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Thermal Imaging Techniques in Agricultural Applications

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Abstract*: Thermal imaging innovation has transformed into an important technique in all fields as a result of its non-ruinous, non-contact method to choose thermal properties and highlights of any object/zone of interest. It is a procedure of improving the permeability of objects in a dark environment by detecting the objects infrared radiation and shaping an image based on that obtained data. This method will be useful in all fields where temperature difference helps in analyzing the area/object. The potential use of this technique in the agricultural field includes irrigation scheduling, soil properties mapping, plant disease detection, crop yield estimation, evaluating the maturity of the crop, etc. This paper briefly reviews some of the works on thermal imaging for agricultural applications.

Keywords—Thermal imaging, agriculture, irrigation scheduling, remote sensing.

I. INTRODUCTION

The farming segment is the principal patron of the Indian economy. Conventional methods for ascertaining agrarian parameters are solid; however they are tedious, requires more labour, and constrained for little size territories. Thermal remote detecting gives precise information for parameter portrayal than regular procedures since it gives ceaseless airborne scope over a wide zone at a particular time interim. Texas Instruments initially produced thermal imaging for military applications in the late 1960s. It is the method of utilizing the heat emitted by an object to create an image of it or to find it. These images can be procured utilizing compact, handheld or heat sensors that are mounted on satellite or a flying machine. The quality of radiation produced by an object relies upon its surface temperature.

Thermal imaging has got various application in agriculture beginning from soil water stress estimation, crop water stress estimation, water system planning, plant disease identification, farming plastic waste location, etc. Thermal imaging framework includes thermal camera furnished with a picture securing framework, a signal processing unit, and infrared indicators. The infrared radiation discharged by the object is absorbed by the locator and is changed over into electrical signal which is sent to signal processing framework where the data will be changed into thermal image. Thermal imaging gadgets are of two kinds to be specific cooled and uncooled. An infrared imaging framework will be viewed as in light of the picture resolution, examine speed and thermal affectability. Figure1 describes the taxonomy of thermal imaging for agricultural applications. The purpose of this paper is to review and condense the major application of thermal imaging in agricultural filed.

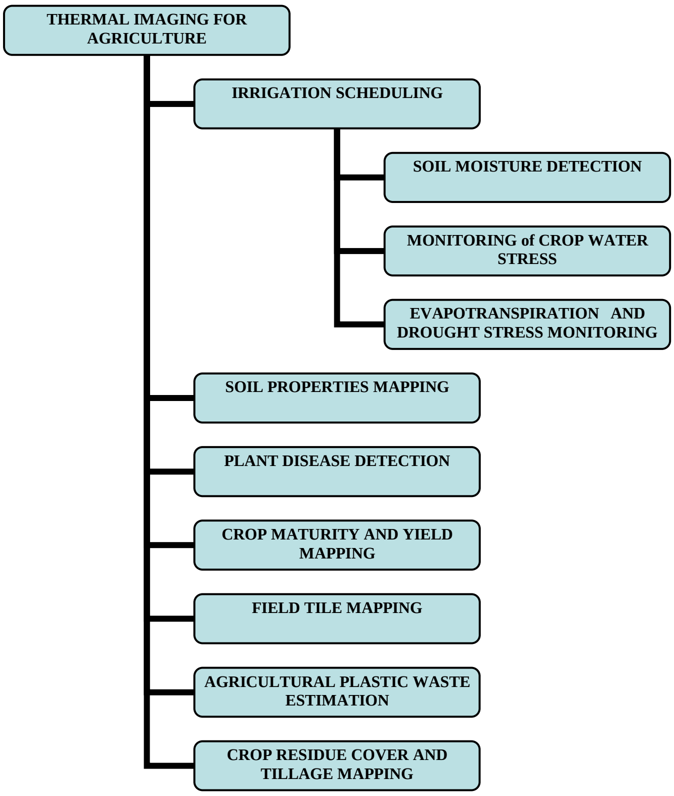

Fig 1: Taxonomy of thermal imaging for agricultural applications

II. THERMAL IMAGING APPLICATION IN AGRICULTURAL SECTOR

Vegetation reflectance spectrum qualities rely upon leaves properties; however, the measure of reflected energy for a wavelength relies upon thickness and leaf pigmentation [1], [2]. Thermal imaging in the agricultural application we have mainly classified into seven sections as shown in the taxonomy (fig1) as irrigation scheduling, crop maturity and yield mapping, soil properties mapping, field tile mapping, agricultural plastic waste estimation, crop residue cover, and tillage mapping and plant disease detection.

