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Chapter 1 : BIPM - thermometry

The concept of humidity is defined, and factors that influence humidity are discussed in a practical context. The clinical importance of measurement and control of humidity is illustrated. Commonly used methods of measuring humidity are described and their underlying physical principles are explained.

Other thermometers One must be careful when measuring temperature to ensure that the measuring instrument thermometer, thermocouple, etc. Under some conditions heat from the measuring instrument can cause a temperature gradient, so the measured temperature is different from the actual temperature of the system. In such a case the measured temperature will vary not only with the temperature of the system, but also with the heat transfer properties of the system. What thermal comfort humans, animals and plants experience is related to more than temperature shown on a glass thermometer. Relative humidity levels in ambient air can induce more or less evaporative cooling. Measurement of the wet-bulb temperature normalizes this humidity effect. Mean radiant temperature also can affect thermal comfort. The wind chill factor makes the weather feel colder under windy conditions than calm conditions even though a glass thermometer shows the same temperature. Airflow increases the rate of heat transfer from or to the body, resulting in a larger change in body temperature for the same ambient temperature. The theoretical basis for thermometers is the zeroth law of thermodynamics which postulates that if you have three bodies, A, B and C, if A and B are at the same temperature, and B and C are at the same temperature then A and C are at the same temperature. B, of course, is the thermometer. The practical basis of thermometry is the existence of triple point cells. Triple points are conditions of pressure, volume and temperature such that three phases are simultaneously present, for example solid, vapor and liquid. For a single component there are no degrees of freedom at a triple point and any change in the three variables results in one or more of the phases vanishing from the cell. Therefore, triple point cells can be used as universal references for temperature and pressure see Gibbs phase rule. For example, the cosmic microwave background temperature has been measured from the spectrum of photons observed by satellite observations such as the WMAP. In the study of the quarkâ€"gluon plasma through heavy-ion collisions , single particle spectra sometimes serve as a thermometer. Non-invasive thermometry[edit] During recent decades, many thermometric techniques have been developed. The most promising and widespread non-invasive thermometric techniques are based on the analysis of magnetic resonance images, computerised tomography images and echotomography images. These techniques allow monitoring temperature within tissues without introducing a sensing element. Instrumental temperature record The temperature of the air near the surface of the Earth is measured at meteorological observatories and weather stations , usually using thermometers placed in a shelter such as Stevenson screen , a standardized well-ventilated white-painted instrument shelter. The thermometers should be positioned 1. A true daily mean could be obtained from a continuously-recording thermograph. Commonly it is approximated by the mean of discrete readings e. Comparison of temperature scales[edit].

Chapter 2 : Thermometry and humidity - National Research Council Canada

Thermometry is the science and practice of temperature measurement. Any measurable change in a thermometric probe (e.g. the dilatation of a liquid in a capillary tube, variation of electrical resistance of a.

