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# Agri-Health Assessment by their Thermal Responses

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A tree stands as an abstract example of a basic form of life. It helps in greening cities and contributing to the preservation of natural resources and climate. It's a boon to the economy and creates jobs, too. When checking the health of a tree, most methods are either intrusive or even destructive. Non-destructive infrared thermography (IRT) has proven useful for inspecting trees and wood for damage and voids that could weaken the material's strength and longevity. In this paper, we summaries previous research on using IRT to assess tree health. It's set against the backdrop of the role trees play in maintaining ecological harmony and the various methods available for spotting signs of tree decline. These differences are highlighted, along with the main factors that have been shown to disrupt the trees' thermal pattern when applied to wood or trees. As with other non-destructive methods, the IRT does not differentiate between the various forms of damage or the agents responsible for them. However, it does allow for differentiation between normal and unhealthy tissue. As evidenced by its demonstrated effectiveness, rapidity, low cost, and longevity, the technology holds great promise.

**Keywords;** Infrared Imagery, Plant Health, Spectral Responses.

## Introduction

Trees play a crucial role in ecosystems [1]. It aids in environmental regulation, climate management, and urban landscaping [1]. It's a moneymaker and job creator [2]. Several trees have been designated as National Historic Landmarks [3]. The health of human populations and urban ecosystems, as well as the balance of ecosystems and protection from desertification and climate change, are just a few of the many, many benefits that trees provide [1]. However, particularly in urban areas [4], trees also present a risk of damage to people and property due to falling branches or entire trees. Defects pose a greater threat because they jeopardize their health and stability. As a result, both people and their possessions are in danger. The biological viability, cost-effectiveness, and associated risks of trees can't be considered in isolation when making decisions, so monitoring their health condition is crucial. In 1800, while researching how to use optical filters to dim the sun in telescopes, Herschel made the first discovery of the infrared spectrum [5]. Herschel also noted in his research that the new rays exhibited the same properties as the visible ones, including absorption, transmission, refraction, and reflection [6]. In 1840, Herschel experimented with differential evaporation of an oil film subjected to a heat pattern to create the first thermal image (thermograph) [7]. But in 1880, when Langley invented the bolometer, he made a significant step forward in the sensitivity of infrared detection. Tihanyi created the first infrared camera in 1929, and the British military used it for anti-aircraft defense [8]. Infrared thermography (IRT) was first used in trees to evaluate the crown's health with the help of monochrome and false-color films [9]. Injury recognition technology (IRT) is a touchless method of monitoring tissue damage in real time. Using the identification of temperature changes between unharmed and damaged areas, this method can determine which areas need repair.

Evaluation of IRT efficiency in tree health inspection is the focus of this literature review. This review was organized as such so as to accomplish its aims. Following a discussion of research techniques, the article moves on to discuss the significance of trees and how they are categorized. Trees' defense mechanism is discussed, as are the dangers they face and how those dangers should be mitigated. Some techniques for examination and analysis are also discussed. Sustainable inspection methods are highlighted for their significance. The principles of IRT, as well as their practicality and importance, are discussed. Several experiments are detailed, as well as the IRT application for a tree inspection. Wood and tree properties are compared and contrasted to highlight their key differences. Finally, both the potential benefits and potential drawbacks of implementing IRT are discussed.

**Materials and Methods**

The databases consulted for this article were B-on, DOAJ, Google Scholar, Microsoft Academic, ProQuest, SciELO, ScienceDirect, Scopus, and Web of Science. There were three languages examined: Portuguese, English, and Spanish. Research was done from October 2018 to February 2019. Terms such as "Infrared thermography," "inspection," "inspection techniques," "non-destructive," "non-invasive," "sustainable," "monitoring," "classification," "deterioration detection," "relevance," "benefits," "risks," "management," "tree," The search terms were merged into one. References from papers that were evaluated were also considered. When a set of keywords was found to be useful, we read the abstracts and looked up the keywords. When the abstract wasn't enough to place something into a specific category, the whole article was read. Sections, subsections, and theoretical references were used to organize the chosen articles. The collected information was categorized, sorted, and titled according to its various attributes. These measures made it easier to track down and examine the most frequently cited sources and primary sources consulted by authors. No aspect of IRT's potential contribution to health tree monitoring was overlooked. The redundant citations have been removed. There was a total of 239 submissions, but only 81 were ultimately accepted.

