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MJERENJE RADNE NAPRAVE ZA KONTROLU KUĆIŠTA VENTILATORA POMOĆU OPTIČKOGA 3D KOORDINATNOG MJERNOG SUSTAVA TRITOP
MEASUREMENT OF JIG FOR INSPECTION OF FAN-HOUSING BY MEANS OF OPTICAL 3D COORDINATE MEASURING SYSTEM TRITOP

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Sažetak: *Rad prikazuje optički 3D koordinatni mjerni sustav TRITOP i njegovu primjenu u mjerenju radne naprave za kontrolu kućišta ventilatora za ventilaciju tunela. Upotreba tradicijskih 3D koordinatnih mjernih strojeva (KMS) raspoloživih u Hrvatskoj u ovom primjeru mjerenja radne naprave kućišta ventilatora za ventilaciju tunela nije bila moguća zbog velikih dimenzija mjernog objekta. Moduli koordinatnoga mjernog stroja TRITOP mjere koordinate bilo kojih traženih obilježja i omogućavaju: CAD usporedbu, verifikaciju tolerancija oblika i položaja, kontrolu specifikacija iz crteža, datoteke ili tablice.*

Ključne riječi:
- mjerenje
- TRITOP optički koordinatni mjerni sustav
- radna naprava za kontrolu kućišta ventilatora za ventilaciju tunela

Summary: *The paper presents an optical 3D coordinate measuring system TRITOP and its application for the measurement of a jig for inspection of the fan-housing for the ventilation of tunnels. The usage of traditional 3D coordinate measuring machines (CMM) available in Croatia, in this example of measurement a jig for the inspection of fan-housing for ventilation of tunnels, was not possible because of too large proportions of the measuring object. The TRITOP modules measure the coordinates for any feature of interest and allow for: CAD comparison, verification of shape and position tolerances, inspection of specifications from drawings, files or tables.*

Keywords:
- measurement
- TRITOP optical coordinate measuring system
- jig for inspection of fan-housing for ventilation of tunnels

1. UVOD

U današnje vrijeme čest je slučaj nemogućnosti upotrebe tradicijskih mjernih strojeva kakvi su mehanički 3D koordinatni mjerni uređaji zbog velikih dimenzija mjernog objekta i njegove složenosti. Mjerni postupak na koordinatnim mjernim strojevima pouzdan je i točan ali vrlo spor, nefleksibilan i skup [1]. TRITOP je moderni koordinatni optički digitalizacijski sustav koji sve češće zamjenjuje tradicijske koordinatne mjerne strojeve. Trodimenzionalnom digitalizacijom dobiva se vjeran računalni model snimanog objekta koji osigurava točno mjerenje i analizu funkcionalnih koordinata proizvoda. Izrazito kvalitetni digitalizirani rezultati omogućili su točnu kontrolu i postupak rekonstrukcije modela u cilju poboljšanja proizvodnog procesa. Konkretan primjer

1. INTRODUCTION

Nowadays, there are frequent cases of impossibility of using the traditional measuring machines such as mechanical 3D coordinate measuring devices because of the large dimensions of the measuring object and its complexity. The measuring procedure of the particular coordinate machines is reliable and precise but tremendously slow as well as inflexible and expensive [1]. TRITOP is a modern coordinate optical digitizing system that frequently replaces the traditional coordinate measuring machines. The exact computer model of the recorded object is achieved by using 3 dimensional digitizing which assures the accurate measurement and analysis of functional coordinates of the product. High quality digitizing results have provided accurate mjerenja radne naprave za kontrolu kućišta ventilatora (prikazan u ovom radu), koju zbog gabarita nije bilo moguće izmjeriti na 3D koordinatnom mjernom stroju, pokazuje mnogobrojne prednosti tih novih mjernih sustava. Zahvaljujući digitalizaciji objekt snimljen kao CAD model moguće je usporediti s izvornim modelom u svrhu provjere izmjera dobivenih u proizvodnji. Takve analize daju nam odgovor na pitanje o traženoj točnosti i preciznosti obrade u proizvodnji pojedinih izradaka.

2. OPTIČKI 3D KOORDINATNI MJERNI STROJ TRITOP

Novi optički digitalizacijski mjerni sustavi mogu se upotrebljavati: za 3D digitalizaciju, kao optički koordinatni mjerni strojevi, za precizno pozicioniranje, mjerenje i kontrolu tolerancija oblika i položaja [2]. TRITOP je industrijski optički mjerni sustav koji se koristi za beskontaktno mjerenje visoke pouzdanosti. Proizvođač je toga mjernog sustava njemačka tvrtka GOM iz Braunschweiga [3]. Karakteristike su toga sustava: pokretljivost uz korištenje standardnoga prijenosnog računala, fleksibilne veličine mjernog objekta od 0,1 do 20 m, lako i brzo prikupljanje snimaka, brzi bežični prijenos slika, automatsko mjerenje digitalnih slika, precizno mjerenje 3D koordinata, markera i adaptera, vizualizacija pomaka i izravna povezanost s drugim digitalizatorima (npr. ATOS). Oprema toga sustava sastoji se od profesionalne digitalne kamere, prijenosnog računala s jakim procesorom i velikim kapacitetom RAM-a, referentnih letvi, nekodiranih i kodiranih referentnih točaka, adaptera te sitnog pribora, što čini sustav lako prenosivim onamo gdje je potrebno pružiti brza i uspješna mjerenja. Prilikom mjerenja tim sustavom relevantne se točke objekta identificiraju s markerima, adapterima ili oznakama, a objekt se snima fotogrametrijskom kamerom visoke rezolucije. Pomoću dobivenih digitalnih slika TRITOP softver izračunava 3D koordinate zalijepljenih markera i adaptera. Taj sustav postiže mjernu preciznost od 0,02 mm po 1 m veličine objekta. TRITOP softver može raditi s više tisuća mjernih točaka i dopušta uporabu raznih uređaja za snimanje. Zbog povećanja točnosti koristi se digitalna kamera visoke razlučivosti od 10 Mpixela. Prstenasta bljeskalica postavlja se oko objektiva tih kamera da bi spriječila refleksiju prilikom snimanja. Na slici 1 prikazan je mobilni koordinatni mjerni sustav TRITOP s dijelovima mjernih letvi. Detaljan prikaz digitalnog aparata i prstenaste bljeskalice vidljiv je na slici 2.

