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OVERVIEW OF THERMAL IMAGING FOR TREE ASSESSMENT

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Summary

The value of thermography for trees is reviewed in relation to the needs of inspectors and diagnosticians in the fields of forestry, arboriculture and veteran tree management. Images obtained with an infrared camera allow the early detection of various kinds of alteration in trees, including bark necrosis, decay and the onset of adaptive growth in response to damage or mechanical stress. Advantages include total non-invasiveness, rapidity of use, the provision of 'real-time' information and the ability to work at a distance of as much as 25 m. In order to assess trees, however, the surfaces must be out of direct sunlight, free from running water and unobscured. The images do not distinguish between different kinds of alteration automatically, but they can usually be correctly interpreted in the light of appropriate knowledge and experience. The technique does not allow a truly quantitative assessment of the relative extent of decayed and sound wood, but it appears to be accurate enough to identify trees which merit either remedial action or more precise assessment.

Keywords: Tree physiology, Tree assessment, Veteran trees management, Habitat assessment, Tree decay, Tree hazard assessment, Thermography, Thermal imaging, Infrared photography, *Phytophthora* spp.

Introduction

Thermography is a well established technique in a range of disciplines, including engineering and medicine. The use of an infrared camera system for the thermographic detection of decay and/or cavities in trees has been described and reviewed (CATENA, 1990; CATENA, 1992). The resulting thermal images represent only the pattern of temperature at the bark surface, but this pattern represents the differing thermal properties of underlying zones of sound and decayed wood, which produce steady-state temperature

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gradients across the bark surface. The pattern appears as a black-and-white or pseudo-colour 'thermal map', in which the bark overlying decayed wood or a cavity (CATENA 1993) is usually cooler than the surrounding area.

Compared with other methods for decay detection, infrared imaging has the clear advantages of being totally non-invasive. As such, it allows data to be collected at intervals without disturbing the tree internally, thus aiding the investigation and accurate monitoring of a potential or confirmed deterioration in health or mechanical integrity. A further advantage is that it can operate at a distance of up to 20 or 25 metres (CATENA *et al*., 1990) and therefore allows the detection of cavities that would otherwise be accessible only by climbing or via hydraulic platforms. Also, the information is provided in 'real-time'. These characteristics can clearly avoid inconvenience and personal risk and save time. Indeed, the technique is less time-consuming in its use than any other technologically advanced system. As with any system, however, practitioners require information about accuracy, reliability, and cost. The present article considers these questions and also considers the value of the technique for the assessment of trees as habitats for wildlife associated with cavities.

The specificity of the system for decay detection

The thermal properties of stems and branches in standing trees may be affected by a number of factors, of which decay is not the only one. For example, as discussed below, bark lesions caused by pathogens such as *Phytophthora* spp. can be detected by thermal imaging while not yet externally visible (CATENA, 2003). On balance, it seems useful that thermal imaging can detect a range of possible defects in addition to decay, or that it can detect decay (in the root system) beyond the direct range of the image. Although it does not provide a specific diagnosis for decay, there will in most cases be other visual evidence that can be used. In particular, decay is associated with easily recognised features, such as pruning wounds or the ageing of the root system (LONSDALE, 1999). Correct interpretation of infrared imaging may, however, require the use of other specialised techniques in some instances.

Qualitative and quantitative assessment of decay

Numerous case studies have been cited to show that extensive zones of decay are represented by correspondingly extensive 'cool zones' on thermal images. This relationship has not been investigated precisely, but it has been broadly verified by 300 general comparisons between thermal images and data obtained using invasive tools and felling (CATENA, 2004). Nothing is yet known about the relationships between thermal images and the different kinds and stages of decay (CATENA, 2003). It is, however, of interest to note that the technique appears able to detect decay caused by *Kretzschmaria* (= *Ustulina*) *deusta* (G. Catena, unpublished data; the trees were measured at the Nottingham Trent University – Brackenhurst Campus). This kind of decay has proved difficult to detect using certain other devices (SCHWARZE *et al.*, 1995) and has therefore come to be regarded as a test of sensitivity (RABE *et al.*, 2004). As is usually the case with decay, the area of bark overlying the decay caused by this fungus was colder than the surrounding bark.

