The Viability of the FLIR One™ Camera for the Corps Of Engineers and Construction Companies

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Abstract
This paper explores the viability of the FLIR One™ camera for use by the U.S. Army Corps of Engineers (USACE) on project sites both in the Continental United States (CONUS) and overseas (OCONUS) and viability of its application for construction worldwide. Objectives were to validate or refute usability and benefits of small pocket-sized, cell phone enabled, thermal imaging cameras in these markets. Overall attitude and perception were balanced against expected expense and ease of use utilizing web based surveys and interviews. Target audiences were drawn from USACE personnel, both large and small construction businesses from both national and local companies. Results of the interviews and surveys provided conclusive evidence that there was a lack of general understanding of the benefits and utility of the application of thermal imaging in construction among a majority of the respondents. Based on this, the recommendation for implementation of use of the selected thermal camera was presented in a three phased approach comprised of familiarization and education, limited fielding in conjunction with a typical user profile, followed by a period of cost-benefit analysis. Benefits of incorporating the new model FLIR One™ into normal business processes with a very minimal upfront investment are provided.

Keywords
Cameras, Construction, FLIR One™, Thermal images, Usability

1. Introduction
Thermal imaging is a rapidly developing technology that is quickly becoming very affordable for government agencies, small businesses, and construction companies. Thermal imaging or producing an image from the infrared radiation of an object can be used for quality assurance, quality control, and fault detection. Depending on the role of the operator, this could entail evaluation of electrical systems, plumbing, roofing, HVAC ducts, and water damage/intrusion, to include building envelope tightness and insulation issues. The benefits of detecting faults or problems early in the life of a project or potential investment allow for cost savings to be realized by reducing rework, identifying costly renovation requirements, and preventing significant losses in capital on investments.

2. Literature review
Thermal imaging provides organizations and individuals with the ability to see and identify anomalies or defects in materials or structures that are not detectable in the normal visible light spectrum. All matter with a temperature above absolute zero continuously emits thermal energy. On the electromagnetic spectrum thermal energy is emitted on the infrared wavelength, which lies between microwaves and visible light (Figure 1.). A thermal camera is an instrument that can capture these infrared emissions and convert them into an electrical signal, which is then used to produce an image of the variations in temperature of the subject under observation. The ability to identify specific problem areas in real time without physical contact or deconstruction of a structure saves time and money. Thermal cameras also provide the ability to

identify transient phenomena or conditions that may not be present at all times, but which could become problematic or are indicative of a developing issue (Balaris and Argiriou, 2002).

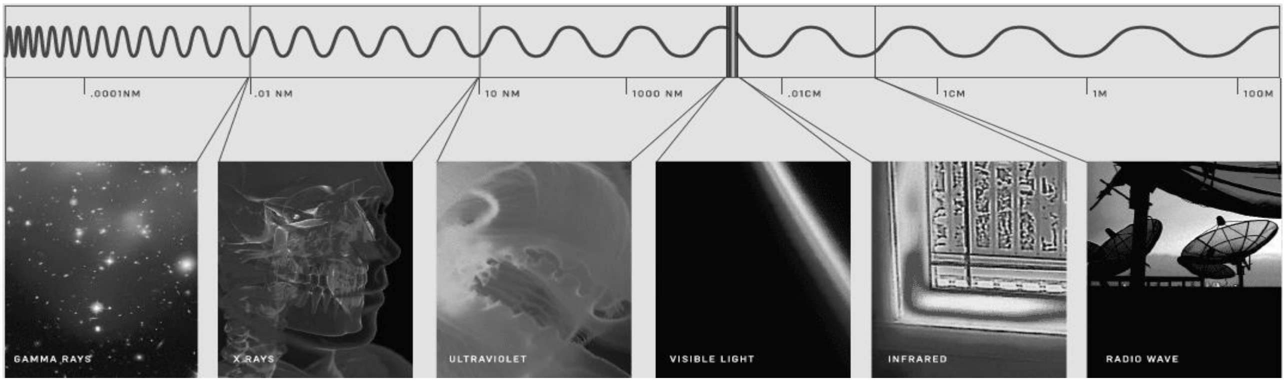

Figure 1: Infrared Wavelength In Relation To Visible Light (FLIR)

Besides enabling non-contact, non-destructive inspection and performance verification of facilities, which can easily identify areas of missing insulation, dampness, moisture ingress, de-lamination, thermal bridging, and thermal leakage, utilizing thermal cameras also is effective for inspections of both electrical and mechanical aspects of a building (Taylor *et al*., 2013). Advantages of using a thermal camera include the ability to inspect electrical and mechanical systems operating under full load conditions, and the capability to survey difficult to access, or hard to reach heating, ventilating, and air-conditioning (HVAC) components and locations. Besides identifying potential or actual problems, thermal cameras can be used to quantify potential energy savings, schedule preventive and predictive maintenance, and set priorities for, or the need for, immediate service to minimize the risk of failure (Balaris and Argiriou, 2002).

