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Application of Infrared Thermography in Pavement Inspection

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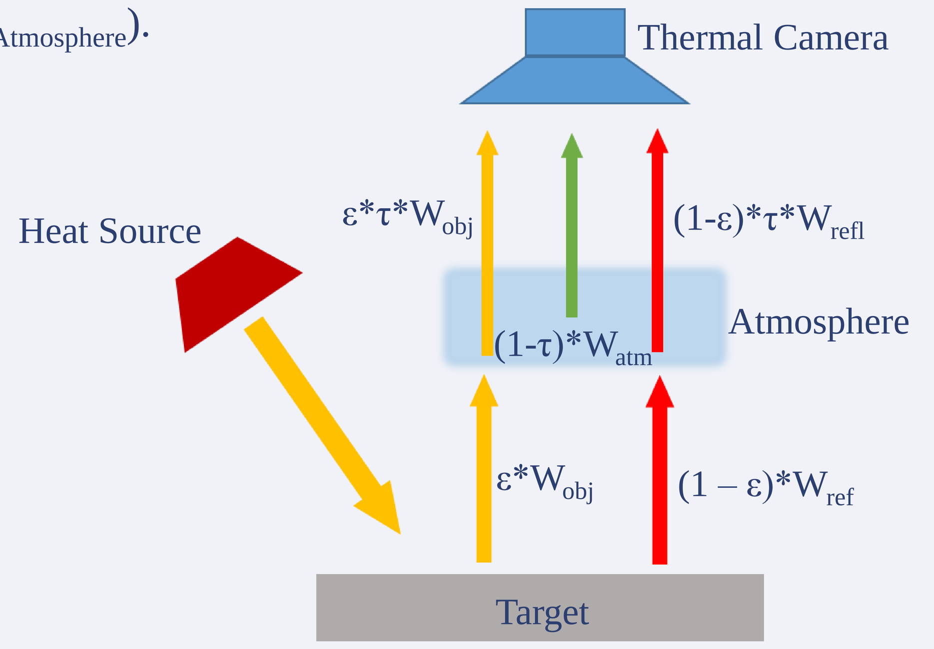
INTRODUCTION

- Infrared Thermography (IRT) is an effective non-destructive testing method in the field of pavement inspection. The method can be widely used for inspection of pavements and bridge decks. Deployment of IRT procedure is straight-forward and no direct contact is required. Its one-side deployment makes it favorable for bridges in which we have access to only one side of the structure.

- IRT captures the temperature gradient of concrete pavement surfaces. When exposed to heat, delaminated parts of concrete will interrupt the heat transfer which will cause temperature gradient on top of the surface of the pavement which can be picked up by thermal camera.

BACKGROUND AND PHYSICS

- Each pixel of infrared thermal image is representing the temperature identity of that specific location on the surface of the specimen. However, this temperature value is not a direct result of converting emitted energy to temperature reading. The major emission entities that are received by the thermal camera are Target emissions (E_{Object}), Surrounding emissions reflected from the surface of the object ($E_{Reflected}$) and atmosphere emissions ($E_{Atmosphere}$).



$$T_{Object} = \sqrt[4]{\frac{W_{Total}-(1-\varepsilon).\sigma.\tau.(T_{Reflected})^4-\sigma.(1-\tau).(T_{Atmosphere})^4}{\varepsilon.\sigma.\tau}}$$

- The following equations govern the physics of thermography in our studies.

Heat transfer in porous medium:

$$(\rho C_p)_{eff}\frac{\partial T}{\partial t} + \nabla \cdot q = Q$$

Where $q = -k_{eff}\,\nabla T$ *and* $k_{eff} = (1-\varepsilon_p)\,kr + \varepsilon_p\,kw$

Stefan-Boltzmann law:

$W=\varepsilon\sigma T^4$

Where W is radiant flux, ε is emissivity and σ is Stephan-Boltzmann constant (equal to $5.67 \times 10^{-8} watts/m^2/k^4$)

Wien's displacement law:

$\lambda_m=\frac{b}{T}$

Where λ_m is the wavelength, T is temperature and b is Wien's displacement constant (equal to $2897\ \mu m/K$)