inspection and a model reconstruction procedure aimed at improving the production process. A concrete example of the measurement of a jig for the inspecton of fan-housing (shown in this paper) which, because of its proportions, could not be measured by a 3D coordinate measuring machine, shows the numerous advantages of these new measuring systems. As a result of the digitizing of an object recorded as a CAD model, it is possibile to compare it to the origin model with the purpose of checking the measures obtained in the production process. These kinds of analyses give us the answers to questions about the accuracy and precision of the production of particular workpieces.

2. OPTICAL 3D COORDINATE MEASURING MACHINE TRITOP

A new optical digitizing measuring system can be used: for 3D digitizing, as optical coordinate measuring machines, for making a precise position, and in measurement and inspections of form and location tolerances [2]. TRITOP is an industrial optical measurement system product that can be used in non-contact measurement of high reliability. The producer of this measuring system is the German firm GOM from Braunschweig [3]. The characteristics of this system are: mobility by using a standard mobile computer, flexible sizes of the measuring objets from 0.1 up to 20 m, a fast and easy way to gather images, a fast wireless transmission of images, automatic measuring of the digital images, precise measurement of 3D coordinates, markers and adapters, visualization of shift and direct connection with another digitizer (e.g. ATOS). The equipment of this system contains a professional digital camera, a mobile computer with a powerful processor and a high capacity of RAM, scale bars, uncoded and coded reference points, adapters and small kit-tools which makes the system easily removable wherever it is taken so that the measurement can be provided quickly and successfully. Upon measurement by this system, the relevant point of the object is identified by the markers, adaptors or signs and the object is recorded by a high resolution photogrametry camera. By means of obtained digital images, TRITOP software calculates 3D coordinate adhesive markers and adaptors. This system achieves the preciseness of 0.02 mm per 1 m of object size. TRIPOP software can work with thousands of measuring points and it allows the usage of different recording devices. Because of the enhancement of accuracy, a high-resolution digital camera of 10 Mpixel has been used. The ringflash light around this camera objective has been set in order to prevent reflection during recording. In Figure 1, the mobile coordinate measuring system TRITOP with parts of the scale bars is shown. A detailed outline of the digital camera and ring flashlight has been shown in Figure 2.
Once adjusted, the settings of the digital camera may not

Jednom podešene postavke digitalnog aparata ne smiju se za vrijeme mjerenja mijenjati jer bi u tom slučaju došlo do razlika u snimljenim sekvencama što bi izravno utjecalo na kvalitetu i točnost mjerenja [4].

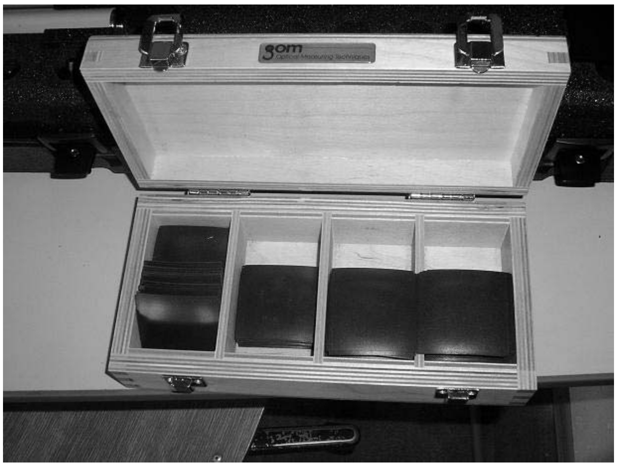
be changed during the time of measurement because it could lead to differences among the recorded sequences, which can directly affect the quality and accuracy of measurement[4].

Slika 1. TRITOP optički 3D koordinatni mjerni sustav
Figure 1. TRITOP optical 3D coordinate measuring system

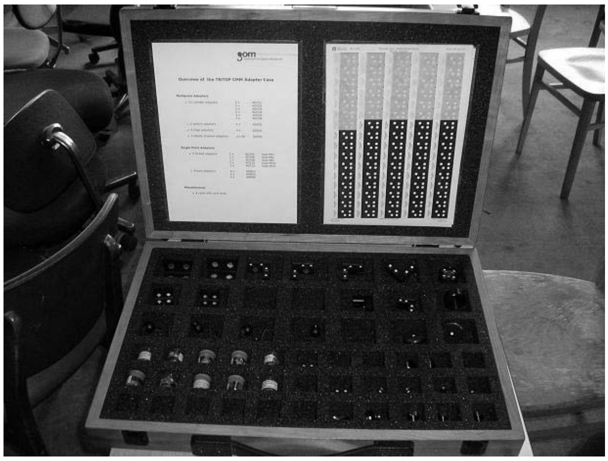
Slika 2. Digitalna kamera sustava TRITOP
Figure 2. Digital camera of TRITOP system

Na slikama 3 i 4 prikazana je oprema toga mjernog sustava.

