Active Thermal Standoff Inspection for Physical Authentication

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Introduction

Arms control and nuclear safeguards inspection regimes require rapid and confident determinations that associated equipment and facilities are authentic and free from tampering. Each party must be able to detect counterfeit items or facility alterations that might enable treaty subversion.

We report on an initial investigation of an active standoff thermal inspection technology, flash thermography, to support arms control and safeguards inspection regimes. We wish to use this approach to help establish the physical integrity of equipment and structures associated with disarmament operations. Periodic inspections must assure the integrity of large structures such as room pipe and duct networks, process containers, and process gloveboxes, since undetected alterations (wall penetrations or hidden ports) may allow material diversion. Inspection to detect tampering or alteration of smaller monitoring equipment such as cabinets, housings, and communications conduit is necessary to support confidence the authenticity of their data and deter material interception. Dismantlement gloveboxes, structural elements, and equipment enclosures must be subject to thorough inspection for subtle alterations to assure confidence in nuclear dismantlement operations. At present, technology for rapid sensing of physical tampering is not available; a broadly applicable standoff method is challenging, since the materials and surfaces in question vary considerably in complexity, composition, and size.

Technology Description

Flash thermography uses a brief but intense pulse of light and an infrared camera to record the surface temperature distribution over time. The dynamic thermal response of the real surface is analyzed for departures from the ideal "black body" cooling response of a uniform semi-infinite slab (Figure 1 and 2). The time derivatives of the infrared intensities at each pixel are computed and mapped . Surface or subsurface nonuniformities or defects can be detected as evidence of tampering in this way since continuum heat transfer is impeded by the material defect. A thorough discussion of the thermographic signal reconstruction (TSR) technique is available.[1]

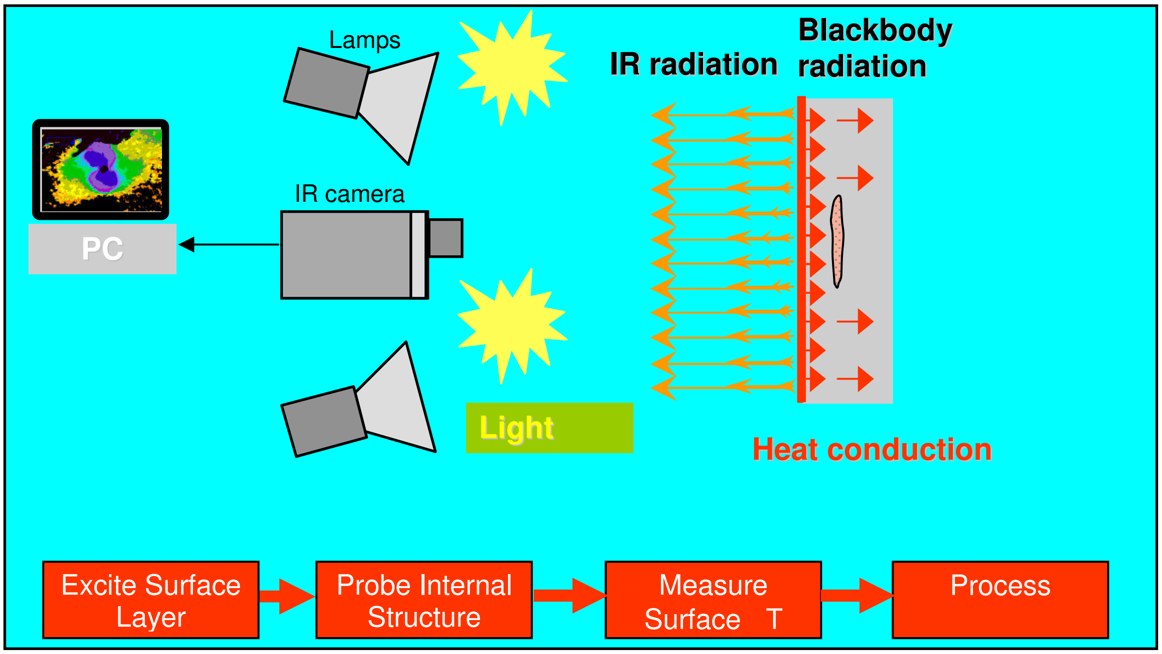


Figure 1. Flash thermography records the transient temperature response to detect material defects