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Irrigation scheduling can again be classified into soil moisture detection, crop water-stress monitoring and evapotranspiration and drought stress monitoring. Challenges and opportunities of satellite and UAV (Unmanned Aerial Vehicle) based agricultural applications have been studied in various journals and books[3]–[7]. For thermal remote sensing mostly, Landsat data is used. In [8], [9] a guide to Landsat pre-processing is given which can be used for monitoring irrigation scheduling, agricultural plastic waste estimation, etc. In this paper, we will be focusing on the works done on various agricultural applications, which is given in the next section.

III. IRRIGATION SCHEDULING USING THERMAL IMAGING

In numerous agrarian areas, restriction underway is principal because of poor water system timing and deficient utilization of water; accordingly, the water system is basic to take care of harvest water demand. As the plant goes into water pressure condition, their stomata start to close making the crop water stress to rise [10]. In [11] demonstration of the outcomes acquired with a low-cost UAV system for farming, applications are done. Soil moisture detection, crop water stress monitoring (canopy temperature), evapotranspiration (ET), and drought monitoring, soil salinity detection, and crop/fruit yield detection will come under thermal imaging irrigation scheduling application, which will be discussed in the next section.

A. Soil moisture detection

Soil moisture content is one of the vital factors in hydrological forms, which impact the trading of water and vitality transitions at the land surface and air interface [12], [13]. For numerous environmental studies, an exact gauge of spatial and transient variety of soil dampness is required. Recent innovative improvement in satellite remote sensing has exhibited that moisture content in soil can be evaluated by various remote sensing procedure with its strength as well as weakness. Remote sensing summary for estimation of moisture content in soil is given in **Table 1**. Change in soil dampness has a high impact on the thermal properties of the soil. The triangle method and soil moisture index are commonly used thermal imaging approaches for measuring soil moisture [14]. Nonstop checking of moisture content in soil is important as it gives supplements to plant development, controls soil temperature, impacts agricultural works like irrigation, planting, etc. [15]. Vegetation that is well water will be having less radiant temperature compared to vegetation subject to water stress [16]. In [17] the author shows that Perpendicular Soil Moisture Index (PSMI) utilizing data from Landsat satellite images is unequivocally connected with observed soil dampness. The exhibition of assessing the spatial appropriation of surface soil dampness in ranch/farm planted with oats by utilizing thermal images is appeared in [18]. In agro-production, the spatial inconsistency of soil dampness can be in charge of low or spatially variable trim yields, as soil dampness is required to make supplements dissolvable for plant assimilation [19]. Another way to estimate soil dampness in light of evaporative fraction (EF) recovered from optical/thermal infrared MODIS information was displayed in [20]. The results can be possibly used to downscale soil dampness estimations got from dormant microwave remote recognizing techniques. Nevertheless, the model required further enhancements to represent extraordinary soil dampness conditions.

A comparison of thermal infrared imaging to thermocouple estimation and evaluation of environmental impact was studied in [21]. The result shows that TIR estimations can be amended to evaluate canopy temperature all the more precisely and that the significance of these correction increments under progressively outrageous surrounding conditions, for example, colder periods. [22] Contemplated LiDAR and thermal images combination for the ground-based 3D portrayal of fruit trees where the framework conveys numerous perspectives of the plantation, providing the client a 3D perspective of the warm conduct of the grove. Utilizing a managed classifier, the executed calculation characterizes focuses on the LiDAR estimations that compare to the canopy. Later thermal camera provides the thermal data by performing coordinating method between such focuses. Utilizing the Iterative Closest point, the whole plantation or just a segment of the grove is remade.

