR/LWIR bands and the cards cannot be used to align axis of thermal imagers and of axis of LRFs.

Third, each laser pulse creates a single burned spot that cannot be removed. Therefore a series of burn paper cards is needed for testing a series of LRFs.

In this situation Inframet has developed a series of techniques of visualization of laser beams emitted by LRF/designators. They can be divided into three main groups:

1. Classical non-reversible burn paper cards,
2. Reversible burn paper cards,
3. SWIR imagers of ultra high dynamic.

MON cards and MOG cards offered by Inframet belong to the first group. When irradiated by transmitter of monoipulse LRF/designator the card creates a burned image of laser spot that becomes visible to VIS-NIR camera. The MOG card is about six times more sensitive than MON card. These cards enable accurate boresight of monopulse LRF/designators relative to visible channel (VIS-NIR camera). The cards need replacement when many laser spots are created on the surface of the card.

Three next cards coded as TEG, TEP and ABS belong to the group of reversible burn paper cards. TEG/TEP cards are to be used for testing monopulse LRFs/designators and ABS card is to be used for testing multi-pulse LRFs.

The TEG/TEP cards generate transient image of laser spot that can be seen by both thermal imagers and VIS-NIR cameras. In other words, the TEG/TEP cards work as convertors of SWIR radiation into VIS light and MWIR/LWIR radiation.

ABS cards is the most sensitive version of the reversible burn paper cards optimized for use with low power multipulse LRFs. These cards create transient image seen only by thermal imagers.

Fig. 18. Photo of several laser sensing cards

Both classical non reversible burn paper cards and reversible burn paper cards are low cost but efficient tools to carry out boresight of LRFs/designators relative to imaging systems. However, the cards can be used only for rough determination of divergence angle of LRFs/designators. SWIR imagers are needed for accurate measurement of divergence angle of LRFs/designators and to improve accuracy of boresight of LRFs relative to imaging systems.

Basically any SWIR camera offered on the market can be used to measure divergence angle of multi-pulse LRFs. These LRFs emits a series of high frequency optical pulses and create a temporally stable image. The real challenge is capturing images of laser spots generated by pulses from mono-pulse LTFs/designators. Time width of such pulses vary from 4 ns to about 100 ns and peak pulse power can be as high as 10 MW.

It is technically possible to use optical attenuators and reduce of irradiance at plane of the imaging sensor to level safe for the sensor. However, pulse time width of incoming laser pulses is roughly 10^6 shorter than frame period in typical SWIR cameras working at 50 FPS speed. It means that peak pulse power during tests of LRFs/designators is millions time higher than during typical camera work. This situation is reason for strong blurring of image of laser spot observed in images captured using typical SWIR cameras. Recorded 2D profile of laser spot is significantly distorted and measured divergence angle can be even two time bigger than true value.

Fig. 19. Photo of SR2 imager

Inframet has developed an SWIR imager (coded as SR2 imager) optimized for capturing images of lasers spots created by LRFs/designators. Both types of LRFs (monopulse and multi-pulse) operating at wavelengths in typical band from about 900nm to about 1570nm can be tested.

The SR2 imager is built using using an image converter lamp integrated with CCD camera. Photocathode of the converter lamp is sensitive up to about 1800nm and is capable to withstand ultra short powerful optical pulses with negligible image blurring. A set of exchangeable attenuators makes possible effective capturing images of laser spots from both low power multi-pulse LRFs and ultra high power monopulse LRFs. The imager is highly linear and output brightness is proportional to power of incoming laser radiation.

9 METERS

Blackbodies and light sources presented in previous sections need to be calibrated. Therefore Inframet has developed two meters (TM6 temperature meter and LM1 luminance meter) that are used for calibration of blackbodies and light sources [12].

Fig. 20. Photo of TM6 temperature meter

Fig. 21. Photo of LM1 luminance meter

TM6 meters are ultra-precision, ultra-stable temperature meters. The meters are characterized by very good temperature resolution and measurement uncertainty. Measurement resolution is 1 mK and is at least 10 times better than resolution of typical temperature meters offered on international market.

TM6 meters have been designed using electronic components of ultra-low temporal fluctuation of their parameters. Further on, advanced auto calibration circuitry was used. All these features enabled to extend recalibration interval of the TM6 meters to six years in case of calibration of blackbodies used for testing imagers for surveillance applications or three years in case of imagers for non contact temperature meters used in measuring applications.

LM1 is a precision luminance meter optimized for two basic applications: A) as an external meter in stations for testing night vision devices, B) as a tool for recalibration of light sources (DAL, SAL, H40, H150, L150). In case of type A application the LM1 meter is used for measurement of luminance of image intensifier screen seen via oculars. Aperture of optical objective of the LM1 meter is optimized for testing night vision devices (below 8 mm). In case of application type B the LM1 luminance meter is used as a small, portable meter that is sent for recalibration to Inframet facilities (or any calibration laboratory that specialize in photometric calibrations). Later the LM1 meter is used for recalibration of earlier mentioned light sources.

10 CONCLUSIONS

Inframet manufactures equipment for testing all types of electro-optical imaging and laser systems and modules of these systems: thermal imagers, night vision devices, VIS-NIR cameras, SWIR cameras, UV cameras, laser range finders, laser designators, laser trackers, laser pointers, multi-sensor systems, fused imaging systems, image intensifier tubes, IR FPAs, VIS-SWIR sensors and optical systems. These ultra expanded test capabilities have been achieved by development of a long series of blocks (collimators, blackbodies, light sources, rotary wheels, targets, laser viewing devices and meters) that are used to built different modular test systems.

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