Rivista Italiana di Paleontologia e Stratigrafia	volume 117	no. 3	pp. 521-530	December 2011

PROPOSAL FOR AN UNIFORM DATA STANDARD FOR ICHNOLOGICAL 3D TRACKING AND POST-PROCESSING

MARCO PETRUZZELLI [1], NOVELLA RAZZOLINI [1] & RUGGERO FRANCESCANGELI [2]

Received: June 17, 2011; accepted: 12 October, 2011

Key words: Dinosaur tracks, Tracking protocol, Post processing, Data standard, Digital archive.

Abstract. Vertebrate fossil tracks have been studied through 3D modelling techniques during the last two decades to improve tracking procedures. Different laser scanners and software have been used during field investigation and this differentiation caused incompatibility between many analysis programs. Post processing procedures are not standardized among scientists and file precision gives different results in additionally constrain comparison. The starting point to find a solution to the problem is to point out the main technologies used to collect data in the field. The resulting protocol does not oblige to uniform hardware but it suggests combining different laser scanners with a minimum post processing to optimize the result. Important linking would be to use 2D relief as a reference to organize 3D tracking procedures. Saving formats during post processing are improved by setting fixed landmarks integrated in the 3D model in a multitask file. The D.I.C.O.M. medical standard (*.cdm format) and the 3D printing international standard (*.stl format) when combined, may be a good solution for uniforming the format. This approach might be the first step for the standardization of source and derived files and the creation of a worldwide 3D ichnological catalogue. This will allow to create a scientific improvement in terms of reproducibility and comparison of the experience.

Riassunto. Le tracce fossili dei vertebrati sono state rilevate negli ultimi venti anni usando la modellazione tridimensionale al fine di migliorare le procedure di rilievo. Ad oggi sono stati usati talmente tanti differenti laser e programmi per il rilevamento da provocare incompatibilità tra i programmi di analisi. Il confronto dei risultati tra ricercatori è ulteriormente limitato dalla non standardizzazione nella modalità di elaborazione dei dati e disomogeneità di precisione. Il punto di partenza per trovare una soluzione è descrivere le principali tecnologie per raccogliere i dati di campagna. Il protocollo risultante da ciò non obbliga ad uniformare gli strumenti di analisi, ma suggerisce di combinare i punti di forza di questi riducendo i passaggi della rielaborazione digitale, ottimizzando così i risultati. Fondamento per combinare vecchi e nuovi dati sarà usare il 2D come un punto di riferimento per tracciare le mappe 3D. Integrare dei punti di riferimento fissi all'interno dei modelli 3D così ottenuti e poi salvarli in file compositi migliora la loro interpretazione e comparazione. Buona proposta per uniformare il formato di salvataggio dati di tale foggia è la combinazione dello standard medico D.I.C.O.M. (file *.cdm) con quello internazionale adottato per le stampanti digitali in 3D (file *.stl). Tale approccio potrebbe essere un primo passo per la standardizzazione dei file di origine e derivati al fine di creare un catalogo 3D internazionalmente riconosciuto per l'icnologia dei vertebrati. Ciò potrebbe permettere di migliorare notevolmente la riproducibilità e la comparazione di tale tipo di esperienza scientifica.

Introduction

Vertebrate tracks preservation is an exceptional event and tracks morphology can vary depending on substrate characteristics (Milan & Bromley 2006; Lockley 2007) and taphonomical processes (Marty et al. 2009). During the tracking process, the substrate mechanic and elastic responses (e.g. Goldilocks effect, Falkingham et al. 2011) determine the shape and the dimension of track. Once a track is produced, pre and post litification erosion phenomena occur, increasing the difficulty of the interpretation. Many samples are poorly preserved and the study of complex preserved dinosaur tracks (Gatesy et al. 1999) is far more entangled (e.g. undertracks or overtracks; Milan & Bromley 2006; Falkingham et al. 2011). During the last two decades, it has been tried to reduce the subjective interpretation of these tracks by using 3D modelling (Ishigaki & Fujisaki 1989; Farlow & Lockley 1993; Graham et al. 1995; Gatesy et al. 1999). After the development of contactless laser scanners (Arakawa et al. 2002; Hurum

1 Institut Català de Paleontologia Miquel Crusafont, Escola Industrial 23, E-08201 Sabadell, Barcelona, Spain. Email: inzone@libero.it, marco.petruzzell@icp.cat; novella.razzolini@icp.cat
2 Università Degli Studi di Bari "Aldo Moro", CISMUS – Museo di Scienze dalla Terra, Via Orabona 4, Campus universitario, 70125 Bari, Italy. E mail: museo@geo.uniba.it

et al. 2006; Adams et al. 2010) 3D modelling and reconstructions quickly and astonishingly evolved improving detail acquisition and analysis power. From the end of the 90es this technology had an important evolution and a first standardizing of result and procedure was made (Levoy 1999). In the years differencing occurred in use between Science, Engineering or play-fiction proposes. Science needs precision and high measurability in detailing real geometry of the object, fiction needs a good rendering and file lightness to allow movie special effects. This is expressed by the algorithm of the software modifying in a radically different way the data obtained by the Laser scanners or Topographical Scanners or 3D x Rays Instruments. Nowadays in scientific field, the great variety of 3D acquisition instruments with different hardware and software, reduces the possibility to apply trading formats and model reproducibility among scientists. It is quite unlikely and unadvisable to uniform the instrumental variety. Field logistic, different time to spend during tracking phase and budget variation among researchers often create a strong vinculum in choosing tracking instruments. On one hand, this fact reduces instrument minimum quality fundamental to obtain an internationally analysable uniform result. On the other hand, a simple solution could be to uniform different lasers detail, post-processing steps and saving formats. The result would be a fully exchangeable and repeatable product. The real entity of these problems, the creation of a glossary, basal hardware and software technical features must be discussed.