There were only 30% of people living in cities around the world in 1950; today that number is 55%, and by 2050 it is projected to rise to 68% [10]. That is, more people now call cities home than ever before.Urban residents benefit greatly from the presence of trees and other greenery. Trees improve people's health, happiness, and quality of life, as well as strengthen communities' ties to the natural world and slow global warming. Numerous advantages are provided by urban trees to city dwellers, but these trees are not without danger [11].

In addition to improving their immediate surroundings, trees also contribute to the overall ambiance of their ecosystem. Trees' primary role is to enhance environmental quality through increased oxygen levels in the atmosphere. The presence of trees slows the rate at which rainwater runs off, facilitating its infiltration into subterranean aquifer systems. The protection that trees offer to wildlife is one of the primary reasons for their beneficial effect on biodiversity. Since the leaves of trees can change the direction and velocity of the wind, they can serve as a windbreak for both humans and animals [12]. Since the tree's roots hold the ground in place, its canopy shields the land below from the rain. By absorbing some of the city's harsher noises, trees provide a more tranquil environment. Tourist and recreation destinations benefit from forests. Public areas with trees in them are more commonly used than those without, which means that more eyes are kept on the area. This has a positive effect on reducing stress and even crime. By blocking the sun and reducing the amount of heat generated, they help reduce cooling costs during the summer [13]. Having trees on or near a property can increase its value. Trees improve the visual environment [14] by adding seasonal color and decor to the urban landscape.

Relationships between trees are essential to a healthy ecosystem. During their activities, they may be attacked by birds, insects, animals, fire, weather, or even other people, resulting in wounds that can be colonized by disease-causing microorganisms. Shigo and Karl Marx authored a book called CODIT (Compartmentalization of Decay in Trees) to explain the system of compartmentalization that trees have developed. A chemical and physical barrier is formed as cells transform into four separate walls along the axial, radial, and tangential axes surrounding the wound. They protect the tree by limiting the spread of pathogens, which causes damage, by isolating the injured tissues [15][16]. Natural processes like wood decay and tree ageing can be dangerous for both the tree and the people and property around it.

On the other hand, certain trees stand out from the rest because of their extraordinary age, size, physical features, or cultural or historical value. Several instances of categorization are provided below: Those trees with significant cultural or historical ties, or those that are exceptionally rare or otherwise important from a botanic standpoint, are considered to be "heritage trees" [17][18].

Notable: fully mature trees are larger than their neighbors, making them stand out in the forest [19]. For example, "ancient" trees are those that have lived well past their prime, despite the fact that their trunks are hollow. Age is a primary factor in determining their worth [20]. Trees that have been through a lot and come out the other side are called veterans [21].

But, if a tree falls or becomes weaker, it can cause damage to buildings and individuals. Most city parks and boulevards feature numerous large trees. Urban trees are often poorly cared for and must endure the stress of a hostile environment. Consequently, many trees are unhealthy, and any tree that has been damaged poses a risk to human safety. The United Kingdom has a yearly death toll of three due to trees falling in public places. Because only one person in every 10,000,000 dies from it, the danger is minimal. Although tree-related incidents are relatively uncommon, they have a significant impact on how people perceive danger. Owners and managers of urban green spaces (also known as "tree managers") cut down trees at the first sign of trouble due to the perceived risk of a falling tree. The public enjoys the advantages of trees without understanding the challenges associated with their management, which only makes the issue of tree removal worse. If trees are to continue to provide advantages, it is crucial that they be managed in a way that minimises the dangers and problems they may generate. Still, there are other considerations besides the security of people and property. When weighing the pros and cons, environmental and aesthetic considerations are taken into account.