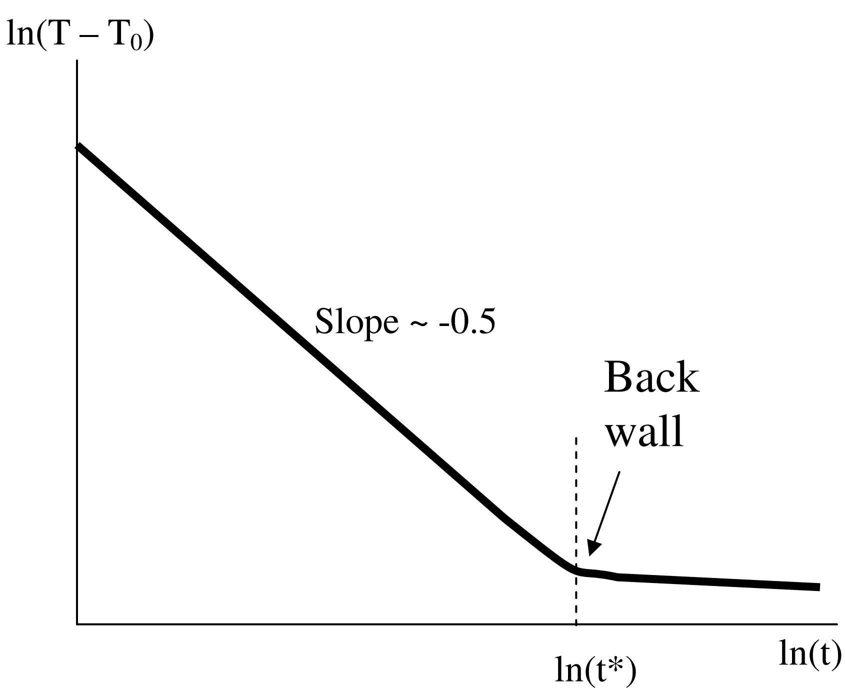
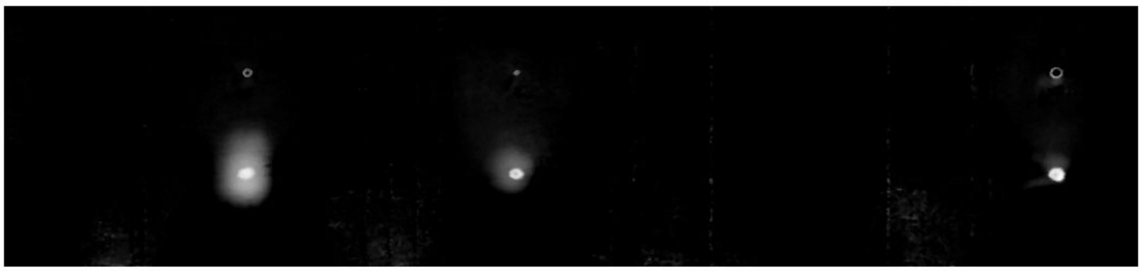