Technical State of the Art

A laser scanner is an electronic instrument that transforms the topography of a scanned object into a file using a laser source. The laser light differential reflection on the surface is translated in space coordinates that constitutes the file directly obtained from the scanner (*raw point cloud*) (Fig. 1). These files are then elaborated by computer software which runs algorithms in order to return the data as a three dimensional image (*derived point cloud*).

Hardware

Every instrument displays *pro* and *contra*, e.g. some would give better results during large surface data acquisition, while others during small surfaces relief. Hence, a qualitative data, e.g. point position and point cloud uniformity (*point cloud precision*), must be preferred to a quantitative one (*point cloud density*) or to the instrumental speed (Fig. 2). Three-dimensional laser scanners can be divided in three main categories.

The most widely used for dinosaur tracking (Hurum et al. 2006), and first to be used in geomorphologic investigations (Moore 2000; Cavaliere 2006) is the Li.-D.A.R. *(Light Detection And Range)*. The Li.D.A.R. uses an intermittent reflected laser (indirect source) that reaches kilometres of distance maintaining a centimetre range resolution. Low resolution needs different manual consecutive scans and heavy post elaboration to increase detail (Margetts et al. 2006a, b). The detail obtained is qualitatively equivalent to a modern stereoscopic photo relief (Breithaupt et al. 2004).

Different types of hardware are the "*diurnal high intensity active sensor scanners*", commonly adopted for architecture scanning. This laser is poorly subjected to external light aberrations during field scanning because it uses a direct continuous laser source compensated by active sensors that modulate simultaneously light source and reaching sensors. The instrument results faster and more precise than Li.D.A.R., but it maintains a good detail on less than a kilometre of distance. Accuracy

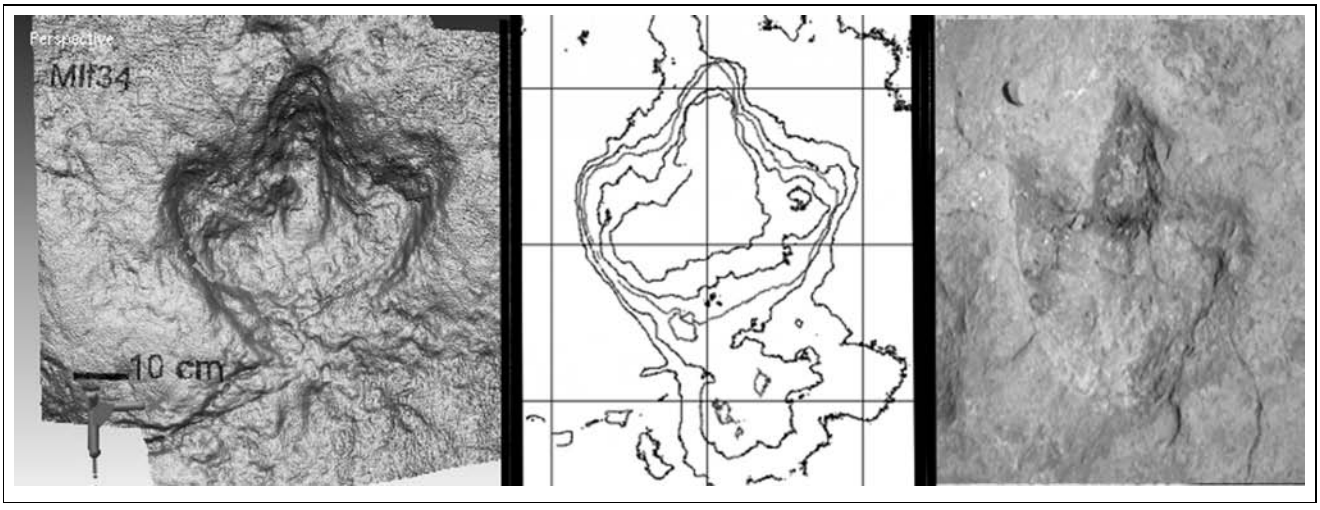
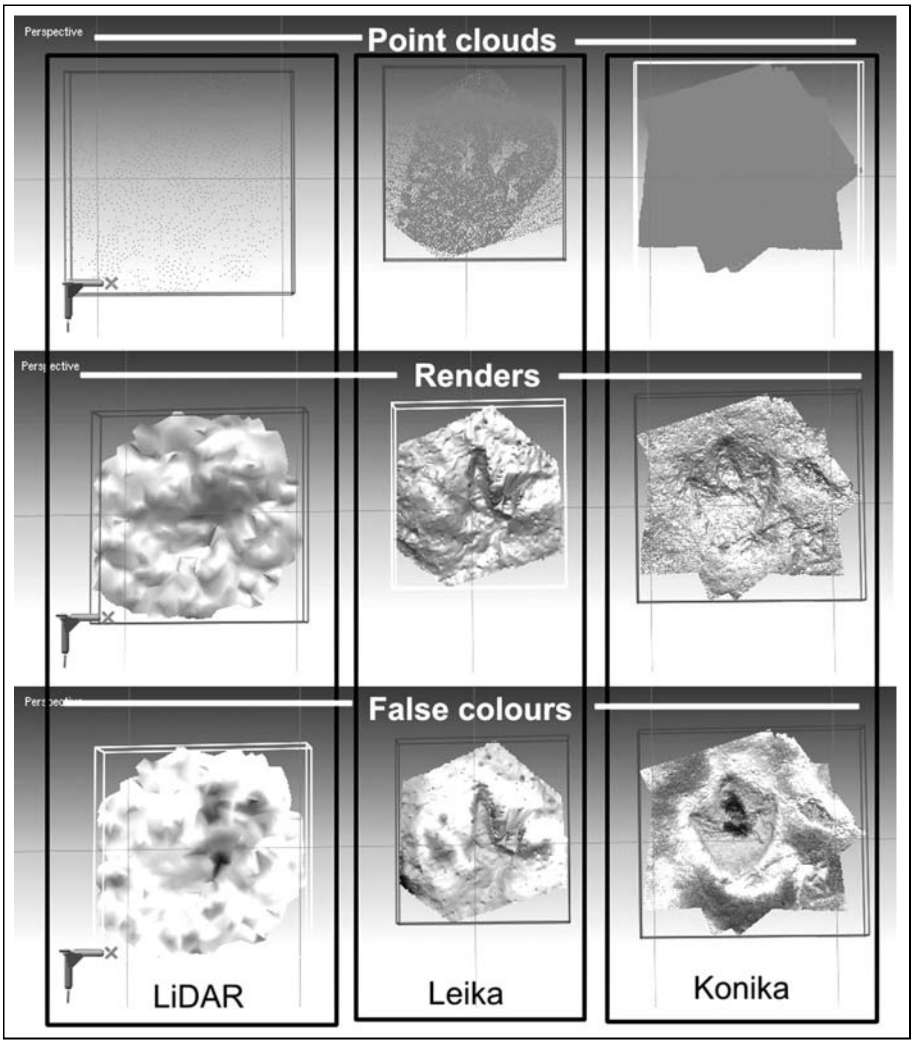


