RASCAN holographic radar for detecting and characterizing dinosaur tracks

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***Abstract*—The development of high lateral resolution holographic radar imaging has stimulated new research on mapping of exposed dinosaurs and detection of tracks hidden in the uppermost layers of potential track-bearing rocks, as well as for the characterization of rock features around tracks. This project involves experiments on tracksites, museum specimens, and laboratory models from around the world. Preliminary experiments indicate that holographic radar will be able to provide comprehensive tracksite mapping with objectivity and total non-invasiveness.**

Keywords: holographic radar, dinosaur tracks, tracksite mapping, preservation, hologram reconstruction.

I. INTRODUCTION

Holographic subsurface radar of the RASCAN type was initially developed for landmine detection and non-destructive testing of construction details of buildings, historic architecture and artworks [1][2]. This type of radar provides very high resolution (approximately ¼ λ), completely non-destructive, but exclusively shallow subsurface imaging. The main feature is much higher resolution and sensitivity to much smaller physical property contrasts (in this case dielectric) than conventional exploration geophysics [3].

Rascan radar produces a plan-view subsurface image that is the raw interference pattern between the monochromatic CW beam partially reflected by the scanning surface and the subsurface target reflections. Because of attenuation of off-nadir reflections, only the central Fresnel rings are retained, and the interference pattern closely mimics the actual shape of the reflector [1]. Rascan radars have an effective scanning depth of up to 30 cm in dry sand and rock at 2 GHz, and 20 cm at 4 GHz [1], and are preferred for this work over traditional impulse subsurface radars because of superior spatial resolution at shallow depths and the smaller , lighter scanning transducer.

This paper describes a new application in development by the Rascan Group: the detection and imaging of dinosaur tracks. Dinosaur tracks are ichnofossils, trace fossils representing simply impressions or markings left by ancient life rather than the remains of ancient life represented by body fossils. Dinosaur tracks are important trace fossils that are by definition found in the location and paleoenvironment where the creature lived, as opposed to the body fossil remains which may be transported before deposition and burial. Thus these trace fossils can reveal information on habitats and behaviors of ancient creatures, as well as anatomy. In particular, if a series of tracks form a trackway, important metrics such as stride and pace lengths allow estimation of velocities (and changes in velocity), in addition to direction and sense of movement. Where there are multiple trackways, on a tracksite, information may be gleaned on herd and parenting and social behavior, and if different types of track are present, information on faunal assemblages or ichnocenoeses may be determined [4][5].

Currently, for a dinosaur track to be exposed, and discovered, and therefore made available for scientific study, requires a perhaps improbable sequence of events: a track must be impressed in a sufficiently fine and cohesive material to record and preserve the track; it may harden or be covered by an evaporitic or other mineral film; then be covered by a subsequent gentle flood that does not erode the track; the flood must deposit material that is lithologically dissimilar to that holding the track (often a clay film or drape [6]); the sedimentary layers must be buried and lithified, and not too severely deformed tectonically; and then re-exposed by uplift and erosion, with spalling or parting of the layers occurring exactly at the layer with tracks (or underprints on deeper layers as depicted in Fig. 1). The combination of tracksite and Rascan radar characteristics suggests several possible applications:

- Detection of hidden tracks where a complete continuous contemporary surface is not exposed
- Detection of underprints in deeper layers where actual tracks may not be preserved
- Prospection for completely hidden and undiscovered trackways in rocks of appropriate age and paleoenvironment.

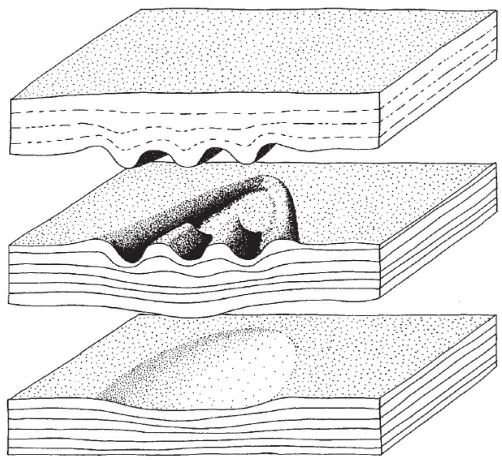


Figure 1: Pictorial description by Thomas Conci of a track mold (center), with cast (top) and underprint (bottom)

All of these could facilitate development of more complete tracksite mapping and analysis. In addition, scanning of tracksites could reveal joints or other discontinuities that might be involved in (for example) frost wedging and therefore play a role in preservation strategies. Furthermore, even for surficial tracks which may occur on fragile surfaces, mapping of both exposed and hidden tracks could be done with a non-destructive, lightweight robotic system.

