UNIVERSITÀ DEGLI STUDI FIRENZE

DINFO
Dipartimento di Ingegneria dell'Informazione

Ciclo seminari DINFO
"Tecniche radar: ricerche in corso"
Lunedì 10/06/2013 – aula 205 (ore 14.00)

Applicazioni del Radar Olografico per Controlli Non Distruttivi

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Laboratorio Ultrasuoni e Controlli Non Distruttivi

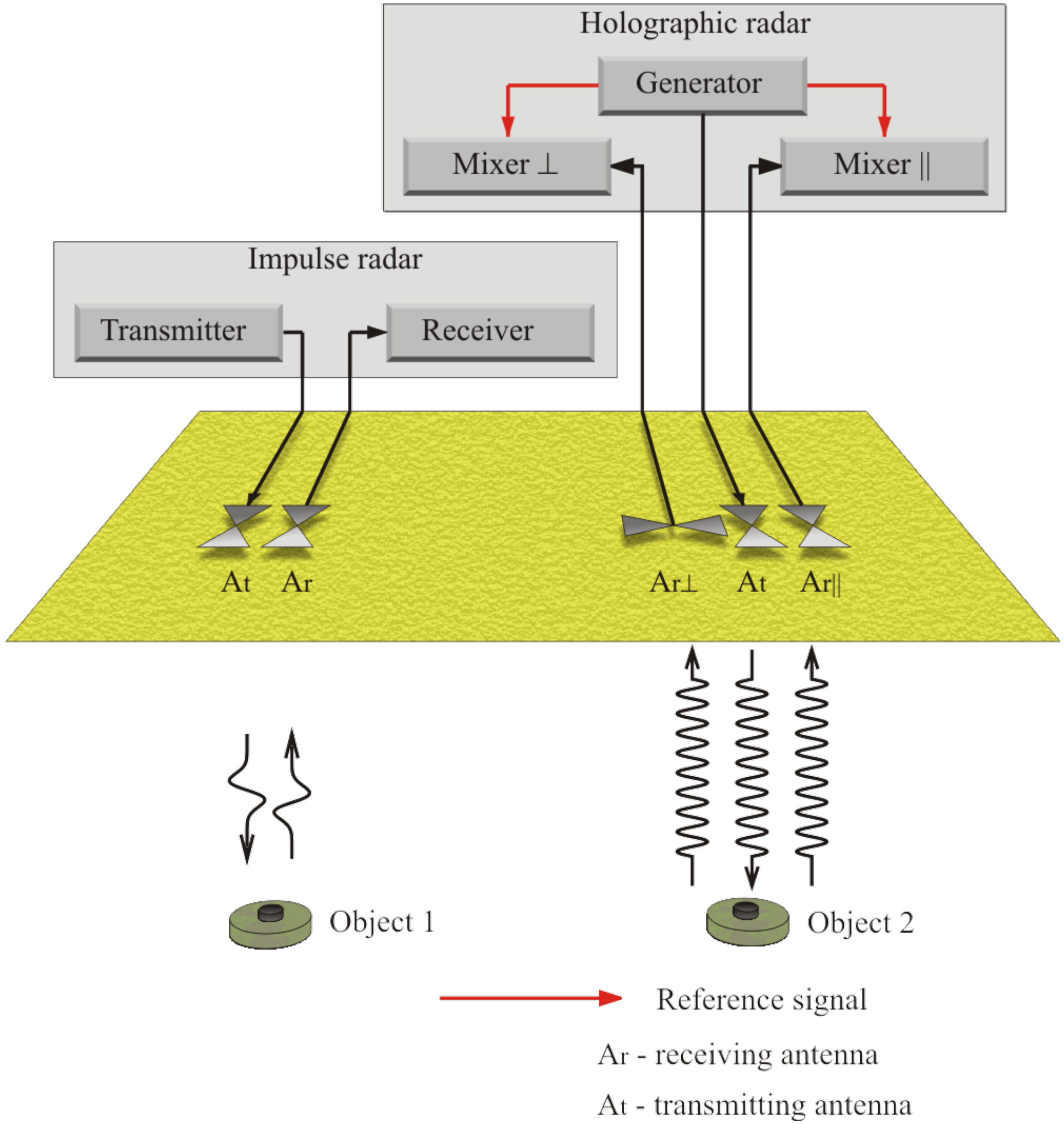
Seminar outline

1. Operating principle of holographic radar
    - Holographic radar *vs* impulse radar
2. Equipment description and scanning methods
3. Case Studies:
    - Civil engineering structures and historical buildings
    - Cultural heritage
    - Landmines detection for Humanitarian Demining

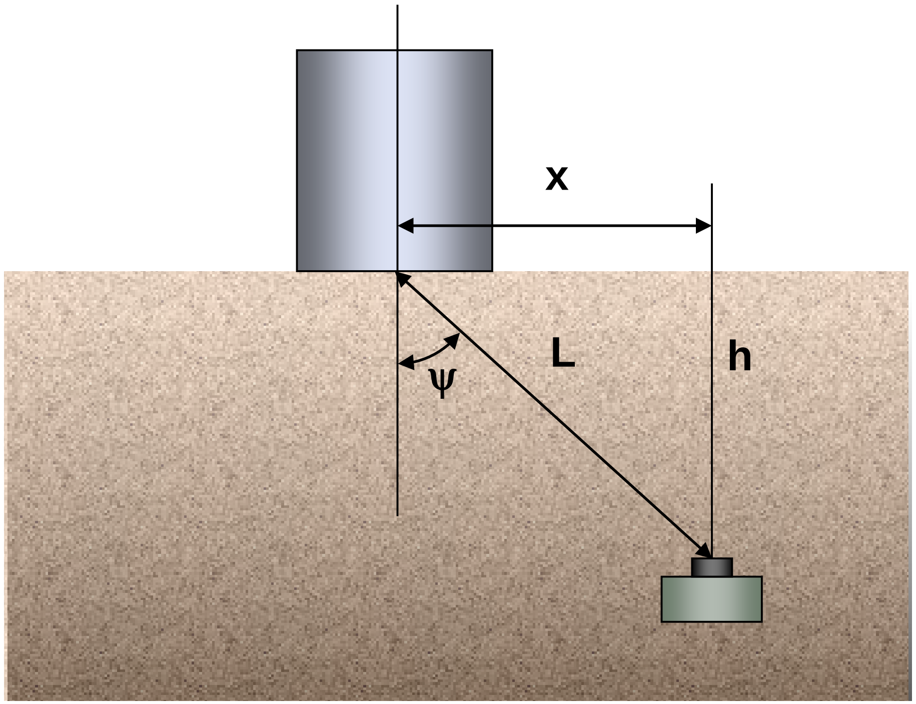
Section 1 :

Operating principle of holographic radar

Comparison of Operational Principles of Impulse and Holographic Subsurface Radars'



Signal Recording in Holographic Radar



Receiving signal

$A_r(L, \psi)\cdot\cos\{\omega t + \varphi_o(h) + \Delta\varphi(x,h)\}$

$\varphi_o = 2\,\omega\,h/c'$; $c' = c/\sqrt{\varepsilon}$

$\Delta\varphi = 2\,\omega(L-h)/c'$; $L = \sqrt{(x^2+h^2)}$

Reference signal

$A_o\cdot\cos\{\omega t + \theta_o\}$;

θ_o – phase shift of reference signal

Signal after mixer at difference frequency

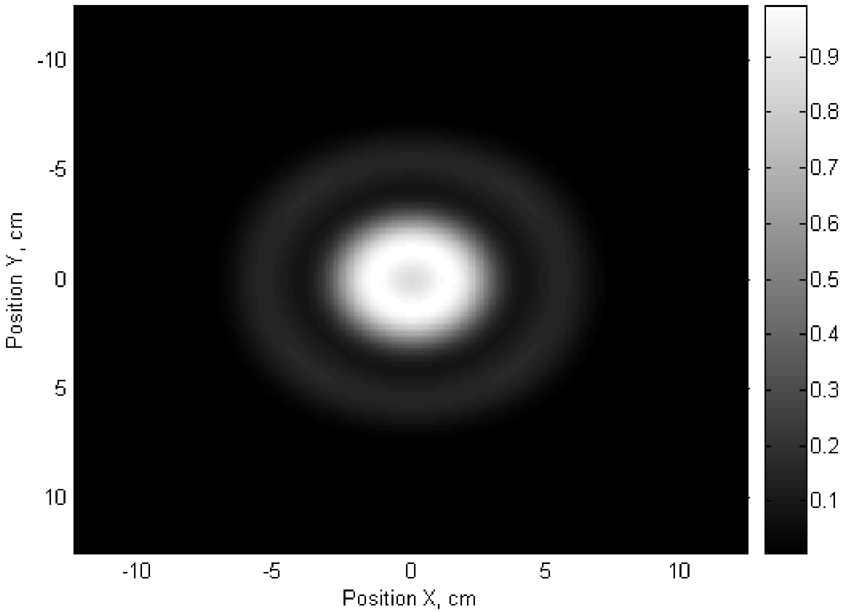
$A_o\cdot A_r(L, \psi)\cdot\cos\{\theta_o - \varphi_o(h) + \Delta\varphi(x,h)\}$

If $\theta_o - \varphi_o(h) = (k+1/2)\cdot\pi$; $k=0,1,2\ldots$, recording signal is minimal at nadir.