In tree risk assessment, it is often necessary to estimate the extent of decay, so as to determine whether it represents a significant weakness, for example by calculating the relative thickness of a residual wall of sound wood in the form of the 't/R ratio' (MATTHECK and BRELOER, 1994). As pointed out by CATENA (2003), thermal images cannot provide such measurements precisely. Also, in certain cases, large cool zones have been found on stem bases that, once the tree was felled, showed only small volumes of decay above ground level. However further investigation revealed that the decay was more extensive below ground-level (CATENA, 2003). This indicates that thermography can enable the detection of decay in the root system, for which there is currently no other technologically advanced method.

Despite some exceptions, most investigations to date have shown a direct relationship between thermal images and the relative extent of the underlying zones of sound and decayed wood. For example, the large tree whose thermographic image of the base is shown in Figure 1 contains a

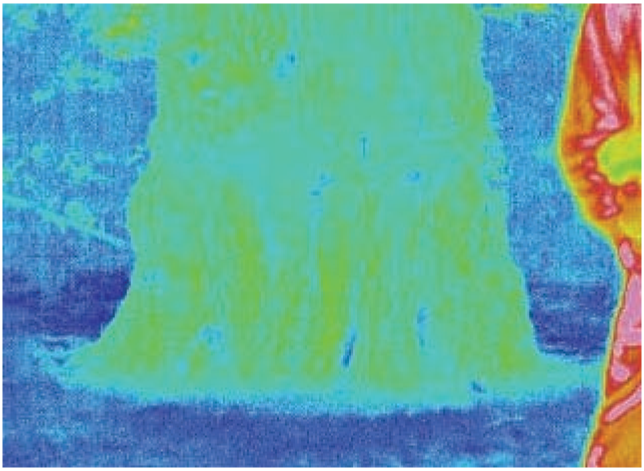

FIGURE 1. This *Horse Chestnut* is totally hollow, but a massive wall of newly formed sound wood provides good mechanical support.

wide cavity all along the stem; this was evident from a cavity-opening on the opposite side. However, the thermal image shows several yellow strips, representing substantial zones of functional, vital tissue, surrounding the cavity which is represented in blue. Thus, the image correctly indicated that the tree's mechanical integrity was not significantly compromised. Generally, it appears that thermal imaging provides a good basis for deciding whether the t/R ratio is either well above or well below a threshold at which other methods might be needed to obtain comparative information.

Assessment of features other than decay

Any feature that substantially alters the thermal properties of wood or bark can be detected by thermography. This might cause uncertainty in the interpretation of thermal images, but it is possible to distinguish between decay and other features if the assessment is made in the light of other evidence and of appropriate knowledge and experience. For example, the formation of new functional tissue by adaptive growth of the cambium can be detected by its thermal properties before its presence is otherwise obvious. For prognosis of the tree's condition, it is important to know whether such tissues are forming in response to damage and/or to mechanical stress. The thermal image in Figure 2 shows a *Sophora japonica* with a light yellow strip of colouration running the full length of the trunk. The dark blue colour indicates a cavity also running along the trunk. Analysis of this image, together with dissection of the tree, showed that the yellow strip corresponded to a strip of increased wood formation, running parallel to the cavity as shown in Figure 3. The thermal image was shot from the direction pointed out by the red asterisk.

