Imperial College London

Detecting Flood Embankment Deterioration and Future Projection

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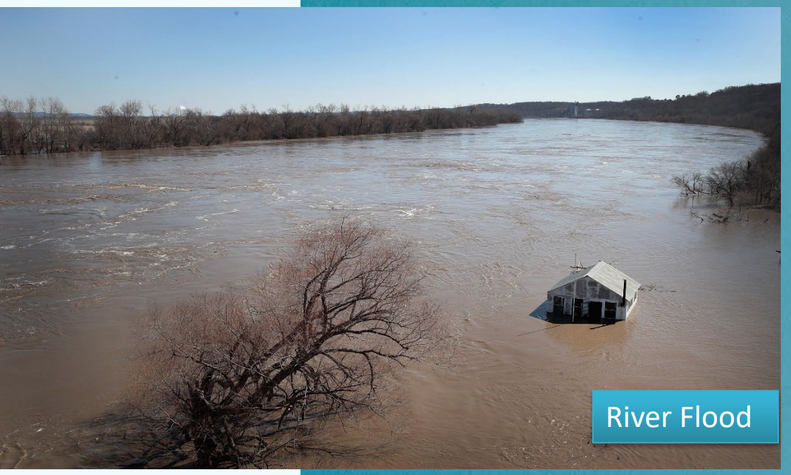
Outline


Flash Flood


River Flood


Coastal floods

Introduction

Flooding is defined as the temporary presence of surface water on, or near an embankment.

Flood is the most frequent and widespread natural disaster in the world and typically destructive. It will continue to be a significant disaster in many countries, including in the United Kingdom (UK).

Better prediction and monitoring of flood events are key factors contributing to the reduction of their impacts on local communities and infrastructure assets.

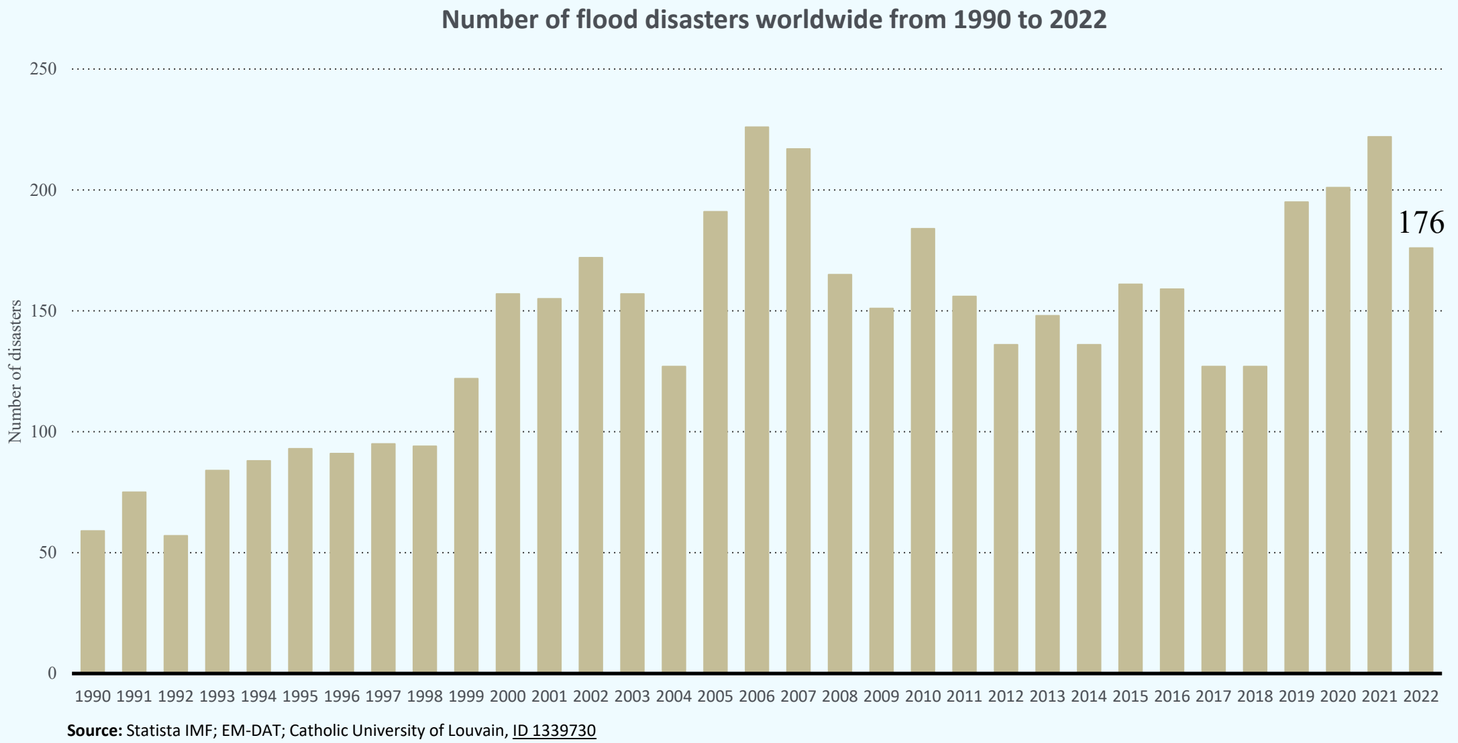
Source: Iqbal et al. (2021

"Disastrous floods driven by rapid urbanisation and extreme weather events have caused millions of fatalities and continue to cause tens of billions of dollars of direct economic loss each year. And under the background of global warming, such losses will continue to increase in the future."

CRED, UNISDR, 2020. The human cost of disasters 2000-2019. https://www.emdat.be/publications. Accessed 26/02/2024

Introduction

Flood is the most frequent and widespread natural disaster in the world.[1] Floods are typically destructive and will continue to be a significant disaster in many countries, including in the United Kingdom (UK).[2]

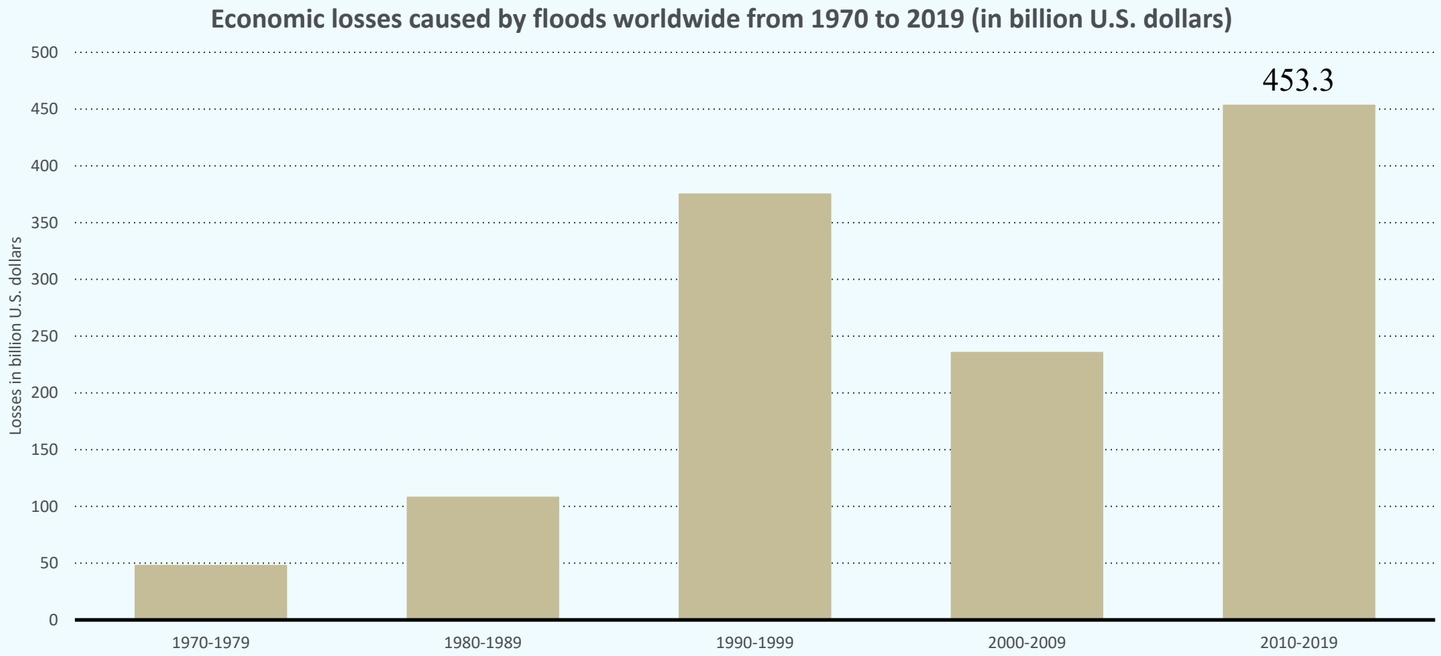


Source: Statista IMF; EM-DAT; Catholic University of Louvain, ID 1339730

[1]Iqbal et al. (2021). How computer vision can facilitate flood management: A systematic review.
[2]Sharp et al. (2013). The international levee handbook.

