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Outstanding Student & PhD candidate Presentation contest

A Scalable and Lightweight Urban Flood Monitoring Solution Utilizing Only Traffic Camera Images

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Background and research objectives

1 Background

- Flooding still has an increasingly severe impact on cities.
- The urgency for accurate flood data persists, but obtaining is challenging.

Guangzhou,
21-22 May 2020,
Metro Line 13 shut down,
causing 4 deaths,
≈ 800 million RMB loss

Zhengzhou,
20 July 2021,
>380 deaths or missing

Table 1. Data requirement of flood researching

Category	Works	Data requirement
Pre-disaster	Risk assessment	Topographic data: DEM, River density, Land use type…
		Metrologic data: Rainfall, Typhoon, Tropical cyclone...
Mid-disaster	Near real-time flood prediction	Hydraulic facilities: Dam, Bump, Drainage…
		Historical flood: Region, Depth, Duration…
Post-disaster	Floodplain inundation hindcasts Recovery and reconstruction	Ocean: Tide level, Wave…
		Civil data: buildings, population, GDP, economic information…

Background and research objectives

1 Background

- Time series data is desirable.
- Therefore, applying image-based method to monitor waterlogging depth is prevalent.

Table 2. Comparison of different waterlogging depth data obtain methods.

Obtain methods	Typical errors	Advantages	Limitations
Water gauge	±0.01–0.02 m	Accurate real-time monitoring	Expensive Fixed (Point data)
Satellite image	0.05–1.5 m (RMSE)	Broad coverage (2D data) SAR could penetrate through clouds and vegetation	Expensive Low accuracy Low scanning frequency
Unmanned aerial vehicle (UAV)	RMSE of ~0.1 m	High-resolution imagery Area monitoring (2D data)	Low endurance Sensitive to weather
Image-based	~0.1 m	Area monitoring (2D data) Real-time monitoring Cost-effective	Limited visibility Privacy concern

Background and research objectives

2 Literature review

Table 3. Literature review of waterlogging depth measurement methods.

	Category & Reference	Object	Scenario	Input	Camera parameter	Methodology	Clear water?
Qualitative (Region)	Liang et al. (2020)	Flood water	River, ocean	Labeled dataset, Video	No need	Convolutional neural network (CNN)	No
	Q. L. Feng, Liu, and Gong (2015)	Texture features	Urban	Unmanned Aerial Vehicle data	No need	Random forest (RF)	No
	Moy de Vitry et al. (2019)	Flood water	Park, river, etc.	Labeled dataset, Image	No need	CNN	No
Semi-quantitative (Discrete waterlogging depths)	Muhadi et al. (2021)	Marked points	River	Labeled dataset, Image, 3-D point cloud	No need	CNN	No
	Vandaele et al. (2021)	Marked points	River	Labeled dataset, Image	No need	CNN	No
	Hao et al. (2022)	Car	Urban street	Labeled dataset, Image	No need	YOLO	No
	Chaudhary et al. (2020)	Car, bike, human	Urban	Labeled dataset, Image	No need	Neural Network	No
	Y. Feng et al. (2020)	Human	Urban	Labeled dataset, Image	No need	CNN	No
	Li et al. (2023)	Human	Urban	Labeled dataset, Image	No need	YOLO	No
Fully quantitative (Continuous waterlogging depth)	Kharazi and Behzadan (2021)	Traffic sign pole	Urban street	Labeled dataset, Image	No need	Neural Network	No
	Park, Baek, Sohn, and Kim (2021)	Car	Urban street	3D image dataset, Image	No need	CNN	No
	Jiang et al. (2020)	Traffic bucket	Urban street	Labeled dataset, Image	No need	CNN	No
	Eltner et al. (2018)	Flood water	River	Images, 3-D point cloud	Known	SfM photogrammetry & histogram analysis	No
	Griesbaum et al. (2017)	Flood water	Local building	Images, 3-D point cloud	Calibration	Photogrammetric method & waterline	No
	Y. T. Lin et al. (2020)	Flood water	Urban street	Images, Digital surface model	Calibration	RF, photogrammetric method	No

Background and research objectives

2 Literature review

Static reference: Traffic sign pole, traffic bucket, wall, stairs, rulers…
【Already known the dimensions】

Dynamic reference: Person, Car, Bike…
【No fully quantitative or using average dimensions】