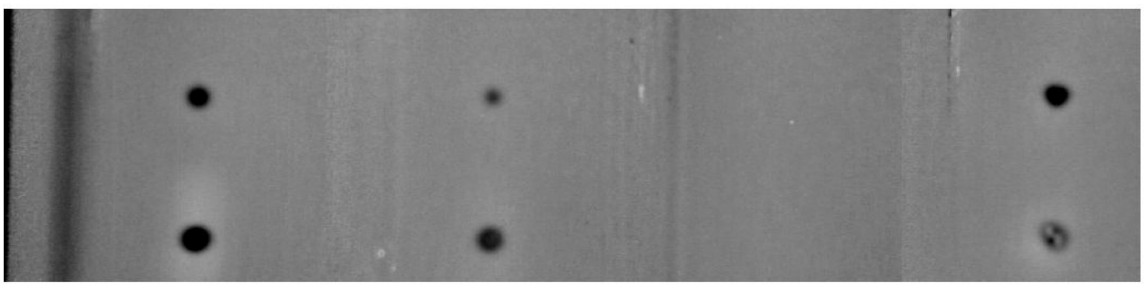
Figure 2. The surface temperature of an ideal uniform slab after an instantaneous light pulse

Exploratory Studies of Tampered Items and Materials

We began studies of flash thermography by attempting to detect artfully repaired holes in a steel instrument case. Such tampering may enable compromise of sensitive electronics. In a prior investigation of eddy current scanning physical authentication [2], a series of small holes (1/16", 1/8", 3/16" diameter) were drilled and plugged so as to remain undetectable in normal visual inspection. We treated the surface of the steel case with a washable black paint coating, and conducted flash thermography analysis. Compared with the eddy current scan, flash thermography detected all but the smallest hole of the set, with the data collection process completed within seconds (Figure 3 and 4). The eddy current scan required a custom fixture, with a data collection period of about 20 minutes.



Eddy Current Scans



TSR image (Flash Thermography – 4 shot MOSAIQ)

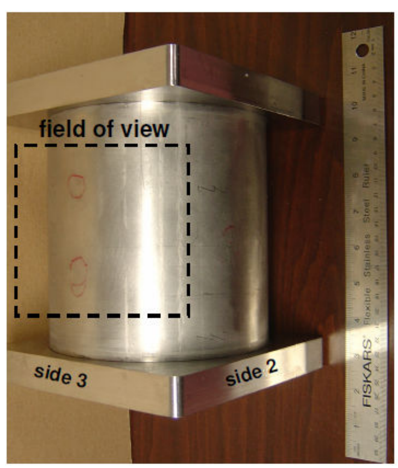
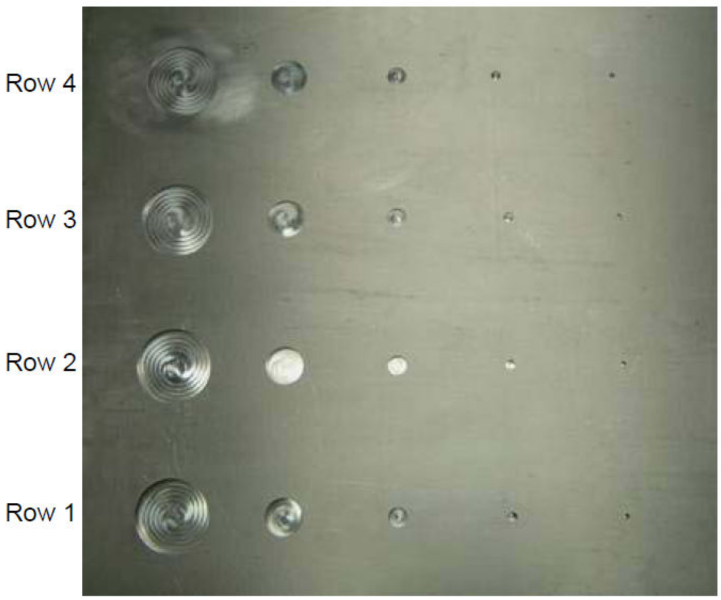


Figure 3. Top: Eddy current scan of steel case with repaired holes. Middle: same case analyzed with flash thermography thermographic signal reconstruction (TSR). Bottom: Steel case with repaired holes region.

We designed a test panel of 0.5” thick aluminum, featuring partially penetrating cylindrical holes (Figure 4, Table 1). The front smooth surface of the panel was analyzed using the black washable paint coating to aid detection (Figure 5).