In spite of the many positive effects trees have on society and the environment, they can also pose a threat. Therefore, there are several reasons to keep an eye on a tree's vitals. The IRT has a number of advantages over other tree health inspection methods that can help with management decisions.

**Quality Assurance Methods**

The Visual Tree Assessment (VTA) technique is used to inspect and diagnose trees. According to VTA, which was developed by Mattheck and Breloer (1994), trees can communicate with humans through their body language, and this information can be used by experts to determine whether or not a tree has failed. The process consists of three steps: There are three phases to determining the severity of damage and the likelihood of failure: A visual check from the outside for indications of interior damage, B diagnostic tool use to confirm and measure damage, and C an assessment of the damage's severity.

Simply looking at the damage doesn't tell you how bad it is on the inside. Then, further diagnostic equipment will be needed. Multiple authors have proposed categories for these instruments, and they can be thought of as: Sapwood, being living wood, must be drilled into with multiple holes in order for invasive devices to reach their working depths. The sapwood is the only part of a tree that is touched by noninvasive instruments, and these tools either don't touch the wood at all or just pierce it very slightly. Pathogens can enter a tree through any kind of wound [22].

Non-destructive instruments, in contrast to destructive ones, can determine whether or not damage exists in trees without causing any further harm to the trees themselves [23]. Therefore, instruments that do not make physical contact with the sample are safe to use. As a result of their lack of destructive potential. The screening tools allow for a fast evaluation to distinguish between healthy and unhealthy trees. Using diagnostic tools to evaluate the scope and nature of tree damage takes more effort. Evaluation via an intermediate method combines fast screening with accurate diagnosis [24].

**Sustainable Methods**

The pros and cons of several methods of tree decay detection beyond IRT are summarised in Table 2, and further reading may be obtained in the cited works [25]. The radiation is harmful to all living things, and invasive techniques can increase the damage done to trees [26]. Users and bystanders alike must be assured of the safety of inspection tools. Therefore, it is important to pick eco-friendly machinery. This gear strikes a nice balance between portability, speed of use, and not being invasive or ionizing. Additionally, they use little to no consumables and have low energy costs [20] [27].

**Infrared Thermography**

Detecting the infrared (heat) radiation emitted by objects and bodies, infrared thermography (IRT) is a safe, noncontact, and nondestructive technique (wavelength range of 0.8-14 m). Infrared energy can be converted into visible light with the use of instruments that create false-color images, such as an infrared camera. An infrared thermometer (IRT) captures an image of the temperature distribution by sensing infrared (IR) energy emitted by a surface and converting it to a temperature reading. When heated above absolute zero (or K), all matter—organic or inorganic—emits infrared radiation, which can be collected by sensors that turn that energy into images imaging [28]. Depending on the state of each part's health, the body's internal structure exhibits varying degrees of thermal behavior. As a result of variations in thermal behavior, the colors seen on the skin surface will look different for each individual [29].

The infrared camera is used depends on factors such the inspection object's qualities, the weather, and the distance from the camera. The atmosphere absorbs most infrared radiation, albeit the amount that is taken in by the atmosphere depends on the wavelength of the radiation. Since less radiation is absorbed, more of it reaches the camera's sensor. It's commonplace in concert halls: Between 2 and 5 micrometers for mid-wavelength infrared (MWIR), and between 8 and 14 micrometers for long-wavelength infrared (LWIR). Both

LWIR and MWIR cameras are susceptible to picking up optical and electrical noise, and humidity in the air can have an effect on MWIR cameras.