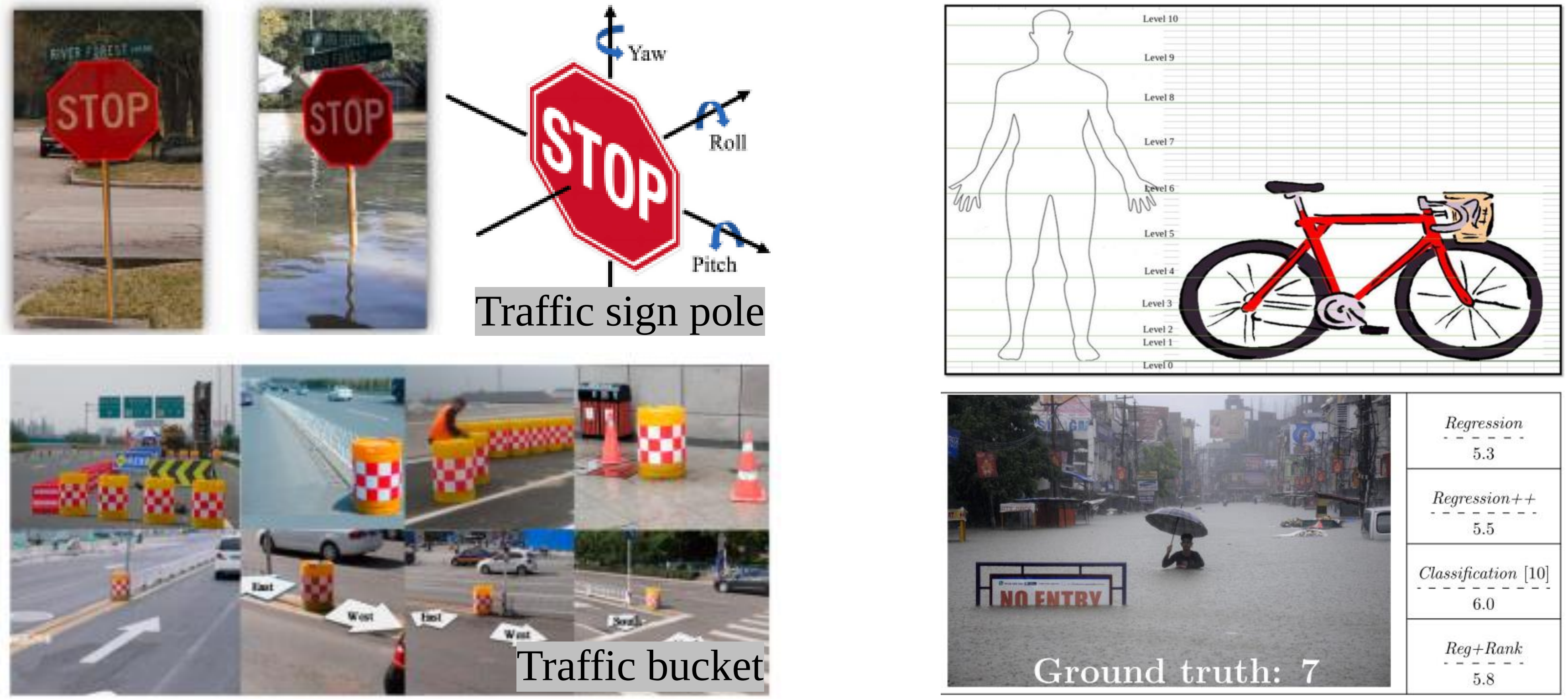


Figure 1. Examples of flood depth with image-based method.

Background and research objectives

2 Literature review

Other approaches: Point cloud data + image analysis = more accurate

But it might not be suitable for changing urban scenarios.

River or stream

Wall of house

Figure 2. Examples of flood depth with image-based method.

Background and research objectives

2 Literature review

Other approaches: Point cloud data + image analysis = more accurate

But it might not be suitable for changing urban scenarios.

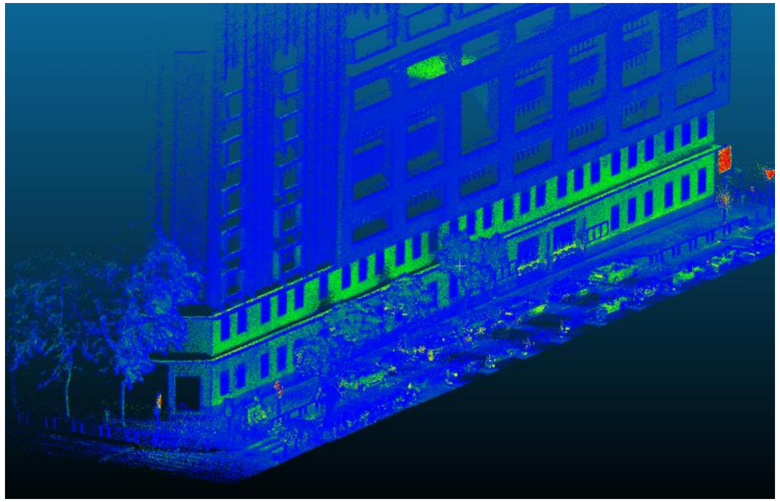


Figure 3. Example of point cloud data of Macao.