T4 for control group was pretty stable during the 10 s of sustained eye opening. No significant differences were found in mean change at any point of time unpaired -test at each 1 s interval, between the two groups for other OST indices during dynamic measures Figure 3. Dynamic measures graphs showing the mean change OST relative to baseline during the 10 s sustained eye opening: Values in boxes represent the cooling rate and net change in OST over the 10 s period in dry eye and control groups, respectively. A comparison of mean at each 1 s interval was performed using unpaired -test,. Discussion The current study demonstrated the ability of IR ocular thermography in assessing dry eye. Ten OST indices were evaluated in two aspects: We believe this is good compromise between single pixels and a larger ROI which would provide less opportunity to analyse specific geographic areas of interest. OST in dry eye was different from controls at different ocular surface areas during static measures upon eye opening s as well as when s and 10 s. As compared to controls, the ocular surface of dry eye subjects was significantly cooler as recorded at the geometric center of the cornea GCC as well as various areas at conjunctiva T4, CT, and CN and limbus LT and LN and causing an overall lower mean ocular surface temperature MOST. As the ocular surface measured by the thermotracer consists of cornea-conjunctiva-limbal complex, it was not surprising to record a significantly lower minimum temperature of the ocular surface and maximum temperature of the ocular surface in dry eye. During dynamic measures, OST was found to drop over the 10 s of sustained eye opening in both the dry eye and control subjects. Only two OST indices out of ten had significant steeper regression line of mean change with greater net change in dry eye. As for the temperature of the extreme nasal conjunctiva T4 , the change was only observed in dry eye subjects and was statistically significant from 3 s onward. Static Measures The primary source of ocular radiation measured by ocular thermography is the tear film [11] so changes in tear film thickness and its composition alter the temperature measured [8]. Lower OST in the dry eye group found in the current study could be due to a thinner tear film as a result of a thinner tear film lipid layer TFLL in dry eye [34 , 35]. TFLL has been reported to be important in tear film stability and evaporation [36] and is abnormal in dry eye [8 , 37]. According to the Dry Eye Workshop report [2], tear film instability is one of the two core mechanisms of dry eye and can lead to thickness variation and an overall thinner tear film. The ocular surface was cooled by a thinner tear film leading to lower temperature recorded on various ocular surface areas geometric center of the cornea, conjunctiva and limbus during static measures at s. OST was likely to be affected by variations in evaporation in the seconds after eye opening, in addition to the effects of convection [8]. Not unexpectedly, lower temperatures were noted in dry eye subjects after 5 s and 10 s of eye opening. Thermography has been reported as an indirect method to evaluate tear evaporation rates and tear film impairment due to its ability to record subtle changes over the corneal temperature [14]. Indeed, tear evaporation in dry eye can cause a fold reduction in tear thickness after a blink [38] and was found to be correlated with lower corneal temperature and subjective discomfort symptoms [22]. This was apparent in the current report revealing a declining temperature on the various ocular surface areas from 0 s to 10 s during static measures. The temperature gradient is varying at different OST indices and suggestive of different evaporation rate at different areas of the ocular surface. Although temperature variation has been reported to be higher in dry eyes when RTD radial temperature difference was studied by Morgan et al. A lower MOST value in dry eye was in agreement with the report by Singh and Bhinder [16 , 40] using remote sensor thermometry but conflicts with the report by Morgan et al. A warmer overall ocular surface has been accounted for by the increased conjunctival hyperaemia in dry eye [11 , 41]. The vascularised conjunctiva is an important heat source [3] to the ocular surface. Certainly, OST is increased during inflammatory disease [3 , 5] and ocular surface inflammation is a core mechanism in dry eye [42]. A higher MOST could also be associated with higher blink rate in dry eye [43]. The conflicting results found in our study as compared to those previously reported may be due to various reasons. Firstly, most of our dry eye subjects did not present with conjunctival hyperaemia, the results were therefore different. Secondly, different experimental methodologies may lead to different findings as suggested by Kamao et al. Furthermore, the ROI studied was the lower half of the ocular surface whereby tear film will thin faster [29] as compared to other areas due to evaporation and leads to a lower MOST in dry eye as shown in the current study. OST measurements by Singh and Bhinder [41] were made in a closed chamber instead of an open atmosphere so comparison with that work is clearly problematic as local environmental factors influence OST [44]. Thirdly, the severity of dry eye varied by report. Dry eye subjects recruited by Morgan et al. In more severe cases, the level of local inflammation and greater conjunctiva hyperaemia may overwhelm evaporative effects, leading to a warmer ocular surface [11]. Last but not least, age of subjects recruited could also cause different results. In previous projects, there was no apparent attempt to age-match the dry eye and the control groups. Dynamic Measures During dynamic measures, our results were in agreement with literatures that ocular surface cooled during sustained eye opening [12 , 45] and rate of the cooling was greater in the dry eye group [12]. This was also in consistent with a mathematical model developed by Peng et al. Tear film thinning and break-up have been shown to correspond to ocular surface cooling over time [45]. Dry eye had a thinner TFLL [34 , 35] and, upon eye opening, the tear film starts to thin due to evaporation leading to drop in temperature [36]. The cooling rate for was twice as much as in dry eye as compared to controls and may indirectly reflect the rate of evaporation in dry eyes as reported by Li et al. A twofold [47] and a threefold [48] increase in the tear evaporation rate in dry eyes has been reported previously. Although tear evaporation was not measured in the current study, tear film cooling in dry eye upon eye opening as a result of tear evaporation as well as greater effect of the positive latent heat of tear vaporisation has also been reported [8 , 12 , 49]. Changes in T4 were only observed in dry eye subjects and could be easily differentiated from their controls Figure 3. Conjunctival temperature was reported to be higher than the central cornea [7 , 50]. Although the reasons remain unclear, temperature of the nasal conjunctiva was reported to be higher than that of the temporal conjunctiva because of the influence of greater blood flow due to more large vessels including the dorsal nasal artery and the angular artery at the nasal conjunctiva [17]. There are more large vessels, including the dorsal nasal artery and the angular artery, on the nasal side of the eye, and the medial rectus muscle has two anterior ciliary arteries, whereas the lateral rectus muscle has only one artery [17]. The difference in vascularisation at nasal and temporal conjunctiva could have created different tear film cooling rate in these two areas upon eye opening and therefore the different results found in T4 and T1. The reason why there was no change in T4 for the controls warranted further investigations. Based on our findings, 10 s of sustained eye opening may not be required as it is hard for dry eye patients to keep their eyes open for 10 s without inducing reflex tearing and blinking. Conclusions Static and dynamic measurement of the OST provided two different aspects in studying the tear film. Both measurements were useful and can be used as clinical tool to assess dry eye. Competing Interests The authors declare that there is no conflict of interests regarding the publication of this paper. The authors thank Dr. Robert Straughan from School of Mathematics and Science for his valuable statistical advice.

