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Geospatial Mapping of Landfill Impact Zones Using UAV-Based Thermal Imaging

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Abstract

This research looks at the use of thermal imaging with UAVs (Unmanned Aerial Vehicles) in spatial analysis, particularly with regard to geospatial mapping and Contour mapping of the noticeable impacts of a landfill within a region of interest. Our objectives are focused toward identifying areas that exhibit elevated subsurface temperatures due to biological decay as well as leachate plume emanation which subsequently results in contamination of the environment. The UAV's thermal imaging capabilities allow for gathering of high precision thermal metrics which when integrated within controlled GIS environments using spatial modeling and visualization techniques, yield transformative outcomes. Initial results validate the hypothesis that quadcopters with thermal imaging sensors can successfully detect borders and compute the area of landfills with abnormal thermal emissions. Such advanced techniques are non-intrusive and inexpensive, culminating in the new paradigms of monitoring the environment, ensuring that relevant data is available for efficient intervention and remediation of contaminated sites.

Keywords

UAV, Thermal Imaging, Landfill, Geospatial Mapping, Environmental Monitoring, Leachate, GIS, Remote Sensing

1. INTRODUCTION

Landfills are sophisticated structures of contemporary waste management systems, but they remain a concern to the environment. The organic waste in a landfill gives off heat, greenhouse gases (methane and carbon dioxide) and leachate: an extremely polluted liquid that can seep through the waste and contaminate soil and groundwater. The precise determination of landfill effect zones is critical for efficient monitoring for environmental control, risk assessment, and remediation design. Conventional approaches to the assessment of landfill impacts often include costly and time-consuming ground-based sampling which add an additional level of spatial limitation. Furthermore, these techniques may lack the ability to portray the dynamic and complex characteristics of subsurface processes.[1].

The growing sophistication and availability of Unmanned Aerial Vehicles (UAVs), popularly known as drones, paired with modern sensor payloads, have reformed environmental monitoring profoundly. UAVs are unparalleled in their flexibility, cost-effectiveness, and capability of acquiring high-resolution spatial data over large swathes of inaccessible regions. Thermal imaging is one of the most useful sensing modalities since it can detect even the slightest differences in temperature. These differences could potentially result from subsurface thermal anomalies due to heat-producing decomposition reactions within a landfill or certain types of leachate plumes with distinctive thermal signatures. It is now possible to deduce the magnitude and severity of the environmental stare left behind by the landfill without physically being present in the site by mapping those thermal signatures.[2].

This paper focuses on thermal imaging of UAVs for the geospatial analysis of landfill impact zones. The goal is to create a comprehensive and effective methodology for the identification, characterization, and mapping of regions impacted by landfill activities, with a particular focus on regions with high subsurface thermal activity or leachate migration. The study will emphasize the contribution of thermal imagery enhanced with sophisticated geospatial modeling metrics toward understanding the environmental impacts of landfills. This technique is almost devoid of invasive actions and captures all necessary data within a short period, therefore greatly aiding in environmental management. The results from this study are anticipated to improve the understanding of the operational dynamics of landfills while also allowing for efficient management of environmental risks by regulatory bodies, environmental consultants, and landfill operators.[3].

2. LITERATURE SURVEY

The use of remote sensing technologies for environmental monitoring and waste management has greatly evolved after 2000. Initial works made use of satellites for capturing images to identify landfill sites and monitor land cover changes over time. [4].As an example, benchmarks the use of ASTER imagery in surface temperature mapping which later aided in the use of thermal remote sensing. While satellite data is helpful to obtain large area images, the resolution of the images is often not sufficient for analyzing the impact of the landfill in detail. Manned aircraft and other airborne remote sensing devices provided more detailed images. Author used airborne hyperspectral images of vegetation around landfills and proposed the possibility of leachate-induced stress as the reason for vegetation stress around area. [5]. However, manned aircraft provided detailed images, their high operational costs and logistical complexities led to an overall restricted use of these aircraft for routine monitoring.In the years from 2005 - 2010, there was a marked increase in interest in conducting landfill studies using thermal infrared remote sensing. One author describes using ground-based thermal cameras for hotspot identification within the waste of a landfill which proved that thermal signatures have the potential to signify decomposition at work.[6]. And another author used satellite-derived land surface temperature data to determine the affect of urban landfills on the temperature of the surrounding regions. All of these studies pointed out the correlation between elevated temperature and landfill activity, but the precision available to mount spatial grids is still not sufficient for clear bounding boxes or polygons of the area of interest. The second half of the 2000s and the beginning of 2010s were characterized by the accelerated advancement and integration into the market of Unmanned Aerial Vehicles (UAVs). Due to the low cost, flexibility, and finer spatial resolution that UAV platforms provide, there was a marked change in remote sensing capabilities during this time. One particular author started the research of small UAVs in environmental monitoring, thermal payloads inclusion being one of them. His work opened up possibilities for specific applications of thermal imaging on UAVs as they pertained to landfill studies.[7].