In order to evaluate the potential for realizing these applications, a sequence of specific questions was addressed in this study:

- Does Rascan have the ability to image exposed dinosaur tracks?
- Can Rascan detect subsurface tracks?
- Can subsurface tracks be discriminated from the effects of surface relief?

These questions were addressed through a combination of field and laboratory scanning of actual and simulated tracks, and numerical modeling.

II. IMAGING OF EXPOSED TRACKS

The first experiments were carried out in Lagarina Valley, near Rovereto, Italy on the western slope of the Coni di Zugna Mountain. Here, the peritidal calcareous rocks of the Monte Zugna Formation (Early Jurassic, Hettangian-Sinemurian Age) outcrop extensively as a result of a famous dip-slope landslide (1300 ± 100 Year Before Present), and contain an abundance of well-preserved trackways – of herbivorous and carnivorous, bipedal and quadrupedal dinosaurs, including the oldest sauropod tracks in Europe. It is one of the most important dinosaur track megasites in the world, and is protected as *Parco dei Lavini*; the dinosaur tracksite, plus an alpine floral preserve, and WWII battle site [4] [5].

At the site, a team from the local Civic Museum of Rovereto selected an area of interest (see Fig. 2) where many dinosaur tracks are exposed, and others are suspected on deeper layers.

Figure 2: Test site in *Parco dei Lavini* with two exposed dinosaur trackways.

A rectangular area with length 3.2 m was chosen as a representative sample, and divided into four quadrants (Q1-Q2-Q3-Q4) that were scanned individually using a Rascan-4 system with 2 and 4 GHz transducers. To perform the scan, an operator moved the radar transducer by hand along parallel lines at 1 cm intervals as marked on a thin microwave-transparent plexiglass sheet. Rascan produces a real-time image (with one raster per scan line) on the display of a PC running the software Multiscan by RSLab [7]. Since Rascan produces 10 simultaneous images (two receiver polarizations at each of five discrete signal frequencies [1]), an algorithm developed in Matlab was used to calculate a single display image. This processing separately removes a constant background level from each image, then combines the 10 matching pixels (from each separate image) as a sum of squares [8].

Figure 3: Photograph of dinosaur track in scan Q4.

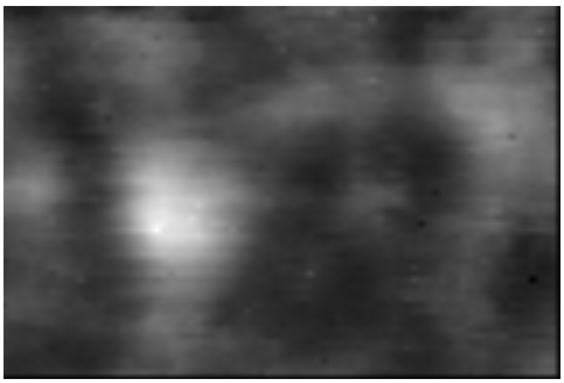


Figure 4: Rascan individual radar image of Q4 at 2 GHz, parallel transmitter-receiver polarization.

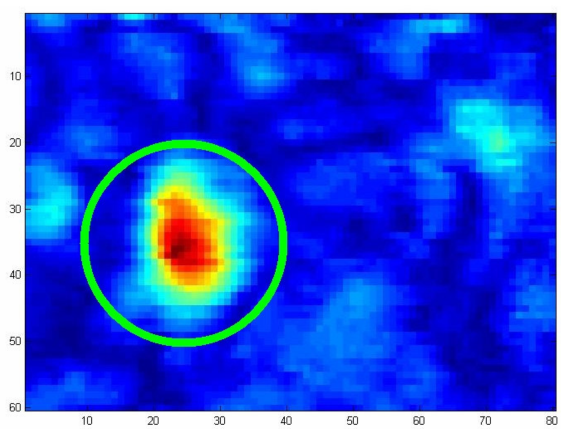


Figure 5: Rascan combined radar image of Q4 at 2 GHz.