If $\theta_o - \varphi_o(h) = k\cdot\pi$; $k=0,1,2\ldots$, recording signal is maximal at nadir.

Point Source Hologram

Parameter	Value
Discretization grid size	256x256
Open space wavelength, cm	7
Point source depth, cm	4
Complex permittivity of lower half-space	4 + 2*i*
Point source reflectivity coefficient	1
Complex amplitude distribution over antenna aperture	in-phase uniform
Aperture type	circular
Aperture size (radius), cm	5.25



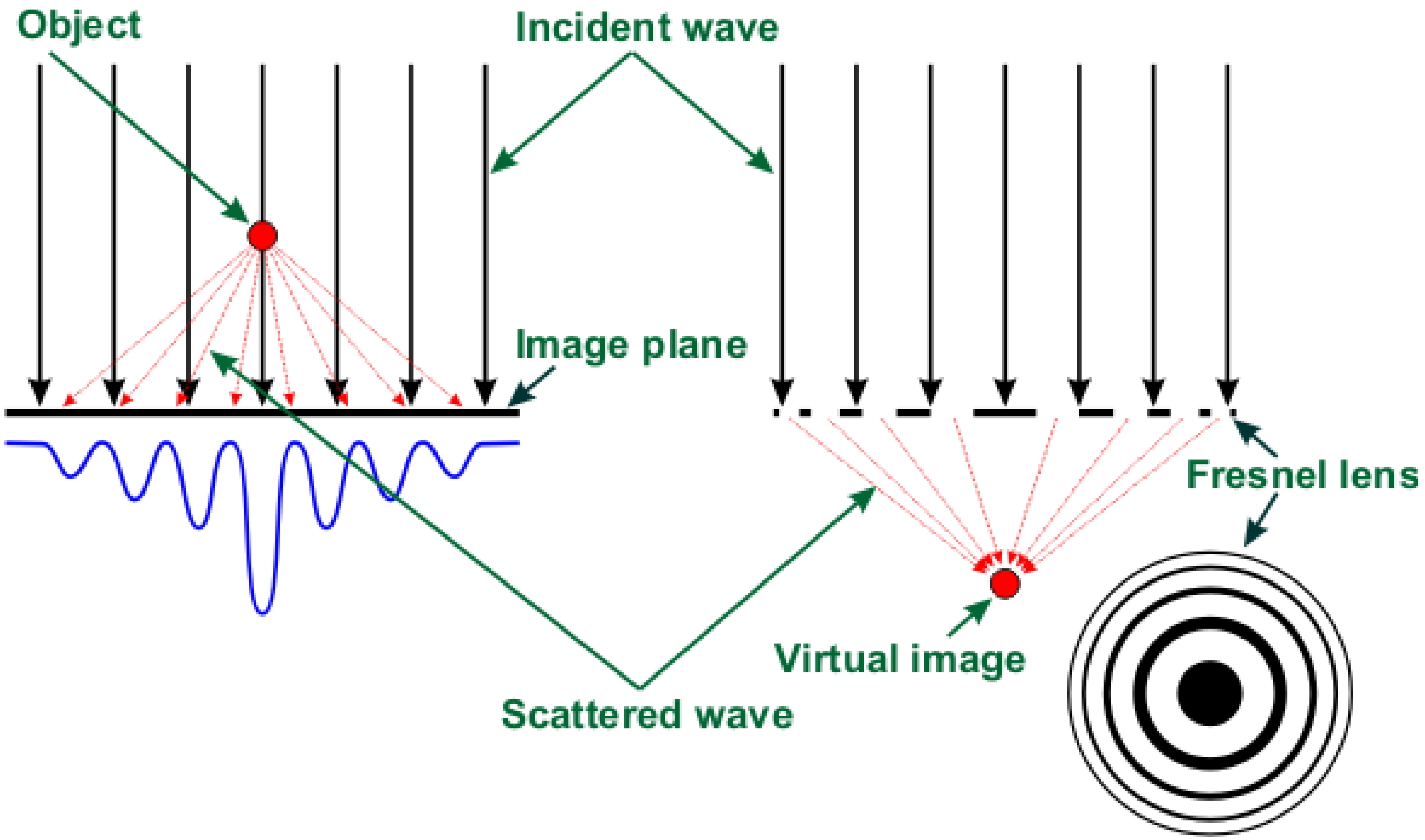
Emerging problem:

* **Hologram is small** and not greater than antenna aperture, there is not many interference rings due to antenna directivity pattern and attenuation in soil

What to expect:

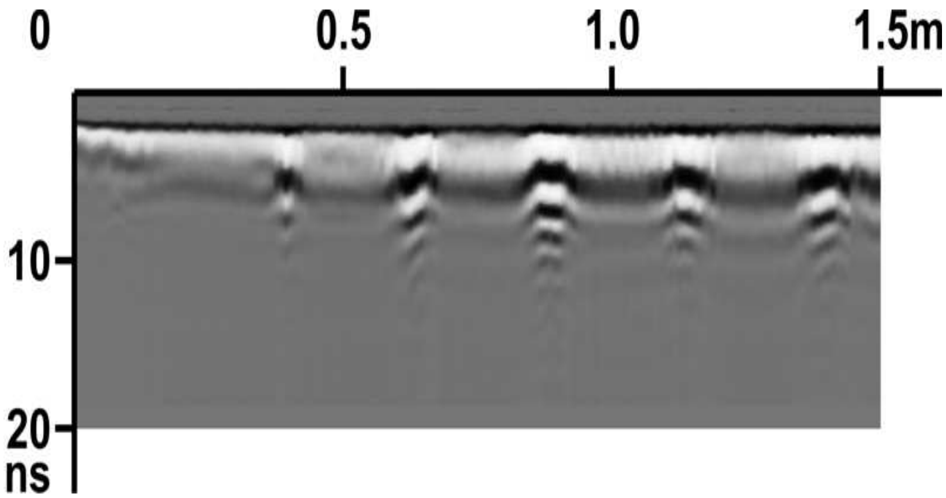
* The best reconstruction algorithm could only give a solid blob of the same size. It is **not possible to improve the result significantly**.

Optical Analogy for Holographic Radar



a) Recording of an interference pattern **b) Reconstruction of a hologram**

Comparison between Holographic and Impulse Subsurface Radar



At shallow depths, holographic radar has a distinct advantage in resolution over impulse radar because the radar frequency range can be easily adapted to the demands of a particular task.

Another extremely important advantage of this holographic radar technology is the possibility that it can image, without reverberation, dielectric materials that lie above a metal surface.

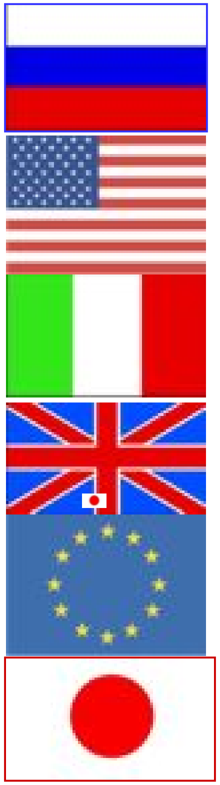
Comparison of Impulse and Holographic Subsurface Radars' Parameters

Parameters	Impulse Radar	Holographic Radar	Remarks
Frequency spectrum	Continuous	Discrete	Rascan works with 5 discrete and programmable frequencies
Penetration depth	Up to 10 λ	1-2 λ	λ – wave length in air
Resolution at shallow depths in plan of surveying	> λ	~ 0.25 λ	λ – wave length in air
Surveying over metal substrate	Hardly possible	Possible	Reverberation prevents using impulse radar over metal surface
Possibility of object's depth measurement	Directly from recorded signal	?	This task for holographic subsurface radar does not have a proper solution yet
Adaptation to the FCC norms	Difficult	Much easier	Frequency spectrum of holographic radar could be selected in advance. Impulse radar has a UWB spectrum that can't be changed or limited arbitrarily
Radar cost, USD	15,000-45,000	~ 5,000	

Section 2:

Equipment description and scanning methods

Research working group

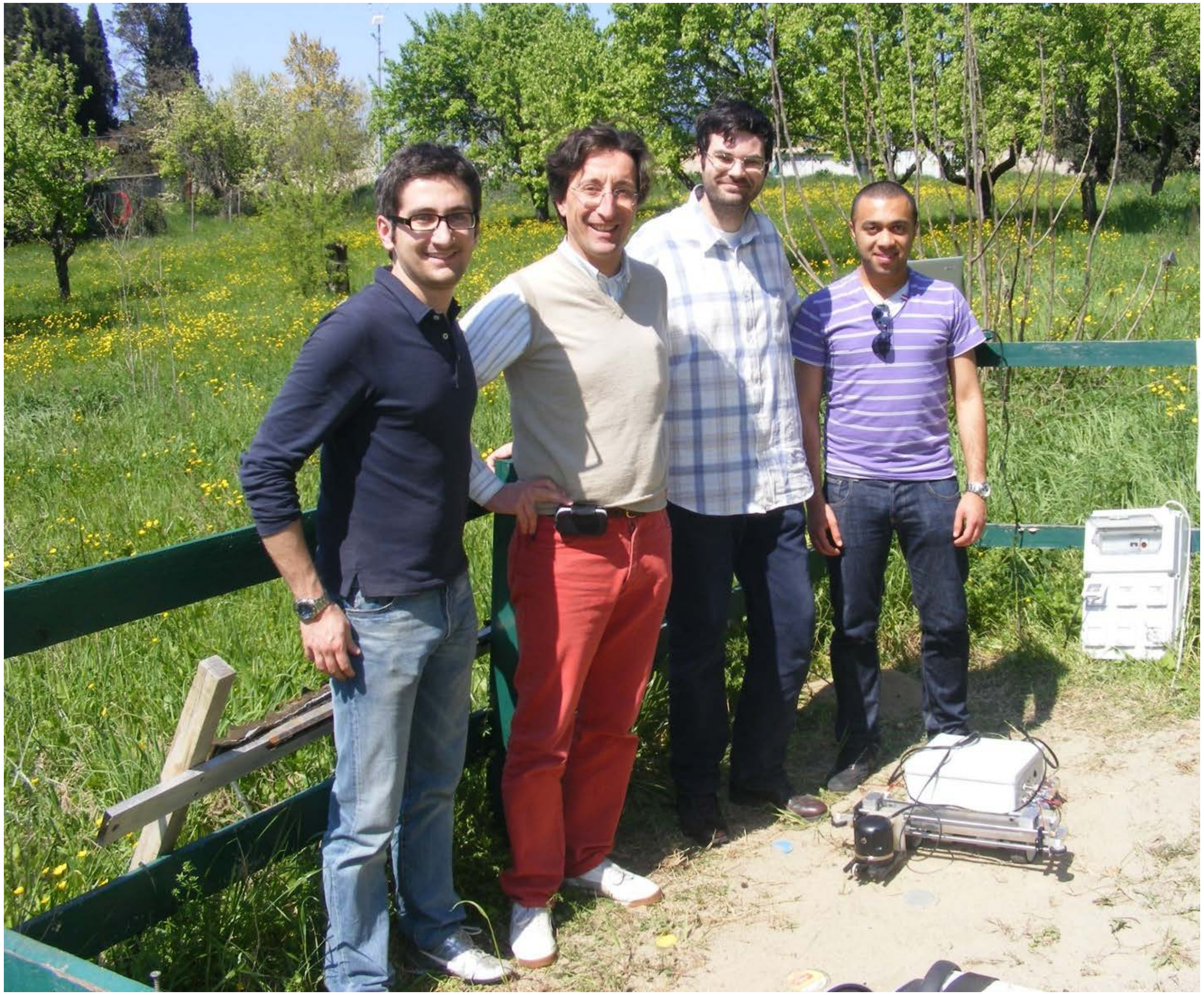


WWW.RASCAN.COM

RASCAN-4/4000 Radar

Manual Scanning Method

ROBOTIC Scanning Method



Scientific American 2010

https://www.scientificamerican.com/video.cfm?id=holographic-radar-u-of-2010-07-21

Section 3:

Case Studies.

- Civil engineering structures and historical buildings
- Cultural Heritage
- Landmines detection for Humanitarian Demining

Inspection of the Senate Building in St. Petersburg, Russia



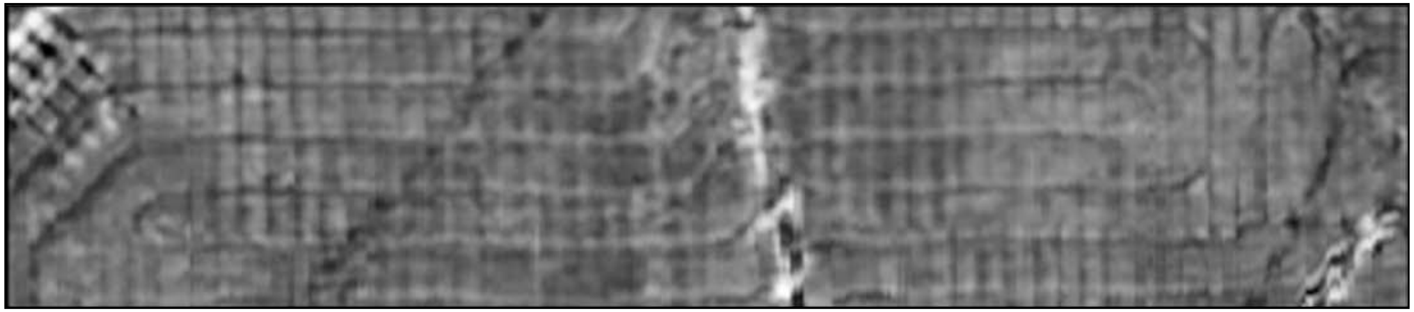
Radar RASCAN-4/2000 in operation

Observation of the wells in the floor revealed presence of power and communication cables, in addition to the heating pipes, whose exact path under concrete cover was undocumented. Those circumstances added to the overall problem.



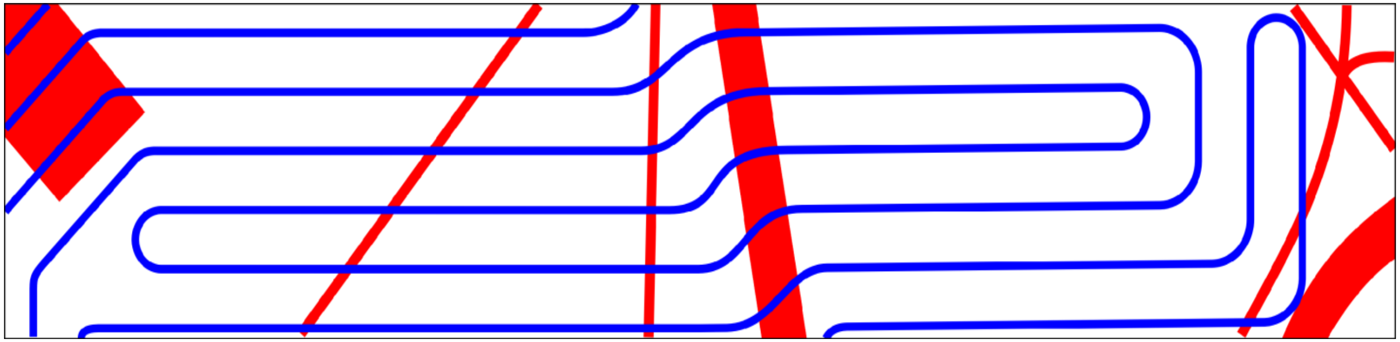
Variety of cables in concrete floor

Parallel polarization



Cross polarization

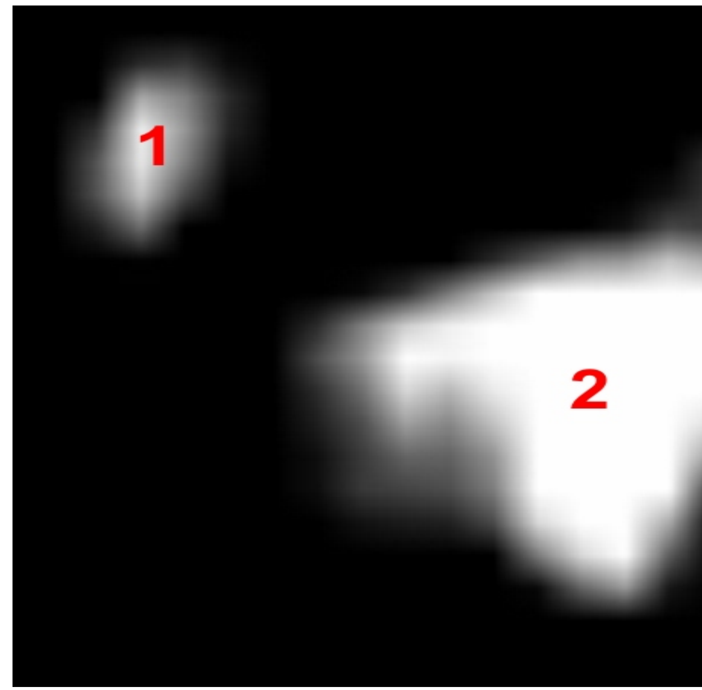
Merged raw radar images at frequency of 2.0 GHz.
The overall image dimensions are 1.70 m x 8.04 m



Layout of pipes and communications

Non Destructive Inspection of Space Shuttle Heat Protection Tiles

Different types of Space Shuttle tiles were used in experiments



A result of tile inspection by Rascan-4/4000 radar

Section 3:

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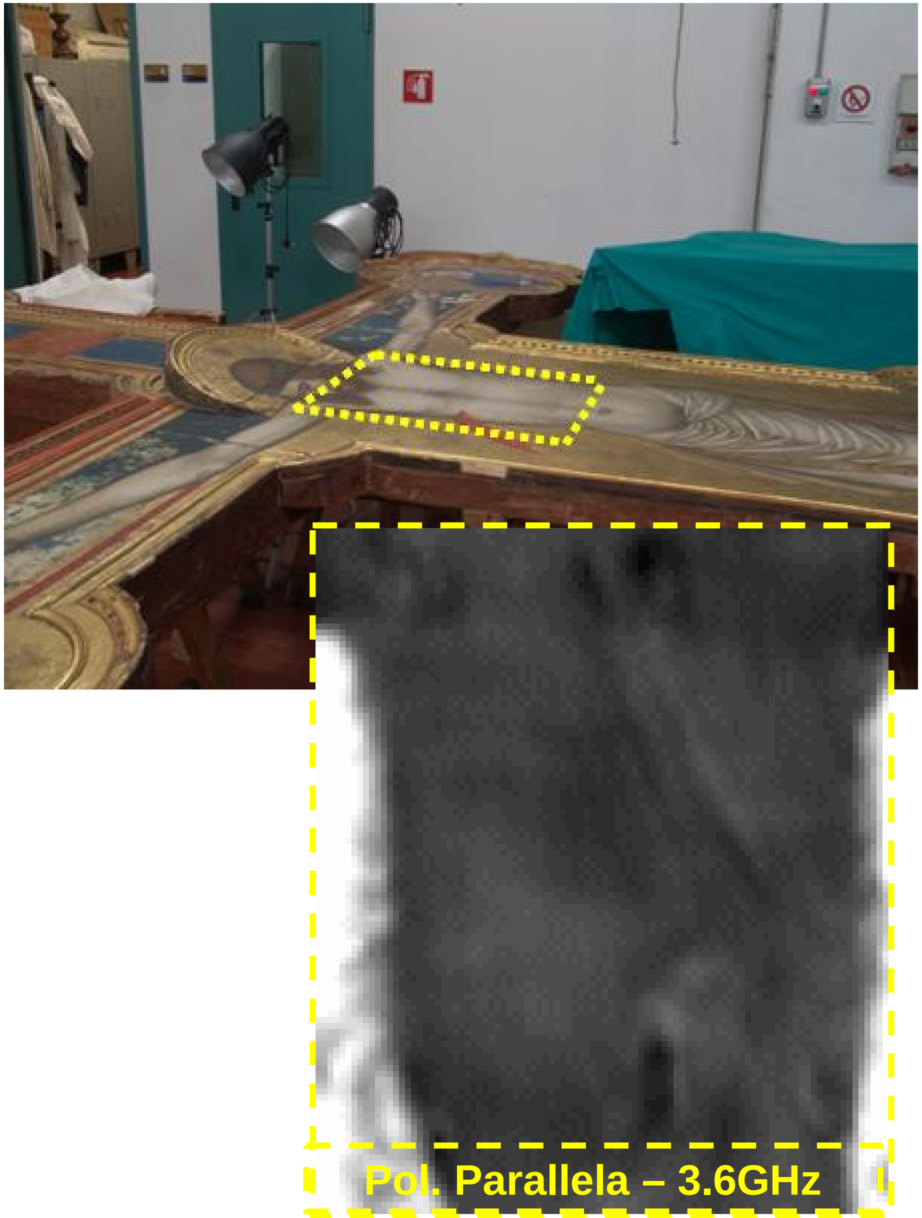
Diagnostica non distruttiva con radar a microonde per opere d’arte murarie e lignee