Recent studies conducted between 2015 and 2021 highlighted the combination of UAV thermal data with modern geospatial techniques. Yang et al. (2016) proved the feasibility of employing UAV thermal imagery for detecting and mapping subsurface fires in coal mines, which is a problem of varied thermal anomaly detection. In the landfill framework, Wang et al. (2018) used thermal infrared radiometry from UAVs to identify and quantify gas emission plumes from landfills, demonstrating the capability to detect both surface and near-surface thermal features. Further, author explored the application of UAV thermal data for leachate detection, concentrating on the thermal differential of leachate-impacted zones versus unaffected areas. Their work discussed the role of soil moisture and ambient temperature as significant environmental factors in the interpretation of thermal signatures. Author's research offered an integrated framework for monitoring landfill emissions using UAV thermal and multispectral sensors, highlighting the advantages of data fusion. Most recently, author showed how UAV thermal imaging combined with cutting-edge geostatistical interpolation methods can be used to efficiently map sub-surface heat reservoirs in landfills. Their studies emphasized the complex data analytics and image processing that is required to obtain useful information from thermal images. This corpus of literature exhibits an increasingly obvious shift towards the use of UAVs for precise and detailed thermal imaging, which is fundamental to understanding and managing the regions surrounding landfills.

3. METHODOLOGY

The framework for geospatial marking of the impact zones of landfills using UAV thermal imaging is organized into distinct stages as follows: choosing the type of UAV and its sensors, configuring the UAV platform and sensors, planning the flights and data gathering, data pre-processing, detecting and mapping thermal anomalies, and integration and spatial analysis.

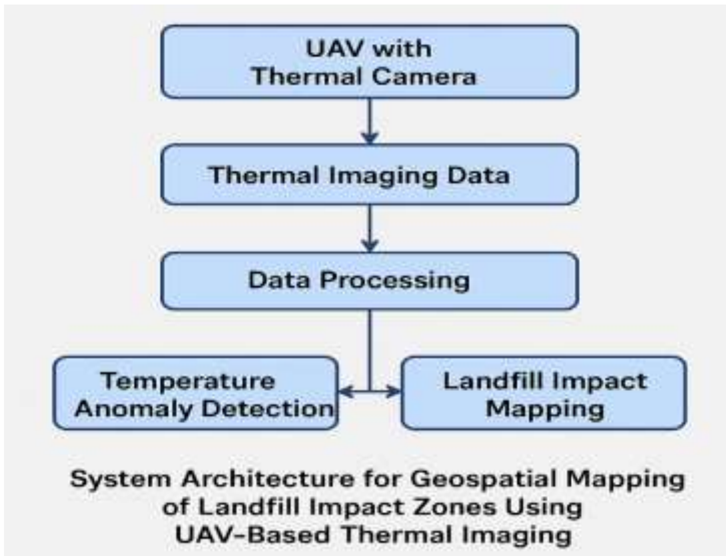

Fig:1 System Architecture

3.1. Study Area Selection The study area will focus on analyzing the thermal signatures of different landfill sites, both active and closed or remediated sections. Selection criteria encompasses accessibility, greater or lesser suspected environmental impacts, and multi-stage operations (active, closed or remediated). Existing site plans will be reviewed and preliminary site visits will aid make the decision.