Observation rate for thermography:

$t \approx \frac{z^2}{\alpha}$ and $c \approx \frac{1}{z^3}$

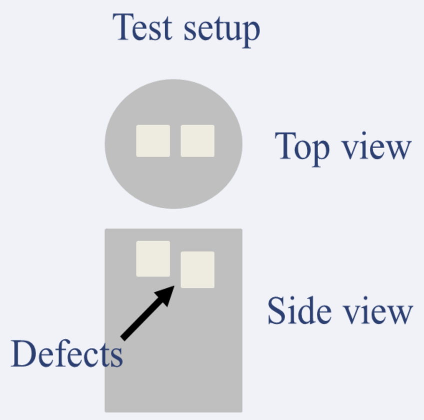
Where z: depth, t: time, α: thermal diffusivity (for concrete is 0.53)

METHODOLOGY

Research study #1: Subsurface defect assessment and IRT

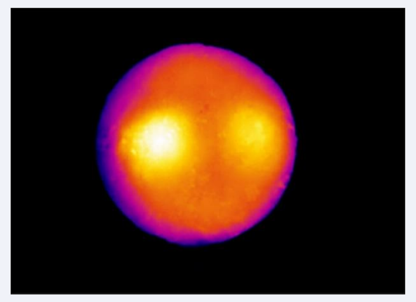
- Subsurface delamination (such as air void) has a different thermal conductivity compared to bulk concrete and asphalt hence acts as an heat insulator.
- Depth of delamination has an effect on the temperature gradient that it generates on the surface of specimen. Delaminations located deeper from the surface have lesser effect on the generated temperature gradient.

- In order to mimic air void defects, styrofoam cubes were inserted in different depths inside of the concrete domain.
- Thermal and visual images of the specimen were recorded by a thermal camera (FLIR 430sc).