A further application of thermography is the detection of bark lesions (e.g. bleeding cankers caused by *Phytophthora* spp.) at a stage before such damage becomes visible to the naked eye. The thermal image in Figure 4, taken in Holland in October 2004, shows an *Aesculus hippocastanum* with no visible signs of damage,

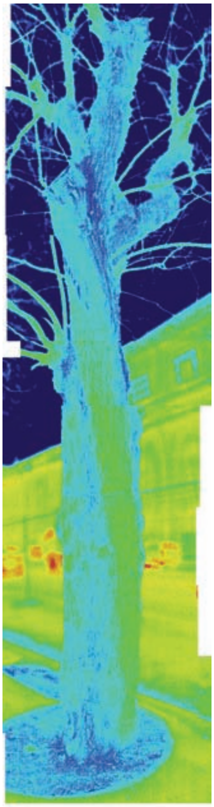

FIGURE 2. Thermal images can reveal new forming strips of functional tissue in trees even when they are not yet visible from the outside. The case of a *Sophora japonica* whose trunk is hollow from the base to the bifurcation: the yellow strip points out the presence of new functional tissue too.

FIGURE 3. The stump of the *Sophora japonica* confirms the presence of the cavity and of the newly formed tissue in the area of the yellow strip.

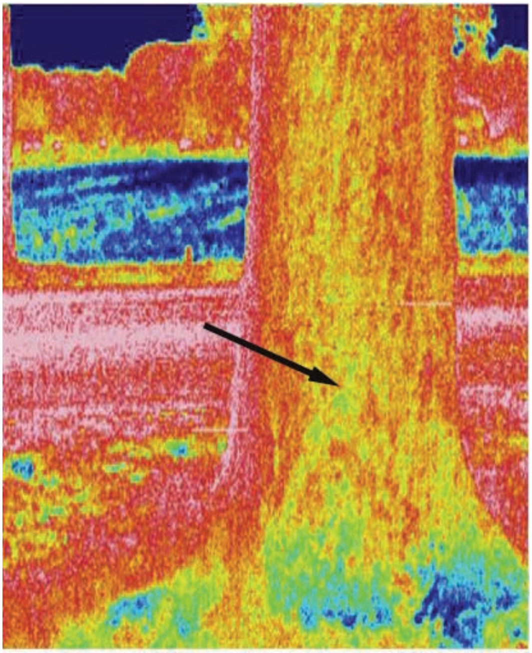

FIGURE 4. The thermal image of this *Aesculus hippocastanum* points out in light blue (black arrow) the presence of internal decay (bark necrosis): it was confirmed by cutting away the outer bark. The grass at the collar is responsible for the dark blue and blue colours in the corresponding area of the thermal image.

Figure 5. The thermal image showed that the tree was affected by delimited tissue lesions (pointed out by the black arrow), the presence of which was confirmed by cutting the bark in the locality indicated as a light blue spot in the thermal image. Although these lesions were of the type caused by *Phytophthora* spp. they were in this instance not identified.

To date, there have been no studies to investigate the application of thermography for the detection of bark lesions caused by *Phytophthora* spp[1]. However, in view of experience with bark lesions so far, it seems highly likely that the technique has considerable value in this context.

Thermography of bark is a relatively new development, compared with the use of infrared imaging of the crowns of trees, using monochrome and false colour films. This has been done for many years in aerial surveillance so as to detect the distribution and spread of damage in forests. Also, when applied to the foliage of individual trees, infrared photography can make a significant contribution to disease detection (BAWDEN, 1933; CATALANO *et al*., 1986; CATALANO *et al*., 1988; CATENA *et al*., 1991), often before damage becomes visible to the naked eye.

Applications for habitat assessment

Over recent years, arboriculture has increasingly embraced new fields of interest and assessment. A particularly important development has been

FIGURE 5. The picture of the same tree shows no damage on the surface of the bark.

[1]It is the intention of the current investigation into Thermography to focus on its role in *Phytophthora* detection.

the recording and investigation of veteran trees, which has been promoted in the UK largely through initiatives involving the Ancient Tree Forum (ATF)[2]. Thanks to these initiatives, there are numerous sites where trees of significant interest for landscape and biodiversity are valued and have been recorded and studied. Decaying wood and cavities within these trees, often formerly regarded only as potentially hazardous, are recognised for their habitat value as well as for the need to undertake risk assessments where appropriate. Thermography should be of value for identifying these features, particularly in cases where other methods would involve the need for tree climbing or the use of hydraulic platforms. Invasive methods might also disturb animals that are nesting, roosting or hibernating within cavities. These may include legally protected species, the disturbance of which could infringe laws such as the Wildlife and Countryside Act (1981) and the Countryside and Rights of Way Act (2000), in the case of the UK.