Introduction

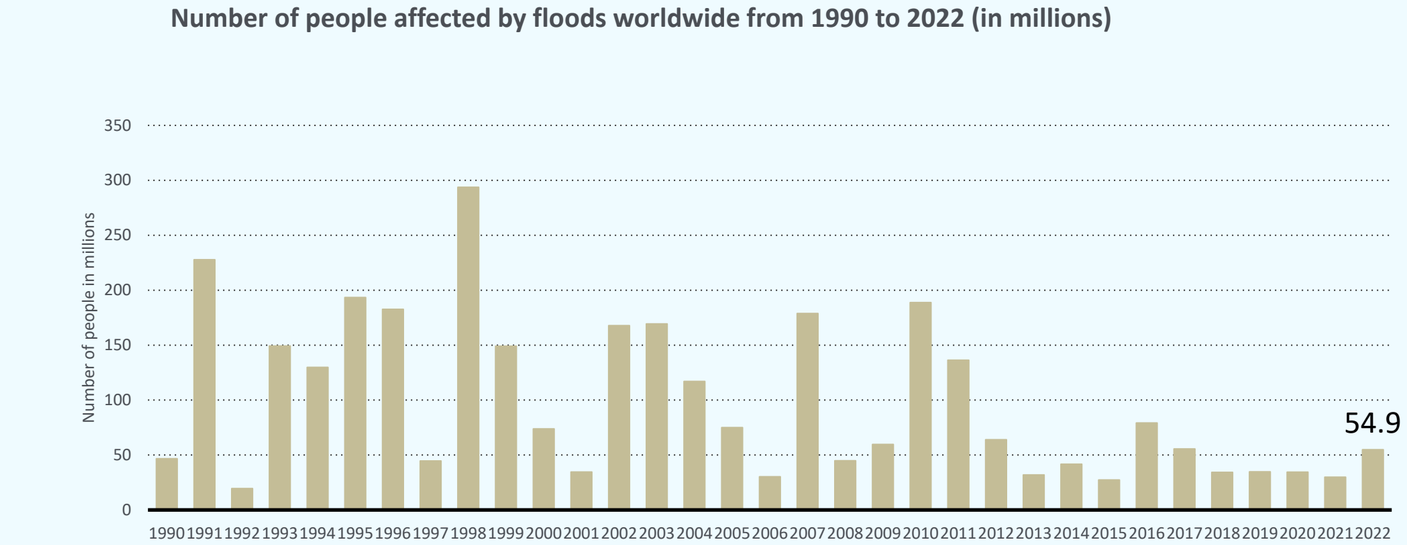
- The flooding in 2015/16 was estimated to cost the economy £1.6 billion.
- The economic losses from flooding between November 2019 and March 2020 are estimated to be about £333 million.
- It would have cost an extra £2.1 billion without flood defences

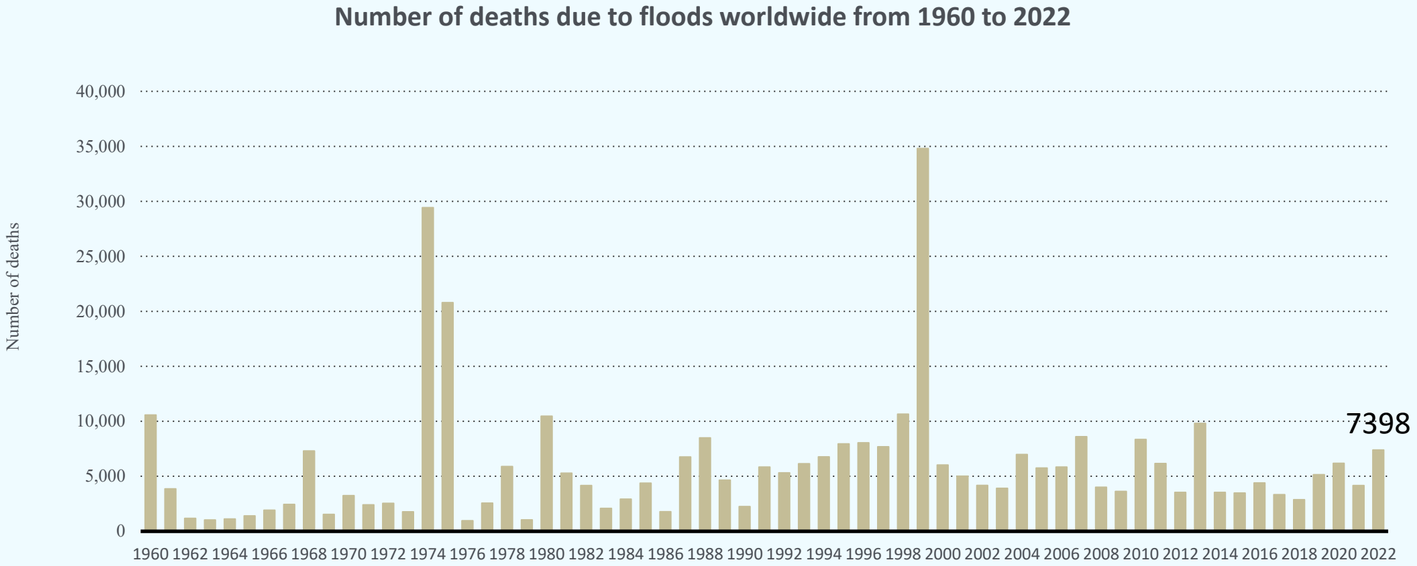


Source: Statista
World Meteorological Organization, ID 1406659
Environment Agency of the UK

Introduction

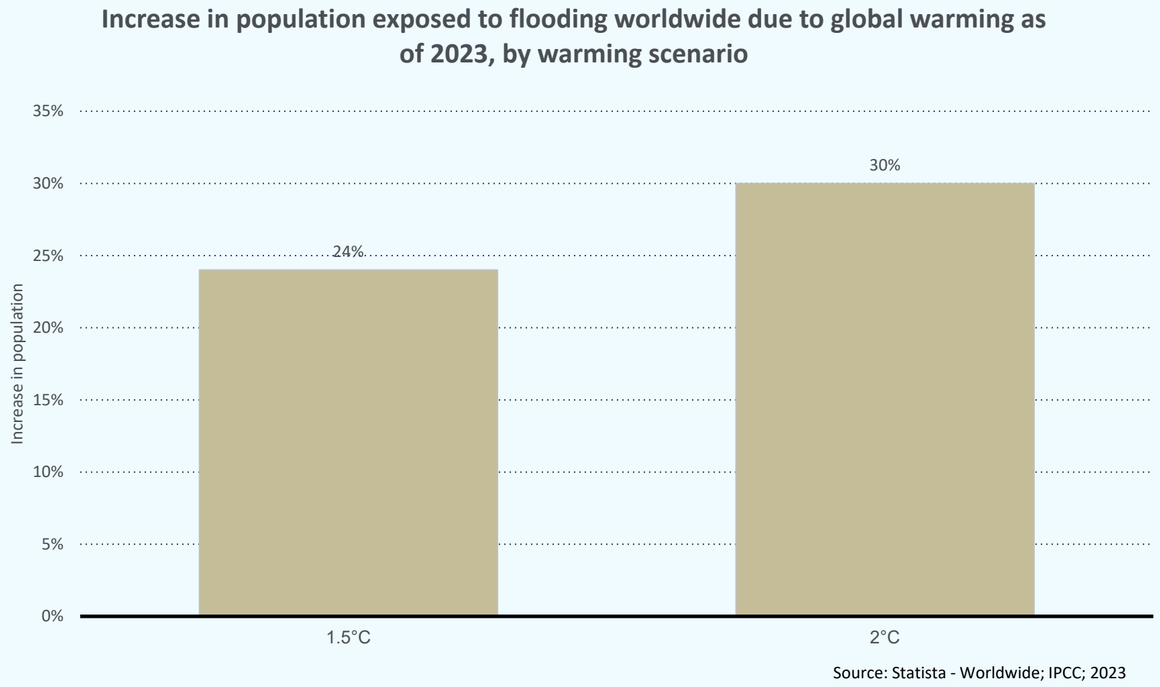
According to the United Nations (UN), floods result in the highest number of casualties in comparison to any other disaster.