One thing that is important to note when using thermal cameras for assessment and inspection of structures is the emissivity value of the material being observed. The emissivity value refers to the efficiency that a particular surface emits infrared energy compared to a surface at the same temperature that is a perfect emitter, a black surface as defined by the Stefan–Boltzmann Law. Non-metallic surfaces tend to have a high emissivity value which indicates thermography will be very effective. Clean, well-polished metallic surfaces have a very low emissivity value, indicating a more challenging inspection using thermography. If these surfaces are coated with paint or oxides, the emissivity increases dramatically (Kylili *et al*., 2014).

Other considerations when working with thermal cameras are atmospheric conditions, such as high winds, dust, and very high or low temperatures. High winds can skew thermal images by transferring temperatures to adjacent areas. High dust content in the air can interfere with accurately reading the surface conditions by obstructing the infrared radiation emanating from the structure. Very high winds can produce thermal drift and result in erroneous measurements. Particularly high temperatures or low temperatures can mask accurate thermal readings. For these reasons, it is recommended that thermal evaluations outdoors take place at night in temperate weather to ensure the most accurate results.

Thermal images are affected by distance from the subject, as well as the incident angle of the observation. Thermal leakage is evident by the dark red areas, and a closer shot at right angles will be required to pinpoint the exact location of concern. Due to the nature of thermal imaging, as the distance from the subject increases, the resolution of the image decreases. This is due to the fact that each image data point represents a larger portion of the entire structure as distance increases (Fox *et al*., 2014). This can be mitigated somewhat by using higher resolution equipment; however, as greater resolution equipment is used, there is an exponential cost growth in price. The benefit gained is minimal and does not justify the additional expense for the type of work being performed. Effective and objective thermal images are taken from a relatively close distance and at right angles to the subject being investigated or documented. Taking the images from right angles is important because the image may be distorted depending on the type of material being examined and how thermal radiation is distributed from that material (Balaris and Argiriou, 2002). There are numerous different techniques that can be used to evaluate a structure using passive thermal imaging. These include aerial surveys, automated fly-past surveys, street pass-by surveys, traditional external perimeter surveys, traditional full scope internal and external surveys, repeated surveys, and time lapse surveys. Based on research conducted, the most usable data is generated using the traditional full scope internal and external surveys (Fox et al., 2014). It is intuitive to come to this conclusion as well, as previously discussed range, angle, and environmental conditions all play a role in the quality and viability of the data gathered. In order to obtain the best data, it was demonstrated that walking thru and around a structure will result in obtaining relevant and actionable images.

Thermal cameras provide organizations and individuals with a non-invasive, rapid, accurate, inexpensive, and safe means of evaluating structures and components. Thermal images are non-invasive, allowing the operator to detect and identify problems without physical contact and without expensive deconstruction (Zou and Huang, 2015). It takes only seconds to capture and reveal defects in a structure or identify potential problems compared to the delayed identification and potential safety considerations when relying purely to visual inspection (Aggelis, et al., 2009). Thermal images provide overwhelming evidence of problem areas that would take much more to explain in text. Recent advances in technology have made thermal cameras very affordable to any sized agency or business all the way down to sole proprietors. Capturing images from a distance and not requiring ladders and scaling unsafe buildings provides a much safer means of data collection. A limitation of thermal cameras is obstructions such as frameworks and scaffolds, which can impede accurate analysis (Azenha, et al., 2011). This capability saves time and capital cost that would otherwise be required to run resistance testing and limits the contact time to the time required to replace or repair the areas of concern. Thermal imaging is consistent from electrical to plumbing to HVAC components. For the construction manager, the benefits of testing or monitoring the project during construction provide early identification of potential problems or defects and serves to reduce the cost of corrections. This also allows for required design changes to be made to correct deficiencies and improve performance.

Limitations when working with thermal cameras are limited to understanding how thermal radiation works. Because there is reflected radiation and absorbed heat on the exterior of structures exposed to sunlight during the day, to be most effective, surveys with thermal cameras should be done at night or indoors, and there is not a standard template or procedure for thermographic testing (Taylor et al., 2013). Experience and knowledge of the thermographer is critical in obtaining viable, actionable images. Thermal cameras are limited to the inspection of solid structures and is considered a 'boundary technique', (Kylili et al., 2014) meaning there is a limit to depth to which detection is effective when scanning.

3. Methodology

3.1 Research design

Both a survey and interview process was used to determine experience, perception, and apparent applicability of thermal imaging by both USACE and the construction industry. These results were then analyzed and compiled to produce a consolidated evaluation of the benefits and applicability of using this technology to generate revenue, save on costs, and enhance organizational credibility.