Methods for utilizing thermal infrared radiation to survey spatial variations in soil water accessibility likewise have utility in precision agriculture [23]. The connection between the soil salinity and canopy temperature, standardized distinction vegetation index and enhanced vegetation index was done in [24]. A remote sensing based trim water pressure index for irrigation schedule was developed by [25] in the sugarcane field. Amid sugarcane, developing season Landsat 8 satellite images were gained. The outcome demonstrates that trim water pressure index can be utilized for checking the water pressure and water system planning for sugarcane fields utilizing satellite images with no requirement for ground auxiliary information. For estimating soil moisture SAR derived remote sensing products (Sentinel-1, SRTM and Landsat 8) can be valuable input features [26].

Table 1: Remote sensing summary for estimation of moisture content in soil

Domain	Properties	Pros	Cons
Microwave	Brightness temperature Temperature of soil	Less atmospheric noise Well understood physical	Spatial resolution low Disturbed by surface roughness and vegetation
Optical	Reflection of Soil	Fine spatial resolution coverage	Limited surface penetration Cloud defilement
Thermal IR	Surface temperature	Fine spatial resolution Large coverage Physical very much understood	Constrained surface penetration Cloud defilement Disturbed by meteorological conditions and vegetation

B. *Crop water stress monitoring*

Identification of crop water stress and investigation of its impact on crop production is essential to advance to decide quantitative loss in crop yield [27-29]. Satellite remote sensing by virtue of its wide coverage, receptivity, and multispectral information becomes an important source for many agricultural applications such as crop condition, crop yield, etc. Momentary variations in status of water within a vineyard are mapped using UAV-based thermal imagery in [30]. The thermal images data turned out to be useful at an occasional time too; in spite of the fact that it did not coordinate regular patterns in status of water yet emulated other process happening at the time of ripening. The reasonableness of a crop water stress index (CWSI) got from very good quality aerial thermal imagery for assessing tree-water status fluctuation in Super High Density (SHD) olive plantations was studied in [31]. Another yield- water stress pointer, the canopy temperature standard deviation inside a thermal image [32] was produced to screen status of crop water utilizing the expectation-maximization algorithm.

Improvement and assessment of thermal IR imaging framework for high spatial and temporal resolution trim water stress observing of corn inside a greenhouse [33] was studied. The outcome demonstrates that the crop water stress index determined by remotely estimating canopy temperature utilizing a thermal infrared imaging framework can be utilized as another water system planning technique to measure spatial and transient soil moisture fluctuation. Recently investigates consolidate thermal imaging with soil remote detecting to upgrade water system administration of sugar beet [34]. In this investigation, it is watched that distinctive water system procedures are required in very heterogeneous plots. An irrigated pinto bean case study on spatial and temporal monitoring is done in [35]. The results demonstrated that the green normalized vegetation index (GNDVI), canopy cover (CC), canopy temperature (CT) were able to differentiate crops with full and deficit irrigation methods at each of the growing region. It showed that the remote sensing method in management of rapid crop stress is much more efficient when compared with the ground-based leaf area index (LAI) estimation.

C. *Evapotranspiration and drought stress monitoring*

Reliable estimation of ET is of great importance for the calculation of irrigation water requirements, assurance of water spending plan particularly where water resources are scarce and fresh water is a limited resource [36], [37]. Accurate ET estimations in agricultural zones can enhance detection of water stress and aides in irrigation scheduling. Factors affecting evapotranspiration is shown in **Table 2**. Connecting thermal imaging to the physiological indicator in papaya under various water condition was considered in [38]. In pots, plants were developed and subjected to various irrigation treatments. Intelligent irrigation monitoring thermal imaging was recommended by [39]. Thermal imaging in conjunction with the eddy covariance system to portray canopy evapotranspiration (ET) from little heterogeneous grassland was studied in [40]. The outcomes demonstrate that mapped transpiration might be more delicate to streamlined conditions or ecological heterogeneity than stomatal conductance.

Table 2: Factors affecting evapotranspiration

Weather parameters	Crop factors	Environmental conditions
• Net radiation • Air temperature • Humidity • Wind Speed	• The difference in resistance to transpiration • Crop height • Crop roughness • Crop rooting characteristics	• Soil water content • Plant density • Ground cover

For arranging proper irrigation management estimation of genuine crop evapotranspiration is exceptionally basic and for that precise estimation of crop coefficient is additionally required. In [41] a satellite-based product coefficient approach is utilized under different vegetation composes and atmosphere conditions. The outcomes demonstrate that it can be used not just to have proper water and farming management yet in addition to investigating and foreseeing crop yield profitability and agrarian drought. Utilizing surface temperature, crop evapotranspiration can be computed. In [42] crop evapotranspiration was figured utilizing two source energy balance (TSEB) which utilized surface temperature estimated by infrared thermometers. The outcome demonstrates that the evapotranspiration computed utilizing infrared thermometers abroad center pivots will be helpful to keep up water efficiency in crops.