Source:
Guha-Sapir et al. (2002).
Statista - OWID (EM-DATID) 1293207

Flood under Climate Scenario



Source: Statista - Worldwide; IPCC; 2023

Two different scenarios describe the population exposed to flooding increase around a third. People living in coastal cities are considered amongst the most vulnerable to sea level rise, storm surges, and coastal flooding.

Flood Management

Structural Approach:

Creating artificial structure

- Dams
- Water diversions
- Embankments
- Levees
- Channel improvements
- etc

Non- structural Approach:

Creating strategy to prevent and mitigate flood event

- Flood plain zoning
- Early warning system
- Flood proofing
- Evacuation plans
- etc

Flood Levee / Embankment

Figure: Tidal Embankment Estuary (source: Boukalava, 2011))

- Natural soils store large volumes of rainfall during storm events, which has a significant mitigating effect on flooding, especially the role in protecting large areas of populated land.
- Levees are raised, predominantly earth, structures (also called dikes, digues or flood defence embankments) whose is to provide protection against fluvial and coastal flood.
- Levees have been built up and extended over decades or sometimes centuries. Few of these were originally designed or constructed to modern standards and records of their construction and historical performance may not exist.

Source: Iqbal et al. (2021)

Consideration

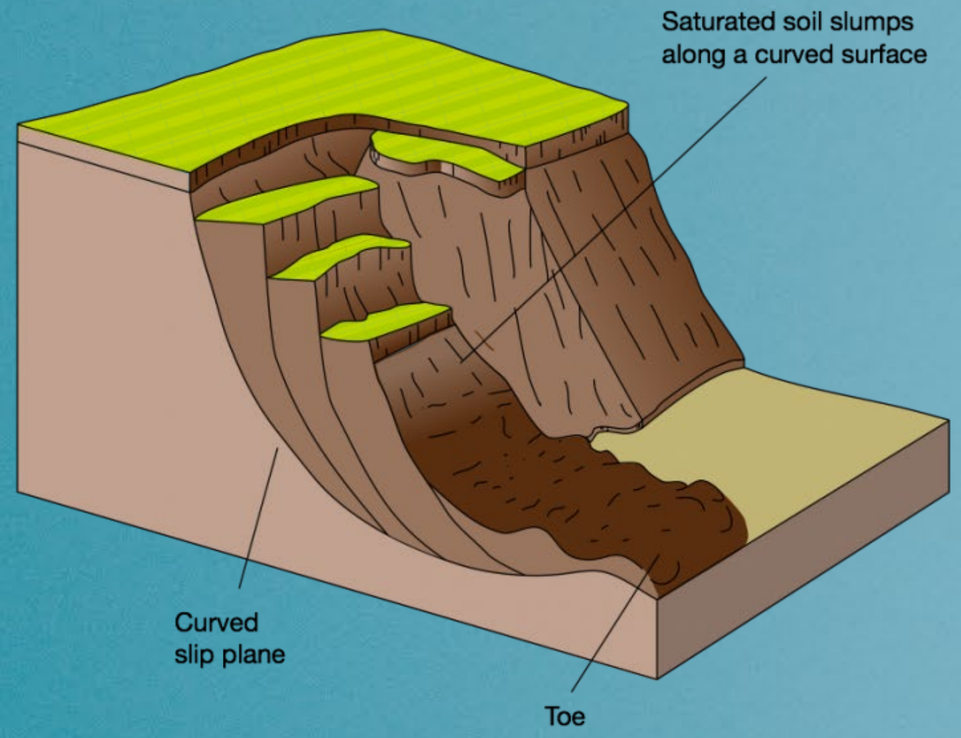
"The structure and components of the embankment should be in a sustainable design, consider the effect of water loading, and understanding climate variability."

Source: Wallingford et al. (2003)

Disaster Potential in Embankment Structure

- Slough slides or slump slides, which are minor landslides, often happen on earthen levees due to instability in the slope caused or exacerbated by factors such as soil cracking, rainfall, or erosion [1].

- During periods of high-water events, these slough slides expose sections to seepage and potential failure, rendering them vulnerable [2].



Source: aanstoos et al., 2011 (1), hossain et al., 2006 (2)

Goal and Objective of the research

Goal

This research aims to calculate the robust deterioration rate of soil embankment, particularly along the Thames and Humber Rivers, and predict future potential failure.

Objective

To find best method to identify potential slide of the embankment

To calculate future deterioration rate of the embankment

To mitigate disaster potential impacting community assets along rivers.

Challenge of the Embankment

It is essential for mitigating flood embankment before extreme flood events and ensuring sustainable flood and coastal defence [1].

The rate of deterioration can be detected through long-term observation and inspection, but monitoring minor deformation processes remains inadequate.

The traditional inspection methods by visual monitoring are inefficient, inaccurate, and dangerous.

The use of algorithms and techniques based on remote sensing can help local government to identify vulnerable levee sections and repair them rapidly with lower costs [2].

Source: morris et al., 2007 (1), mahrooghy et al., 2015 (2)

Unmanned Aerial Vehicle (UAV)

One form of remote sensing is unmanned aircraft vehicle (UAV). Some reasons why UAV are being considered for use in this research:

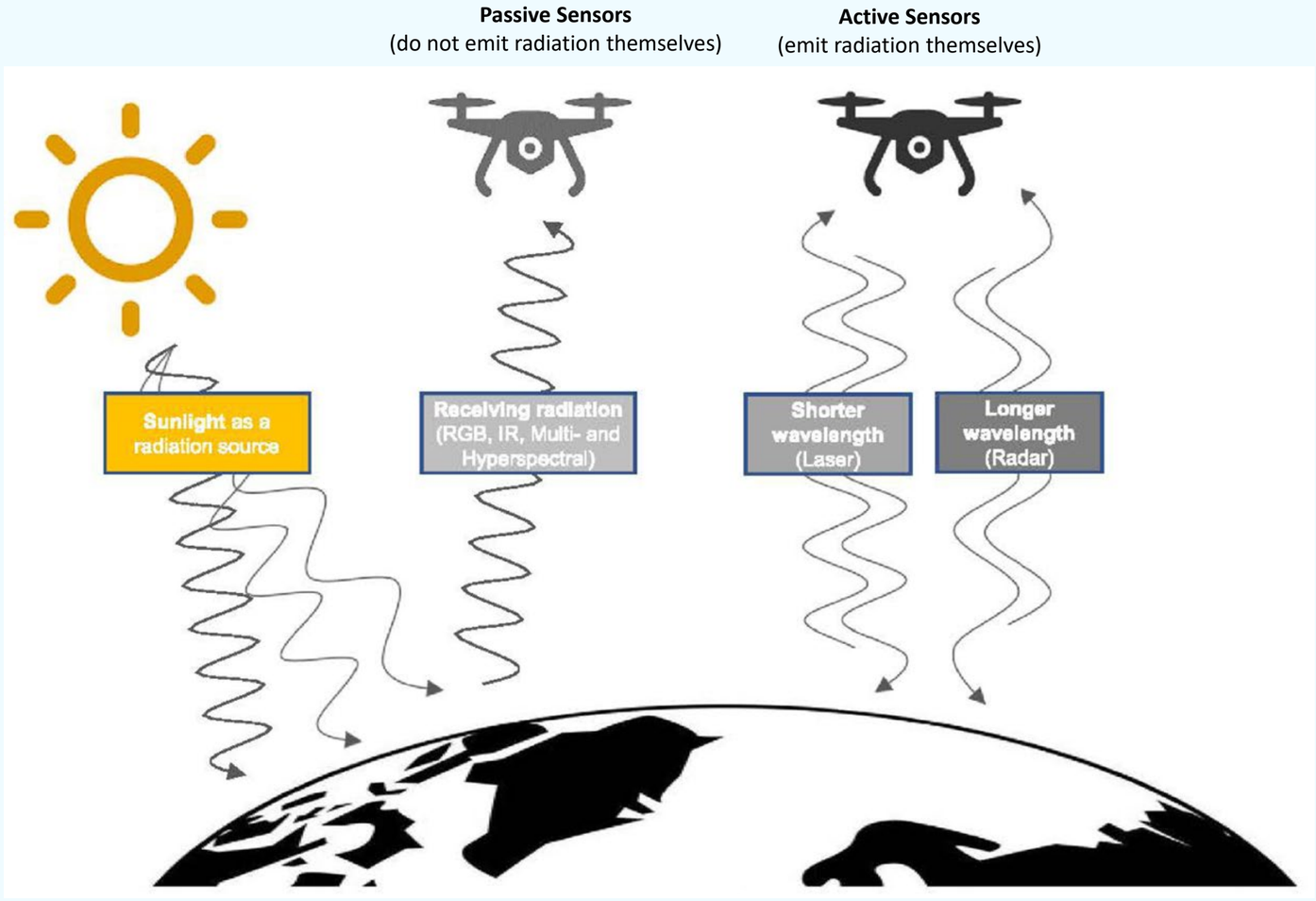
UAVs equipped with sensing technologies have replaced certain on-site measurements or satellite-based monitoring, as they provide both in situ and satellite measurements with sufficient accuracy..