Chapter 3 : Thermometer | measurement instrument | calendrierdelascience.com

Thermometry and humidity Services A complete range of temperature and humidity calibrations is available for resistance thermometers, liquid-in-glass thermometers, thermistors, thermocouples, humidity sensors and non-contact thermometers.

Published online Jul Find articles by Julio Molleda Francisco G. Find articles by Francisco G. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license http: This article has been cited by other articles in PMC. Abstract The intensity of the infrared radiation emitted by objects is mainly a function of their temperature. In infrared thermography, this feature is used for multiple purposes: This paper presents a review of infrared thermography especially focused on two applications: A general introduction to infrared thermography and the common procedures for temperature measurement and non-destructive testing are presented. Furthermore, developments in these fields and recent advances are reviewed. Introduction Infrared thermography IRT is a science dedicated to the acquisition and processing of thermal information from non-contact measurement devices [1]. It is based on infrared radiation below red , a form of electromagnetic radiation with longer wavelengths than those of visible light. Any object at a temperature above absolute zero i. The human eye cannot see this type of radiation. Thus, infrared measuring devices are required to acquire and process this information [3]. Infrared measuring devices acquire infrared radiation emitted by an object and transform it into an electronic signal [4]. The most basic infrared device is a pyrometer, which produces a single output using a single sensor. Most advanced devices include an array of sensors to produce a detailed infrared image of the scene. The difference between a visible image and an infrared image is that the visible image is a representation of the reflected light on the scene, whereas in the infrared image, the scene is the source and can be observed by an infrared camera without light. Images acquired using infrared cameras are converted into visible images by assigning a color to each infrared energy level. The result is a false-color image called a thermogram [5]. IRT has many advantages over other technologies [6]. In general, the main advantages of IRT are the following: IRT is a non-contact technology: In this way, the temperature of extremely hot objects or dangerous products, such as acids, can be measured safely, keeping the user out of danger. IRT provides two-dimensional thermal images, which make a comparison between areas of the target possible. IRT is in real time, which enables not only high-speed scanning of stationary targets, but also acquisition from fast-moving targets and from fast-changing thermal patterns. IRT has none of the harmful radiation effects of technologies, such as X-ray imaging. Thus, it is suitable for prolonged and repeated use. IRT is a non-invasive technique. Thus, it does not intrude upon or affect the target in any way. IRT provides particular advantages in the medical and veterinary field, as it provides accurate readings without invasive procedures. The fact that IRT is a non-contact technique is very important in this field, because this means that it is a painless procedure. Moreover, as the instrument is non-contact, it does not affect the result of the measurement and can be carried out remotely. Other alternatives can be painful, and when the sensor is in contact with the animal, it can affect the measurement. Therefore, IRT is very effective, not only for measuring the temperature of the animal, but other variables, such as stress [7]. Due to all of these advantages, thermography has been established as an effective tool in many different applications [8]. However, IRT is not without its drawbacks. Fast and affordable hardware has recently become available, but an infrared camera is still an expensive device. However, these inexpensive models with high spatial resolution provide lower accuracy, which makes them unusable for some applications. Infrared images can also be difficult to interpret; in general, specific training is required. IRT is also highly dependent on working conditions, such as the surrounding temperature, airflow or humidity. Therefore, IRT must be used in controlled environments. The intensity of the infrared radiation emitted by objects is mainly a function of its temperature; the higher the temperature, the greater the intensity of the emitted infrared energy. Many different applications can take advantage of this feature [9], from the temperature control of domestic induction cook tops [10], to mobile-robot positioning in intelligent spaces [11], to name but two recent applications. Some of the main fields where infrared thermography is used include medicine [12], veterinary medicine [13], maintenance and process monitoring [14], building inspection [15] and non-destructive testing [16]. Temperature is a very good indicator of health, as changes of just a few degrees on skin cutaneous or superficial can be used as an indicator of possible illness [17]. Thus, medical applications use IRT as an alternative diagnostic tool. For example, IRT is used to detect superficial body tumors, such as breast cancer [18]. Tumors generally have an increased blood supply that increases the skin temperature over them [19]. Therefore, IRT can be used as an effective early indicator of breast cancer [20], which results in a much higher chance of survival [21]. In these applications, IRT is a complementary diagnostic tool with high efficiency only in the detection of