In Figure 3 and 4 the equipment of the measuring system is shown



Slika 3. Kutija s kodiranim referentnim točkama
Figure 3. Box with coded referent points



Slika 4. Kutija s adapterima
Figure 4. Box with adapters

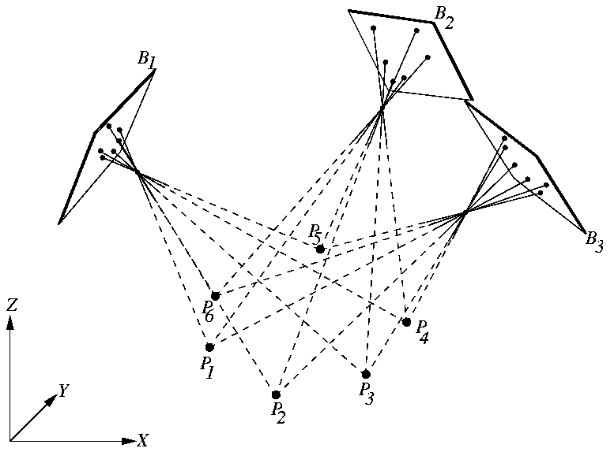
3. PRINCIP RADA SUSTAVA TRITOP

Fotogrametrija [5, 6] je postupak mjerne tehnike kojim se iz jedne ili više međusobno povezanih fotografija određuje položaj, oblik i veličina snimljenog predmeta. Principi fotogrametrije poznati su još od kraja 19. stoljeća, ali je njihova prava primjena u industriji postala moguća tek s razvojem digitalnih kamera visoke razlučivosti i razvojem računala. Oblik i veličina ravnoga dvodimenzionalnog predmeta mogu se odrediti iz samo jedne fotografije, dok je za mjerenje prostornoga, trodimenzionalnog objekta

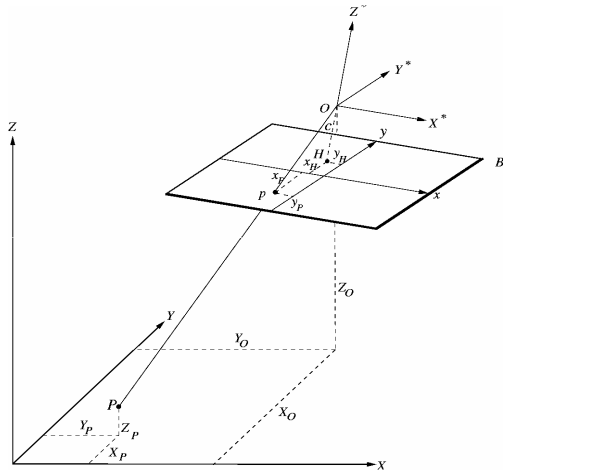
3. TRITOP SYSTEM WORKING PRINCIPLE

Photogrametry is the procedure of the measuring technique by which it is possible from one or more connected photographs to determine the location, form and size of the recorded object. The principles of photogrammetry are known since the end of 19th century, but their real application in the industry only became possible with the development of high resolution digital cameras and with the development of computers. The form and size of the plane two dimensional system can be potrebno upotrijebiti najmanje dvije digitalne fotografije snimljene s dviju različitih lokacija. Dobivene se digitalizirane fotografije uz pomoć posebnih instrumenata promatraju stereoskopski, a optički se model može iskoristiti za mjerenje snimljenog predmeta. Takav postupak naziva se stereofotogrametrija. Pozicija točke u 3D prostoru može biti određena triangulacijom višestrukih snopova promatračkih zraka. Ako je prostorna orijentacija svakog snopa poznata u koordinatnom sustavu objekta, presjek zraka pruža točnu 3D koordinatu objekta, kako je prikazano na slici 5. Slika 6 prikazuje model centralne projekcije točke objekta na površinu slike.

determined from just one photograph while for the measurement of a spatial, three dimensional object it is necessary to use at least two digitally recorded photographs shooting from two different locations. The digital photographs, obtained by means of special instruments, have been observed stereoscopically, and an optical model can be used for the measurement of the recorded object. That procedure is called stereophotogrametry. The position of a point in the 3D space can be determined by triangulating multiple bundles of observation rays. If the spatial orientation of each bundle is known in the object coordinate system, the intersection of the rays delivers the desired 3D object coordinates, as shown in Figure 5. Figure 6 shows the model of central projection of the object point onto the image surface.