UAVs equipped with sensing methods experience fewer spatiotemporal constraints and offer superior resolution with reduced data gaps compared to satellite-based measurements.

Source: morris et al., 2007 (1), mahrooghy et al., 2015 (2)

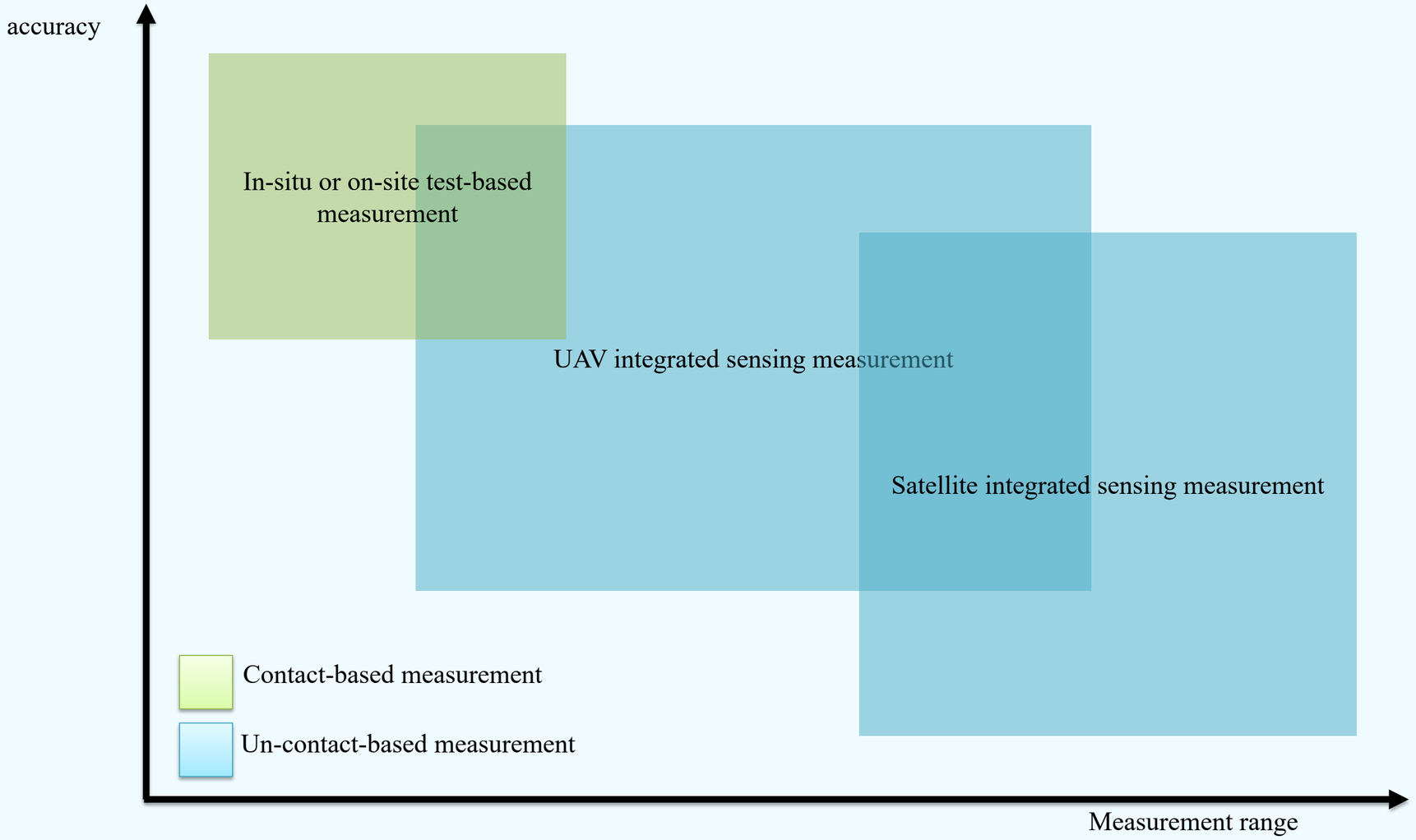
Unmanned Aerial Vehicle (UAV)

Advancements in sensor and UAV technologies have facilitated more intelligent monitoring and inspection of sites prone to failure.



Source: kim et al., 2023

Comparison of UAVs Sensing Measurement



Source: kim et al., 2023

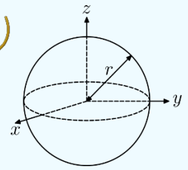
The Advantage of LiDAR

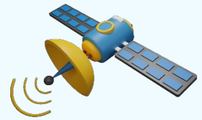
- One of the UAVs is Light Detection and Ranging (LiDAR) which technology marks a significant advancement in producing 3D surface features [1].
- LiDAR excels in capturing data with both high spatial and spectral resolutions, facilitating the generation of precise classifications, detection of surface alterations, environmental monitoring, and various other applications [2].
- LiDAR technology, capable of penetrating vegetation cover, is applicable in rainfall analysis and has been deployed on UAVs to map regions prone to landslides and evaluate landslide susceptibility [3].

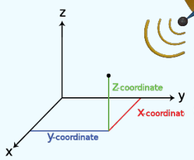
Source: jin et al., 2018 (1), kahraman et al., 2021 (2), mezaal et al., 2018 (3)

The Advantage of LiDAR

The IMU (inertial measurement unit) gives the precise orientation of the scanner

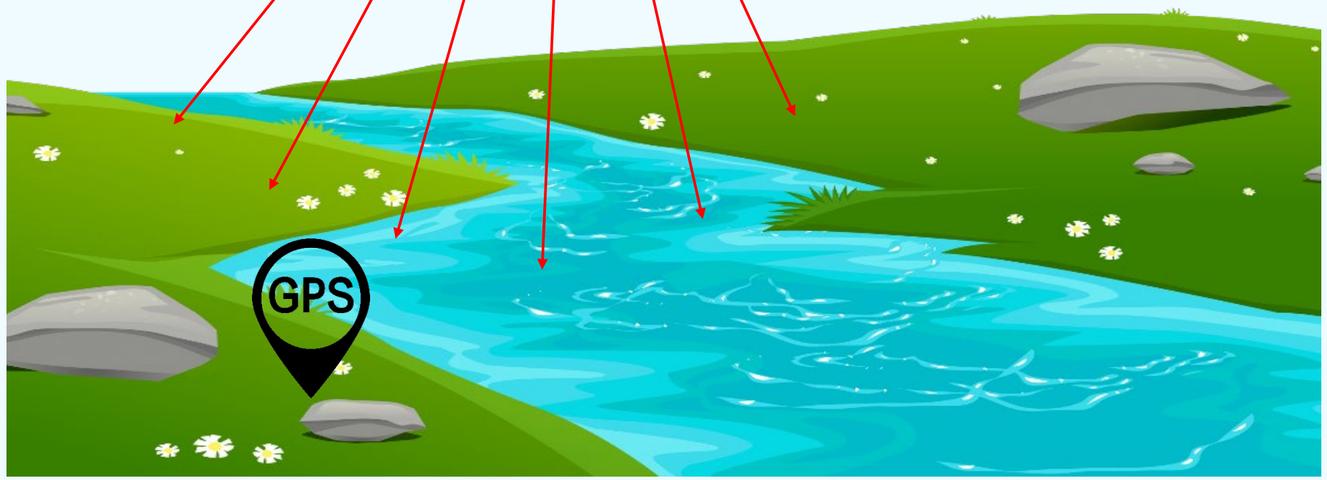






The GPS gives the precise location of the scanner

The laser scanner emits infrared pulses which reflect off the surface of the earth and objects on it. The returned pulses are captured and recorded.