Aluminum			Aspect
Row	Diameter (in.)	Depth (in.)	Ratio
4	2	0.4	5.0
	1	0.4	2.5
	0.5	0.4	1.3
	0.25	0.4	0.6
	0.125	0.4	0.3
3	2	0.3	6.7
	1	0.3	3.3
	0.5	0.3	1.7
	0.25	0.3	0.8
	0.125	0.3	0.4
2	2	0.2	10.0
	1	0.2	5.0
	0.5	0.2	2.5
	0.25	0.2	1.3
	0.125	0.2	0.6
1	2	0.1	20.0
	1	0.1	10.0
	0.5	0.1	5.0
	0.25	0.1	2.5
	0.125	0.1	1.3

Figure 4. Rear surface, Al panel

Table 1. Defect sizes, Al panel

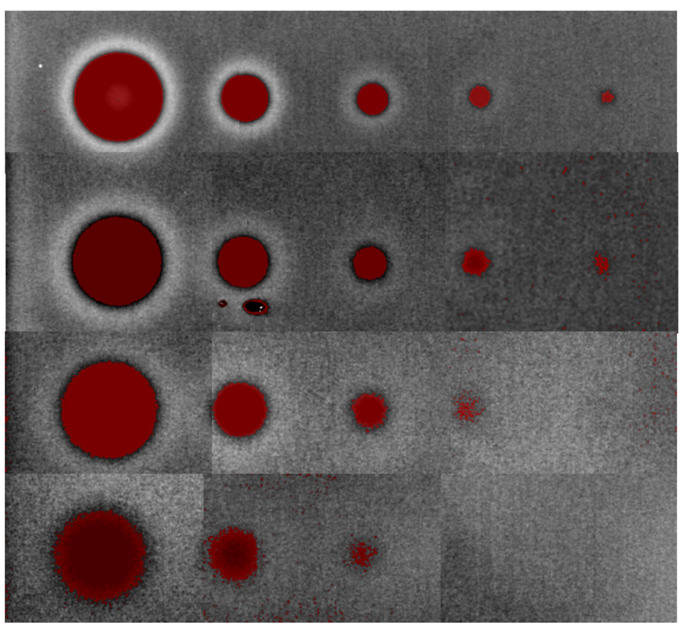
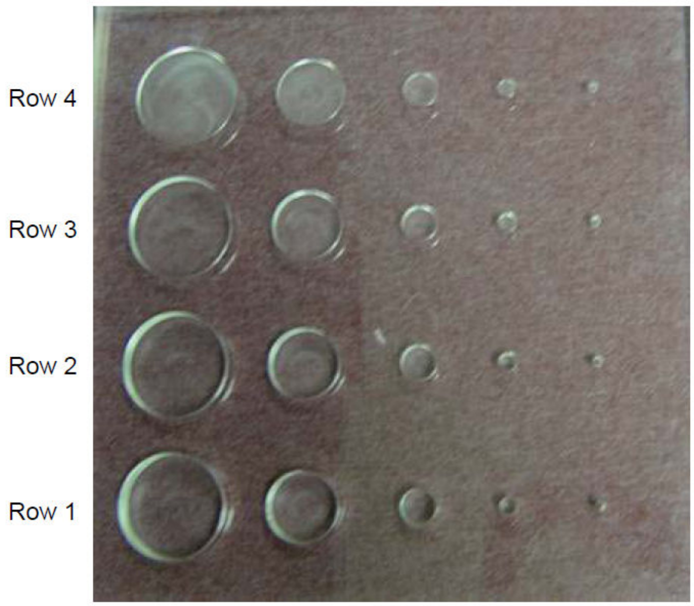


Figure 5. TSR map of detected rear wall defects (red) in Al panel at 0.2 to 0.8 seconds post flash, with features of dimater to depth ratio > 1 confidently detected.