Fig. 1 - Different views of the same theropod track coming from the Molfetta site, Bari, Southern Italy. From right to left: picture of the track, track's curve level graph (Grapher software) and 3D raw model of the sample (Rapidform 2006 software).

Fig. 2 - 3D Images of three theropod tracks showing different detail of instruments; each image is made with a single hardware scan procedure and the same software passages. Point cloud (up), render view of models (centre) and false colour model (down). From left to right model obtained using: LiDAR (Riegel) 30 m scan distance, model coming from outdoor active sensor scanner (Leika) 15 m scan distance, model coming from high density lab scanner (Konika) 5m scan distance. (Visualization with Rapidform 2006).



obtained by the use of replayed scan procedures (Petti et al. 2008, 2011) is millimetric. Details are improved by the high definition photogrammetry and by working at the same light condition, reducing errors to a 0.3 mm average (Remondino et al. 2010).

The third type is the "*Lab high density laser scanners*" designed for lab reconstruction of small objects between 5 millimetres and 5 metres (Balzani et al. 2009) although, nowadays, it is also used to scan dinosaur tracks (Arakawa et al. 2002). The red laser stereoscopic active sensor cannot be used during daylight because its light frequency interferes with the sun's light. Thus, scanning procedures have to be taken during night hours or under artificial shadowing conditions (Adams et al. 2010). Artificial shadows are the perfect condition to repeat different scans at the same experimental condition improving the detail. Since this laser produces heavy files, surfaces and trackways should be divided in different sectors as different 3D partial overlapping photogram. Precision is of tenths of millimetres (sometimes it can also scan the grain of the sediment) and scan distance never overcome the 10 meters. This instrument includes an integrated high-resolution camera that simultaneously and stereoscopically acquires photogrammetric details of the object. Two main types of scanner are distinguished: "*fix station*" and "*portable station*". The former is placed on a trestle and scans the object positioned on a rotating table; the latter is handled and is passed above the object to be scanned.

Software

Software are even more diverse than hardware. We will not discuss software differences and details, but how to avoid general problems that occur during elaboration.

Software elaboration normally decreases file definition after every step. Therefore, a reduction on software steps would improve file fidelity.

Software applies a random mathematical model independent from topography. Thus, it is here suggested that nothing has to be left to software automatic choices (*wizard options*). Moreover, some software do not save the absolute position of the object respect to other objects or to surface topography when separately saved. Consequently, absolute referring points must be placed on the 3D model to rebuild their absolute or relative position.

Small errors in 3D model (millimetric holes, surface undetected details, spikes, crossed faces or isolated single wrong positioned points) can be corrected by software, while major errors, always need new field scan procedures to avoid false data.

The file must be prepared to allow a fast eventual manual translation from a file format to another. Nonetheless, laser scanners and software fast evolution implies a continuous revision of the issues exposed. For this reason these procedures should become the starting point for the discussion of this issue more than solving general problems.

Results: the method

Field and post processing procedures have been ideated after a 4-year-work in dinosaur tracksites of the Apulian Carbonatic Foreland, Southern Italy (Petruzzelli 2008, 2010). Other researchers successively used the same instrumental acquiring method effectiveness during indoor natural heritage 3D scanning in the Museum G. Capellini, Bologna (Balzani et al. 2009). A strict and firm protocol was then created to obtain field data with the same precision and repeatability obtained in the laboratory. The protocol is divided in three schematic operative steps. The two first steps are here reported to testify a new field approach. The main part is the post processing process which tries to give worldwide standard results maintaining detail and file formats after data acquirement.

1stPhase

This first *sine qua non* phase consists in ordinary field preparation (cleaning) and geological analyses, together with an introductive 2D mapping positioned with G.I.S (*Geographic Information System*). Creating a classical reference map and/or a photogrammetric one before 3D relief could appear as a superfluous work and it is not obligatory but it brings some advantages. In fact, it creates an absolute independent referring system which gives a secondary manual control system during the 3D mapping and coordinate creation.

2ndPhase

Different lasers can be used for a 3D relief and as already mentioned above, each instrument differs in characteristics and results. Our specific case combines different instruments to amplify the hardware strength points. Instrument used are Leika Digital Station (Fig. 3), an active laser sensor for wide surfaces and VIVID 910 from Konica Minolta^{TM} (Fig. 3), a short range stereoscopic laser for the single track and small trackway topography. Leika D.S. scanner obtains a maximum resolution of 0.3 mm detail and point density of 1.7 million points/cm while laser scanner VIVID 910 obtains a maximum resolution of 0.9 mm after 3 auto-