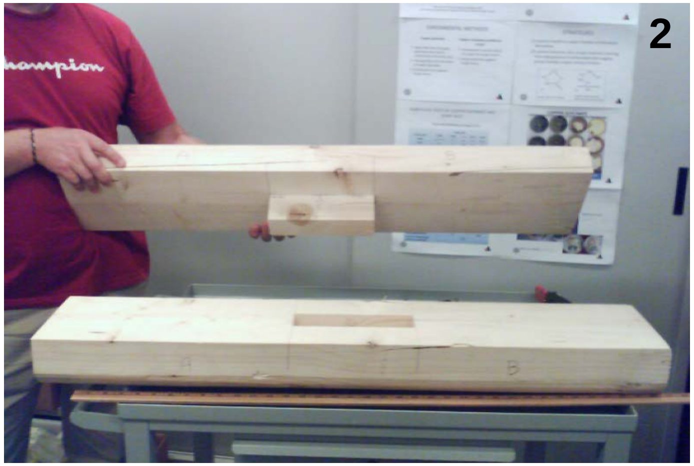
FLORENS 2010

Salone de’ Dugento , 15 Novembre 2010

Analisi della Croce di S. Marco

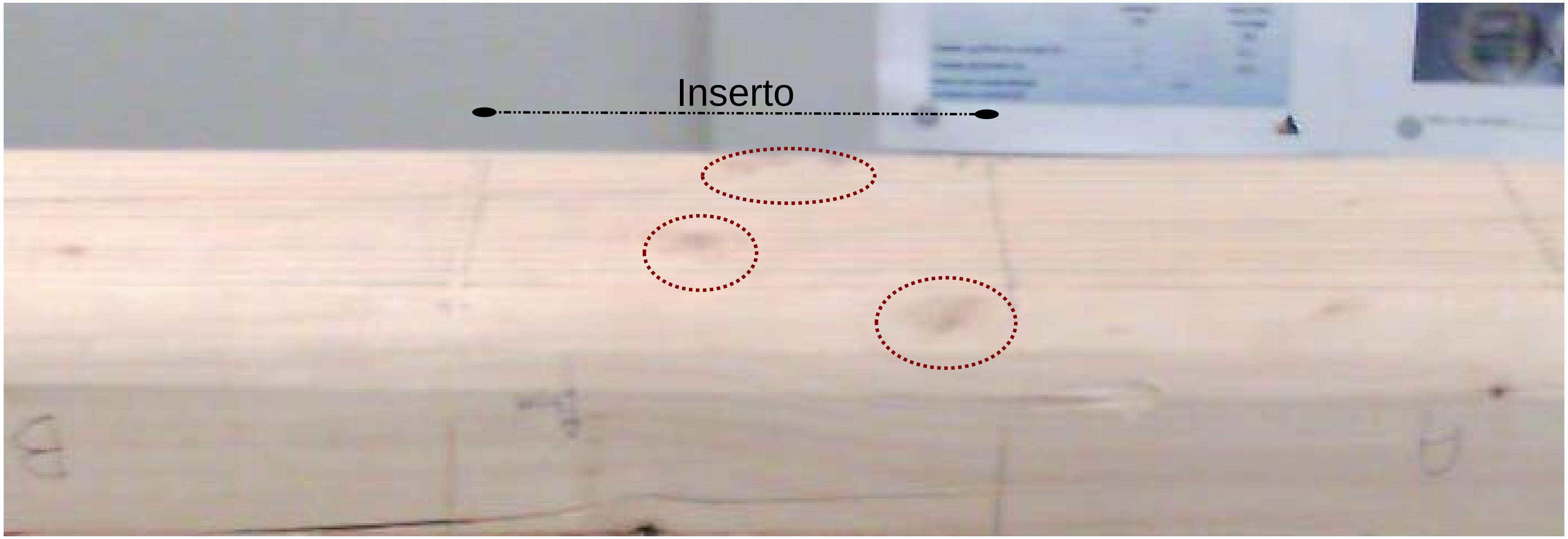


Trave con attacco da insetti simulato



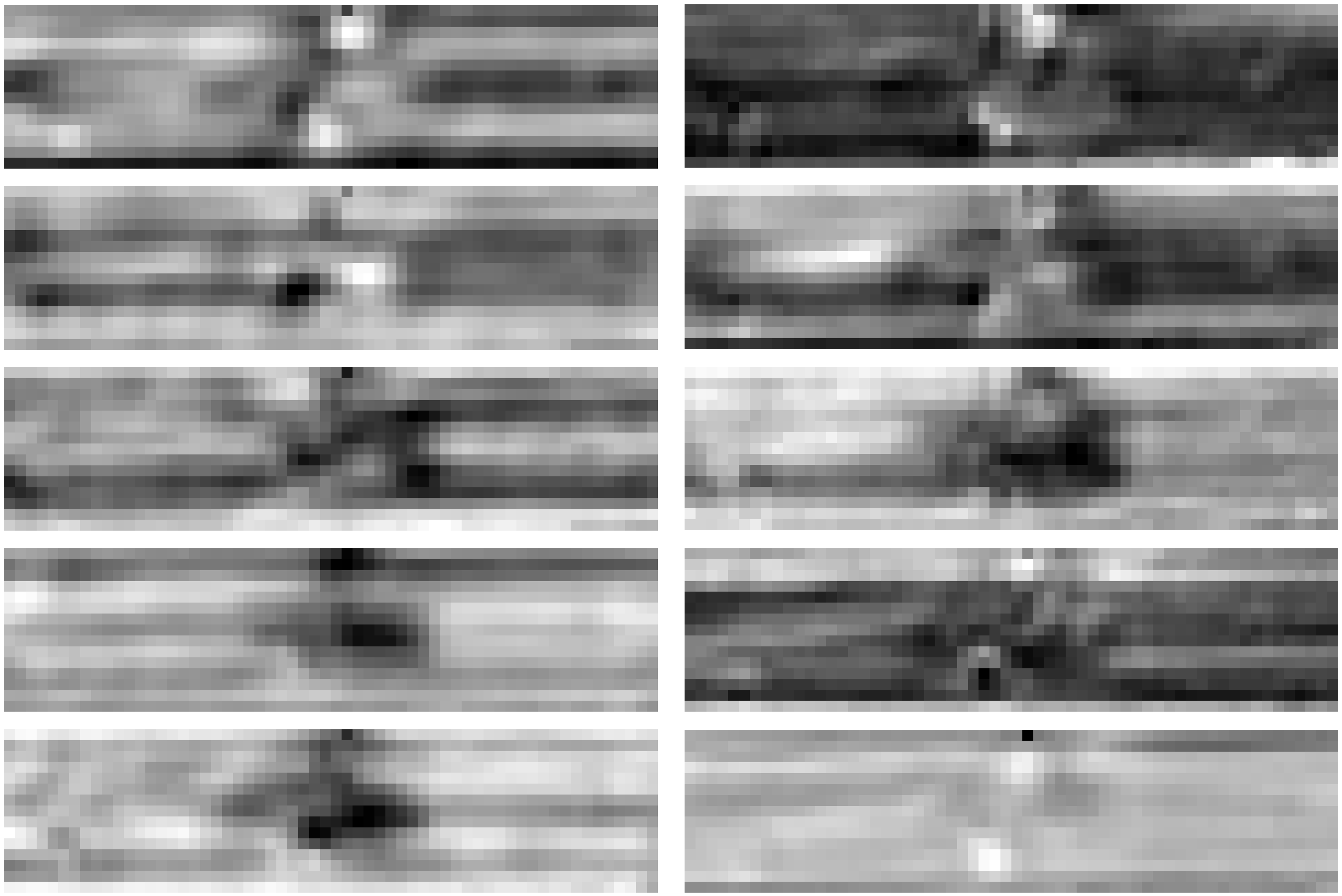
Stato della zona di inserto

- La trave presenta tre nodi nella zona dell'inserto.
- Lunghezza d'onda nel legno a 4GHz va da 2cm a 3cm, la profondità di penetrazione da 4cm a 6cm ==> necessità del radar a 2GHz.