early warning signals. This early detection is the main advantage of IRT compared with other methods. IRT is used in many other medical applications, such as the diagnosing of diabetic neuropathy or vascular disorders [22], fever screening [23], skin diseases [24], dentistry and dermatology [25] and heart operations [26]. Maintenance is another area where IRT is successfully applied [27]. The electrical field, the mechanical field and insulation are three of the most common areas where IRT is used. IRT is used in electrical and mechanical maintenance to detect early signs of malfunction, so costly breakdowns can be avoided. In the electrical field, abnormal temperature patterns can indicate faulty connections [28], whereas in the mechanical field, they can indicate excessive friction due to improper lubrication or material fatigue [29 , 30]. In the insulation field, IRT is used to detect hidden losses of heat that can drain performance and increase costs [31]. IRT is also used in other areas of the maintenance and process monitoring field, such as monitoring of plastic deformations [32], evaluation of fatigue damage in materials [33] and weld inspection [34]. Another area where IRT is successfully applied is building inspection. The temperature distribution on the facade of a building provides very useful information to discover many hidden conditions related to the building performance and maintenance [35]. For example, it can be used to detect where and how energy is leaking from a building envelope. Besides the detection of heat loss, IRT is also used to discover other anomalies, such as water infiltration and moisture [36 , 37]. A wet mass in a wall has a differentiated thermal inertia that can be discovered using IRT. Recent applications of IRT for moisture detection can be found in [38] and [39], which use IRT for sub-surface moisture detection in masonry structures and for moisture mapping in ancient buildings, respectively. Moisture detection using IRT is not limited to buildings. It can also be applied to paper [40], soil [41] or aircraft structures [42]. The presence of water inside aircraft structures may lead to ice formation with a volume variation and consequent mechanical stresses. Two different approaches are employed in IRT: In passive IRT, the radiation coming from the target object is measured without any external heat stimulation. This information can be used for temperature measurement. On the other hand, in active IRT, the specimen is subjected to external thermal stimulation [44 , 45]. In this case, the measured radiation comes from the thermal response of the target to the external excitation. Passive IRT is used in quality control and process monitoring applications. Temperature plays a crucial role in any industrial process. Thus, temperature measurement and monitoring during and after the industrial process is critical to achieve optimal results, such as steel rolling or sinterization. However, the computation of temperature from infrared images is not only based on measured radiation; it also depends on the internal camera calibration, as well as on the emissivity of the object radiating energy. Thus, a calibration setup is required to obtain accurate measurements. Active IRT is mostly used in non-destructive testing applications, where an external stimulus is applied to the specimen in order to induce relevant thermal contrasts between regions of interest [46]. It is applied to the inspection of materials for subsurface defect detection and also to detect areas of the specimen with different properties below the surface. Some subsurface anomalies are very subtle. Therefore, the signal levels associated with them can be lost in the thermographic data noise [47]. In these cases, different post-processing methods can be used to improve the signal-to-noise SNR content of thermographic data. This review focuses on IRT for temperature measurement and non-destructive testing, two of the main fields where IRT-based sensors are used. This work is organized as follows. Section 2 presents the principles and essential theoretical background of IRT. Section 3 describes how temperature measurement is carried out using IRT and the measurement setup. Some examples of image processing methods and data analysis are presented and discussed. Section 4 presents a review of non-destructive testing using IRT, how this field has evolved in recent years and advances in the field. Principles of Infrared Thermography Infrared radiation is the energy radiated by the surface of an object whose temperature is above absolute zero [48]. The emitted radiation is a function of the temperature of the material; the higher the temperature, the greater the intensity of the infrared energy emitted. There are three ways by which the radiant energy striking an object may be dissipated: The fractions of the total radiant energy that are associated with each of these modes of dissipation are referred to as the absorptivity, transmissivity and reflectivity of the body [50]. Three parameters are used to describe these phenomena: These three parameters are wavelength dependent. The sum of these three parameters must be one at any wavelength, as in Equation 1: It could also be said that the striking energy that is not absorbed is reflected.

Chapter 4 : Radiation thermometry: The measurement problem | calendrierdelascience.com

Infrared thermography (IRT) is a science dedicated to the acquisition and processing of thermal information from non-contact measurement devices. It is based on infrared radiation (below red), a form of electromagnetic radiation with longer wavelengths than those of visible light.