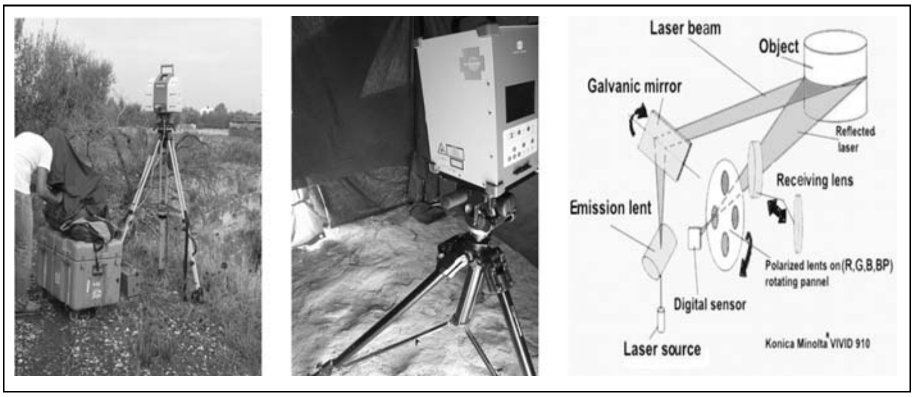


Fig. 3 - The two reference scanners at work, from left to right: Leika scanner measuring a trampled quarry; Konica scanner under the tent controlling natural light; working scheme of a laser scanner (Konica Minolta 2004).

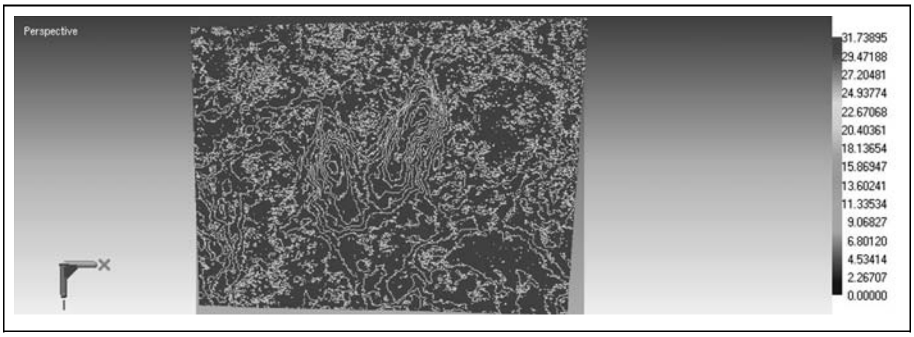


Fig. 4 - High curve level density of the 3D model obtained; each curve is placed at 2 mm each other.

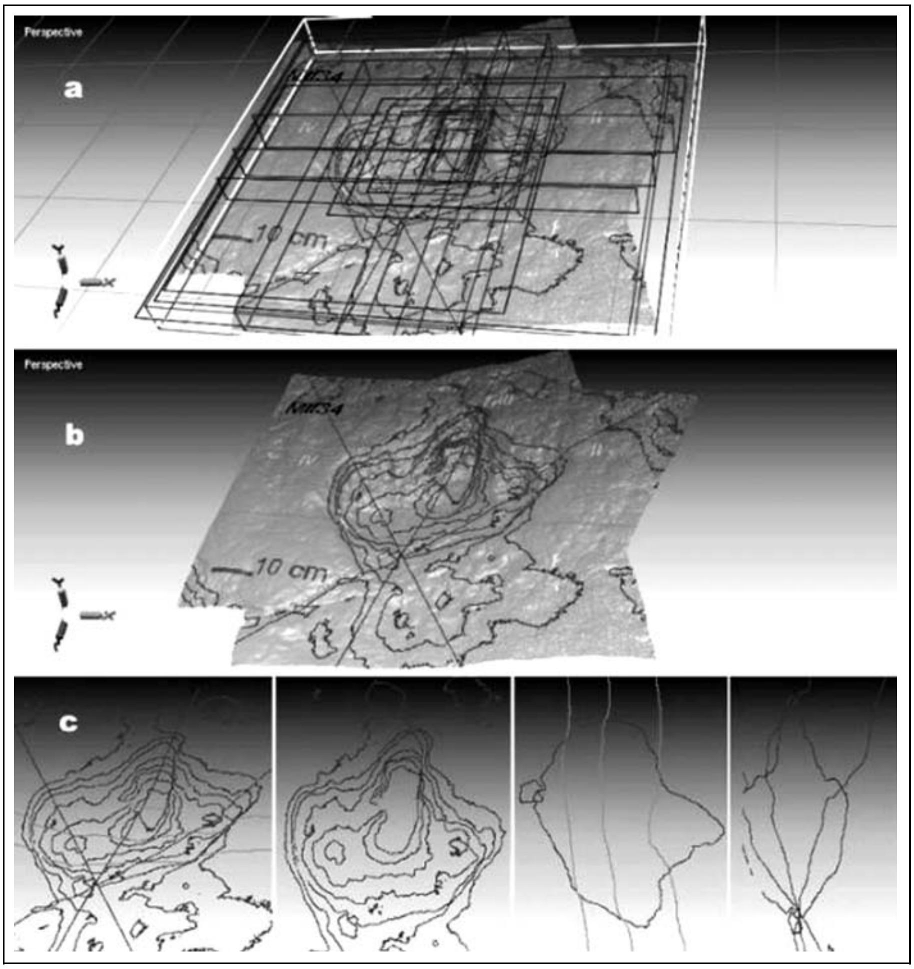


Fig. 5 - Example of the multitask derived file used for measurements. a) 3D model where sections, curve level lines, scale, name etc. are delimited by marks. b) How the multitask file could appear cleaned and comprehensible on the screen. c) Isolated snapshots of elements derived by the model.

matic laser steps and a point density maximum of 2.5 million of points/cm (Fig. 4).

3rdPhase

In our specific, it consists on the elaboration of raw data from VIVID 910 and Leika Digital Station with Poligon™ (KONICA Minolta 2004) and Cyclone™ (LEIKA geosystem 2005) software, respectively.

Rapidform™ (INUS Technology 2006) software is chosen for the post elaboration phase because of its rapidity and multiple options while viewing the object. This post processing could be repeated using many other 3D modelling programs, considering their power and detail during files elaboration.