Slika 5. Određivanje točaka objekta P_i trianguliranjem
Figure 5. Determining of the object points P_i by triangulating



Slika 6. Model centralne projekcije točke objekta na površinu slike
Figure 6. Central projection model of object onto the image surface

Točka objekta $P(X_P, Y_P, Z_P)$ i njezina opservacijska pozicija $p(x_P, y_P)$ u ravnini slike *B* kao i centar projekcije $O(X_O, Y_O, Z_O)$*)* na jednoj su projekcijskoj crti (slika 6). Odnos između objekata i koordinate slike može biti opisan matematički prema izrazu:

An object point $P(X_P, Y_P, Z_P)$ and its observation $p(x_P, y_P)$ in the image plane *B* as well as the projection center $O(X_O, Y_O, Z_O)$ are on one projection line, see (Figure 6). The relationship between the object and image coordinates can be described mathematically according to mathematical expression:

$$\begin{bmatrix} x_P \\ y_P \end{bmatrix} = \frac{-c}{Z_P^*} \cdot \begin{bmatrix} X_P^* \\ Y_P^* \end{bmatrix} + \begin{bmatrix} x_H \\ y_H \end{bmatrix} + \begin{bmatrix} dx \\ dy \end{bmatrix}, \quad \begin{bmatrix} X_P^* \\ Y_P^* \\ Z_P^* \end{bmatrix} = R \cdot \begin{bmatrix} X_P - X_O \\ Y_P - Y_O \\ Z_P - Z_O \end{bmatrix}, \tag{1}$$

gdje je c glavna udaljenost; x_H, y_H koordinate slike izvorne točke; x_P, y_P koordinate slike projicirane točke objekta P; dx, dy distorzija objektiva; R rotacijska matrica; X_O, Y_O, Z_O koordinate objekta projekcijskog centra *O*; X_P, Y_P, Z_P koordinate objekta promatrane točke objekta P; X_P^*, Y_P^*, Z_P^* pomoćne koordinate točke

where c is the principle distance, x_H, y_H are the image coordinates of the principle point, x_P, y_P, are the image coordinates of the projected object point P, dx, dy, are lens distortions, R is the rotation matrix, X_O, Y_O, Z_O are the object coordinates of the projection center *O*, X_P, Y_P, Z_P are the object coordinates of the observed objekta P. Parametri kamere kao glavna udaljenost *c*, koordinate glavne točke (x_H, y_H) i elementi za opis distorzije objektiva *(dx,dy)* zovu se unutarnji orijentiri. Vrijednost projekcijskog središta (X_O, Y_O, Z_O) i rotacijske matrice *R,* koja ovisi o poziciji kamere u globalnom koordinatnom sustavu, utvrđuju vanjsku orijentaciju. Ortonormalna rotacijska matrica koristi se za pretvaranje globalnih koordinata u pomoćne koordinate.

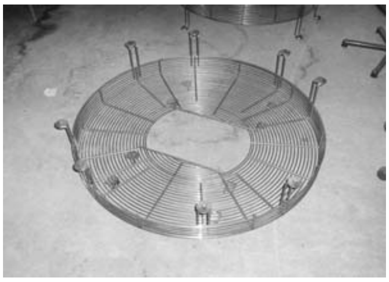
object point *P*, and X_P^*, Y_P^*, Z_P^* are the support coordinates of the object point P. The camera parameters like the principle distance c, the coordinates of the principle point (x_H, y_H) and the elements to describe the lens distortions (dx, dy) are called inner orientations. The values for the projection center (X_O, Y_O, Z_O) and the rotation matrix *R*, which depends upon the camera position in the global coordinate system, establish the outer orientation. The orthonormal rotation matrix is used for the transformation of global coordinates into support coordinates.

4. MJERENJE RADNE NAPRAVE ZA IZRADU KUĆIŠTA VENTILATORA

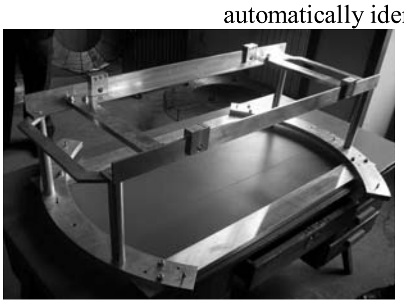
Kućište ventilatora (slika 7) koje će biti postavljeno na radnu napravu izrađeno je od žičanih profila (8 i 5 mm), savijano i zavarivano. Po obodu je postavljeno osam prstena za montažu prema kojima su definirane osnovne koordinate mjerenja. Maksimalno dopušteno odstupanje položaja prstena od ravnine montaže zadano je nacrtom. Za pravilnu izradu, mjerenje i provjeru ispravnosti proizvoda bilo je potrebno napraviti radnu napravu prikazanu na slici 8. Radna naprava izrađena je od aluminija, a služi za provjeru različitih nepravilnosti odstupanja od osnovne ravnine da bi žičana kućišta ventilatora bila što točnije izrađena. Na slici 8 vidljivi su i klinovi za kontrolu ispravnosti položaja prstena za montažu na žičanom kućištu. Spoj kućišta ventilatora i radne naprave vidi se na slici 9. Prije početka mjerenja prema nacrtu se određuju bitne točke mjerenja koje su definirane i označene kao funkcionalne. Nakon određivanja funkcionalnih koordinata na kontrolnu je napravu postavljeno 16 referentnih mjernih točaka za kontroliranje zračnosti. Nekodirane su mjerne točke samoljepljive i nanošene su ručno na izradak. Nekodirane referentne točke koriste se za određivanje 3D koordinata objekta koji će se mjeriti i automatski identificirati TRITOP sustavom.