Visual image

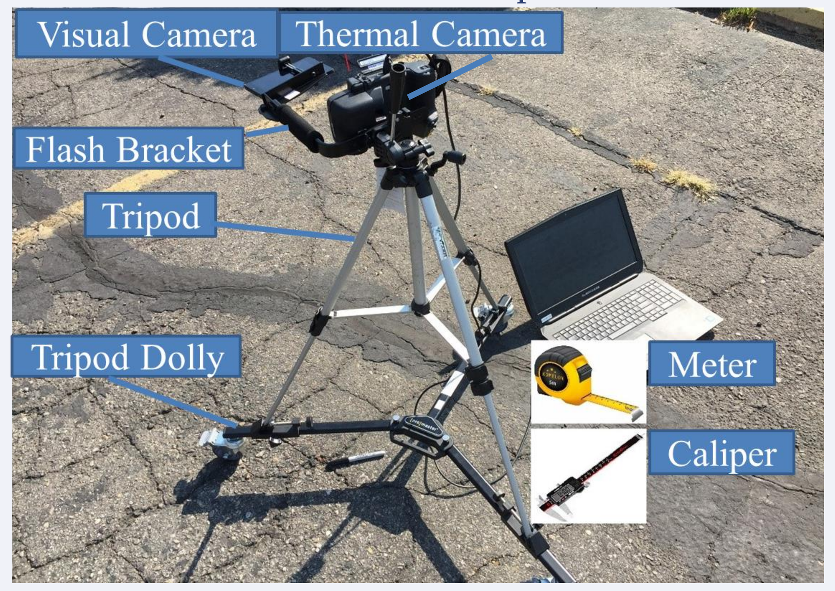
Thermal image



Research study #2: Surface defect assessment & IRT

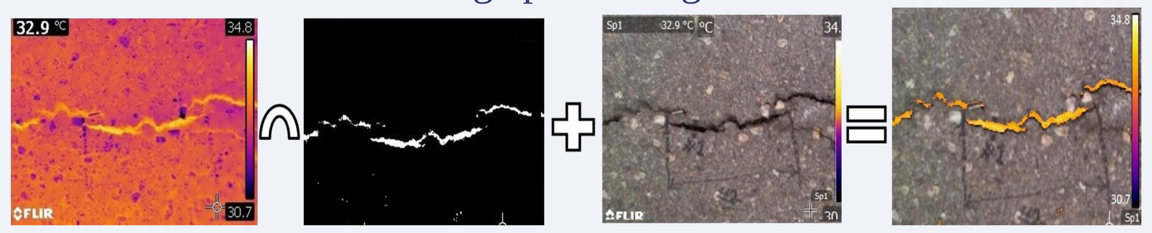
- A real-time thermal imaging-based system for asphalt pavement surface distresses inspection and 3D crack profiling is proposed in this study.
- A mobile setup is introduced which is capable of collecting a series of both thermal and visual images from the pavement surface.

Field test set-up



- A computer program is developed for segmenting the thermal images.

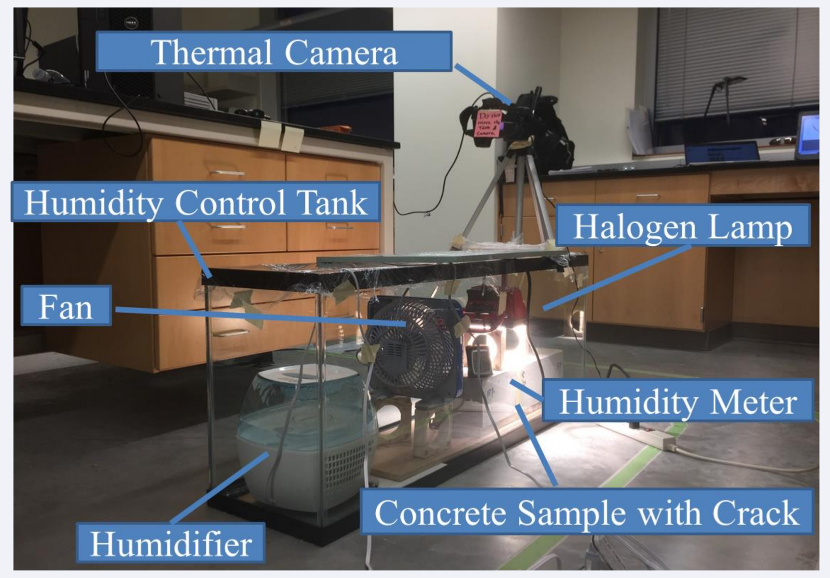
Image processing



METHODOLOGY

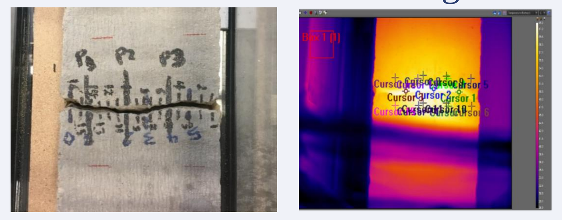
Research study #3: Effects of weather conditions on IRT

- A full-scale experimental study of the effects of different climatic conditions on infrared thermography and surface delamination assessment in concrete structures is presented in this study.
- For laboratory experiment, a controlled laboratory testing system is developed which is capable of imitating a variety of weather conditions that can affect thermography.

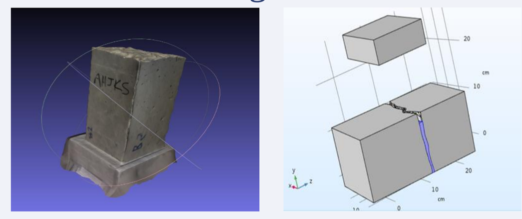


- Digital image base 3D surface scanning technology is used to simulate the crack.
- The multi-physics experiment is simulated using finite element software.