LST Retrieval methods from Landsat-8 thermal infrared sensor data is shown in [43]. Assessment of thermal remote sensing lists to evaluate crop evapotranspiration coefficients was done in [44]. To decide the stress coefficient four thermal techniques Crop Water Stress Index – CWSI, Canopy Temperature Ratio – Tcratio, Degrees above Non-Stressed – DANS, Degrees Above Canopy Threshold – DACT were utilized. Results demonstrate that stress location techniques that require fewer data sources are more receptive to water stress. A survey of various satellite-based remote sensing methods is presented in [45]–[47]. It surveys different SEBAL, basic theories, observation methods for evaluating ET from areas with satellite-based land surface temperatures and tabulates the drawbacks of those methods

IV. SOIL PROPERTIES MAPPING

Accurate estimation of variation of soil organic matter is required to accurately estimate soil fertility, structure, porosity, etc. This is required to find out the soil quality as it affects crop production. In [48], [49] studies showed that the timely series satellite data can give proper mapping for soil organic matter in low relief farming areas. Land surface temperature influences the amount of water a soil can hold. Clay soil will be having higher water content and their LST will be low whereas a sandy soil will be having less water holding capacity which in turn results in higher LST [50], [51]. The result in these studies shows that remote sensing using thermal imaging will help in mapping soil properties more accurately which will help farmers for precision agriculture.

Table 3: Soil texture, soil moisture and LST relation

Soil texture	Soil moisture	Land surface temperature
• Sand	• low	• moderate
• Silt	• moderate	• high
• Clay	• high	• low

Soil property mapping using thermal remote sensing helps in providing various information such as crop suitability assessment, land capability classification, irrigation monitoring, etc. Thus, a comparison study between thermal remote sensing and land surveying will help in soil property mapping. **Table 3** shows the soil texture, soil moisture and land surface temperature relation [52]. In [53] author shows thermal remote sensing for classification of hotspots, vegetation, and an assessment technique for use in urban planning. There will be a reduction in land surface temperature with enhancement of urban vegetation cover. Results show that air temperature and LST follows similar patterns at coarse spatial resolution.

V. PLANT DISEASE DETECTION

For proper economic growth and production in agriculture, plant disease should be minimized. It is demonstrated by different researches that thermal imaging helps in identifying the pre-symptomatic impact of illness and pathogen on the plant [54], [55]. The physiological condition of the contaminated tissue, for example, photosynthesis, transpiration, and stomatal conductance are altered during plant-pathogen disease [56]. The decline and increment of the contaminated leaves temperature were clarified in [57] while they were surveying scab illness on apple leaves utilizing thermography and found that the maximum temperature difference (MTD) enhanced with scab advancement and was strongly associated to the measure of disease locales. This MTD can be utilized for infection measurement moreover. Thermal imaging is a vital decision for giving data to plant disease, even though just a couple of studies have utilized this innovation to contemplate and analyze illness and pathogen discovery [58]. Different plant diseases detected by thermal sensors are shown in **Table 4**. Studies show that thermal imaging can be used to determine bruises at the early stage, to certain accuracy insect infestation could be determined.

Table 4: Plant disease detected by thermal sensors

Crop	Disease	Reference
• Grape	• Downy mildew	[59]
• Apple	• Apple Scab	[57]
• Cucumber	• Downy mildew	[60]
• Sugar beet	• Cercospora leaf spot	[61]
• Rose	• Powdery mildew	[62]

VI. CROP MATURITY AND YIELD MAPPING

Despite the fact that few programmed techniques are accessible, crop maturity assessment is accomplished by crop analyzation and visual review. These methodologies are both works escalated and restricting perception number made by a single eyewitness. It is realized that until the point that the plant achieves the most extreme esteem, the plant physiological esteem increases, and this esteem concurs with the phase of maturity so thermography can be utilized to evaluate the yield development. The assurance of the ideal gather date and the adjusted outline of postharvest hardware [63] should be possible utilizing thermal imaging frameworks. Farmers can do crop insurance, planning of harvest and storage requirements if there is an accurate and early estimation of crop yield. The commonly used method for yield estimation is time-series data models, but it is observed that there is a high deviation in the actual yield from the predicted yield. In this situation thermal imaging can be used for the yield prediction as it is based on the objects own heat radiation.