Figure 6 shows a black-and-white picture of a relatively young Plane Tree: it was of some interest as there were two small woodpecker holes

FIGURE 6. Young Plane Tree with no external sign of damage but two Woodpecker holes. One is pointed out by the black arrow

[2]The ATF is a UK multidisciplinary non-governmental agency, whose aim is to improve the scientific knowledge about ancient trees, for the benefit of their effective sustainable management and protection.

on the trunk (one is pointed out by a black arrow), but no other signs of decay. The monochrome thermal image (Figure 7) taken with an early form of the apparatus shows a wide cavity in dark grey, at the bifurcation going up along the two branches but mainly in the one on the left side of the image.

FIGURE 7. Black-and-white thermal image of the Plane in Figure 6 taken with an early form of apparatus. It reveals the presence of a large cavity at the bifurcation level going up mainly along the branch in the left side of the image.

The same apparatus showed the presence of a substantial cavity, shown in dark grey, in a *Casuarina* from which a Tawny Owl (*Strix aluco*) was later seen to fly (Figure 8). The cavity was not visible from ground level. From the thermal image it is impossible to identify the large bird. This is because both the high insulating power of its feathers and of the wood prevent the detection of a living, warm body inside the trunk. In the case of large colonies of bats, it could theoretically be possible that the heat they produce could be recognized flowing out of the cavity.

Limitations: surfaces that are unsuited for thermography

For the reasons stated by CATENA (2003), thermography will be unsatisfactory if the bark surface is obscured by anything such as moss or other vegetation, or if it is wet or has been heated by direct exposure to sunlight. The latter limitation can, however, be avoided in many cases, by obtaining images only from a permanently shaded portion of the stem or branch. Also, the system has been found to perform well over a wide range of ambient temperature (from +2ºC to +35°C in tests so far), by day or by night.

It might be argued that the sensitivity or accuracy of the system might be affected by the thickness or the insulating properties of the bark of various tree species. To date, a few thousand trees of many different species have been satisfactorily assessed, including broadleaved – as well as cork trees (CATENA, 1993), coniferous and palm trees (CATENA, 2004): therefore there is no evidence to support the above argument.

Potential for further development of thermography of trees

There is a need to investigate the mechanisms whereby thermography reveals decay and other alterations in trees. A thorough understanding of these mechanisms and of the extent to which thermography can reveal the nature and dimensions of alterations should allow the technique to be further developed and to assist users in interpreting the images that it provides.

Type of Apparatus and Specifications

Almost any type of currently available infrared camera can be used for the thermal imaging of trees, provided that it has high geometric resolution and thermal sensitivity and includes a monitor for visualising the images of the area being filmed (CATENA, 2003). At present apparatus is sold at reasonable prices (£3,500 – £5,000/€5,000 – €8,000): in the UK can even be rented on a daily basis.

FIGURE 8. The thermal image of this *Casuarina* shot with the same appartus as Figure 7 shows the presence of a big cavity at the bifurcation, not perceivable from the ground. It harboured the nest of a Tawny Owl that was seen after the image was made.

Conclusions

Thermography of trees provides a means of detecting alterations relating to mechanical integrity, physiological function, tree vitality, disease and habitat conservation. In particular, it appears to have special value for detecting the early stages of such alterations, including those that involve the root system. The technique does not automatically distinguish between different kinds of alteration, but a correct diagnosis is usually possible in the light of appropriate technical knowledge and experience (CATENA, 2003) and occasionally with the use of other methods. Although, with current knowledge, thermal images do not precisely measure the dimensions of features such as cavities, they provide enough information to help decide whether there is a need for remedial action or a more detailed kind of assessment. The main advantages of thermography over other diagnostic techniques are that it is totally non-destructive, rapid in its use and capable of use at a considerable distance from the object.