Data coming from the laser must be first saved to maintain the original source. After each software step we suggest to control data precision decrease rate, and to compare each derived file with the raw one. Derived files in our case are accepted only with a deviation tolerance range of a maximum 3-4% for scans coming from Leika D.S. and 0.4% for scans coming from VIVID 910. Subsequently, a copy of the source file must be cleaned and uniformed to avoid software surface misinterpretations. The cleaning consists in deletion of useless point cloud parts (plants, covered or useless areas, light aberrations). If the source file is a point cloud and not a surface mesh the latter will be created with better results interpolating different prospective scans. A mesh file is a software interpolation of a point cloud which creates a surface that reproduces the actual topography through special points. The majority of scientists prefers working with a non-mashed point cloud causing visual mistakes of the object. Furthermore, since different 3D photogram need to be recomposed in a unique surface, it is advisable to operate on a mashed surface and not on a raw point cloud to improve precision.

After this first operation, the raw point cloud deviation tolerance must be compared with the derived file one maintaining the standard desired detail. The file produced can be digitally placed in the relative position within the outcrop in order to obtain panoramic 3D digital reconstructions of big surfaces using referring 2D map to control their position.

Each file obtained is the raw referring model coming from raw data. Each referring model is divided into single derived models as single 3D snapshots to analyse (Fig. 5). A 3D snapshot is a 3D model cropped from a bigger 3D model (e.g. a track from trackway). Each

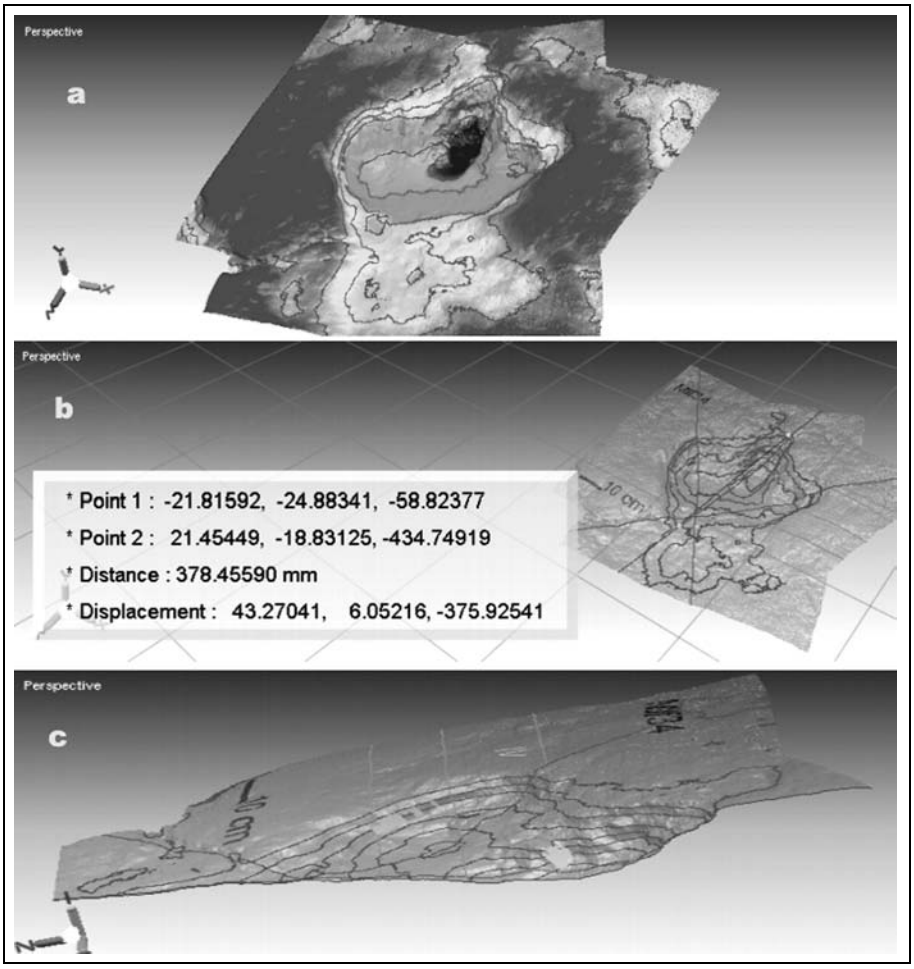


Fig. 6 - Example of some repeatable measurements that could be done using the guidelines of a multitask derived file. a) False color representation. b) Track length measurement. c) Longitudinal section, III toe and tarsal area.

snapshot model is positioned in the space following the relative *xyz* axes to optimize the analysis (Arakawa et al. 2002). To every file is given a name (the same of the real sample if possible), externally as file name and integrated in the 3D file; then other integrated data are inserted in the model. A scale, fixed referring points, sections and dimensional high precision are needed for analysis and points where measurements are taken need to be integrated (Fig. 5). The advantage that this approach presents is that each integrated dimensional data can be isolated as a separated file from the original one (as 3D file or as numerical data) and it can be used for mathematical analysis with programs like Past, Surfer^{TM} or Matlab^{TM} (Fig. 5). This measurement does not involve modification in the raw model when transforming the derived file in the result analysis data (Fig. 6).