Point cloud data is **constant**.

Figure 4. Example of flooding process captured by CCTV.

But **urban street is changing**.
(Vehicles, pedestrians, floating trash and so on)

- There are lots of references on urban street, how to use them?
(Unknown dimension or various dimensions)

Transparent: Background

Phenomenon

Transparent flood is becoming more frequent, but there are no studies on the measurement.

Figure 14. Clear flood examples.

Figure 15. Refraction-caused displacement of road markings in clear flood.

Transparent: Background

Bottleneck

Traditional CNN is hard to obtain the accurate waterline with transparent dataset.

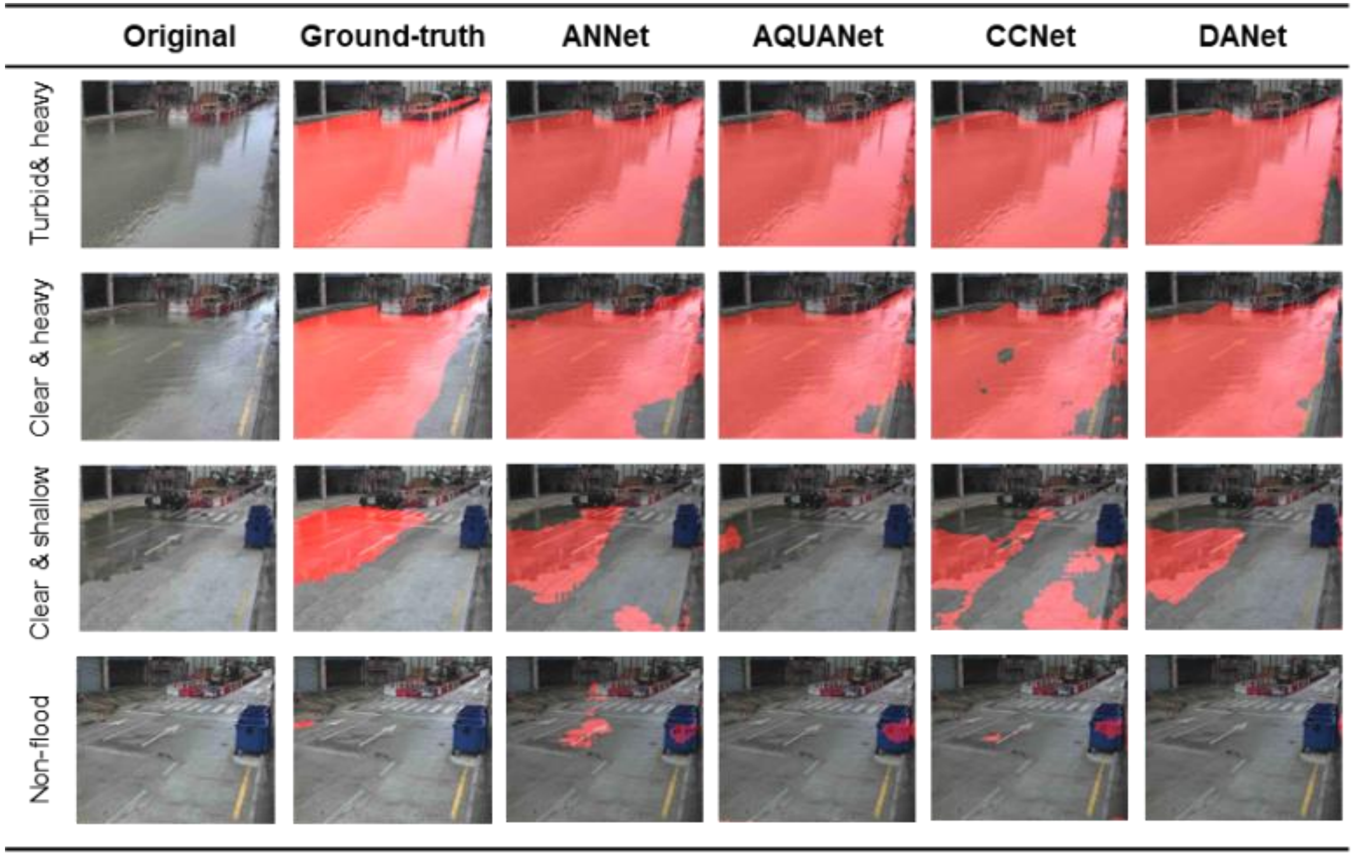


Figure 16. The flooded region identification results from ten neural network models.