This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. This thermogram shows excessive heating on a terminal in an industrial electrical fuse block. Thermal images, or thermograms, are actually visual displays of the amount of infrared energy emitted, transmitted, and reflected by an object. Because there are multiple sources of the infrared energy, it is difficult to get an accurate temperature of an object using this method. A thermal imaging camera is capable of performing algorithms to interpret that data and build an image. Although the image shows the viewer an approximation of the temperature at which the object is operating, the camera is actually using multiple sources of data based on the areas surrounding the object to determine that value rather than detecting the actual temperature. Emitted radiant power is generally what is intended to be measured; transmitted radiant power is the radiant power that passes through the subject from a remote thermal source, and; reflected radiant power is the amount of radiant power that reflects off the surface of the object from a remote thermal source. This phenomenon occurs everywhere, all the time. However, in the case of infrared thermography, the above equation is used to describe the radiant power within the spectral wavelength passband of the thermal imaging camera in use. The radiant heat exchange requirements described in the equation apply equally at every wavelength in the electromagnetic spectrum. If the object is radiating at a higher temperature than its surroundings, then power transfer will be taking place and power will be radiating from warm to cold following the principle stated in the second law of thermodynamics. So if there is a cool area in the thermogram, that object will be absorbing the radiation emitted by the warm object. The ability of objects to emit is called emissivity , to absorb radiation is called absorptivity. Under outdoor environments, convective cooling from wind may also need to be considered when trying to get an accurate temperature reading. The thermal imaging camera would next employ a series of mathematical algorithms. Since the camera is only able to see the electromagnetic radiation that is impossible to detect with the human eye , it will build a picture in the viewer and record a visible picture, usually in a JPG format. In order to perform the role of non-contact temperature recorder, the camera will change the temperature of the object being viewed with its emissivity setting. Other algorithms can be used to affect the measurement, including the transmission ability of the transmitting medium usually air and the temperature of that transmitting medium. All these settings will affect the ultimate output for the temperature of the object being viewed. This functionality makes the thermal imaging camera an excellent tool for the maintenance of electrical and mechanical systems in industry and commerce. By using the proper camera settings and by being careful when capturing the image, electrical systems can be scanned and problems can be found. Faults with steam traps in steam heating systems are easy to locate. In the energy savings area, the thermal imaging camera can do more. Because it can see the effective radiation temperature of an object as well as what that object is radiating towards, it can help locate sources of thermal leaks and overheated regions as well. Emissivity[edit] Emissivity is a term that is often misunderstood and misused. Each material has a different emissivity, which may vary by temperature and infrared wavelength. An example of a substance with low emissivity would be silver, with an emissivity coefficient of. An example of a substance with high emissivity would be asphalt, with an emissivity coefficient of. A black body is a theoretical object with an emissivity of 1 that radiates thermal radiation characteristic of its contact temperature. Thermogram of a snake held by a human An ordinary object emits less infrared radiation than a theoretical black body. The fraction of its actual emission to the theoretical emission of the black body is its emissivity or emissivity coefficient. For quick work, a thermographer may refer to an emissivity table for a given type of object, and enter that value into the imager.

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In order to get a more accurate temperature measurement, a thermographer may apply a standard material of known, high emissivity to the surface of the object. The standard material might be as complex as industrial emissivity spray produced specifically for the purpose, or as simple as standard black insulation tape , with an emissivity of about 0. There are situations, however, when such an emissivity test is not possible due to dangerous or inaccessible conditions. In these situations, the thermographer must rely on tables. Night vision infrared devices image in the near-infrared, just beyond the visual spectrum, and can see emitted or reflected near-infrared in complete visual darkness. However, again, these are not usually used for thermography due to the high temperature requirements, but are instead used with active near-IR sources. Starlight-type night vision devices generally only magnify ambient light. Abnormal temperature profiles at the surface of an object are an indication of a potential problem. Passive thermography has many applications such as surveillance of people on a scene and medical diagnosis specifically thermology. In active thermography, an energy source is required to produce a thermal contrast between the feature of interest and the background. The active approach is necessary in many cases given that the inspected parts are usually in equilibrium with the surroundings. Advantages[edit] It shows a visual picture so temperatures over a large area can be compared. It can be used to measure or observe in areas inaccessible or hazardous for other methods. It is a non-destructive test method. It can be used to find defects in shafts, pipes, and other metal or plastic parts. It has some medical application, essentially in physiotherapy. Fewer pixels reduce the image quality making it more difficult to distinguish proximate targets within the same field of view. Many models do not provide the irradiance measurements used to construct the output image; the loss of this information without a correct calibration for emissivity, distance, and ambient temperature and relative humidity entails that the resultant images are inherently incorrect measurements of temperature. Kite aerial thermogram of the site of Ogilface Castle, Scotland. UAS thermal imagery of a solar panel array in Switzerland.