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References

BAWDEN, F.C. (1933) Infra-red photography and the plant virus diseases. *Nature*, **29** July, 168.

CATALANO, M., CATENA, G. and PALLA, L. (1986) Impiego dell'infrarosso per l'individuazione di alcuni fenomeni morbosi negli alberi. *Agricoltura Ricerca*, **59**, 7–16.

CATALANO, M., CATENA, G. and PALLA, L. (1988) Fotografia all'infrarosso e termografia nella patologia vegetale. *Genio rurale*, **2**, 35–38.

CATENA, G. (1990) A new application of Thermography. *Atti della Fondazione Giorgio Ronchi*, **6**, 947–952.

CATENA, G. (1992) Une application de la Thermographie en Phytopathologie. *Phytoma*, **439**, 46–48.

CATENA, G. (1993) Utilizzazione di uno scanner termico per la diagnosi di cavità negli alberi. *Ingegneria agraria*, **2**, 67–75.

CATENA, A. (2003) Thermography reveals hidden tree decay. *Arboricultural Journal*, **27**, 27–42.

CATENA, A. (2004) Thermographie et dendrodensimetrie pour l'évaluation de la stabilité des arbres. Comparaison de résultats. *Révue forestière française*, **2**, 164–170.

Catena, G., Catalano, M. and Palla, L. (1990) Thermal infrared detection of cavities in trees. *European Journal of Forest Pathology*, **20**, 201–210.
Catena, G., Catalano, M. and Palla, L. (1991) Problemi e tecniche di tutela e di gestione del verde storico. *Quaderni di Botanica Ambientale e Applicata*, **2**, 11–21.
Lonsdale, D. (1999) *Principles of Tree Hazard Assessment and Management*, Research for Amenity Trees, **7**, The Stationery Office, London, 388 pp.
Mattheck. M. & Breloer, H. (1994) *The Body Language of Trees: A handbook for failure analysis*, Research for Amenity Trees, **4**, HMSO, London, 240 pp.
Schwarze, F.W.M.R., Lonsdale, D. & Mattheck, C. (1995) Detectability of wood decay caused by *Ustulina deusta* (Fr.) Petrak in comparison with other tree decay fungi. *European Journal of Forest Pathology*, **25**, 327–341.
Rabe, C, Ferner, D., Fink, S. and Schwarze, F.W.M.R. (2004) Detection of decay in trees with stress waves and interpretation of acoustic tomograms. *Arboricultural Journal*, **28**, 3–19.

About the authors

Alessandra Catena was born in Rome, Italy. After a year spent at the Istituto Superiore di Sanità of Rome, to learn and specialise in the use of Thermography in assessing tree safety and hazard, she graduated in Forestry on 19.12.2000 at the University della Tuscia, Viterbo, Italy, with a thesis that included the use of thermography to assess trees. She is a freelance tree consultant; the only one in Italy specialised both in tree stability assessment and in the use of thermography. She has undertaken several hundred thermographic investigations on numerous tree species. She is a member of the International Society of Arboriculture, Italian Chapter. She has presented papers and posters on the use of thermography for tree assessment at some international conferences; she has published and is writing articles on the same topic for Italian and international journals.

Giorgio Catena was born in Rome, Italy, on 19.05.1941. Graduated in Chemistry, he is an expert in Remote Sensing (aerial photography and thermal imaging). For 29 years, Dr Catena was Director of the Remote Sensing Unit he set up in 1974 at the Italian National Institute of Health. He has extensively used photographic and thermal infrared imagery and first applied its use for tree Assessment in 1984; in his archives he has more than 40,000 images, shot during thirty years' work. Dr Catena is now the General Manager of Catena & Thermography, a company co-owned with his daughter Alessandra, a professional tree consultant with a degree in forestry. Their purpose is the development of thermography in tree assessment: to this end, they have been abroad several times, to the UK, the Netherlands and Germany. He is the author and co-author of more than

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CONTENTS

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