4. MEASUREMENT OF JIG FOR FAN HOUSING MANUFACTURE

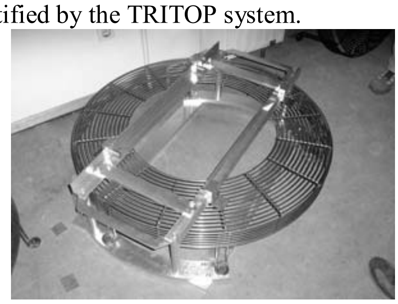
The fan-housing (Figure 7), which will be placed onto a jig that is manufactured from wire profiles (8 or 5 mm), bent and welded up. Onto the circumferent, eight rings for assembling are placed and according to these rings the basic coordinates of measurement have been defined. A maximal allowed deviation of the rings location from the assembling plane is given in the diagram. For standard manufacture, measurement and inspection of product correctness was necessary to make the jig shown in Figure 8. It has been made from aluminum and it serves for checking the different irregularity deviations from the basic plane so that the wire fan-housing could be produced accurately. Plug gages for the inspection of the ring's location correctness for assemblage onto the wire housing has been shown in Figure 8. Coupling of the fan-housing and the jig has been shown in Figure 9. Before the beginning of measurement according to the diagram, the relevant measurement points that were defined and marked as functional were determined. After determination of the functional coordinates, 16 referential measuring points were placed onto the jig for inspection of clearance. Uncoded measuring points are self-adhesive and have been placed by hand. Uncoded reference points have been used for determinination of 3D object coordinates, which will be measured and automatically identified by the TRITOP system.



Slika 7. Kućište ventilatora
Figure 7. Fan-housing



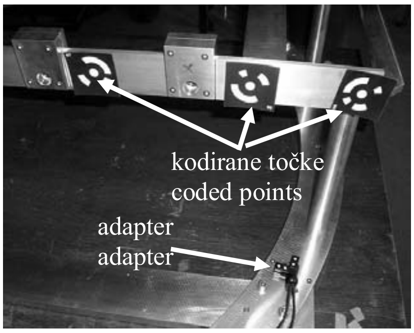
Slika 8. Naprava za provjeru valjanosti kućišta ventilatora
Figure 8. Jig for checking the validity of fa- housing



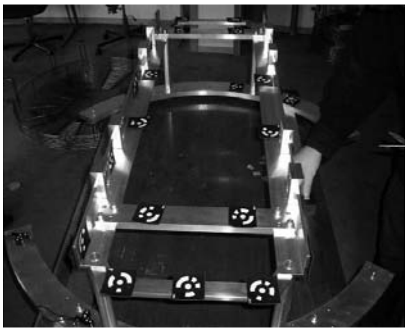
Slika 9. Spoj kućišta ventilatora i radne naprave
Figure 9. Coupling of fan-housing and jig

Pozicije nekodiranih referentnih točaka na objektu ovise o zahtjevima mjerenja. TRITOP može poluautomatski identificirati 3D točke uzoraka ili crta koje su nacrtane na objektu. Prednost je korištenja referentnih točaka potpuna automatska identifikacija 3D pozicija. Pri pozicioniranju referentnih točaka potrebno je paziti da su prilikom snimanja vidljive s najmanje triju različitih pozicija. Nakon primjene nekodiranih mjernih točaka na uzorak se postavljaju adapteri za mjerenje cilindričnih oblika. Adapteri se odabiru prema potrebi, te se postavljaju uz cilindrične izdanke uz pomoć elastične vrpce i držača. Kodirane mjerne točke zapisane su na magnetsku pločicu, a u slučajevima kada mjereni dio nema magnetska svojstva mogu se postaviti na mjerenu površinu uz pomoć samoljepljive trake. Oblik isprekidane vanjske kružnice označava barkod prema kojem će točke biti točno definirane u prostoru. Na slici 10 prikazane su kodirane točke koje su postavljene prema utvrđenom mjernom planu. Broj postavljenih kodiranih točaka i njihovo pozicioniranje na objektu nije strogo definirano. Važno je samo da prilikom snimanja bude uključeno od 5 do 10 točaka (slika 11). Kodirane referentne točke (slika 12) osiguravaju postavke slika za automatski izračun pozicija kamere. Glavni je cilj procesa snimanja vidjeti što je moguće više referentnih točaka raspoređenih preko cijelog objekta u svrhu dobivanja visoke točnosti mjerenja. Sustav može raditi s 10-bitnim, 12-bitnim i 15-bitnim postavama referentnih nizova.

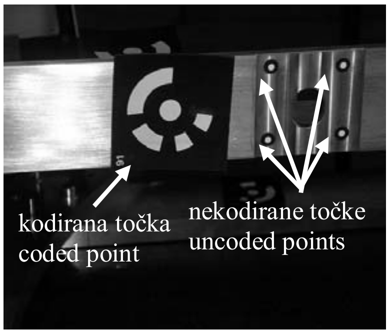
The positions of the uncoded reference points on the object depend on the measurement requirements. 3D points or sample lines that are drawn on the object can be identified semi-automatically by the TRITOP. The advantage of the use of reference points is complete automatic identification of 3D positions. At Upon the positioning of reference points it is important to take care that they can be seen from at least three different positions. After uncoded measuring points have been applied, the cylindrically shaped adapters for the measurement of cylindrical forms are put in place. Adapters are chosen according to necessity, and they are set beside the cylindrical offset by means of self-adhesive strips and holders. Coded measuring points are written onto the magnetic plates and in cases when the measured part has no magnetic features they can be set on a measured surface with the self-adhesive tape. The form of the dashed outer circle signifies the barcode according to which the points will be exactly defined in space. The coded points that are set according to the determined measuring design are shown in Figure 10. The number of the set coded points and their positioning on the object are not strictly defined. The only important thing is that in the recording process, 5 to 10 points must be included (Figure 11). Coded reference points (Figure 12) assure the settings of images for the automatic calculation of camera location. The main goal of the recording process is to see as many reference points as possible, especially those arranged all across the object with the purpose of high accuracy of measurement. The system can work with 10-, 12- and 15- bit reference sets.