Chapter 5 : Temperature Measurement Standards

Infrared thermography (IRT), thermal imaging, and thermal video are examples of infrared imaging science. Thermographic cameras usually detect radiation in the long- infrared range of the electromagnetic spectrum (roughly 9,, nanometers or Âµm) and produce images of that radiation, called thermograms.

Published online Oct This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license http: Abstract The aim of this study was to investigate the suitability of active infrared thermography and thermometry in combination with multivariate statistical partial least squares analysis as rapid soil water content detection techniques both in the laboratory and the field. Such techniques allow fast soil water content measurements helpful in both agricultural and environmental fields. These techniques, based on the theory of heat dissipation, were tested by directly measuring temperature dynamic variation of samples after heating. For the assessment of temperature dynamic variations data were collected during three intervals 3, 6 and 10 s. To account for the presence of specific heats differences between water and soil, the analyses were regulated using slopes to linearly describe their trends. For all analyses, the best model was achieved for a 10 s slope. Three different approaches were considered, two in the laboratory and one in the field. The in-field experiment was performed by active infrared thermometry, heating bare soil by solar irradiance after exposure due to primary tillage. In order to obtain more general and wide estimations in-field a Partial Least Squares Discriminant Analysis on three classes of percentage of soil water content was performed obtaining a high correct classification in the test The prediction error values were lower in the field with respect to laboratory analyses. Both techniques could be used in conjunction with a Geographic Information System for obtaining detailed information on soil heterogeneity. Introduction Recently, the need to measure in-field the variability of soil characteristics has increased following both sensor engineering developments, as well as the necessity to apply innovative crop management systems [1]. Changes in soil characteristics such as cation exchange capacity, organic carbon and water content may occur as the sampling point changes, even by few cm. A fine analysis carried out with conventional methods would require a lot of manual and laboratory work and incur high costs for the numerous samplings needed [2]. Researchers have investigated several approaches in order to automate these procedures [3] and to overcome the critical aspect of soil management in collecting representative samples [4]. For these reasons, methods increasing the acquisition of a high number of sample variables at a relatively low cost and time, such as vehicle-mounted optical sensing devices, represent promising application perspectives [5]. These multi-devices systems could include mobile instruments i. These could be used to measure different surface-layers soil parameters such as reflectance, absorbance and temperature. An important soil property is the spatial variation of water content measured at a proper depth and time [6]. The description of spatiotemporal soil water content SWC changes requires understanding of both spatial and time variability but results are relevant for many applicative agricultural contexts such as for example: Generally, the most common techniques to analyse SWC use punctual, destructive, expensive or time-consuming procedures [8 , 9], mainly based on opto-electronic, gravimetric, nuclear, electromagnetic, tensiometric and hygrometric processes [10]. Within the opto-electronic methods, near infrared NIR spectroscopy is one of the most used to calculate SWC in surface and subsurface layer, but its results show a tendency to underestimate values at higher water levels [11 â€” 13]. Another similar approach was carried out by Maltese et al. In this work the technological development of imaging sensors acquired in the visible VIS , NIR and thermal infrared TIR , renewed the research interest in setting up remote sensing based techniques aimed at retrieving SWC variability in the soil-plant-atmosphere system SPA. The soil thermal inertia method soil resistance to surrounding temperature change is an additional method widely used to estimate soil moisture from TIR and VIS bands for bare soil [15 , 16]. This technique requires readily available soil characteristics such as soil texture and bulk density. Among the gravimetric methods, the oven-drying technique is probably the most widely used. This method is considered as the standard for the calibration of all other soil moisture determination techniques. Nevertheless, it has some disadvantages, being a destructive test requiring sample removal and making it impossible to measure the water content at exactly the same point at a later date [17]. Another method is neutron scattering. Among the electromagnetic techniques there are those that measure the soil electrical resistivity, obtaining hence its water content. In this case, the disadvantages regard the instable calibration over the time affected by ionic concentration and the cost of equipment [10]. Another widely used method for small spatial scale estimates of SWC is the measurement of soil thermal properties such as the heat dissipation technique and the heat pulse technique [19]. These are over a certain period of time permanently modified invalidating future readings [10]. These indirect methods exploit changes in soil thermal properties due to variation of SWC. In soil, the driving force which regulates its temperature is the water content, being its specific heat i. In fact, the