Source: adopted from mezaal et al., 2018

Previous Research in utilising LiDAR

Jaboyedoff et al. (2012) applied LiDAR to monitor landslides, rockfalls, and debris flows by generating an accurate slope map.

It is not straightforward to use a LiDAR system because significant technical expertise is required.

Utilising machine learning or deep learning approach.

Source: Jaboyedoff et al., 2012

Study Area

River Thames

The Thames is the largest river in England, with a total length of 354km, housing a fifth of the UK population, including London.

River Humber

The Humber is about 64 km long, the River is lined by the major ports of Kingston upon Hull, Grimsby, and Immingham.

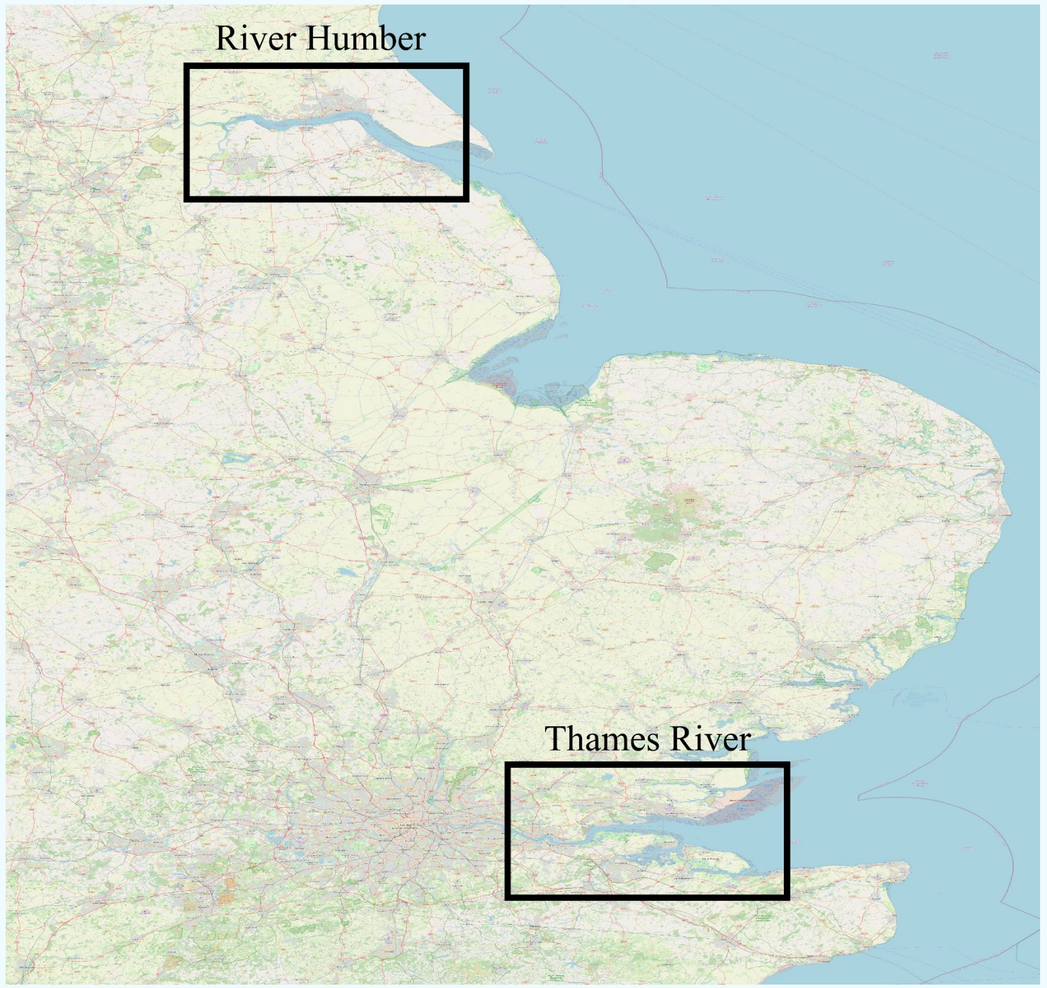
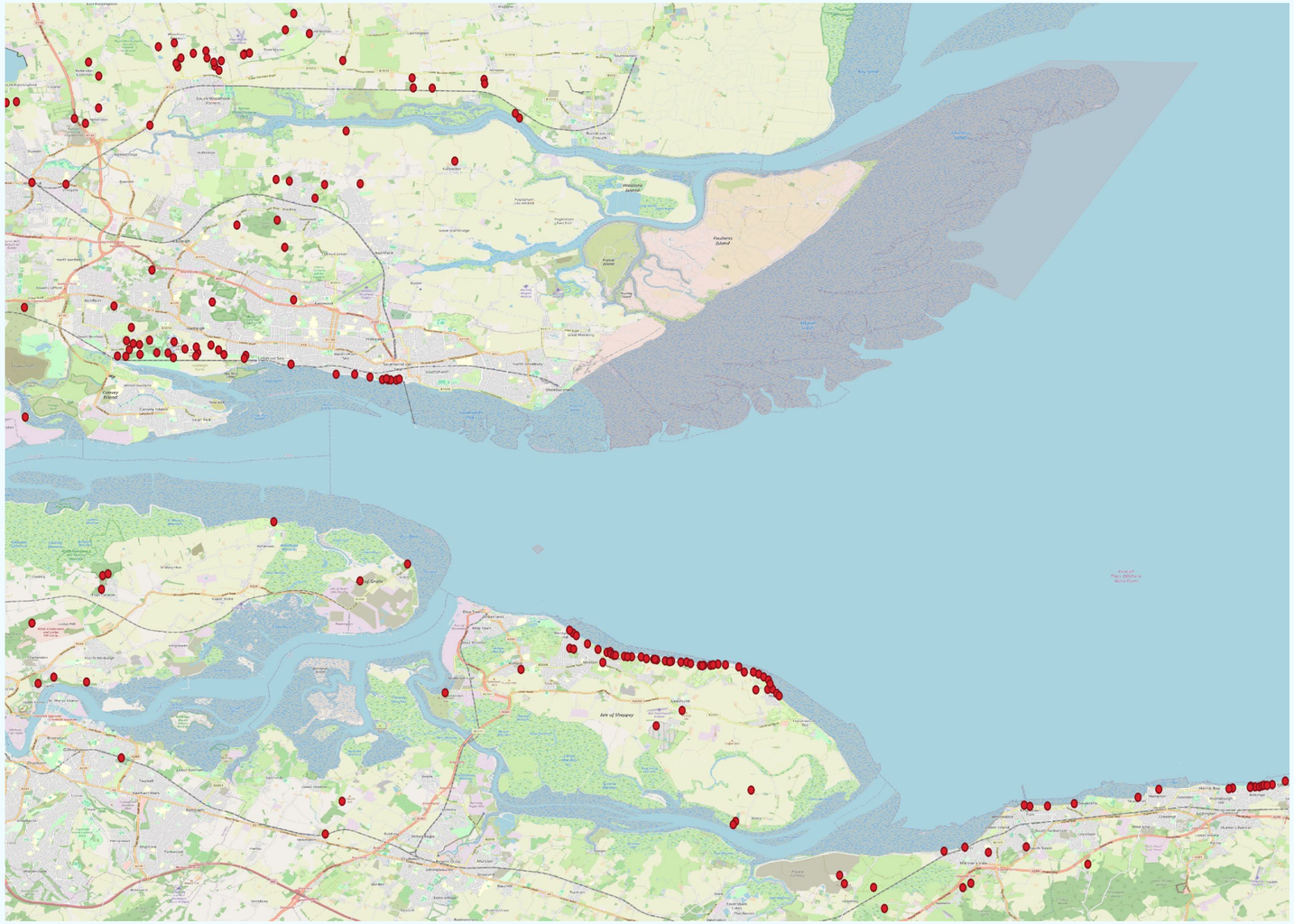


Figure. Study Areas

source : https://www.britannica.com/place/

Previous Landslide along River Thames



Source : https://www.bgs.ac.uk/datasets/national-landslide-database/

Previous Landslide along River Humber

Source : https://www.bgs.ac.uk/datasets/national-landslide-database/

Milestone of Methodology

Utilising point cloud data from LiDAR in Python involves several steps to yield high-quality results.

Lidar Data Acquisition and Pre-processing

Gathering the data sources and comprehend the data typology.

Segmentation and deterioration analysis

to isolate specific research areas and identify key features from the segmented data relevant to assessing the health and stability of flood embankments.