Slika 10. Adapter, kodirane i nekodirane točke
Figure 10. Adapter, coded and uncoded points



Slika 11. Pozicioniranje kodiranih točaka
Figure 11. Positioning of coded points

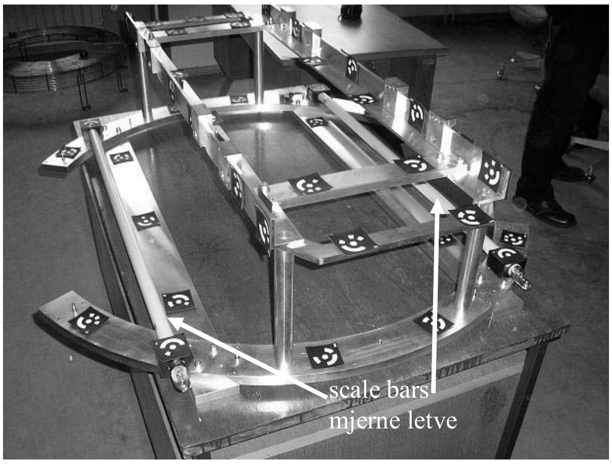


Slika 12. Kodirana točka i nekodirane točke
Figure 12. Coded point and uncoded points

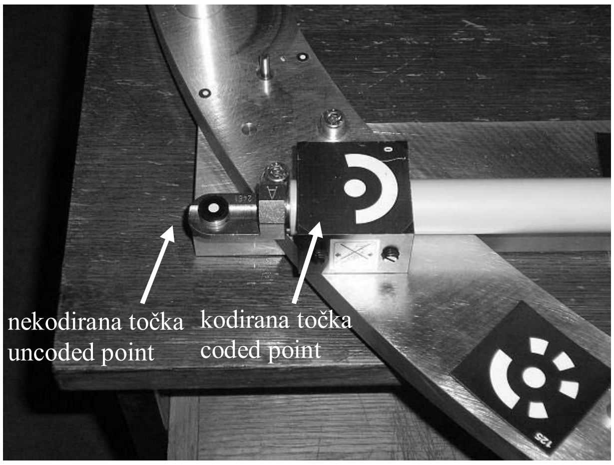
10-bitni postav referentnih točaka znači da postav sadrži 100 referentnih točaka s definiranom identifikacijom brojeva od 0 do 99. TRITOP automatski identificira kodirane referentne točke. Kod pozicioniranja kodiranih referentnih točaka potrebno je poštivati sljedeća načela: bolje je koristiti više kodiranih referentnih točaka nego premalo, osigurati stabilne pozicije referentnih točaka, primijeniti točke na sve dimenzije visine, dužine i širine objekta, svaka slika mora sadržavati najmanje 5 kodiranih referentnih točaka, pobrinuti se da su referentne točke

A 10-bit reference point set means that the set consists of 100 reference points with the defined identification numbers ranging from 0 to 99. TRITOP automatically identifies the coded reference points. When positioning the coded reference points, the following principles are complied with: better to use too many coded reference points than too few, ensure stable reference point positions, apply points to all dimensions of object length, object width and object height, each image must contain at least 5 coded reference points, make sure the reference dobro raspoređene i izbjeći stvaranje crta kodiranih referentnih točaka, postaviti kodirane točke pod kutom od 45° (koristeći kutne adaptere) što rezultira da u spajanju slika objekt koji se mjeri ima izrazitu 3D strukturu. Mjerne letve odabiru se prema veličini mjernog objekta. Općenito, koriste se 2 mjerne letve. Pomoću mjernih letvi TRITOP sustav izvodi kalibriranje i definira veličinu mjerenog objekta (slika 13). U ovom su primjeru korištene mjerne letve dužine 1000 mm. Na slici 14 prikazane su kodirana i nekodirana referentna točka koje sadržava mjerna letva.

points are well distributed and avoid creating lines of coded reference points, set up coded points at a 45° angle (by using angle adapters) which results in connecting images for objects to be measured having distinct 3D structures. The scale bars have been chosen according to the measuring object size. Generally, 2 scale bars are used. By means of scale bars, the TRITOP system performs the calibration and defines the size of the measured object (Figure 13). In this example, scale bars of 1000 mm were used. In Figure 14 the coded and uncoded reference points contained in the scale bar have been shown.



Slika 13. Mjerne letve
Figure 13. Scale bars



Slika 14. Kodirana i nekodirana referentna točka koje sadržava mjerna letva
Figure 14. The coded and uncoded reference points contained in the scale bar

Prije početka postupka mjerenja snimaju se 4 kalibracijske snimke (slika 15). Kalibracijskim se snimkama nazivaju one snimke koje su snimljene iz središnjeg položaja kamere svaka zaokrenuta za 90º (uzduž optičke osi kamere). Te su četiri kalibracijske snimke potrebne za izračun optičke distorzije objektiva i pozicije glavnih točaka. Nakon toga pripremljeni se objekt snima digitalnom kamerom iz različitih pozicija (slika 16).