Raw point cloud and derived file must be saved separately, the former to preserve an unaltered source, the latter to uniform measurement and analysis. During the saving process, two possible procedures can be followed. Each derived group of files can be saved into a directory or into a multitask session in a composite file composed by different layers. Each layer is a single point cloud. A file that does not support multitask functions is called raster file. A multitask file is more efficient and ordinate than a directory one for storing data. Multitask files solve many translation and compatibility problems. The use of raster files requires opening many single raster files to obtain a multitask session in a program and during the saving process it is not advisable to

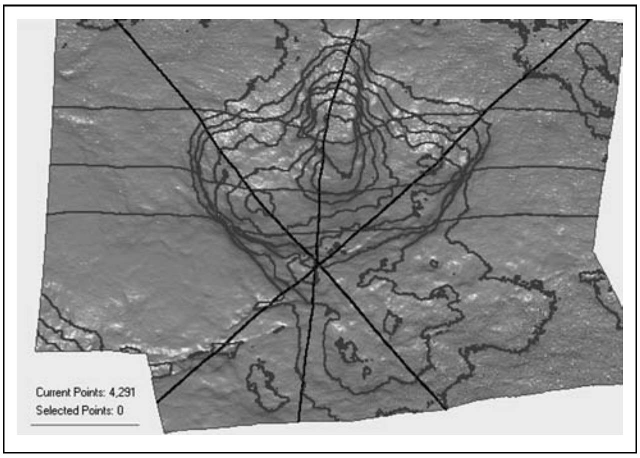


Fig. 7 - Reference 3D vectorial multitask file opened with Geomagic11^{TM} after manual translation of each single multitask element from a program to the other, an inadvisable operation if applied on many samples.

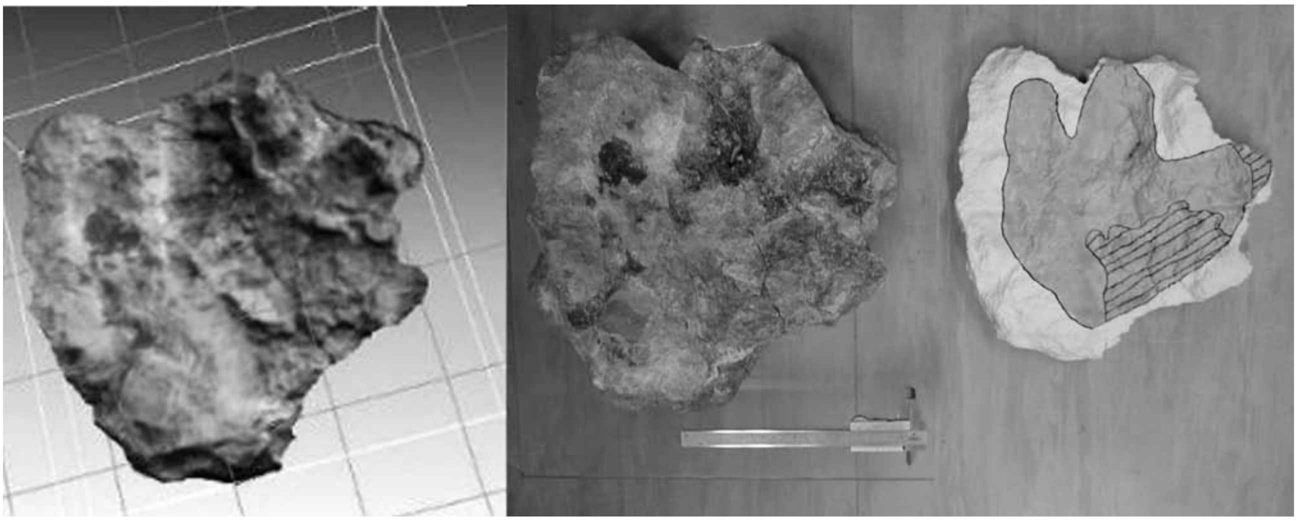


Fig. 8 - Comparison between 3D model, the real sample and the Z-printer replica on an ornithopod track coming from the Apulian region, 20 cm scale. Earth Science Museum, University of Bari "Aldo Moro", Italy.

operate manually due to translation problems. Manual or "numerical software done" translation of a 3D file resulted inadvisable in time and precision, for example a raster translation between Rapidform 2006 and Geomagic™ software. In this case, each layer is saved as a single *.ascii raster file to translate the file maintaining its features (Fig. 7) and then it is reconstructed in the new program through the transportation and repositioning of the point cloud. Only a standardized file format and minimal details in file requirements can solve the problem and we propose to combine two previous standards to do this.

The first is the *.stl format, light raster files for printers and numerical control machines. 3D printers and numerical control machine use this file to reproduce real solid replicas of the 3D models. During the 2005, another 3D multitask file format was chosen as a standard for the 3D modelling. This format is the D.I.C.O.M. *(Digital Imaging and Communications in Medicine)*: the 90% of the medical 3D C.T. and stereoscopic x-ray instruments save the scan object in *.cdm 3D multitask point cloud format. This standard not only defines file format but also the minimum detail required in scanning, allowing hospitals to obtain the same detailed data ready to be exchanged. If a D.I.C.O.M. or *.stl-like standards could be applied to ichnology, it would be the key to solve many issues. Software opening *.cdm files are also capable to open *.stl files with a total compatibility. An international standard would be able to save 3D dinosaur tracks in multitask files, with clear file compatibility, high detail and no particular innovative technology or expensive software acquisition.

Discussion

The protocol proposed offers two main innovations. The first one is a sort of a field procedures guideline suggesting how to choose instruments and to integrate old 2D method with the 3D procedures. The second one is about post processing and file saving format to standardize the results to be internationally catalogued.

In the field, it is important to obtain a uniform data result. Areal scanners are compatible with large surfaces, while precision scanners are needed to track single samples. The combination of the two types of scanners would be the simplest way to maintain data details. Hardware minimum details and their characteristics are essential for a comparable analysis. Another important field aspect is to create a relationship between the old method in tracking (bidimensional) and the new one (tridimensional). The old method should be the basis to build the 3D new relief and should not be forgotten. The 2D relief must be used as a secondary manual control system for relative and absolute 3D track positioning of models. Manual and classic 2D interpretation is fundamental on paper representations and it is more understandable than the 3D one. Palaeontologists' interpretation could be improved using 3D models combined with millimetric level curves obtained by 3D and topographic interpretation.

Reduction of post elaboration steps is fundamental to uniform software procedures and data details in a standard and it allows translation among different file formats and replica reproducibility through 3D printers.