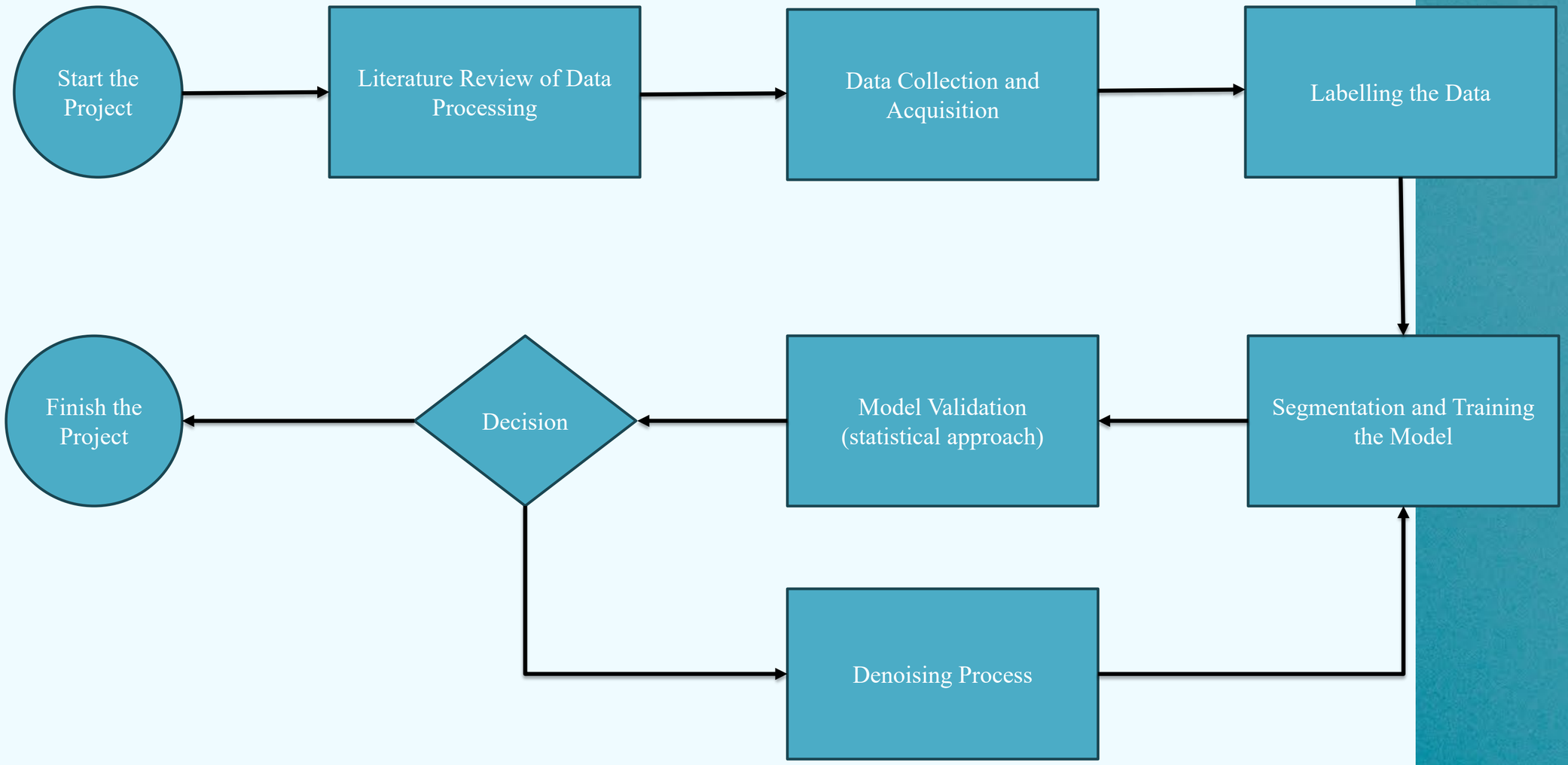
Data Enhancement and Denoising

to refine data quality for improved feature detection.

Predicting and Analysing Future Potential

To project the embankment deterioration rate by applying real-world scenarios to inform decision-making processes in civil engineering.

Timeline


Start the Project
Literature Review of Data Processing
Data Collection and Acquisition
Labelling the Data
Segmentation and Training the Model
Model Validation (statistical approach)
Decision
Finish the Project
Denoising Process

Training Datasets

Defra Datasets

Type of Data: Scalar Field with extension *.laz format

All products are available in 5km tiles aligned to the survey grid.

⊕ For 50 cm this increases to 4 point per square meter (ppsqm) and 25 cm resolution is 16 ppsqm.

⊖ First Data is starting in November 2016.

Surveys are undertaken during winter months (approximately November to April each year).

For a 1 m DSM surface model the point cloud will have an average point density across the survey of at least 1 ppsqm.

(Data Source: https://environment.data.gov.uk/defra/)

Digimap Datasets

Type of Data: Scalar Field with extension *.laz format

⊕ Vertical aerial photography data has been captured regularly since 2006.

Images of the ground are captured at resolutions between 10cm and 50cm.

⊖ Some certain datasets areas are not available

(Data Source: https://digimap.edina.ac.uk/)

? Conducting a field survey with the integration of compatible high-resolution sensors is essential to achieving the desired resolution and temporal accuracy. The methodology employed should be meticulously tailored based on the specific goals and objectives of the research endeavour.

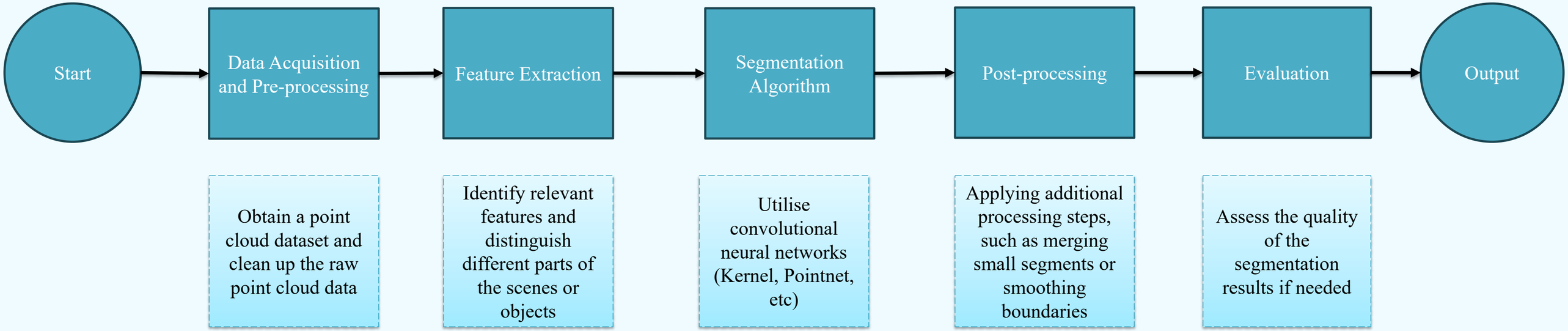
Method Approach

	Object-Based (1)	Voxel-Based (2)	Segment-Based (3)
Explanation	Detecting and segmenting individual objects within the scene	Converted into a volumetric representation by dividing the space into small cubic volumes called voxels	Divided into segments or regions of interest based on geometric properties, such as curvature, normal vectors, or point density
Application	Autonomous driving, urban planning, and infrastructure monitoring, where the precise detection and classification of the object is required	Reconstruction, volumetric analysis, and environmental modelling, where a volumetric representation of the scene is required	Object recognition, scene understanding, and semantic segmentation, where the focus is on identifying and analysing specific object.
Advantage	Interpretable, robust, flexible, and well-established	Regularised representation, efficient processing, and scalable	Localised analysis, flexible, and interpretable
Drawback	Dependency on segmentation, computational complexity, limited to object detection	Resolution limitation, memory intensive, difficulty in handling spare data	Segmentation sensitivity, over-segmentation, and computational complexity

Overall, a segment-based approach offers a systematic and effective methodology for analysing scalar field data representing surface features to detect embankment cracks

Source: Qi et al., 2018; Lang et al., 2019; Zeng et al., 2018

Segmentation Process



Segmentation Approach

	Semantic	Instance
Advantage	High-level understanding, simpler, faster inference	Precise localisation, fine-grained understanding, more information
Drawback	Lack of details, limited object localisation	Complex annotation process, and slower inference

Why using Semantic Segmentation?