Pulse thermography has a practical limit of detection related to defect depth and diameter. Below a diameter:depth aspect ratio of 1, the thermal diffusion process limits detection, and the results of the aluminum panel test are consistent with this and prior published work.[1] In Table 1, features with no detection are shown in red. For a 1" thick Lexan panel, long pulse heating via forced air was used (Figure 6, Table 2).



Optical image of machined side

Figure 6. Rear surface, Lexan panel

Lexan			Aspect
Row	Diameter (in)	Depth (in.)	Ratio
4	3	0.78	3.8
	2	0.78	2.6
	1	0.78	1.3
	0.5	0.78	0.6
	0.25	0.78	0.3
3	3	0.57	5.3
	2	0.57	3.5
	1	0.57	1.8
	0.5	0.57	0.9
	0.25	0.57	0.4
2	3	0.36	8.3
	2	0.36	5.6
	1	0.36	2.8
	0.5	0.36	1.4
	0.25	0.36	0.7
1	3	0.17	17.6
	2	0.17	11.8
	1	0.17	5.9
	0.5	0.17	2.9
	0.25	0.17	1.5

Table 2. Defect sizes, Lexan panel

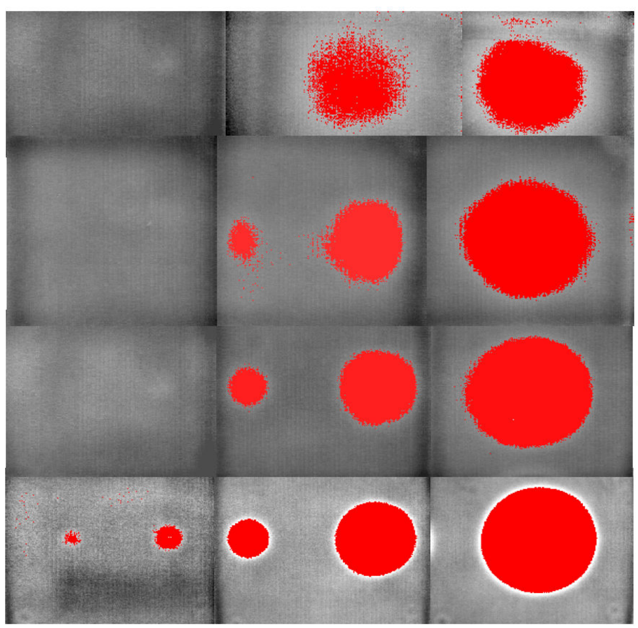


Figure 7. TSR map of detected rear wall defects (red) in Lexan panel at 42 to 484 seconds post heating, with features of diameter to depth ratio > 1 confidently detected.

Future work with the aluminum and Lexan reference defect panels will focus on development and evaluation of field-compatible surface treatments and application methods. Inspector use requires comprehensive evaluations and reliable performance.

Our next studies focused on architectural materials (terra cotta tile, dense ceramic tile, and concrete). We produced artfully tampered samples in which 7" diamater circular sections were removed from the tiles. The front surfaces of the tiles were cosmetically repaired to conceal the damage. The samples represent wall, floor, and ceiling areas that may be used to penetrate protected spaces and serve as removal pathways for fissile material. For all tiles studied, flash thermography was able to detect the penetration under the cosmetic repair. The sound and tampered dense ceramic tile and its corresponding 2nd derivate TSR map are shown Figure 8 as a typical result.