same amount of heat supplied to certain soil samples with different water contents can lead to different temperature differentials. Commercial heat dissipation sensors are broadly available. They basically consist in a heat source usually a heated needle and temperature sensors, immersed in a porous ceramic that equilibrates with the surrounding soil at a given water content. The needle is heated and the rate of heat dissipation is measured by the temperature sensors [20]. However, sensor use is limited by the need of calibration for any type of soil and by the long time to reach hydraulic equilibrium with the surrounding soil. The time required to reach the hydraulic equilibrium between heat dissipation sensors and soil depends on both the magnitude of the SWC and the hydraulic conductivity. Typically this equilibration time is on the order of minutes or tens of minutes [21]. In order to overcome the limits of heat dissipation sensors, in this study we propose the use of a new technique based on the same underlying theory of the heat dissipation methods. Unlike heat dissipation sensors, we propose to directly measure temperature changes of soil samples, after heating, by using active infrared thermography and thermometry. The assumption is that these techniques could lead to the development of a faster SWC measurement system and could represent informative and non-destructive tools to remotely assess the dynamic variation of soil temperature [22 , 23]. Moreover, these could be implemented on vehicle-mounted systems to shorten sampling time and the amount of soil surveyed. The main principle of these applications concerns the measurement of the thermal infrared spectrum of electromagnetic radiation emitted by soil samples depending on their temperature [24 , 25]. For in-field applications this technique should measure surface soil 0â€”60 cm temperature, that is influenced by soil-atmosphere interactions. This aspect makes unsuitable the use of calibration curves to relate temperature to SWC as physical or empirical relationships, which describe all the soil-atmosphere interactions. In fact the general model describing the soil-atmosphere interaction is given by the energy balance equation [26]: Adapting the energy balance Equation 1 to the proposed study and analyzing the water content on a bare soil after primary tillage and exposed to soil irradiance, the M becomes negligible and G is equal to: In this case, these parameters will be dependent on agro-pedological and meteorological parameters such as air temperatures and humidity, SWC, irradiance, wind regimes, soil water potential and soil roughness. The deterministic modelling of the environmental variables influencing the physical process which is developing in such a short time of analysis few seconds would have been very complex. For the above mentioned reasons the system could be approached in a statistical way and the estimation of SWC innovatively implemented by using a multivariate analysis [27 , 28], taking into consideration different soil thermal properties and meteorological parameters as input variables. Differently from deterministic models, stochastic ones do not explain the underlying physical processes generating the observations and the model randomness. Modeling spatiotemporal distributions, resulting from dynamic processes and evolving in both space and time, is critical in hydrology and soil science. Statistical spatiotemporal models provide a probabilistic framework for data analysis based on joint spatial and temporal dependence among observations [7]. In this study, a multivariate statistic approach Partial Least Squares regression, PLS, and Discriminant Analysis, PLSDA is used to estimate the SWC with active infrared thermal methods by warming up and measuring, at different time steps, several non-factorial soil samples with different water contents. Three different hypotheses were considered, two in the laboratory and one in the field. The laboratory experiments were carried out to determine the best performing one. The latter was then chosen in order to be applied in-field. The first one tested in the laboratory is based on active infrared thermography, which considers only the measurement of temperature variation as independent observed variable. The second one examined in the laboratory added the irradiation of soil samples as independent variable and it was based on active infrared thermometry. Finally the in-field experiment was based on active infrared thermometry and also considered some meteorological parameters as independent variables i. Laboratory Analysis In order to develop models for the statistical interpretation of the phenomenon, according to the previously indicated thermo-physical context, a series of progressive laboratory tests were performed. These laboratory tests were developed to highlight the limits and possibilities of the techniques and chose among them the most suitable one for an in-field application. The experimental laboratory protocol consists in warming up soil samples with different initial temperatures and water contents and in measuring for a few seconds the dynamic temperature variations. This investigation was carried out in two different steps: In a second step, an infrared thermometer was used to simplify the measuring system by introducing among the independent variables also the irradiance produced by photographic bulbs W and 2, K to approach in-field applications. In both cases, air temperature and air relative humidity were considered as constant. The dynamic variation of sampled soil temperature was identified by an operator analyzing a specific thermal image area called the Region Of Interest ROI. The temperature values were collected at four different intervals:

Chapter 6 : Thermography - Thermography South Seattle

Gene Nutter wrote this and many other technical articles on the subject of radiation thermometry, including another classic, "A High Precision Automatic Optical Pyrometer" in Temperatures ITS measurement and Control in Science and Industry, Vol. 4, , Instrument Society of America ().

Best practise in thermometer calibration contact and immersion probes is to rely on calibration baths or thermostat baths and dry block calibrators. The latter provide, along stabillity and reliability, almost maintenance-free robustness and short response time at wide temperature ranges, whether utilized at the stationary laboratory or on-site. Standard platinum resistance thermometers indicate marginal drift and result in measurement uncertainties below 15 mK. Electrical base parameters for thermoelectric voltage and resistance are traceable to the electrical calibration laboratory, resulting in measurement uncertainties below 2 mK. Calibrating the Temperature Scale To record and calibrate temperature is of vital importance to many industrial procedures. Monitoring temperature is determined a key quality criteria for numerous products among multiple industries e. In addition monitoring and evaluating temperature has a direct impact on production control systems. Indicated, measured temperature is converted into electrical signals in order to be electronically processed. Vast stability and reliability Modern day calibration capabilities for temperature and thermometers are based upon themoelectric relation between voltage and resistance and realized applying thermocouples and resistance thermometers. Starting point is defining the temperature scale according to ITS, supporting fixed or triple points. As opposed to freezing point temperature, the triple point is not affected by air pressure, oxygen level and as such repeatable at any time. Pyrometry classifies measuring techniques characterizing surface temperatures. The latter is identified by energetic or spectral thermal radiation emitting from a surface. A pyrometer, also commonly refered to as a radiation or infrared thermometer, is used to perform the actual measurement. In contrast to pyrometry, thermography is best described as imaging pyrometry. Pyrometer enable "punctual" surface temperature characteristics. Reliable calibration consider the corresponding surface temperature emission ratio. Deviation is defined by the emission factor. The emisson factor is dependent on material, surface texture, temperature and wavelength. Calibrating Temperature Wells, Bathes and Climatic Test Cabinets and Climate Chambers The currently most accurate method in charaterizing temperature sources or temperature testing equipment, e. The technique complies best with calibration directive DKD-R block calibrator calibration and subsequently is considered the predominating practice. Calibration procedures for climatic chambers refer to DKD-R Calibrating Relative Humidity Calibration for temperature recorders, temperature loggers and temperature test equipment is performed in stabilized humidity airflow climatic generators. The corresponding calibration standard is a highly precise dew point transmitter enabling tracability in consideration of thermodynamic correlation, absolute humidity and temperature. Continuous evaluation of quick response capacitive precision humidity sensors is realized simultaneously. The dew point is refered to as the point of time resulting in condensate formation. Dew point measurement is performed applying a heated mirror and tied to the fundamental principle of direct measuring.

Chapter 7 : Temperature measurement - Wikipedia

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See Article History Thermometer, instrument for measuring the temperature of a system. Temperature measurement is important to a wide range of activities, including manufacturing, scientific research, and medical practice. The accurate measurement of temperature developed relatively recently in human history. The invention of the thermometer is generally credited to the Italian mathematician-physicist Galileo Galilei â€” This general principle was perfected in succeeding years by experimenting with liquids such as mercury and by providing a scale to measure the expansion and contraction brought about in such liquids by rising and falling temperatures. By the early 18th century as many as 35 different temperature scales had been devised. The first centigrade scale made up of degrees is attributed to the Swedish astronomer Anders Celsius , who developed it in It was known simply as the centigrade scale until in the name was changed to the Celsius temperature scale. Any substance that somehow changes with alterations in its temperature can be used as the basic component in a thermometer. Gas thermometers work best at very low temperatures. Liquid thermometers are the most common type in use. They are simple, inexpensive, long-lasting, and able to measure a wide temperature span. The liquid is almost always mercury, sealed in a glass tube with nitrogen gas making up the rest of the volume of the tube. Electrical-resistance thermometers characteristically use platinum and operate on the principle that electrical resistance varies with changes in temperature. Thermocouples are among the most widely used industrial thermometers. They are composed of two wires made of different materials joined together at one end and connected to a voltage-measuring device at the other. A temperature difference between the two ends creates a voltage that can be measured and translated into a measure of the temperature of the junction end. The bimetallic strip constitutes one of the most trouble-free and durable thermometers. It is simply two strips of different metals bonded together and held at one end. When heated, the two strips expand at different rates, resulting in a bending effect that is used to measure the temperature change. Other thermometers operate by sensing sound waves or magnetic conditions associated with temperature changes. Magnetic thermometers increase in efficiency as temperature decreases, which makes them extremely useful in measuring very low temperatures with precision. Temperatures can also be mapped, using a technique called thermography that provides a graphic or visual representation of the temperature conditions on the surface of an object or land area. Learn More in these related Britannica articles:

Chapter 8 : IRApps â€“ Applications of Infrared Thermography & Thermometry

In contrast to pyrometry, thermography is best described as imaging pyrometry. Pyrometer enable "punctual" surface temperature characteristics. Signal transformation (temperature radiation = measurement value) for pyrometers and thermography systems is similiar and refers to the identical physical principles.

Chapter 9 : Static and Dynamic Measurement of Ocular Surface Temperature in Dry Eyes

The temperature of leaves and canopies of plants has long been recognised to be an indicator of plant water stress and can be assessed by thermometry or thermography.