Profondità blocchetto: 3cm

Polarizzazione parallela | Polarizzazione ortogonale



3.6GHz

3.7GHz

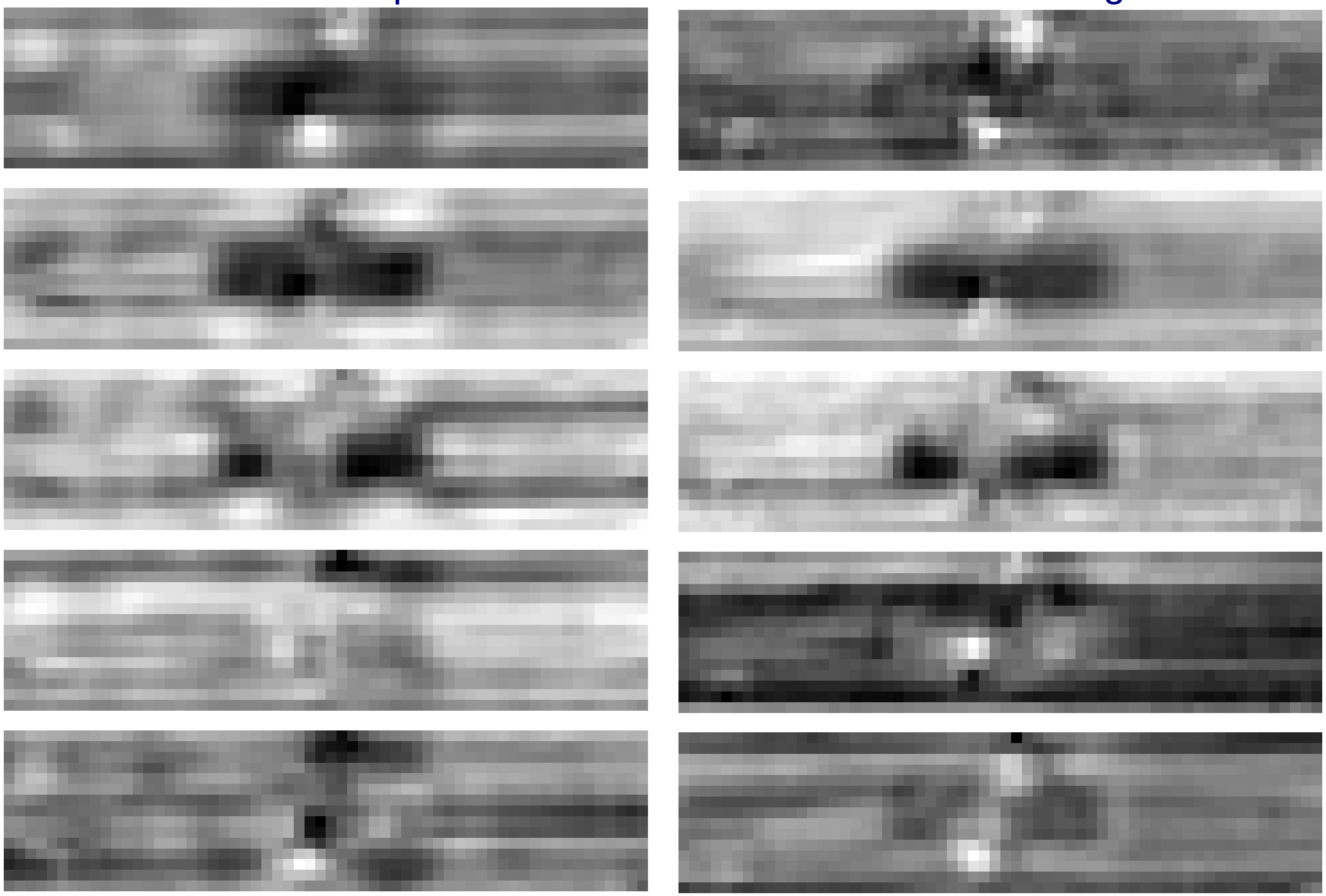
3.8GHz

3.9GHz

4.0GHz

Profondità vuoto: 3cm

Polarizzazione parallela | Polarizzazione ortogonale



3.6GHz

3.7GHz

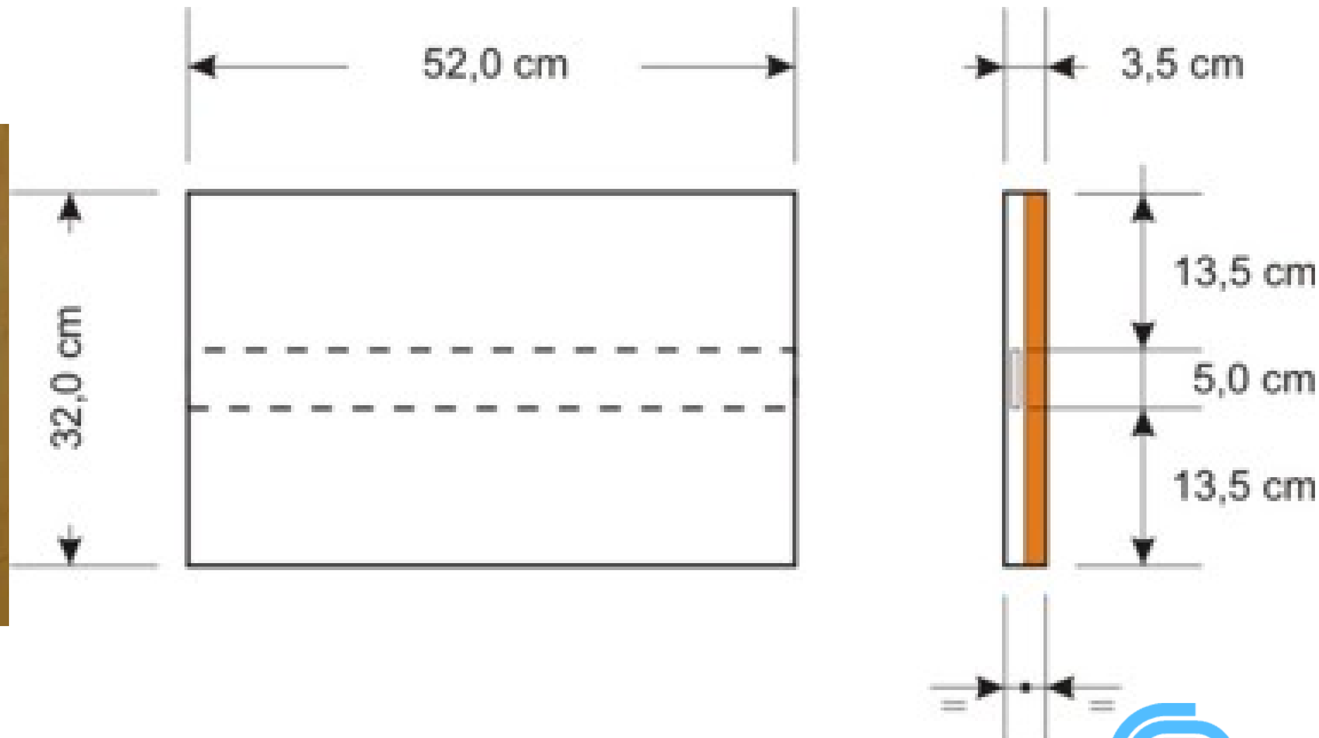
3.8GHz

3.9GHz

4.0GHz

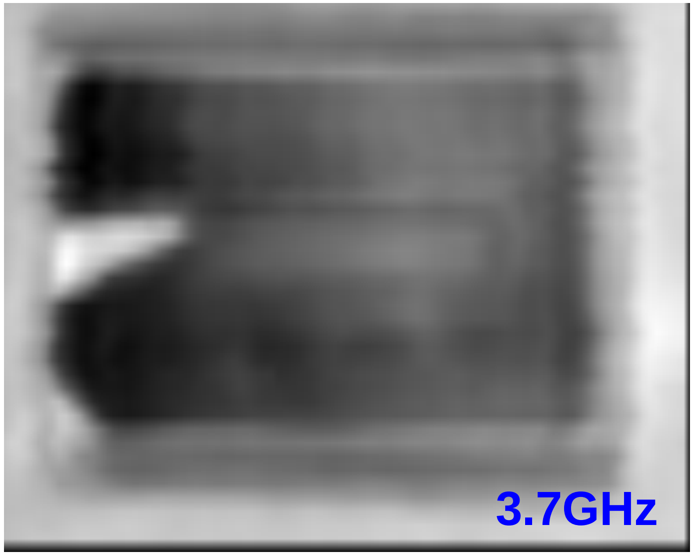
Misure su modelli: Provino di arriccio

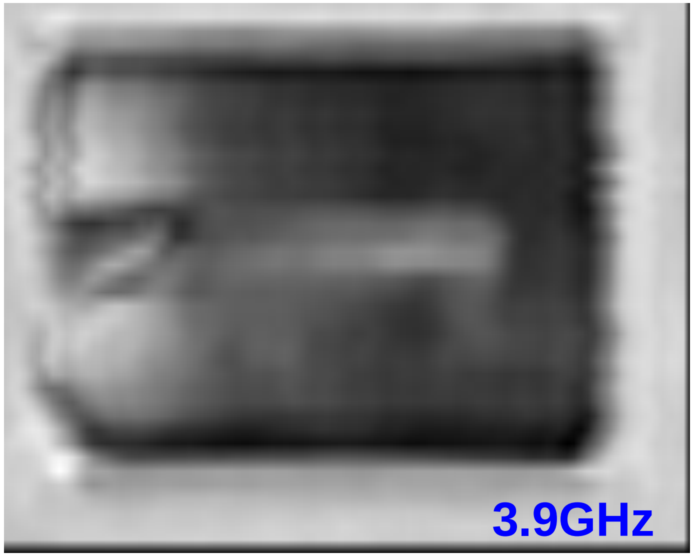
- Provino di malta (arriccio) su supporto di terracotta (pianella) con fessura praticata nello strato di arriccio ad una profondità di circa 1cm.

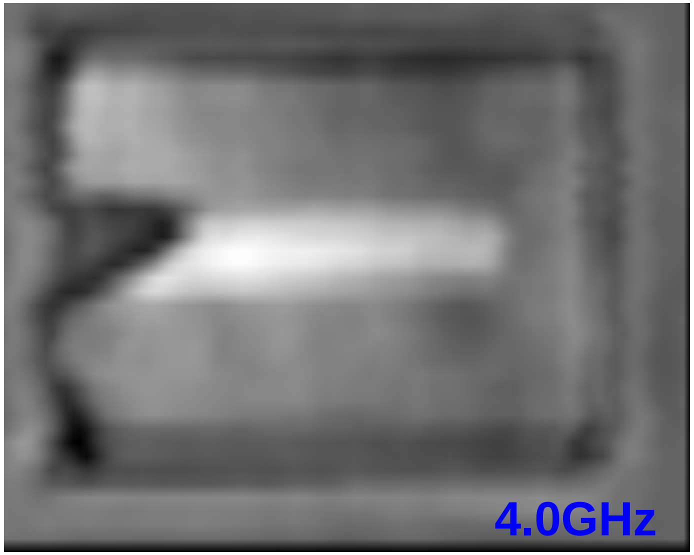


Immagini con Radar Olografico

- Area: 50x40cm^2
- Campionamento: 1cm
- Frequenza max: 4GHz
- Polarizzazione: parallela







Indagini per la ricerca di reperti in ambito di siti di interesse paleontologico e archeologico

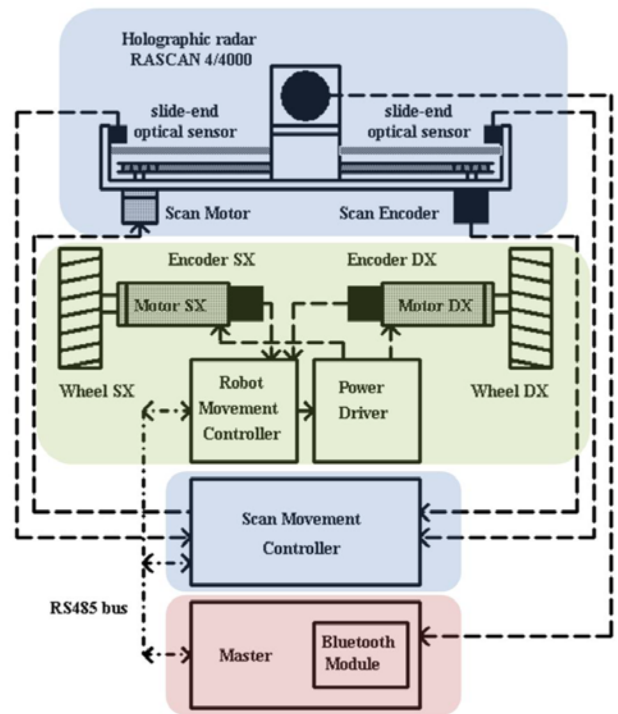
Requisiti:

- Scansioni subsuperficiali di grandi aree
- Superfici irregolari e/o in pendenza
- Immagini in tempo reale per il riconoscimento di forma e dimensioni degli oggetti

RADAR OBJECT Scanner
High-Resolution - *real-time* subsurface imaging

See video Radar Object Scanner at :
http://www.youtube.com/watch?v=G6lM2-Qixyg&feature=youtu.be

Block diagram of the robot

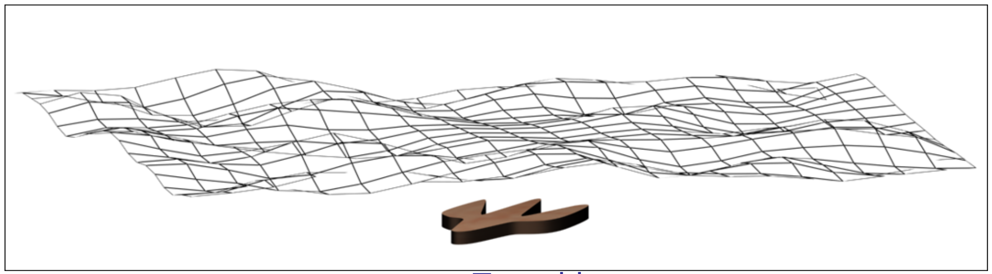


Scanning control system

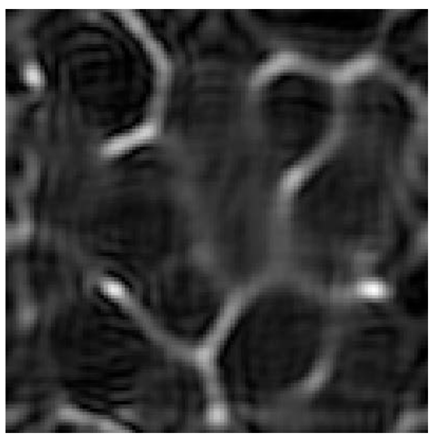
Movement control system

Communication control board

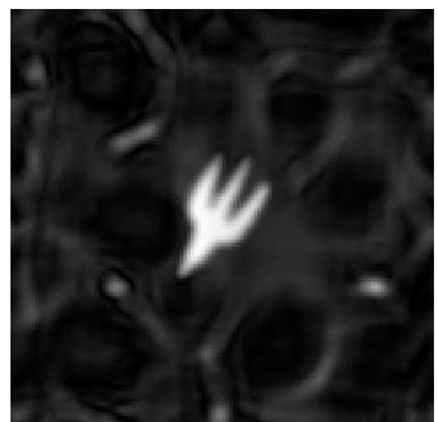
Simulazione dell’immagine olografica a microonde di un’impronta di un dinosauro tridattile



Test object



for one frequency hologram
***f* = 6 GHz**
(you can see nothing)



for wide-band hologram
***f* = 6–12 GHz**

Result of reconstruction

Images submitted for publication at IWAGPR2013 by RASCAN group (www.rascan.com)