Thermal and visual images



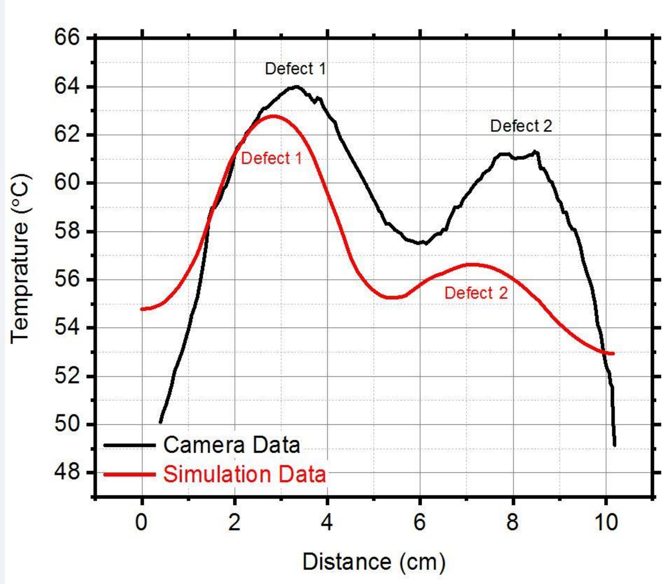
3D scanning of the crack



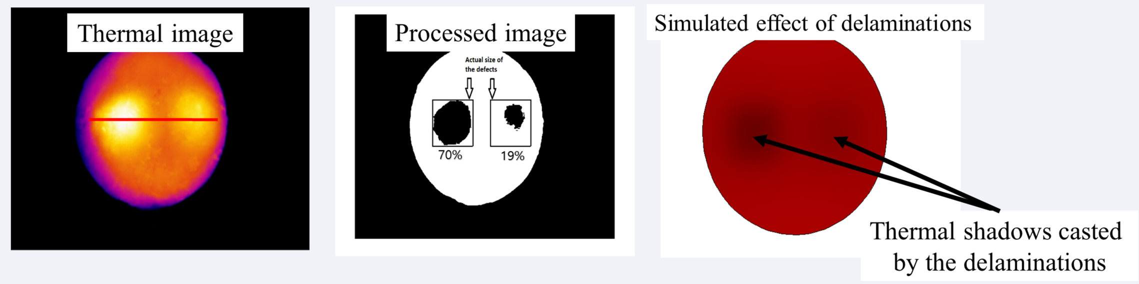
RESULTS & DISCUSSIONS

Results from research study #1

- A temperature profile along marked line on the sample (shown in thermal image) is plotted in the following graph. Simulation results along the same line in computer model is also shown.
- Simulation results had similar trend as the experimental results



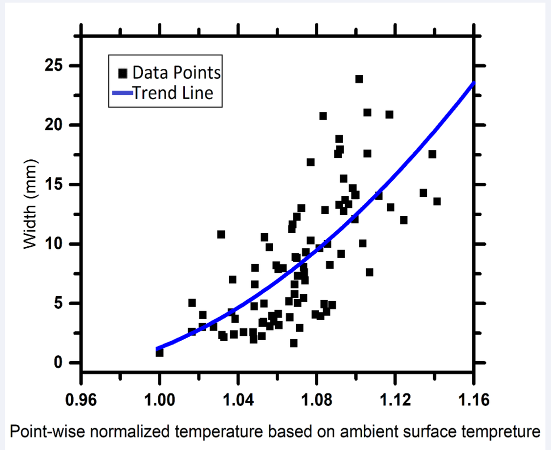
- The segmented image shows the area on top of the sample affected by the presence of the delamination.