- Most crack detection methods rooted in semantic segmentation networks have demonstrated notably improved outcomes compared to traditional methodologies. There are fewer studies on embankment crack detection based on semantic segmentation networks, so relevant datasets are also lacking.
- It is well known that deep learning is a class of data volume-driven methods, and crack detection accuracy is affected by the data volume level.

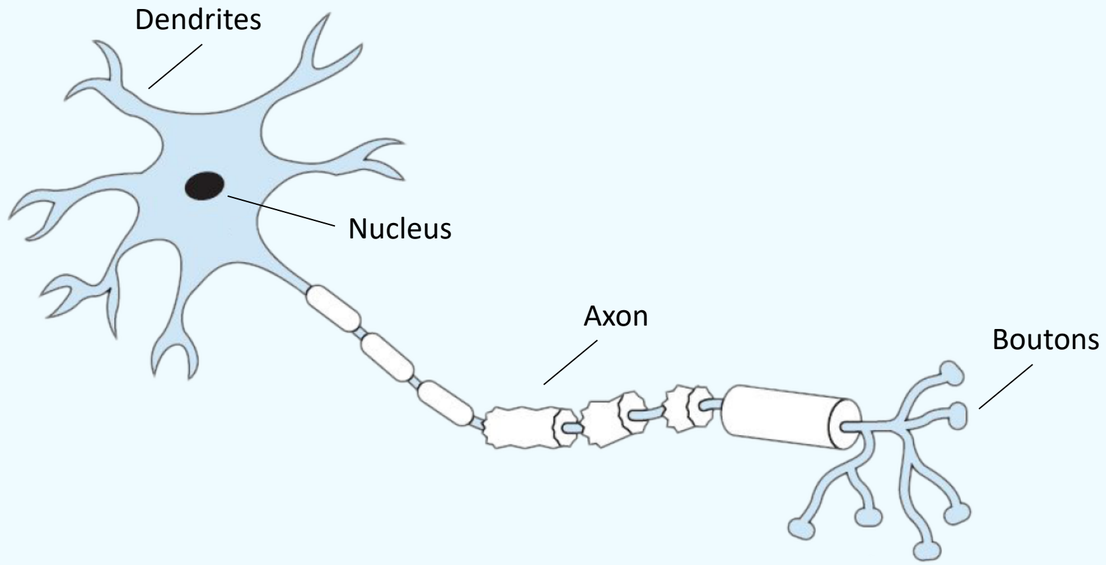
Source: Cheng et al., 2023

Motivation

Architecture

Convolutional Neural Network (CNN)

U-Net Concept



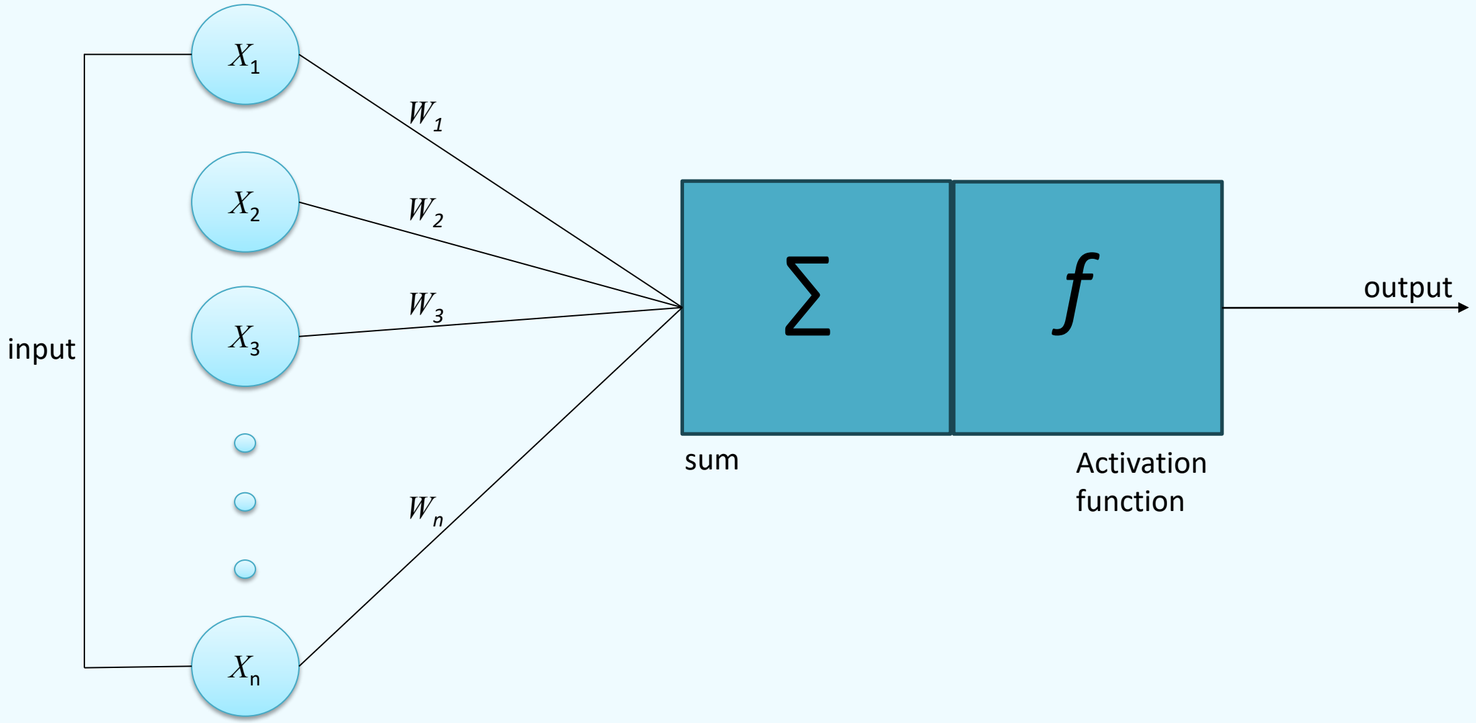
Our brain uses the extremely large interconnected network of neurons for information processing and to model the world around us. Simply put, a neuron collects inputs from other neurons using *dendrites*. The neuron sums all the inputs and if the resulting value is greater than a threshold, it fires. The fired signal is then sent to other connected neurons through the axon.

Neural networks loosely mimic the way our brains solve the problem: by taking in inputs, processing them and generating an output. Like us, they *learn* to recognize patterns, but they do this by *training* on labelled datasets.

Source: Cheng et al., 2023

Perceptron

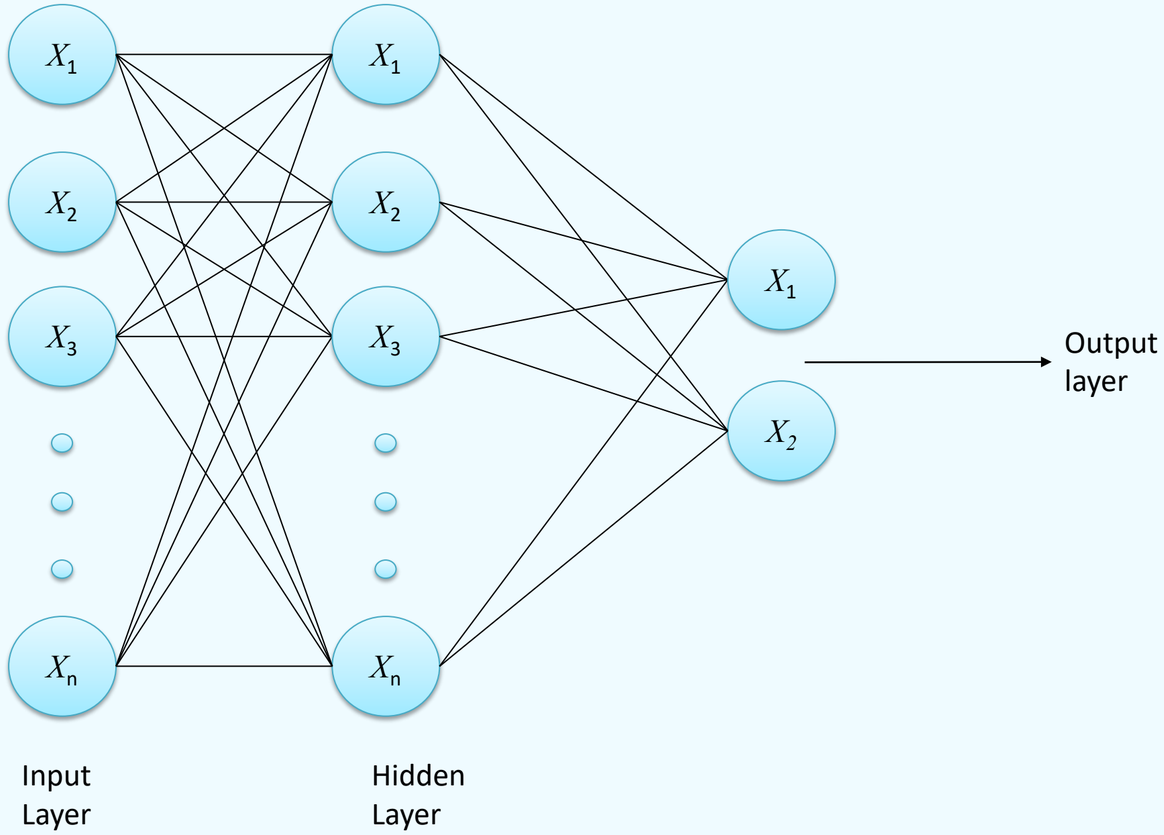
the most basic of artificial neural neurons by following the general principles set of perceptron.