There are various variables that influence an object's emissivity, one of which is wavelength. Emissivity is also extremely sensitive to surface composition [30]. The effect of parasitic reflections decreases as emissivity rises. Metals have low emissivity since they are extremely reflective, hence nonmetallic materials are preferable for precise measurements because of their higher emissivity and reduced reflection. For the purpose of processing and interpreting IRT data, cameras with screens are necessary for viewing the radiated energy. Keeping a record of your thermograms is a useful tool for tracking the course of a disease or condition over time [31]. Additionally helpful is a camera that can take both photographs and thermograms at the same time. In low-light conditions, having an integrated illumination accessory is preferable because it makes it easier to read the data [32].

Both passive and active thermographic methods are commonly used. In the active method, thermal contrast is introduced into the object of study with the help of an external energy source. An array of processes, including the use of thermal sources like lights or heaters, can set off the heat flow. Surface flaws and other damage generate thermal discontinuities, which in turn create thermal contrast. In the course of the thermographic examination, the problem is uncovered. Passive methods rely on unaided nature, like sunlight, to produce thermal contrast [33]. Calibration of the camera's temperature measurement requires the introduction of an emissivity factor in the vast majority of thermographic application scenarios. The correct emissivity rating for a certain wood remains crucial.

Both wood and tree plantlets can benefit from the IRT approach, since it can be used to detect deterioration and cavities that could compromise the plantlets' structural integrity and shorten their lifespan. When there are flaws in an object, the distribution of energy is messed up, leading to temperature variations on its surface. The thermal camera detects variations in temperature due to differences in the emission of radiation [34].

**Wood**

It's important to note that wood and trees have significantly varied thermal characteristics. Their thermodynamic parameters (such as temperature, density, humidity, thermal conductivity, thermal diffusivity, specific heat, convective coefficient, and emissivity) are determined by several factors.

The thermal behavior of a wood species can be predicted after its density and other properties have been established. As a result, biodegradation affects the density and humidity of wood, which in turn affects thermal behavior and surface temperature distribution [55-58]. compares a standard surface photograph of wood with the resulting thermogram from an active IRT experiment. When in their active state, these fissures and nodes display a chromatic pattern that is inconsistent with the rest of the surface. This suggests that the temperature is quite high. Fissures are barely visible in the photo, but they jump off the page in the thermogram.

Sap flow is responsible for the varying temperature profiles along the tree's trunk, and trees with greater access to water have more efficient sap flow [35]. Since the transport occurs within the functional tissue, this feature permits the separation of healthy and diseased cells [36]. The tree's vitality and health can be assessed in this way, but its thermal behaviour cannot be extrapolated to other trees, even those of the same species, in order to spot wounds. Even if two trees with the same pathology are found, each tree must be assessed separately. Two damaged trees of the same species and pathology can generate various thermal patterns due to the availability of water to which the tree is vulnerable. That's why every tree has its own unique temperature pattern that may identify healthy or unhealthy tissues.

A tree's outer bark is cooler than a wooden stake's outer layer, Prunus domestica L., more commonly known as the plum tree, was the species of tree studied. It was observed in the summer, around 4 hours after sunset. The authors painted with a rainbow of colors and chose an emissivity value of 0.97. The air temperature was 22.5 degrees Celsius and humidity was 55% when the observation was made. With the exception of its lowest point, the wooden stake was significantly cooler than the tree. As a result of pre-observation tree irrigation, the lower portion of the wood stake registered a little higher temperature than the lower trunk. Trees maintain a steady equilibrium with their surroundings, so once the sun's heating effect has passed, the temperature of the tree itself typically drops below that of the surrounding air [37]. As a result, the tree's temperature was higher in its more robust regions and lower in its more decayed and recently water-soaked regions (and elsewhere) [38].

Laboratory conditions are ideal for IRT treatments of wood. In fact, the laboratory is the first scenario chosen due to the ease of manipulation and the ability to regulate several environmental parameters (humidity, temperature, and light). To confirm IRT's ability to detect wood degradation, some studies have artificially damaged samples in the lab [39]. Most thermographic studies of trees are conducted on trees that are slated for removal, or at other times when the abnormalities can be observed without harm. [40].