The resulting images were particularly interesting for quadrant Q4 as shown in Fig. 3 (photograph), Fig. 4 (Rascan image single image), and Fig. 5 (Rascan combined images in a single display). Note that the holographic radar reproduces quite accurately the overall shape of the footprint due primarily to the variation of the reflector surface depth from the scanning plane. These variations are much less than one signal wavelength (λ=15 cm at 2 GHz) but are detectable due to the interferometric nature of Rascan holographic radar. Rascan interferometry also conveniently records relief [9], in a manner similar to the way that moiré photographs of tracks have been employed [10], but with the advantage that the relief of even hidden tracks might be quantifiable with Rascan. This quantification of relief could be an advantage for Rascan mapping (even for exposed tracks) over photographic or line drawing (even GIS-based) mapping.

Also, the dielectric impedance contrast of the air-soil interface is strong. Lower intensity reflections might be expected from subsurface dielectric constant variations. In fact, more subtle, and undoubtedly subsurface, reflections are visible in the combined image 2 GHz scan in Fig. 5. These appear as radial striations in dark blue emanating from the track footprint itself. These are interpreted as vertical cracks possibly related to desiccation/cementation of the track prior to cover-up, or possibly stress-related (unloading) joints. Some types of cracks or joints are not visible by eye, and the dielectric contrasts in the rocks on either side should be negligible. However, in the possibly microscopic joint aperture there may be different materials that could produce suitable impedance contrast. These materials include air gaps, microbial or vegetative films, moisture, mineralization (particularly metal oxides), and stylolitic material (insoluble residue from carbonate dissolution). These may be inter-related in that oxides, moisture, and dissolution may either encourage, or be produced by, organic activity along bedding planes. Iron oxide in particular has been observed in outcrop at this site, and is known to contribute to the distinctive coloration of tracks at other locations [11].

The 4 GHz scan better resolves the shape of the track. However, it does not show the inferred subsurface radial cracks, probably due to the lesser effective penetration depth for the higher frequency 4 GHz signal.

A second set of scanning experiments at *Parco dei Lavini* have been completed using a robotic scanner prototype. These suggest that a fully developed system could provide very rapid (approximately 0.5 square meters per hour), fully objective, and completely non-destructive surface (and possibly subsurface – see below) mapping of dinosaur tracksite features.

Holographic radar scanning was also completed for a slab of Early Jurassic shale from the Newark Rift Basin of New Jersey, USA in the collection of the University of Pennsylvania. This slab displays a *Grallator* track (see Fig. 6). A 32 by 28 cm scan was completed at 1 cm scan line spacing using Rascan-4 with a 4 GHz transducer on a plexiglass sheet.

The Rascan image at 3.8 GHz and cross polarization is shown in Fig. 7, and clearly reproduces the tridactyl outline of the track. However, there are other contrast patterns that are certainly related to the relief of the irregular slab outside of any tracks, and possibly to subsurface features. However, this specimen was collected relatively freshly-exposed, and has been indoors for over 50 years. Thus it may be unlikely that there is much internal moisture or biotic material or deposits to enhance the dielectric contrast of subsurface discontinuities.

These results on indoor and outdoor specimens indicate that Rascan radar does have the resolution and sensitivity to record exposed dinosaur tracks of suitable dimensions.

Figure 6: Early Jurassic Grallator track from the collection of the University of Pennsylvania.

Figure 7: Rascan image at 3.8 GHz and cross polarization.

III. Imaging of Hidden Tracks

To determine whether Rascan radar can detect hidden tracks, several experiments were completed. The *Parco dei Lavini* tracks may have been preserved in a carbonate mud that may have hardened through crystallization and dessication in a manner "similar to quick dry cement"[12]. At the Lavini site, both dessication and dolomite mineralization are important as evidenced by mud cracks and chips close to the tracks, and some tracks with a preserved dolomite film. In order to perform a controlled experiment on the detection of hidden tracks, a cast was taken of a *Anamoepus* track from the Early Jurassic rocks of Dinosaur State Park in Connecticut, USA. The cast was done with a quick dry lime plaster consisting of calcium carbonate and silica sand which had, after oven-drying, dielectric properties very close to the peritidal carbonate rocks of the Lavini tracksite. The cast was then covered with a layer of plaster to make a tight-fitting mold. When together, the cast and mold could be scanned from either surface, with the hidden dinosaur track at a depth of about 3 cm (see Fig. 8).