3.2 Quantitative data compilation

Quantitative data evaluated in this study is limited to the capabilities of four thermal cameras. The specific tolerances and capabilities of each model were provided by the manufacturer. The weighting of the importance of each area evaluated was based on the results of the surveys conducted and the interviews. The relative importance of each factor was assigned a corresponding weight, which was then applied to the qualities of the specific thermal camera. The higher the importance of a factor based on the data provided through the interviews and the survey, the higher the weight of the evaluation factor.

3.3 Qualitative data compilation

Qualitative data was compiled through topic related interviews and a questionnaire distributed to individuals within USACE, the construction industry, and other related commercial industries. The survey, created on Survey Monkey® was posted on the website Linked-In® and distributed by e-mail to over fifty companies that are members or are associated with the Society of American Military Engineers (SAME). The development of the questionnaire was specifically geared to address the current and potential use of thermal cameras, as well as perceptions of usability and applicability across a wide spectrum of activities. Questions were divided into six sections to include: general information concerning thermal imaging perception within the construction industry, thermal imaging as a company marketing tool, thermal imaging as a project specific tool, thermal imaging as a company training venue, limitations and challenges associated to thermal cameras, and benefits of thermal imaging relative to communication and collaboration.

The interviews were conducted in person, over the phone, and ultimately, via e-mail when the first two alternatives proved to be unworkable. The interview used a set of sixteen specific questions that were primarily open-ended, designed to gauge perceptions and experience with thermal imaging. A few questions were population or classification type questions to allow for segregation of results. One question was designed to elicit the subject to rank order, from one to thirteen, those salient features that could be used to distinguish different thermal camera models based on perceived need or user preferences.

3.4 Compilation of results

Upon completion of the interviews and collection of the survey responses, the results are evaluated and main findings are produced. The evaluation is a compilation of the results of the analysis of both quantitative factors and qualitative factors that were explored in the literature review, the survey, and the interviews. This was based on the compilation of the quantitative factors for the four identified thermal camera units based on the relative importance of each specific factor, as determined by the subjects interviewed. Additionally, the subjective evaluation of responses in the qualitative portion of the survey and interviews was used to finalize the findings and produce the ultimate recommendation.

4. Results and main findings

4.1 Qualitative and quantitative results

The interviews have been used to determine what salient factors are important when considering the application of thermal cameras for USACE and the construction industry. One question in the interview asked the subject to rank order thirteen different items pertaining to thermal cameras. Those qualities that had the same or very similar values were excluded from the ranking question because those particular factors had no impact on the camera selected. Interestingly, software, warranty, and environmental protection were considered to be less important than other characteristics given the austere operational environment of many of the subjects. There were 14 interviews conducted, and of those, 13 completely rank ordered the factors, a response rate of 93%.

Based on the relative importance of the factors, each of the four cameras has been rank ordered using the weighted values. The original FLIR One™ was not the best choice for use by the construction industry even though the price was significantly lower. The enhanced features of the SEEK™ models and the new FLIR One™ outweighed the price savings offered by using the original FLIR One™. The difference between the FLIR One™ (New) and both SEEK™ models is almost negligible, indicating that either would be a reasonable choice for application. The most important factors based on this data were cost, followed by resolution, then quantitative readings. The factors are slightly different than those of the interview, but the general results are the same. Cost was considered the most important, followed by resolution and size.

4.2 Questionnaire results

The survey concerning thermal imaging in construction was developed and the online resource Survey Monkey® was utilized to distribute the questionnaire to 250 individual companies within USACE and construction industries. Twenty-nine (29) completed surveys were obtained, giving a response rate of 11.6%. The distribution of respondents leaned towards government, design, construction, and prime contractors with respondents mostly 40- 59 years old in the acquisitions and engineering departments. The range of experience (in years) in the construction industry was fairly evenly distributed from zero to over thirty years. An overwhelming majority of the respondents do not use thermal imaging devices. Almost half of those surveyed indicated their organization did not use thermal imaging. Of those that did, a little over 10% indicated daily use of this technology. Over 50% of respondents felt that thermal imaging would be an effective means of disseminating real time information on construction projects. Internal communications, training, and collaboration all were perceived as strengths by a majority of respondents. Security considerations received a generally neutral response balanced between yes, no, and not sure. 50% of the respondents indicated that the risk of implementing thermal cameras was worth the benefit gained, with another 45% unsure. More than 50% of respondents believed that thermal imaging would enhance internal and external communications and collaboration efforts. The most telling question in the survey was question 24, which asked the respondents why they thought organizations within the construction industry were not using thermal cameras. While respondents could choose as many responses as they'd like, from a total of eight different responses, the results showed 77% chose 'Lack of Understanding' and 50% chose 'Too expensive'. The next closest percentage was 'Lack of interest' with 27%, just over half of the lesser of the top two. This indicates that there is a fundamental lack of knowledge concerning thermal cameras and the progress concerning technology development in recent years, as well as the typical 'It is not my job" attitude that seems to have become more prevalent in society today.