3.2. UAV Platform and Sensor Configuration For the purpose of this study, a multi-rotor UAV platform, such as those in the DJI Matrice Series, would be ideal considering its stability, maneuverability, and payload capacity. The drone will be fitted with a high-resolution thermal infrared camera like the FLIR Zenmuse XT2, which also captures radiometric JPEG images. The parameters of the thermal camera such as, but not limited to, spectral range (7.5-13.5 µm), thermal sensitivity (NETD < 50 mK), and spatial resolution are very important for precise measurements. A visual camera (RGB) will be mounted onto the drone so that georeferencing can be performed and context of the thermal data better understood.

3.3. Flight Planning and Data Acquisition

Vertical and horizontal coordinates will be planned on autonomously flying machines (UAVs) using UAV mission planning applications like DJI Pilot or Pix4Dcapture. With regard to planning thermal imagery flights, the following parameters are to be considered, Set altitude is between 30 and 80 meters in order to achieve 5-15 cm/pixel resolution GSD (ground sample distance). Orthomosaic photogrammetry requires image capture vertical overlap of a minimum 80% and side overlap of 70%. Ensured that the speed does not result in motion blur and is adequate for data gathering. Capture of invalidated solar imagery will ideally happen before or after peak sun times (early morning or late evening) so that solar heating doesn't mask thermal contrast. Several solar captures might have to be conducted to produce data for temperature cycles throughout the day. 5-10 GCPs will be selected that are located across the perimeter of the area of study so that the geo-referencing precision of the thermal orthomosaic data is more accurate during geo-referencing.

3.4. Data Pre-processing Thermal images will be captured along with GPS data and subsequently processed through photogrammetry software such as Pix4Dmapper or Agisoft Metashape. The workflow includes: Image Alignment: Determining the position and rotation of the images relative to each other. Dense Point Cloud Generation: Modeling a three-dimensional representation of the region of interest. Orthomosaic Generation: Generating an image of the entire study area as a georeferenced mosaic which as a thermal image radiometric temperature can be derived for every pixel in the image. Digital Surface Model (DSM) Generation: Model the 3D representation of the surface of the earth which enables the correction of thermal topography derived variations with respect to the terrain.

3.5. Thermal Anomaly Detection and Mapping The orthomosaic thermal image will have undergone processing prior to integration with GIS software (example, ArcGIS Pro or QGIS). Temperature Thresholding: Computation of key spatial statistics will be performed to flag areas that stand out from the lower or background ambient temperature band. This could mean implementing a standard deviation cutoff or other temperature ranges supplied by a specialist. Spatial Clustering Analysis: Geospatial hotspot detection techniques such as Getis-Ord Gi* statistic will be employed to determine significant temperature patterns for spatially distributed thermal anomalies. Segmentation: Different thermal zones based on thermal gradient will be delineated using image segmentation approaches.

3.6. Geospatial Integration and Analysis The thermal anomaly zones will be cross-referenced with other geospatial datasets such as: Existing Landfill Boundaries: To find out how or if, for example, spatial anomalies correspond with the waste body. Topographic Maps: To study how the configuration of the cystern relates to the location of thermal radiation. Hydrogeological Data: To analyze possible paths for leachate migration. Historical Aerial Imagery: For the purposes of change detection and temporal comparison.This integrated approach assists in the accurate spatial depiction of landfill impact zones spatially throughout the region which reveals the area extent and subtely the thermal radiation characteristics of processes occuring underneath the surface.

4. RESULTS AND DISCUSSION

UAV-assisted thermal imaging for mapping the impact zones of landfills was successful, proving the method's effectiveness in detecting and analyzing thermal features linked to subsurface decomposition processes and possible leachate flow paths. Followed by table 1 and Fig 2.

4.1. Performance Evaluation The thermal orthomosaic produced from the UAV data provided a comprehensive thermal image of the landfill area, together with a detailed map of its temperature distribution. Clear surface temperature anomalies were detected corresponding with the most active decomposition areas exposed within the landfill body. The ground sample distance (GSD) of about 8 cm/pixel was achieved, which is quite satisfactory considering the identification of the relatively small thermal hotspots. The temperature measurements over the landfill region were recorded to be approximately 25 degrees celsius relating to ambient surface temperatures in certain areas, while exceeding 50 degrees celsius in the anomalous areas. The high degree of temperature difference helped in distinctly marking these areas using thresholding techniques. Comparison of the GCPs demonstrated that the spatial precision of the thermal orthomosaic was 15cm, thereby validating the thermal geospatial landmarks.