Before starting of measurement procedure, 4 calibrating images have been recorded (Figure 15). Calibrating images are images recorded from a central camera position each turned by 90º (along the optical camera axis). These four calibrating images are needed for computing the optical distortion of the lens and the position of the principle point. Afterwards, the prepared object is recorded by the digital camera from different positions (Figure 16).

Slika 15. Snimanje kalibracijskih slika
Figure 15. Recording of the calibrating images

Slika 16. Snimanje objekta s višeg nivoa
Figure 16. Recording of object from a higher level

O veličini objekta i broju referentnih točaka ovisi i broj načinjenih snimaka. Digitalne snimke objekta s 27 kodiranih i 57 nekodiranih točaka, nakon završenog snimanja prebačene su (slika 17) u računalo (na obradu) uz pomoć USB čitača memorijskih kartica (slika 18). Također, TRITOP sustav može biti izravno povezan na računalo preko WLAN adaptera koji može automatski, uz pomoć bežične mreže, prenositi snimke u računalo.

The number of the recorded images depends on the size of the object and on the number of reference points. Digital object images with 27 coded and 57 uncoded points are transmitted (Figure 17) to computer (to be processed) by means of USB memory card reading device (Figure 18). Also, the TRITOP system can be directly connected to a computer over a WLAN adaptor, which can automatically by means of a wireless network transfer the images to the computer.

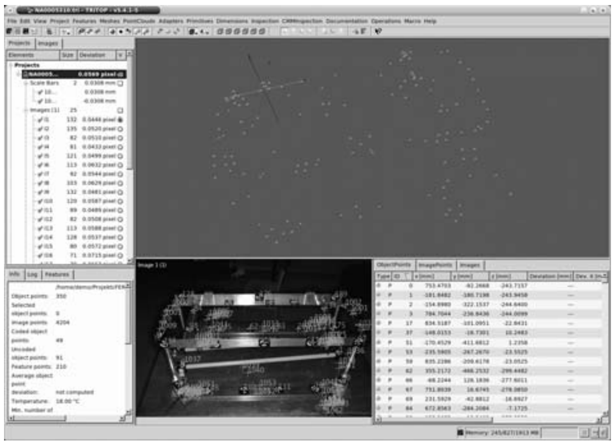
Slika 17. Prijenos snimaka u računalo
Figure 17. Images transfer to computer

Slika 18. Uređaj za čitanje USB kartica
Figure 18. USB card reading device

TRITOP softver, nakon učitanja, automatski proračunava koordinate slika, položaje kamera i koordinate objekta preko mjernih točaka i prikazuje ih u određenim bojama. Sustav dopušta statističku procjenu mjerne nesigurnosti. Na slici 19 vide se žutom bojom prikazani položaji kamere, zelenom bojom adapteri, kodirane i nekodirane točke, a kao žute crte prikazane su mjerne letve. Izgled ekrana kod mjerenja tzv. "screen capture" prikazan je na slici 20.

TRITOP software, after reading the data, automatically calculates the coordinates of images, the camera locations and the objects coordinates via the measuring points and presents them in the determined colors. The system allows for statistic evaluation of measuring uncertainty. In Figure 19, the locations of the camera are presented in yellow color, adapters, coded and uncoded points are presented in green color, and the scale bars are presented as yellow lines. The display view upon measurement of the so-called "screen capture" is presented in Figure 20.

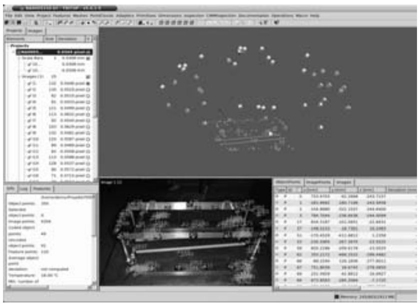
Slika 19. Prikaz rezultata na zaslonu računala
Figure 19. Results outline onto computer display



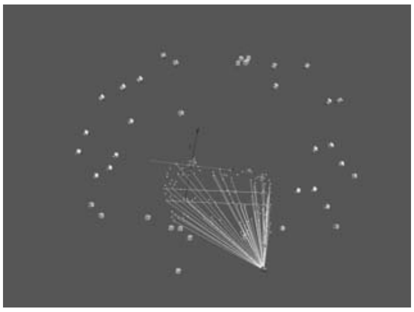
Slika 20. Izgled ekrana pri mjerenju tzv. "screen capture"
Figure 20. Display view of measurement with the so-called "screen capture"

Slika 21 prikazuje položaj kamera u trenutku mjerenja i položaj mjernih letvi, slika 22 prikazuje optičke osi kamere, a slika 23 prikazuje sve optičke osi kamera za jednu točku. Svaka se točka može vidjeti iz triju različitih pravaca.

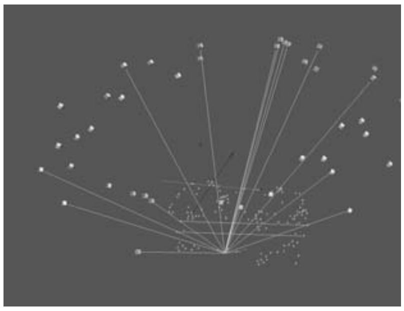
Figure 21 presents the location of the camera at the moment of measurement and the location of the scale bars, Figure 22 presents the optical axis of the camera and Figure 23 presents all the optical axes for one point. Each point can be seen from three different directions.