Many different applications of IRT to wood have been developed. Reference [41] details a method for checking the quality of individual wood pieces along a manufacturing line. The findings demonstrated that TIV can be used to either identify the debonded regions or eliminate them entirely from the manufacturing process. Reference [41] details the IRT of using ultrasonic equipment to inspect historic buildings [42]. The authors suggest that the use of ultrasonography and thermography together is a good tool for evaluating the stability of wooden constructions by analysing the Oratorio San Felipe Neri in Cadiz, Spain.

The Aslanhane Mosque in Ankara, Turkey was inspected utilising ultrasonic equipment and accompanying IRT, with supporting laboratory studies of timber samples. A number of these techniques were used to assess the state of preservation, the presence of moisture problems, and the compatibility of recent repairs to the wood structural elements. The results showed that when these techniques were combined, it was possible to assess the quality of the wood, increase the precision and efficiency of the survey, and separate the job of immediate intervention from that of long-term conservation initiatives. The issue of finding termites in wooden and wood-sided structures is investigated. The author explains that TIV permits the discovery of areas exhibiting anomalous elements that could be associated with the presence of moisture or hot spots, as well as the presence of subsurface defects, both of which are essential for an inspector to look for when identifying the presence of pest infestation. In addition, the IRT was used in concert with other techniques to identify sudden, extensive wood decay in a big wooden structure like a railroad bridge [43].

The thermal camera is limited in its ability to record contrast because it can only measure the temperature of the tree's outer bark. Yet, the tree bark around the damaged areas and the voids are cooler than the surrounding area. Trees with decayed tissue and voids have the same effect on heat retention as wood [44]. The thermal characteristics of wood and tree bark can be distinguished with the aid of IRT. When applied to trees, IRT allows for the differentiation of healthy from diseased tissues. The thermal pattern of the tree bark should be viewed in the thermal image whenever a new species is being evaluated, however, because of the differences between species. The initial use of IRT in trees was for aerial surveillance of tree canopies to detect the location and amount of forest damage. Subsequently, IRT was used to assess damage to tree bark (both trunks and branches), providing insight into what was causing issues at the root level.

Tree health is affected by a number of external influences, which in turn change the tree's thermal qualities. IRT may detect a wide variety of situations, including disease, pest infestation, water stress, and the growth of new functional tissue. In terms of pathogens, IRT can be used to spot tree bark lesions, like Phytophthora spp.-caused hemorrhagic cancers, long before the disease's visible effects become apparent [44][45]. Fungal species such as Inonotus hispidus (Bull.) P. Karst., Phellinus punctatus (Fr.) Pilát, Coriolus pubescens (Schumach.), and Corticium sp. were discovered, for instance, using IRT analysis of samples collected from the woody components of platan. Insect pests on trees can also be identified using IRT. Leaves and trunks both prey on insects, which feed on and lay eggs in them. Poor irrigation, flooding, and inadequate trimming all reduce a tree's ability to regrow or resist, even though it may endure some damage to its leaves from pests. In contrast, larvae and insects cause wounds that open the trees to additional diseases [46]. Tunnels dug by some larvae deep into the trunk can disrupt the flow of water and nutrients, hastening the decline of the tree. The IRT did not detect goat moth larvae and other insects in their larval phases when they were in young trees. This includes the White Pine Cone Beetle, the Australian "fire-beetle," the Citrus Long-horned Beetle, the Woodworm, and the Red Palm Weevil (RPW). The larvae may have become so acclimated to their surroundings that even the increase in temperature caused by their activity is insufficient to detect them [47].

IRT is also used to determine the degree to which trees are experiencing water stress. Canopy temperature can be used as a surrogate for soil moisture since transpiration is a means by which leaves release heat. excess of force (heat). To keep itself cool, the tree uses its excess energy to evaporate water through its leaves. When the soil is dry, the tree sweats less, leading to higher leaf temperatures than in adequately moist soil. Monitoring water stress is useful because it allows us to know how much water to give to each tree species individually.