Sperimentazione con robot scanner presso il Parco dei Lavini di Marco (Museo Civico di Rovereto)

Sperimentazione preliminare su impronta di un dinosauro tridattile

Immagine olografica di una impronta sub-superficiale

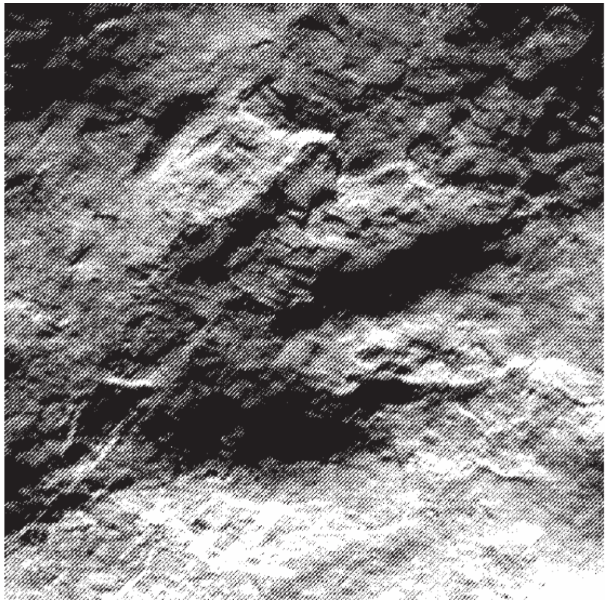


Immagine ottica di una tipica impronta superficiale

Section 3:

Case Studies.

- Civil engineering structures and historical buildings
- Cultural heritage
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Comparison of Impulse and Holographic Radar

Impulse	Holographic
	
GSSI: Hudson, New Hampshire, USA	**RSLab: Bauman Moscow Technical University, Russia**
StructureScan	**RASCAN-4/4000**
1.5 GHz Center Frequency	**5 Discrete Frequencies, 3.6-4.0 GHz at 2 polarizations**
	To mimic the MiRASCAN/ISTC Device, a separate MetalScan head was also used

Sensors Characteristics

	MetalScan	RASCAN	StructureScan
Nominal Parameters			
Frequency spectrum:	2MHz induction	3.6, 3.7, 3.8, 3.9 and 4.0GHz	UWB centered at 1.5GHz
Penetration depth:	5cm	1-2 λ	up to 10λ
Resolution at shallow depths in image plane:	3cm	0.25 λ	> λ
Imaging Capabilities	Direct from recorded signal	Direct from recorded signal	Indirect (requires migration and stacking of B-scans)
Target depth measurement:	None	None	Direct from time-of-flight
Ease of adaptation to EMI reference standards:	Simple	Simple	Difficult
Relative Cost:	Low	Low	High

Landmine Simulants

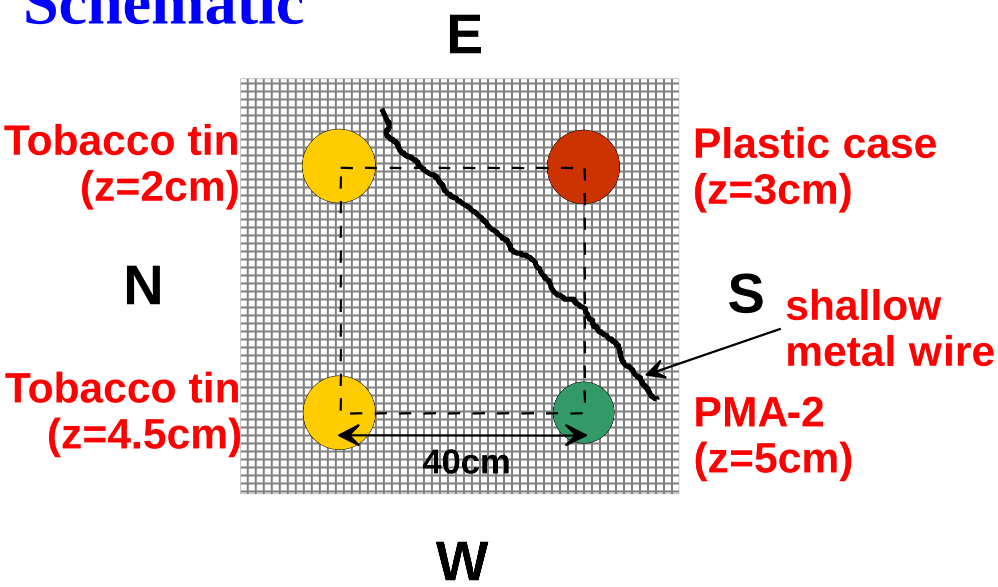
PMA-2 model by C. King Associates Ltd.
∅=6.9cm
Plastic Body
Filled with RTV 3110 (k similar to actual trotyl explosive)

Pipe Tobacco Tin
∅=10.5cm
Metal Body
No Filling

Headlamp Case
∅=10.5cm
Plastic Body
No Filling

Landmine Simulant Geometry

Schematic

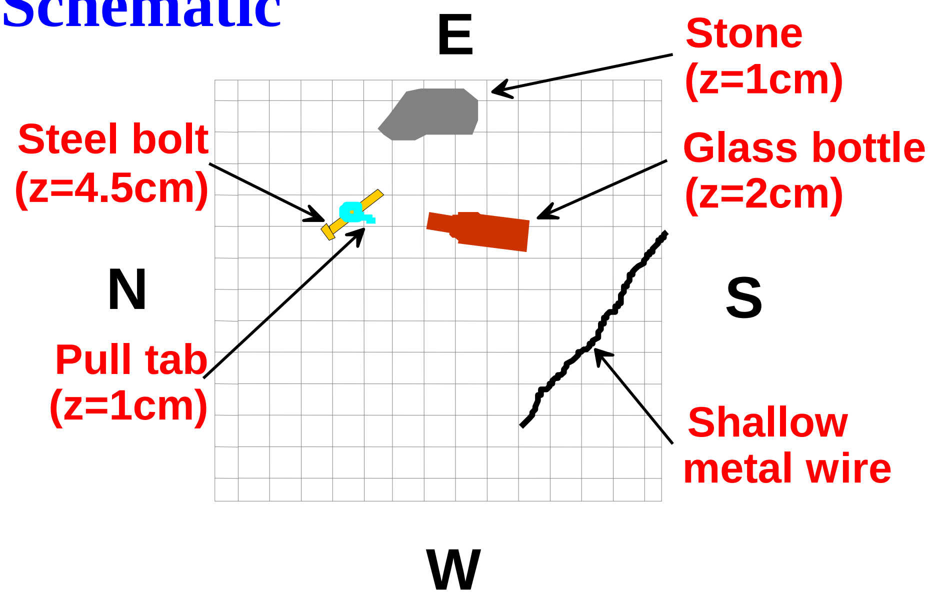


Photograph

Depths were determined by probing following burial.

Clutter Geometry

Schematic



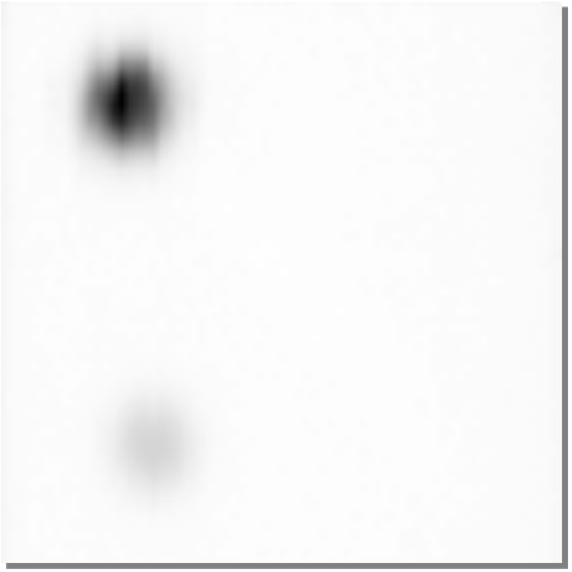
Photograph

Pull tab was inadvertently installed on top of bolt.

Depths again determined by probing following burial.