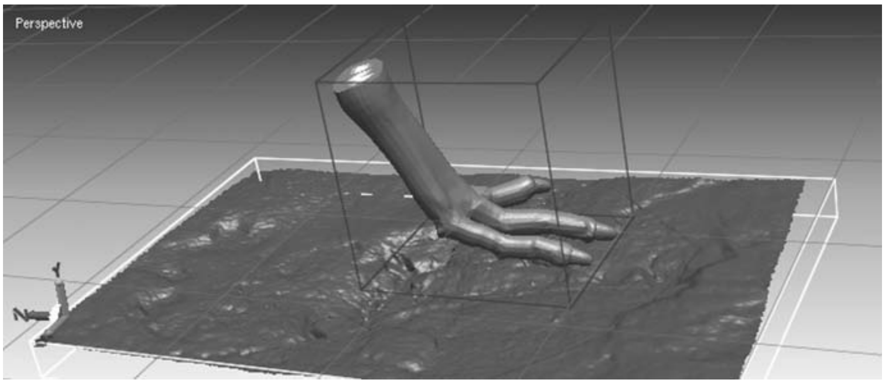


Fig. 9 - Reconstruction of a theropod pes placed in scale with a real dinosaur track 3d model. Sample SEG.Tt1 from Giovinazzo site Bari, Southern Italy (Petruzzelli in press).

Another 3D standard has been created using two different file formats, the first one for raster files and the second one for multitask files. The former is the raster *.stl format supported by 90% of 3D printing systems (Fig. 8).

This file format is supported by many freeware programs able to repair errors in model using wizards, thus it is quite a good base among 3D printing instruments. Its point of strength is the light format and compatibility although its raster nature is quite an issue. Some authors suggest *.obj or *.ply ready publishable on web (Adams et al. 2010) as potential raster interchangeable files. Anyhow, saving the same 3D model in *.obj, and in *.ply formats is heavier than in *.stl one. An advantage in using *.stl format is that many 3D modelling database are based on this format and it could be used to improve tracks study (e.g. 3D digital catalogues in engineering, in forensic medicine and biomechanics for science or cinematography). On the other hand, D.I.C.O.M file is a multitask format and it is compatible with many *.stl printing programs. The other file format proposed is *.cdm. This format can easily save a raster point or a vectorial multitask data that can be opened by high performance software (e.g. Rapidform ™, Mimix ™, Rinos™ etc.). Furthermore, if *.cdm files are used as the source, it records the different density of the scanned object (identifying the nature of the tissue scanned in CT scans). In the future, if a track is superficially scanned using laser scanners and CT scan and analysed in a tomography, each strata of the sample would be divided by density and singularly analysed. Adopting a file that owns more potentiality than the one needed today would be the base to compensate technical future evolutions (Fig. 9). A contra in *.cdm file is that big multitask files are often very heavy and files are not publishable if not converted in *.stl. Another disadvantage is that no freeware software could support the *.cdm format. Nonetheless, advantages are still more than contra if we consider that the programs able to support the format are part of a worldwide standard that already exists and works.

Conclusion

Field and post processing 3D dinosaur tracking protocol conversion into a standard could be a solution to create a 3D ichnological data catalogue to allow scientific and divulgative data exchange. Classical relief method to control 3D scanning procedures should be supported to avoid digital tracking common errors. What should be remarked is to uniform file format and detail of results. A possible solution for the creation of this standard may be the combination of *.dcm multitask format together with *.stl raster format, to keep a uniform point cloud, proportional in density and detail respect to the surface scanned point cloud. The detail required for the single research should be evaluated and assured by a minimum millimetre of detail precision and centesimal deviation among source and elaborated files. On the other hand, the maximum detail obtainable would be connected to the hardware/software power used and the amount of detail needed for the research. The proposed protocol reaches a precision of less than 0.7 millimetres and a deviation among elaborated files and origin ones of a 4%. Lastly, the derived point cloud obtained a deviation from the original topography of a 0.4%. The integration of additional data in the point cloud gives a uniform way of analysis and comparison maintaining extreme precision in measurements.

Future research and further experimentation might be the key of improvement and challenging of the proposal presented.

Acknowledgements: We wish to sincerely express our gratitude to the Earth Science Museum of Bari and C.I.S.M.U.S. for the instrumental support, and the Geology and Geophysics Department of the Università degli Studi di Bari Aldo Moro. The constant help and encouragement of prof. G. Baldassarre is gratefully acknowledged. We also thank prof. A. D'Alessandro, prof. A. Iannone and prof. R. La Perna (Università di Bari). This work would have not been possible without the help of Dr. A. Galobart and Dr. B. Vila from I.C.P. (Insititut Català de Paleontologia Miquel Crusafont) and the project CGL 2008-06533-01/BTE from the Spanish Ministry of Science and Innovation. We wish to thank also for the critics of F. M. Dalla Vecchia also from I.C.P. and the reviewers M. Avanzini and an anonymous colleague. Finally all the work was not possible without the financial supports by the Apulia Regional Authority in the context of "Bollenti Spiriti 2009" project and Ecolevante S.p.A.

REFERENCES

Adams T. L., Strganac C., Polcyn M. J. & Jacobs L. L. (2010) - High Resolution Three-Dimensional Laser-Scanning of the Type Specimen of *Eubrontes (?) glenrosensis* Shuler, 1935, from the Comanchean (Lower Cretaceous) of Texas: Implications for Digital Archiving and Preservation. *Palaeontologia Electronica,* 13, 3; 1T:11p; http://palaeo-electronica.org/2010_3/226/index.html.

Arakawa Y., Azuma Y., Kano A., Tanijiri T. & Miyamoto T. (2002) - A new technique to illustrate and analyze dinosaur and bird footprints using 3-d digitizer. *Mem. Fukui Prefectural Dinosaur Mus.,* 1: 7-18.

Balzani M., Fanti F., Ferrari F., Vai G. B. & Vanucci C. (2009) - Collection of paleontologic type in the Museo Geologico Giovanni Capellini: creation of digital database on morphometrics acquired with 3d survey technology for the study of fossils. In: *Diplodocus* 2009 - International conference of vertebrate Paleobiogeography and continental bridges across Tethys, Mesogea, and Mediterranean Sea, Museo Geologico Giovanni Capellini, 28 -29 September 2009, Bologna, Italy. Abstracts Book: 7-11.