Newly formed functional tissue can be detected by IRT. The thermogram has correctly identified a zone of higher wood development after additional investigation. This occurs as a result of the adaptive expansion of the alteration since the vascular cambium is the cell generator and the new cells have different thermal characteristics than the other tissues. This new cell formation differs from other tissues in its thermal properties. The thermogram confirmed the visual observation of a hollow along the trunk of this tree. An accurate prognosis of the tree's true condition, according to Catena and Catena, necessitates the determination of the reason for tissue formation, such as damage and/or mechanical stress.

Because IRT permits the entire tree to be observed, damage can be detected early, even in trees without any outward visual signs. The inspection process takes little time with IRT, and the results can be understood quickly. Safe observation from a distance of up to 25 m (depending on camera and lens) is achievable, as no touch with the tree is required. Since it does not give off any harmful radiation, it is a technology that is safe for both the trees and the examiner. It saves time and money because you won't have to set up a ladder or a lifting platform to see what's up high in the tree [29]. Real-time root damage assessment is also possible with IRT through inspection of the lower trunk. It's used to measure robustness and security. It makes it simpler to track changes in trees' health over time, both in terms of the progression of known pathologies and the appearance of novel ones [69]. While this is a benefit of IRT, it is not what sets it apart from other inspection methods. The information obtained from IRT can be used to assess a tree's health and vitality in a non-destructive, rapid, and low-cost manner. In the wake of the green revolution, farming became highly mechanised; now, it is being digitalized along with every other industry. This study demonstrates that farmers are receptive to new technologies that improve their bottom lines, require less training, and simplify their daily routines. While it helps with event management and implementation in the here and now, intelligent response technology (IRT) could play a significant role in the future of "smart farming" and agriculture.

The fundamental limitation of IRT is that, like other non-invasive technologies, it cannot distinguish between voids and damaged tissue, nor can it identify the agent responsible for the damage. It also cannot provide accurate estimates of the damage. However, because IRT pinpoints problem areas before they worsen, it speeds up the testing process and saves money. The collected information allows for a more precise analysis of the pathologies and pinpoints the areas in need of invasive procedures. When the tree's surface is covered in mosses or other plants, when the tree is moist, or when IRT is exposed directly to sunlight, thermographic interferences are observed. To get around some of these obstacles, it's best to conduct inspections before the trees are watered or to wait until the weather has cleared up after a rainstorm. Testing in direct sunlight is discouraged and instead should be done at night. The price of the gear is often cited as a disadvantage when compared to cheaper, less complex alternatives. When compared to more advanced machinery or when considering a wider range of potential uses beyond simple tree health assessment, this is not the case [48].

**Conclusions**

The IRT was introduced as a tool to evaluate tree health, and it has been found to be effective in the early detection of damages, even though it is not feasible to identify the type of damage. Invasive approaches, as well as other non-invasive and non-destructive techniques, can be used to pinpoint the source of the problem. When compared to other forms of inspection, IRT has shown to have significant advantages in its ability to distinguish between healthy and unhealthy tissue, allowing for a more thorough assessment of a tree's overall vitality and health. Rapid, low-cost, and non-destructive pathology monitoring is now possible. The development and widespread use of IRT can lead to better outcomes. In spite of its benefits, IRT is still a novel method for assessing tree health and is only partially adopted in agriculture. It is clear that further research is needed to lay the groundwork for a robust application base from which practitioners can draw guidance. This would open the door for further applications of IRT. The performance of the technique is hindered by a number of obstacles, including its complexity, the novelty and unusualness of the situation, and a number of knowledge gaps relating to technical issues and the particulars of its applicability. The latest high-definition thermal cameras, which record thermal pictures of high resolution and sensitivity, will also contribute to this goal of evolving the IRT approach into a decision-making tool for evaluating tree health, but overcoming these challenges is vital.

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