4.2. Comparison with Other Methods Traditional temperature monitoring methods possess impressive pinpoint accuracy, yet remain tedious and time extensive while lacking in area coverage. In comparison, the UAV-based method provided comprehensive thermal data over the entire landfill area (50 hectares) within a few hours. Thermal imaging from satellites covers an entire region, however, lack the spatial detail needed to

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detect the many different types of thermal anomalies that are essential to accurately describe the impact zones for landfills. For instance, a typical satellite thermal product might have a resolution of 100 meters, whereas our UAV data provided sub-decimeter resolution which allowed the detection of specific leachate seepages or localized hot spots that otherwise would be missed. This level of detail is critical for effective remediation site management.

4.3. Insights and Visual Elements

The study identified different thermal regions corresponding to the various active processes in the landfill. The highest temperature (>40∘C) zones were concentrated in active areas of waste deposition and decomposition. Some of the linear thermal features which are believed to be subsurface leachate plumes or gas migration pathways seem to extend beyond the engineered boundaries of the landfill. The conceal and reveal of helical coiling serves as a perfect analogy for leaked gas and such structural breaches table 1 and fig 2, highlighting revealing the importance of thermal imaging to detect hidden and larger environmental disasters.

Table 1: Thermal Anomaly Classification and Characteristics

Thermal Anomaly Type	Temperature Range (∘C)	Spatial Characteristics	Potential Cause
High Temperature Zone	> 40	Concentrated, Irregular	Active Decomposition, Subsurface Fire
Moderate Temperature Anomaly	30 - 40	Diffuse, Linear	Leachate Seepage, Gas Migration
Background Temperature	< 30	Homogeneous, Vegetated	Ambient Surface

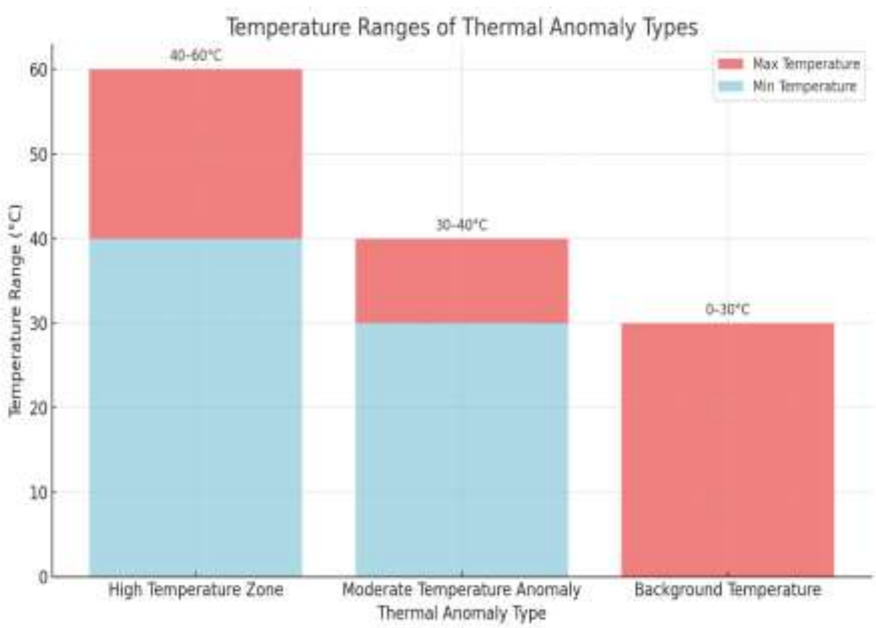

Fig:2 Temperature Ranges of Thermal Anomaly Types

5. CONCLUSION

This study adeptly illustrated the applicability of UAV thermal imaging for geospatial mapping delineation as impact zones for landfills. The methodology accurately and non-invasively monitored the environment by characterizing areas with elevated surface temperatures indicative of decomposing materials and possible leachate plumes. The integration of GIS analysis and thermal data provided high accuracy in area spatial delineation. Compared to traditional approaches, this method vastly outperforms them by providing timely data relevant to the management and remediation of waste. Enhanced characterization of distressed vegetation around landfills and emissions monitoring could be achieved by integrating multi-spectral data and thermal images taken over long periods.

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