VII. FIELD TILE MAPPING

There can be extensive damage to crops due to flooding during plant growth periods [64], [65]. Due to excess soil, moisture or high water table during growth season can result in reduced crop growth. By using subsurface drainage this condition can be alleviated. Most of the farmers won't be having the records of the layout of the drainage system in their farms which was laid more than 50 years ago. So, they won't be able to get the benefit of subsurface drainage which will help in improved crop production. Thermal remote sensing helps in addressing these issues by assessing temperature differences within a field [66]. In [67] Remote Sensing based image differencing methods and GIS-based decision tree classification (DTC) were tested for subsurface tile drained area. Studies show that image differencing using remote sensing images provided a more precise classification of tile-drained areas when compared to DTC method. UAS (Unmanned Aircraft System) sensors can be used for drainage pipe mapping [68]. UAS thermal infrared sensors mapped 60% of the drainage pipes in dry soils when compared with unmanned aircraft system visible and near-infrared sensors. In [69], [70] remotely sensed data were used for the identification of subsurface drainage system. But the studies have shown that there is limited success in field tile mapping due to the spectral similarity between crop residue and soil.

VIII. AGRICULTURAL PLASTIC WASTE ESTIMATION

Plastic material use in agriculture has got great benefits but it ends up in large amount of plastic waste to be disposed of [71]. Support Vector Machine was used for image classification with Landsat 8 images. In [72], [73] the efficiency of various image analysis methods applied to hyperspectral satellite data is analyzed. It was used to detect olive oil waste disposal on the island of Crete. A survey of agricultural plastic waste generation and consolidation in Europe is presented in [74]. It represents a systematic effort to map waste analysis. If we are not properly estimating agricultural plastic waste it will create a problem for the future generation. But only very few studies have been done in this field.

IX. CROP RESIDUE COVER AND TILLAGE MAPPING

For creating a protective layer on the agricultural field such as erosion prevention, moisture loss reduction, quality of soil, etc crop residue is essential. Conservation tillage was introduced for the benefit of soil and agricultural environments [75]. Mapping of tillage practices in broad scale is still challenging in thermal remote sensing due to variation in the timing of planting and soil preparation, low revisit time of satellite such as ASTER and Landsat, confounding issues due to soil variation, etc. exact evaluation of crop residue is necessary for proper tillage implementation [76]. Many studies show that thermal imaging technique (both satellite and ground-based) could explain the variability in the amount of crop residue when compared with the visible and near-infrared images [77].

Thermal imaging process plays an important role in many agricultural applications [78]–[80]. While some still need research [81]–[83]; which seems to have great potential in the near future. One such example is ice formation in plant tissues detection, which is challenging, as many methods available were difficult and time-consuming. For the study of freezing behavior and ice-nucleation of potatoes and cauliflower [83], [84] thermal cameras were used. It gave information about ice nucleates and how it spreads into potatoes and cauliflower. Infrared video thermography was used [85] to study the freezing of barley which showed that initial spread of freezing was not problematic but the damage was caused by the second freezing event, which was initiated by the first event.

X. CONCLUSION

This survey has briefly analyzed the current situation of the major application of thermal remote sensing. Thermal imaging systems have been developing quick and assuming an imperative part in different fields of agribusiness. Nonetheless, intensive looks into should be created for its potential application in different procedures of agribusiness, for example, agrarian waste identification, pesticide float in aerial spray applications that are not yet much researched. In spite of the fact that it could be utilized as a part of numerous agricultural operations, it has a few downsides when compared with other imaging techniques; good-quality thermal imaging is costly and to build up an all-inclusive procedure for agrarian applications may not be conceivable since thermal conductivity of crops/fruits shift with change in climatic conditions.

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