The mold and cast were scanned first with nothing but the microscopic air gap separating them, and this produced no recognizable contrast pattern. However, when the mating surface was painted with a very thin clay-water mixture (Fig. 9), and allowed to dry overnight (air dry, not oven dry), a shape strongly resembling the track appears (Fig. 10). Note that the long middle toe is clear, and the shape of the heel is obvious, but the outer toes are subtle at best. This indicates that the presence of the mineralogically (and dielectrically) dissimilar clay film was required to produce an image of the hidden tracks. Part of the reason that the smaller outer toes are unclear is related to the geometric spreading or "defocussing" of the Rascan interference pattern image that occurs as the range (or depth) to a target increases [1].

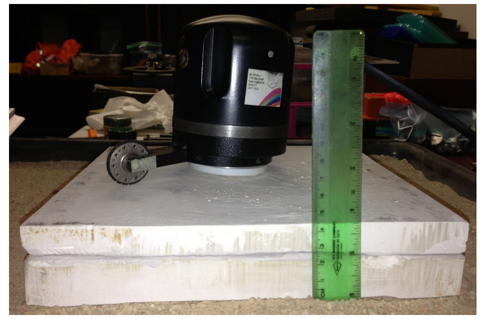


Figure 8: *Anamoepus* mold and cast with Rascan 4 GHz.

Figure 9: *Anamoepus* cast with clay film coating.

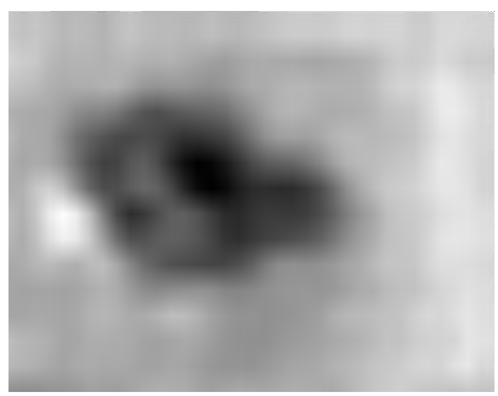


Figure 10: Rascan 3.8 GHz cross polarization image for clay film on the cast-mold interface.

A similar result was obtained for mock tracks formed in slightly damp loam soil which was allowed to dry, and then covered with the same dry loam soil (Fig. 11). A Rascan 4 GHz image shows the location and approximate outlines of tracks, but not clearly the outline of the toes (Fig. 12).

However, when two of the three tracks are covered by dissimilar sandy soil (Fig. 13), the tracks at the mineralogically distinct interface record better the track outline (Fig. 14). These results indicate that hidden tracks (of suitable size) can be detected.

Figure 11: Mock tracks formed in loam soil prior to covering with the same material.

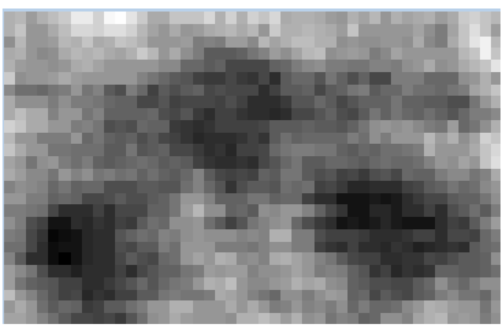


Figure 12: Rascan 4GHz image of mock tracks with similar sediments above and below the imprint.

Figure 13: Mock tracks in loam soil, with two out of three (top and right) covered by dissimilar sand.

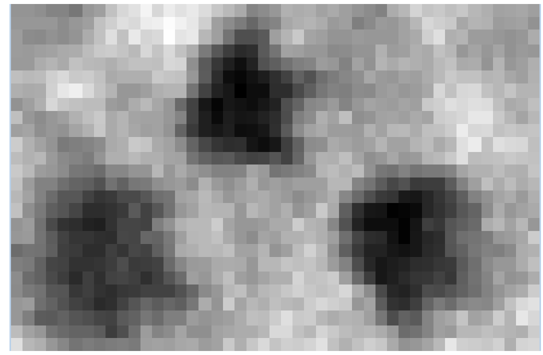


Figure 14: Rascan 4 GHz image of mock tracks in loam covered by dissimilar sand (top and right), and identical loam (left).