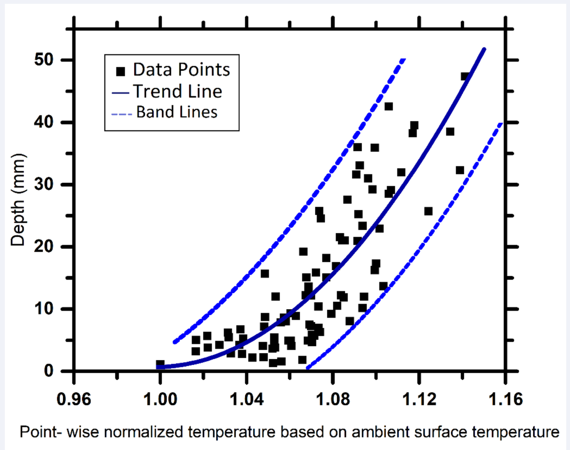


RESULTS & DISCUSSIONS

Results from research study #2

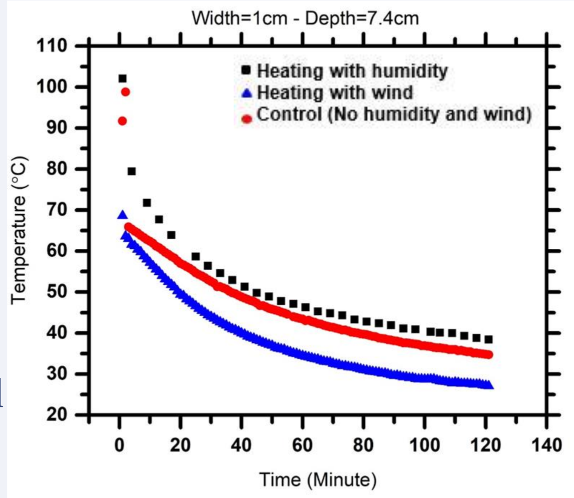
- In this study a relation between crack temperature and its profile is studied.
- Correlation between temperature and depth of crack was higher (R^2=70%) compared to the temperature and width of crack (R^2=50%.). The temperature data represented in the graphs are normalized based on the localized average surface temperatures.



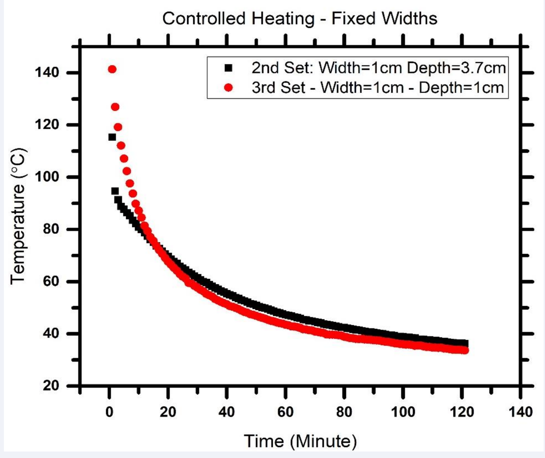


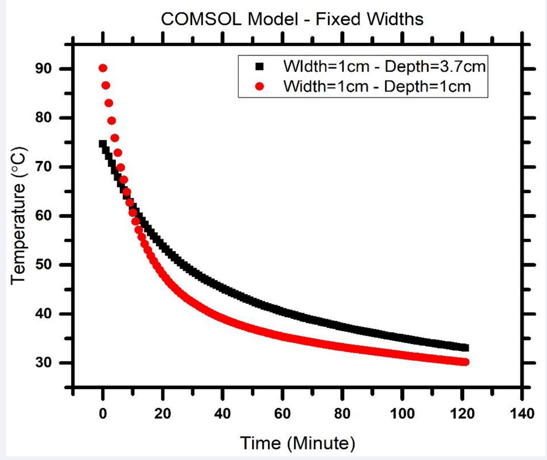
Results from research study #3

- Temperature reading during the cooling cycle shows the effect of humidity (= 80%) and wind (=3.5 m/s or 7.8 mph) on the temperature reading of the camera.
- Heating under normal conditions (humidity = 16% and no wind) is taken as control.



- Temperature readings for cracks with different depth sizes based on the results from experimental data and the computer model are show in following graphs
- Temperature change during the cooling cycle follows the same trend in both the experiment and the simulation.





CONCLUSION

- Thermography can be used for the inspection of subsurface delamination inside concrete and asphalt pavements. Studying the effect of delamination depth on the temperature gradient will assist the better understanding of the effectiveness of thermography in application.
- A new approach based on normalization of the temperatures shows that deeper cracks have higher temperature in the temperature profile that is captured by using thermal camera.
- It is also found that cracks heat up more and lose heat slower in humid condition. Also, deep cracks are more prone to the effects of humidity than shallow cracks.
- Studying different aspects of IRT may help in development of a system to automatize the inspection of surface and subsurface defects in pavements by using thermal imagery.