Slika 21. Položaja kamera i mjernih letvi u trenutku mjerenja
Figure 21. The location of camera and scale bars in the moment of measurement



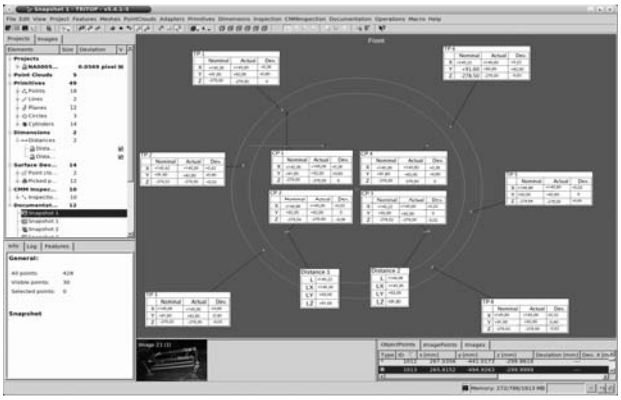
Slika 22. Optičke osi kamere
Figure 22. The optical axis of camera



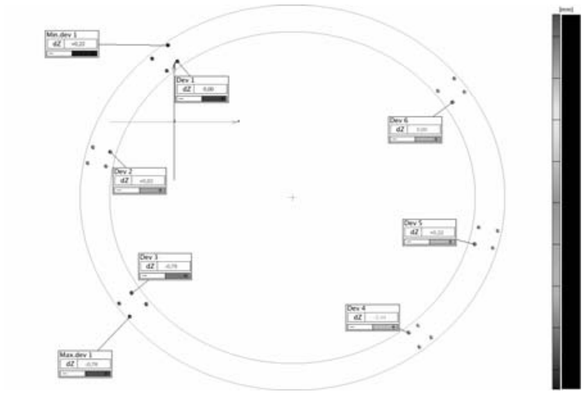
Slika 23. Sve optičke osi kamera za jednu točku
Figure 23. All optical axes of camera for one point

Softverska mogućnost prikaza izmjera i njihova odstupanja od osnovne ravnine prikazana je na slici 24, dok slika 25 prikazuje mogućnost predstavljanja odstupanja izmjerenih pozicija od referentne ravnine.

The software's ability of measures presentation and their deviation from the principle plane is shown in Figure 24, while Figure 25 shows the possibility of presenting the deviation of the measured position from the reference plane.



Slika 24. Usporedba izmjerenih i referentnih vrijednosti
Figure 24. Comparison of measured values and reference values



Slika 25. Odstupanje izmjerenih pozicija od referentne ravnine
Figure 25. Deviation of the measuring positions from the reference plane

5. ZAKLJUČAK

Mjerenje radne naprave za kontrolu kućišta ventilatora pomoću optičkoga 3D koordinatnog mjernog sustava TRITOP prikazano u ovom radu pokazalo je mnogobrojne prednosti primjene toga mjernog uređaja. Rezultati digitaliziranih oblaka točaka radne naprave kućišta ventilatora uspoređeni su s funkcionalnim koordinatama na crtežu radne naprave u svrhu provjere funkcionalnih koordinata dobivenih u proizvodnom procesu. Ova mjerna

5. CONCLUSION

The measurement of the jig for the inspection of fan-housing by means of the optical 3D coordinate measuring system TRITOP presented in this paper has shown the numerous advantages of the application of these measuring devices. The results of the digitizing clouds of the points of the fan-housing jig are compared with the functional coordinates on the jig drawing with the purpose of the checking of the functional coordinates obtained in analiza dala je odgovor na pitanje preciznosti i točnosti samoga proizvodnog procesa. Prednost se toga mjernog uređaja nad konvencionalnim računalom upravljanim 3D koordinatnim mjernim strojevima također pokazala kad je riječ o mjernom objektu velikih gabarita. Lako i brzo prikupljanje snimaka kao i njihov brzi bežični prijenos u računalo popraćeno vrhunskom vizualizacijom pokazalo je da moderna fotogrametrija ima važno mjesto u današnjoj mjernoj tehnici.

the production process. This measuring analysis has given the answer to the question regarding the precision and accuracy of the production process. Large proportions of the measuring object have also shown the advantages of this measuring device above the conventional computer controlled 3D coordinates measuring machines. Easy and fast collection of images as well as their fast wireless transmission to a computer accompanied with top quality visualization has shown that modern photogrametry has an important place in present-day measuring techniques.

6. POPIS OZNAKA

6. LIST OF SYMBOLS

distorzija objektiva	dx, dy - mm	lens distortions
glavna udaljenost	c - mm	principle distance
koordinate objekta projekcijskog centra	X_O, Y_O, Z_O	object coordinates of the projection center
koordinate objekta promatrane točke objekta	X_P, Y_P, Z_P	object coordinates of the observed object point
koordinate slike izvorne točke	x_H, y_H	image coordinates of the principle point
koordinate slike projicirane točke objekta	x_P, y_P	image coordinates of the projected object point
pomoćne koordinate točke objekta	X_P^*, Y_P^*, Z_P^*	support coordinates of the object point
rotacijska matrica	R	rotation matrix

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