Source: Source: https://towardsdatascience.com/a-beginners-guide-to-neural-networks-b6be0d442fa4

Multi-Layer Neural Network

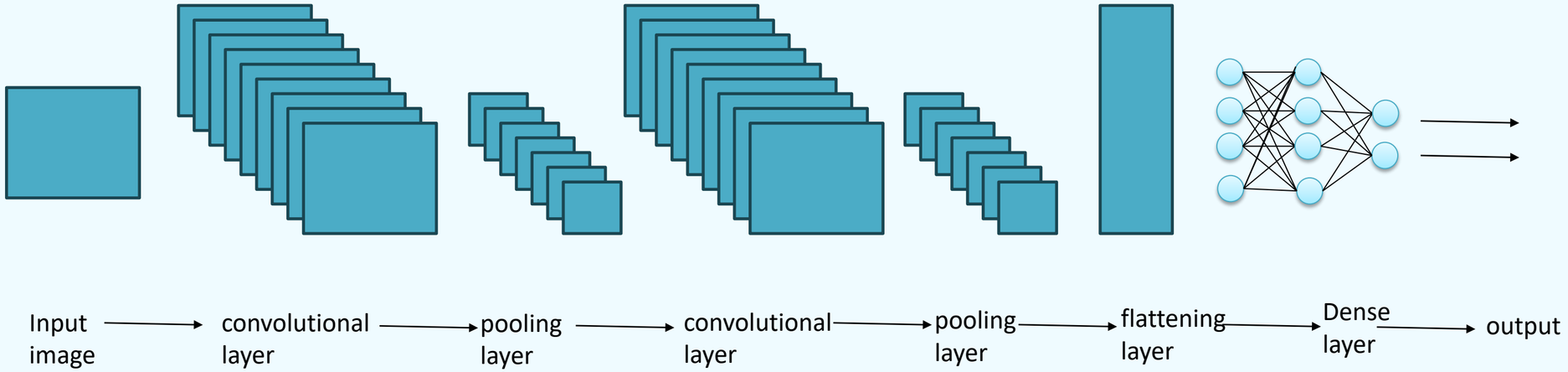
Once a training sample is given as an input to the network, each output node of the single layered neural network takes a weighted sum of all the inputs and pass them through an activation function and comes up with an output.



Source: Source: https://towardsdatascience.com/a-beginners-guide-to-neural-networks-b6be0d442fa4

Convolutional Neural Network

- Convolution is used to apply filters (also known as kernels) to an image.
- Pooling layers reduce the dimensionality of each feature map but retain the most important information.
- Flattening layer serves as a bridge between output of the convolutional layers and the fully connected (dense) layers.



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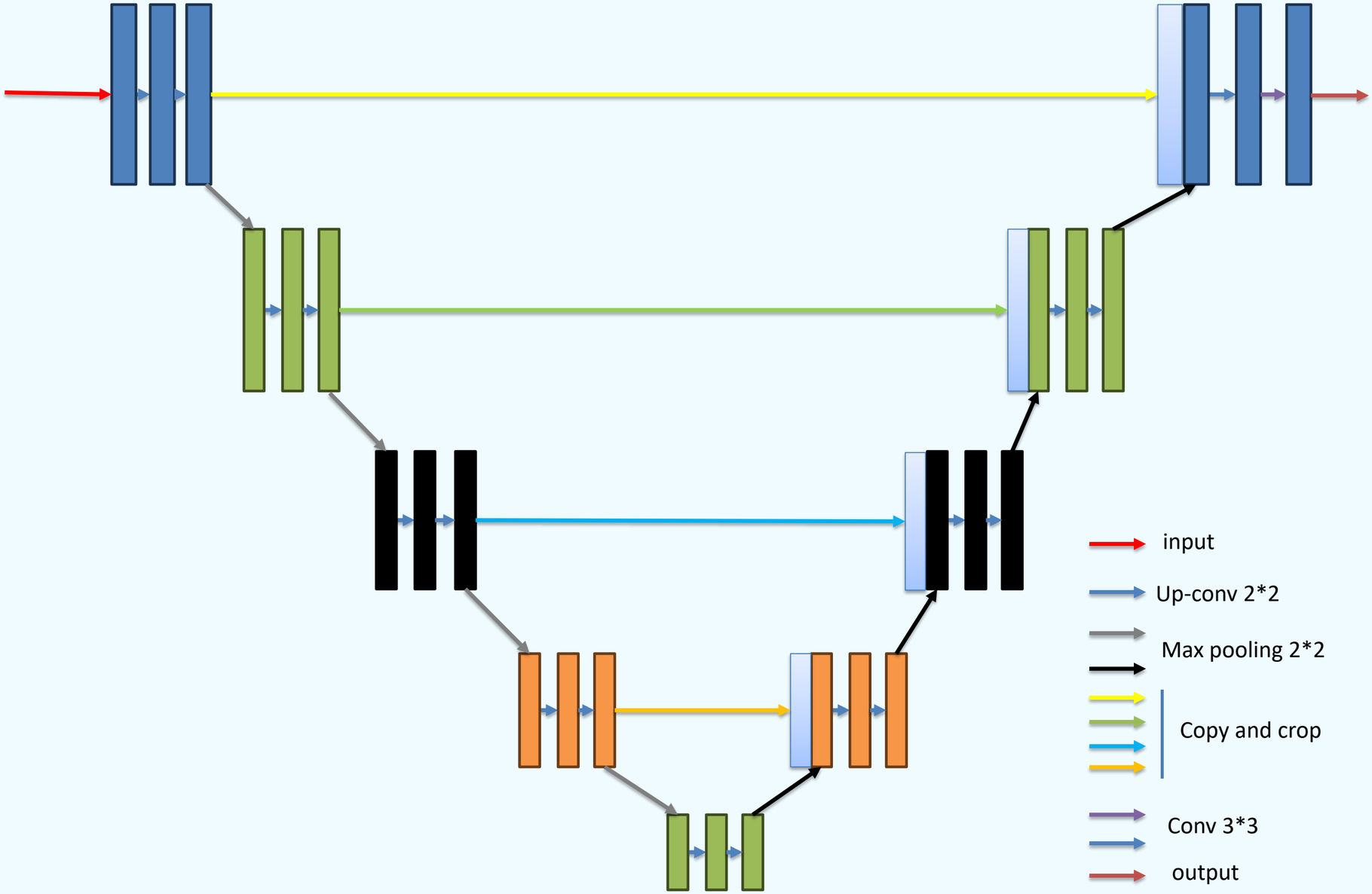

Training Methods

Climate Induced

Flooding is defined as a temporary condition of surface inundation, or near an embankment (1). However, 3D point cloud data provided by a terrestrial laser scanner could play an interesting role for flood mapping (2).

Challenge

One of the most main challenges in examining the impact of flooding on geotechnical assets, like embankment, is that no one single dataset in the public domain is properly detailed to describe for primary research (3).

Water loss from subgrade soil subjected to dry weather is possible to cause soil cracking. On the contrary, intruded water will cause pavement failures because of the wetting swelling or collapsing of the subgrade soils

Solution

Currently, the risk of floods is mapped on a global scale using technology like satellite imagery and remote sensing. LiDAR derived flood inundation model can be used to simulate flood hazard estimation using probability analysis and flood scenario. Airborne LiDAR-derived DEM and a 3D dam model are integrated can be used to analysing inundation and develop flood risk mitigation using machine learning

Source: Johnston et al., 2021 (3)

Reference

THANK YOU