Breithaupt B. H., Matthews N. A. & Noble T. A. (2004) - An integrated approach to Three-Dimensional data collection at dinosaur tracksites in the Rocky Mountain West. *Ichnos,* 11: 11-26.

Cavaliere G. (2006) - Coastal Processes, Tools and Planning. Hydrographical Survey. In: Technical Observations and Strategic Role for Sustainable Development, Shaping the Change, XXIII Congress, Münich, Germany, October 8-13, 15 pp.

Falkingham P. L., Bates K. T., Margetts L. & Manning P. L. (2011) - The "Goldilocks" effect: preservation bias in vertebrate track assemblages. *J. R. Soc. Interface* (published online 13 January 2011); doi: 10.1098/rsif.2010.0634.

Farlow J. O. & Lockley M. G. (1993) - An osteometric approach to the identification of the makers of Early Mesozoic tridactyl dinosaur footprints. In: S. G. Lucas & M. Morales (Eds) - The Nonmarine Triassic. *New Mexico Mus. Nat. Hist. Sci. Bull.* 3: 123-131.

Gatesy M. S., Middleton K. M., Jenkins Jr F. A. & Shubin N.H. (1999) - Three-dimensional preservation of foot movements in Triassic theropod dinosaurs. *Nature*, 399: 141-144.

Graham R. W., Farlow J. O. & Vandike J. E. (1995) - Tracking ice age felids: identification of tracks of *Panthera atrox* from a cave in southern Missouri, U.S.A. In: K. M. Stewart & K. L. Seymour (Eds) - Palaeoecology and Palaeoenvironments of Late Cenozoic Mammals: 331-345, University of Toronto Press.

Hurum J.H., Milàn J., Hammer Ø., Midtkandal I., Hans A. & Sæther B. (2006) - Tracking polar dinosaurs - new finds from the Lower Cretaceous of Svalbard. *Norwegian J. Geol.,* 86: 397-402.

INUS Technology (2006) - Rapidform 2006^{TM}, instruction manual. Internet address http://www.rapidform.com/

Ishigaki S. & Fujisaki T. (1989) - Three dimensional representation of *Eubrontes* by the method of moiré topography. In: D. D. Gillette & M. G. Lockley (Eds) - Dinosaur Tracks and Traces: 421-425, Cambridge University Press, Cambridge.

Konica Minolta (2004) - Mod. VIVID 910. User manual.

Leika Geosystems (2005) - Mod LEIKA PRO STATION. User manual.

Levoy M. (1999) - The Digital Michelangelo Project: creating a 3D archive of his sculptures using laser scanning. Computer Science Department Stanford University March 16, 1999. http://www.cs.cmu.edu/~seitz/course/SIGG99/papers/levoy-abs.pdf.

Lockley M.G. (2007) - The morphodinamycs of dinosaurs, other anchilosaurs, and their traceways: holistic insights into relationship between feet, limbs, and the whole body. In: Sediment- organism interactions: A multifunctional Ichnology. *SEPM Spec. pub.,* 88: 27-51.

Margetts L., Smith I.M., Leng J. & Manning P.L. (2006a) - Parallel three-dimensional finite element analysis of dinosaur trackway formation. Numerical Methods in Geotechnical Engineering: 1-6, Graz University of Technology.

Margetts L., Smith I.M. & Leng J. (2006b) - Parallel 3D finite element analysis of coupled problems. In: III European Conference on Computational Mechanics Solids Structures and Coupled Problems in Engineering, ECCM, 5-8 June, Lisbon, Portugal.

Marty D., Strasser A. & Meyer C. A. (2009) - Formation and Taphonomy of Human Footprints in Microbial Mats of Present-Day Tidal-flat Environments: Implications for the Study of Fossil Footprints, *Ichnos*, 16: 1, 127-142.

Milan J. & Bromley R. G. (2006) - True tracks, undertracks and eroded tracks, experimental workwith tetrapod tracks in laboratory and field. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 231: 253-264.

Moore L. J. (2000) - Shoreline mapping techniques. *J. Coastal Res.*, 16: 111-124.

Petruzzelli M. (2008) - Gargano Murge and Salento highlands, proposed as a unique dinosaur megatracksite Apulia, south Italy. In: Acts of the Second International Congress of ichnology, Ichnia 2008, Krakow, Poland. Abstract book, p. 103.

Petruzzelli M. (2010) - Orme di Dinosauro nel Calcare di Bari. 1° I siti ad orme di dinosauro in Puglia. 2° Metodi di studio. 3° Il Parco Cresce. In: Bollenti Spiriti Camp, Giovani Idee Cambiano la Puglia, 6-7 February 2010, Fiera del Levante Bari. Regione Puglia e Unione Europea. Posters.

Petti F. M., Avanzini M., Franceschi M., Girardi S., Remondino F., Belvedere M., Ferretti P. & Tommasoni R. (2008) - New approaches to study dinosaur tracks: 3D digital modelling by fotogrammetry and active sensors. In: Ichnia 2008,Acts of the Second International Congress on ichnology, Cracow, Poland. Abstract book, p. 105.

Petti F.M., Bernardi M., Ferretti P, Tomasoni R. & Avanzini M. (2011) - Dinosaur tracks in a marginal marine environment: the Coste dell'Anglone ichnosite (Early Jurassic, Trento Platform, NE Italy). *Ital. J. Geosci.*, 130(1): 27-41. doi: 10.3301/IJG.2010.19.

Remondino F., Rizzi A., Girardi S., Petti F. M. & Avanzini M. (2010) - 3D Ichnology-recovering digital 3D models of dinosaur footprints. In: The Photogrammetric Record, September 2010 (Extended version of a paper presented at the RSPSoc Annual Conference held at the University of Leicester, 8th to 11th September 2009), 25(131): 266-282.