4.3 Interviews

The interviews revealed very few individuals had personal knowledge concerning thermal cameras, and even fewer had not ever used them. This created a dynamic of requiring more time just explaining the qualities and capabilities of thermal imaging than time devoted to the actual interview questions. All interviews were conducted using the subjects' working knowledge and experience of thermal cameras. Following the interview, further discussions went into more detail about the benefits and applications of thermal imaging. The general consensus of the interviewees was that thermal imaging could be beneficial, but limited knowledge and experience would limit acceptance and application initially. The concept of using thermal imaging for collaboration and information sharing was seen as a positive addition for most; however, lack of understanding and experience resulted in hesitancy and apprehension. The biggest misconception encountered was the perceived cost of the individual units. After finding out how economically these portable thermal cameras were, all subjects displayed significantly greater interest. Only a few of the subjects interviewed had actual hands on experience with thermal cameras, and those individuals provided more pointed and relevant answers to the various questions. Twenty-five subjects in all were interviewed, however, those included interviews for this research were complete, meaning all questions were answered and the salient features were rank ordered (Table 1).

Table 1: Rank Order Of Preferences When Considering A Thermal Camera

	Rank Order of Importance (1 = most to 7 = least) Responses							Ranking	Response
Factor	1	2	3	4	5	6	7	Average	Count

Cost	13	2	1	0	2	1	3	2.59	22
Size	2	4	2	1	2	6	4	4.48	21
Multi-platform availability (iOS, Droid, Windows, etc...)	1	4	4	3	4	1	4	4.14	21
Resolution	3	5	4	6	1	1	0	3.00	20
Qualitative Readings – Contrasting Temperatures	2	2	4	2	7	2	1	4.00	20
Quantitative Readings – Exact temperature differences	1	2	5	4	2	4	1	4.05	19
Battery Life	0	1	1	3	3	4	8	5.60	20

5. Conclusion and recommendations

Few respondents expressed any knowledge or in-depth understanding concerning the capabilities of thermal cameras, and even fewer had actually utilized this technology. This limitation resulted in more general answers to questions that were looking for more specific and detailed responses concerning thermal cameras and the benefits within an organization. There was a general consensus that the most important factors were cost, size, and weight and display size, in that order. This indicates that besides cost, the real considerations are portability and view-ability (display size). Being able to utilize thermal imaging is viable if obtaining the capability is not cost prohibitive and is not a hindrance in terms of size and weight. Market research has shown that recent advances in technology have enabled manufacturers to produce pocket sized thermal cameras at very reasonable prices compared to those encountered just ten years ago. Historically, thermal cameras have been well beyond the price range of the casual user or even small businesses, and were definitely not a piece of equipment that would be provided to a majority of personnel.

The major limitation that inhibits the application of this technology in USACE is the DoD adherence to the Blackberry platform, which runs on its own proprietary operating system and is incompatible with every model of portable thermal camera currently on the market. This is a problem, but not an insurmountable one for USACE. Many employees have iPhones or Android type phones that are compatible with the thermal cameras evaluated, and using personal phones to take thermographs of unclassified construction projects and then moving them to the Corps network could be accomplished via an air gap machine (a stand-alone computer not attached to the network) to down load the pictures and write them to CD, or by e-mailing the images to themselves.

Based on the results of the on-line surveys and interviews conducted, a three phased approach should be used. The first phase should consist of familiarization training designed to educate and enlighten personnel concerning the use and benefits of thermal cameras. This phase is essential, as the study demonstrated an overwhelming lack of knowledge and understanding concerning this technology by respondents. Additionally, buy in from senior management is required to ensure follow through on the implementation and initial funding support. After the initial training and education, phase two implementation will begin with purchasing and issuing a limited number, based on organization size and project portfolio, of new model FLIR One™ cameras to designated individuals with the organization. These individuals should be those that perform surveillance and inspections of projects as part of their normal duties, so that using the FLIR One™ is just an extension of the work already being performed. These individuals should be provided specific instruction on the types of thermal images to be taken of the individual projects based on the type of work being performed and can be added to the reports generated as part of their normal duties. Evidence of problems should be detected earlier and remediated at a lower cost than previously using only conventional observation and inspection. Phase three would begin after a one-year test phase; this would compile and evaluate the cost/benefit of using the FLIR One™ in conjunction with standard construction inspection techniques. Using the results of this evaluation, the leadership of the district or company could choose to expand, maintain, or curtail further utilization of this resource.

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