Landmine Simulant Images

MetalScan



Single induction metal detector image

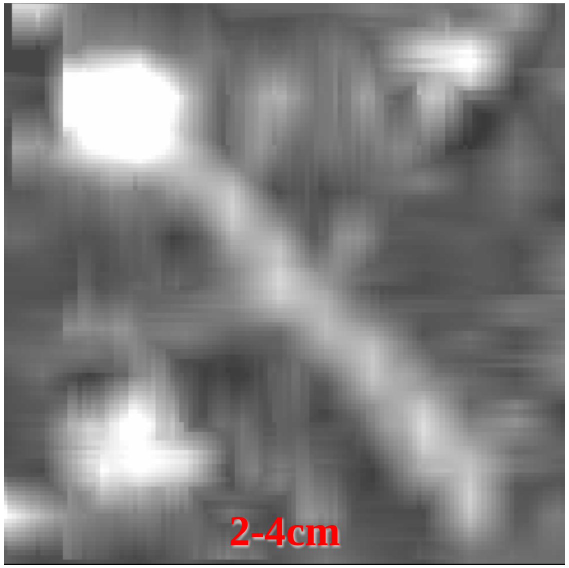
- Two metal targets
- No image of wire

RASCAN

Cycling through 10 images (5 frequencies at 2 polarizations)

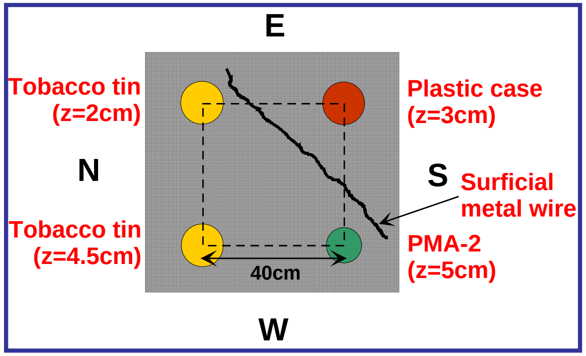
- Two metal, one plastic targets
- PMA-2 off grid ☹
- Clear image of wire
- Visible knee print (porosity effect?)

StructureScan



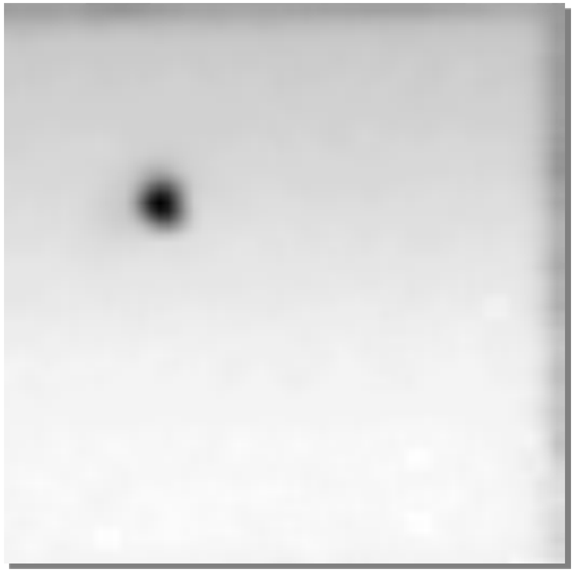
Cycling through 5 depth slices

- Two metal, one plastic targets
- PMA-2 off grid ☹
- Clear image of wire



Clutter Images

MetalScan

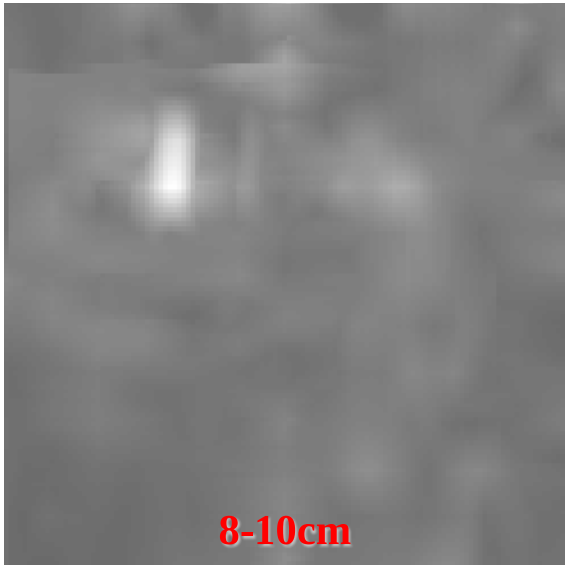


Single induction metal detector image

RASCAN

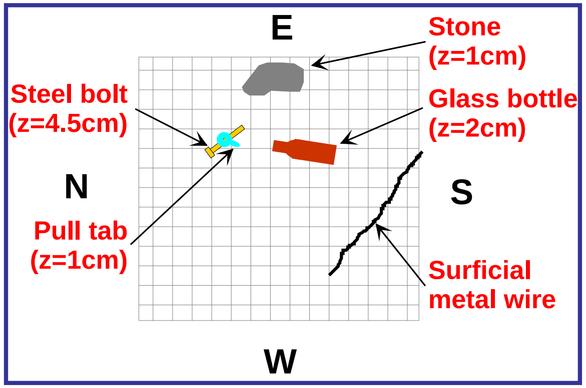
Cycling through 10 images (5 frequencies at 2 polarizations)

StructureScan



Cycling through 5 depth slices

- Shallow pull tab only



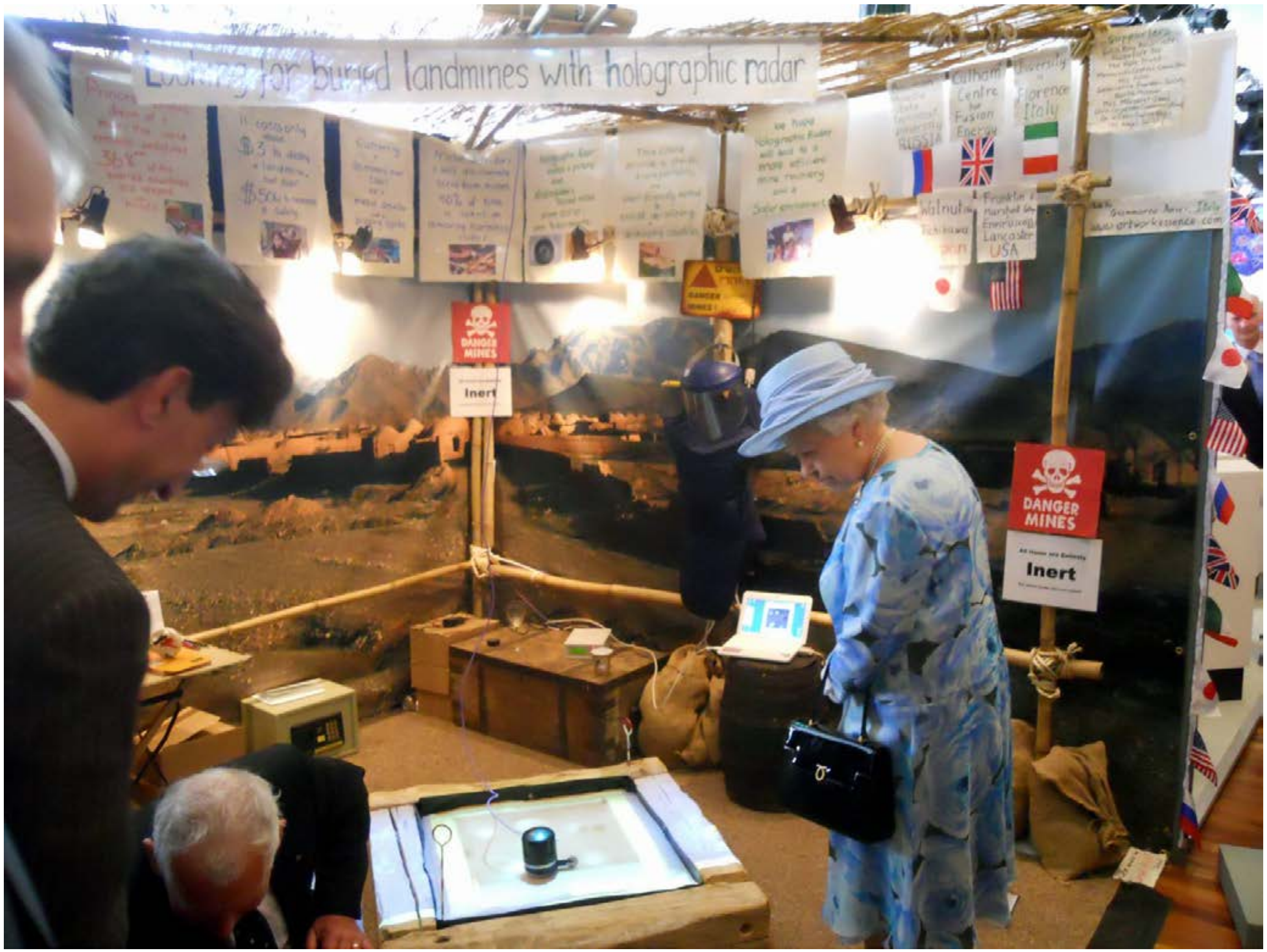
- All targets visible
- Pull tab distinct from bolt
- Clear image of wire

- Pull tab and rock visible
- Deep target may be bolt or ringing of pull tab
- Wire is not clear

Performance Summary

	MetalScan	RASCAN	StructureScan
Observed Parameters (this study)			
Target detection	Good for shallow metal	Good for all targets	Good for Landmine simulants, fair for clutter
Target discrimination	Good for shallow metal	Good for all targets	Good for Landmine simulants, poor for clutter
Target depth measurement	None	None	Accurate
Plan-view imaging of detected targets	Accurate	Accurate	Accurate for landmine simulants, inaccurate for clutter

Summer Science Exhibition – opening cerimony of 350° anniversary Royal Society, London, 23 June 2010



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Prof C.G. Windsor (visiting Professor)

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