IV. SURFACE RELIEF EFFECTS

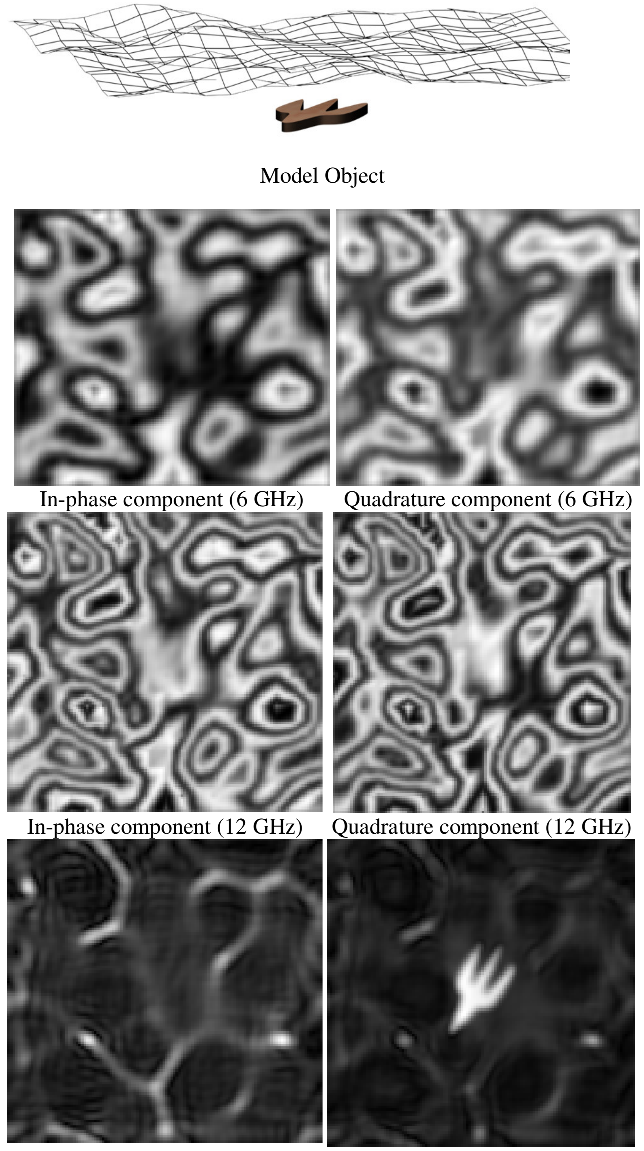
Note that the successful hidden track scans (section III) were performed on models with flat scanning surfaces, and that the scans of actual tracks exposed on real surfaces (section II) display contrast patterns related to the relief of the surface. Thus it is expected that the contrast patterns from relief on actual surfaces could serve to overprint and obscure hidden tracks.

To address this anticipated difficulty, two approaches are underway. One is to build a lightweight robotic scanner [13] [14] that would not only obviate walking of human operators on potentially fragile tracksites, but the robot could either control or measure the sensor height using LIDAR or ultrasound, thereby eliminating surface relief effects from the raw images.

An even simpler alternative may be to use an inert material (such as sand) with dielectric matching the local rock to produce a smooth scanning surface. Of course, our experiments suggest that this will obscure in the Rascan images any exposed tracks that do not have a biotic or mineral coating different from the non-track rock surfaces.

Alternatively, a recently developed variety of Rascan that uses both phase difference and quadrature information [15] could be combined with algorithms that are being developed to “focus” the Rascan images at specific depths. Fig. 15 depicts a model of a track (representing any type of dielectric contrast) beneath an undulating surface. Fig. 16 shows a single image display of the reconstructed hologram for a Rascan 6 GHz image using the combined phase and quadrature data, along with data similarly processed but for a range of frequencies between 6 and 12 GHz.

This modeling shows that processing to remove surface effects will require broadband in-phase and quadrature data to produce images beneath non-smooth surfaces. This development may be more difficult and distant than the modification of an existing robotic system [13] [14] to create raw images recorded without surface relief effects.



Model Object

In-phase component (6 GHz) Quadrature component (6 GHz)

In-phase component (12 GHz) Quadrature component (12 GHz)

Components combined for one frequency hologram (6 GHz)

Components combined for wide-band hologram (6 – 12 GHz)

Figure 15: Reconstructed holograms for a model track hidden beneath an irregular surface.

V. CONCLUSIONS

Scanning of real, mock, and numerical model dinosaur tracks has shown that Rascan can detect both exposed and hidden dinosaur tracks, and could be a valuable tool for making complete mappings of only partially exposed trackways or tracksites. However, contrast patterns due to the scanning surface relief will obscure hidden tracks. We have identified and performed preliminary evaluations of several methods that might be used to overcome this obstacle, and hope that we can eventually provide a tool for rapid and completely non-destructive detection and mapping of dinosaur tracksites.

VI. ACKNOWLEDGMENTS

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