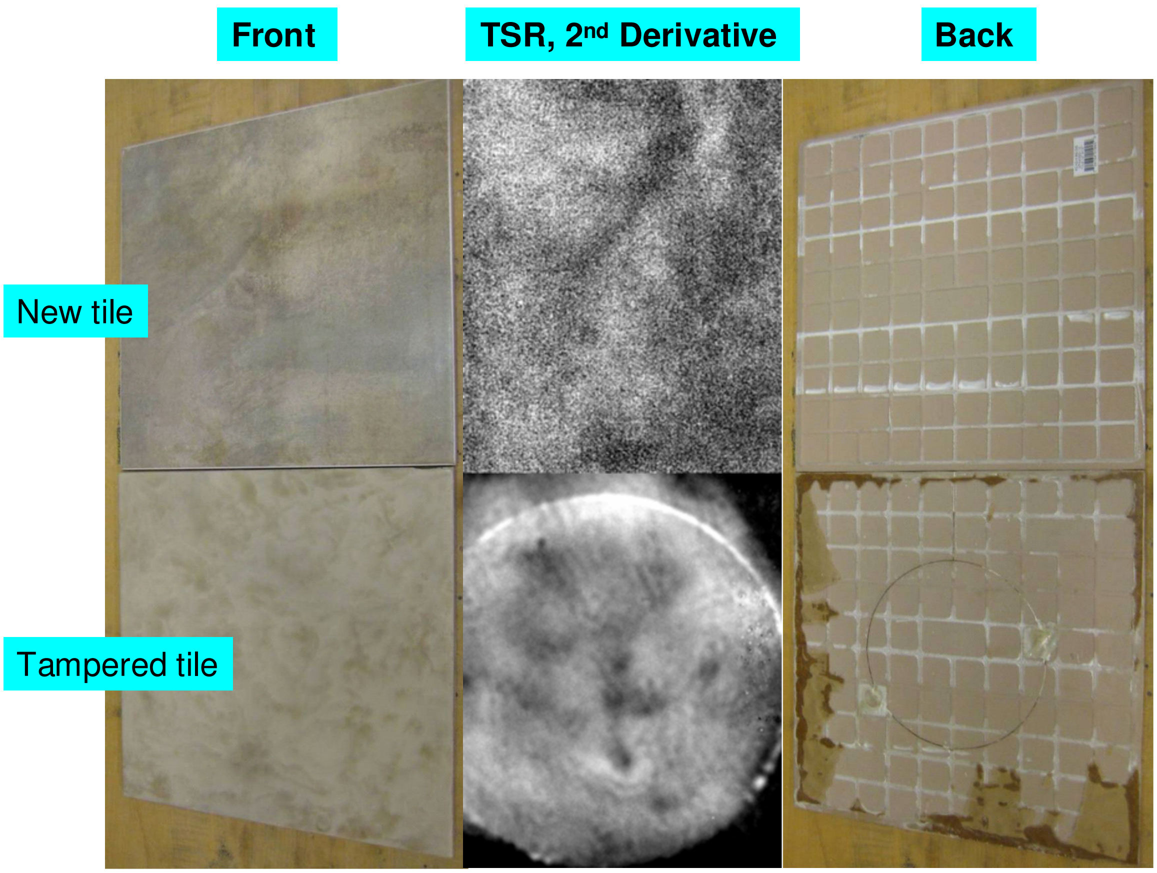


Figure 8. Dense ceramic tile, showing new sound tile (top row) and tampered tile (bottom row). The TSR map of the second time derivative thermal response clearly shows the hidden portal.

Discussion

Our limited exploratory studies suggest that active thermography shows promise for field use in arms control inspection protocols. The ability to detect unusual structural changes in materials, or any unexplained variation from an expected structure, comprises a deterrent against tampering. Physical authentication is only one aspect of the enterprise authentication problem, but it supports data authentication by deterring tampering of enclosures for data generating, storing, and transmitting equipment.[3] The method's apparent flexibility in examining a wide variety of materials (metal, plastic, organic and inorganic composites) points to broad utility in the authentication of equipment and facilities for disarmament and safeguards; indeed, all high security operations and installations may consider such a techology worthy of serious consideration. We must respect, rather than dismiss, the ingenuity of adversaries to successfully exploit vulnerabilities of critical infrastructures for arms control and nuclear safeguards. These enterprises require comprehensive security analyses and robust deterrent measures.[4]

Acknowledgments

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