Transparent: Background

Bottleneck

Traditional CNN is hard to obtain the accurate waterline with transparent dataset.

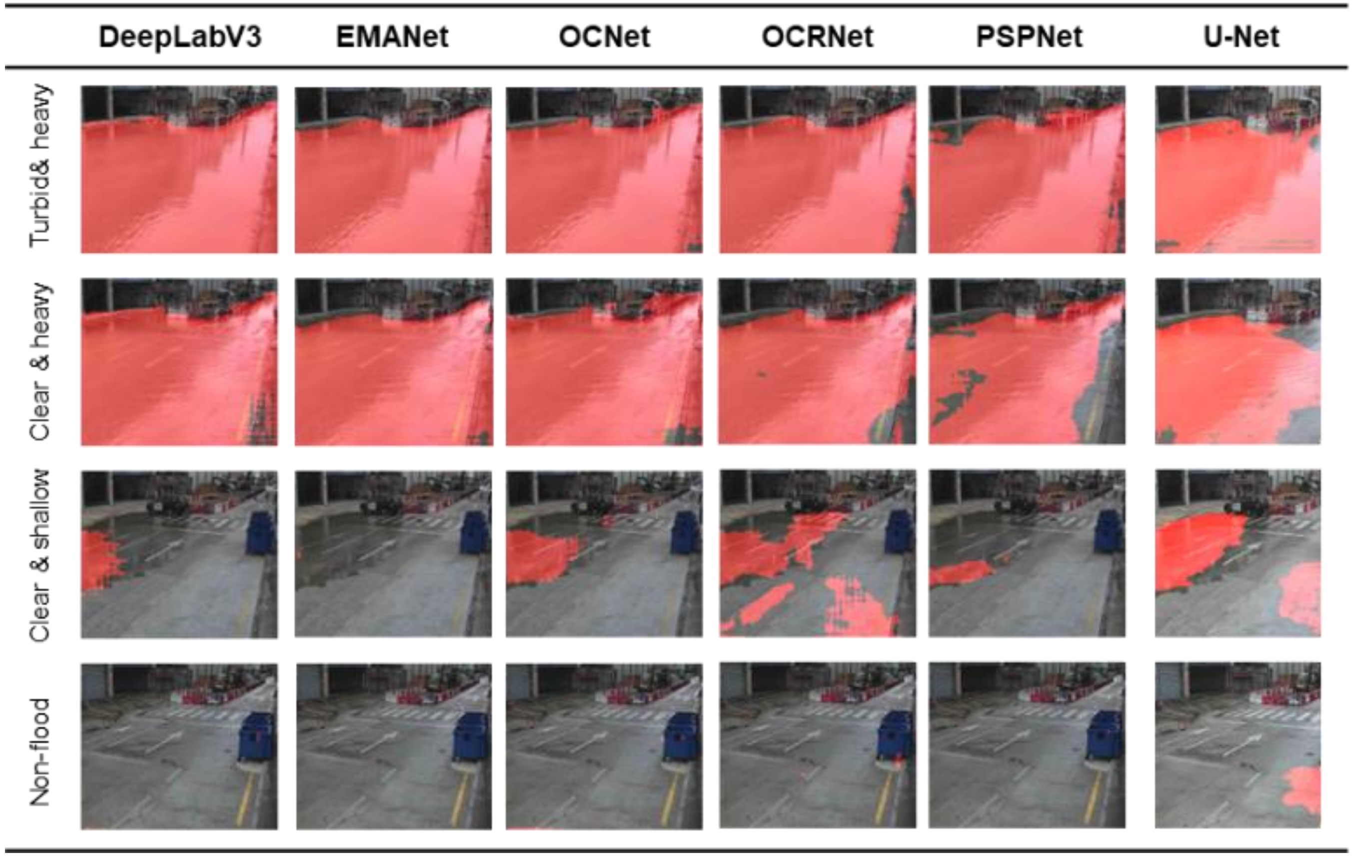


Figure 16. The flooded region identification results from ten neural network models.

Transparent: Background

Bottleneck

Sometimes, annotations are difficult.

But maybe refraction phenomenon would help?

Figure 17. Example of transparent waterlogging in urban street.

Transparent: Methodology

1 Methodology

Propose a method for quantitative monitoring the water level using CCTV only:

- Camera calibration
- Feature matching
- Refraction calculation

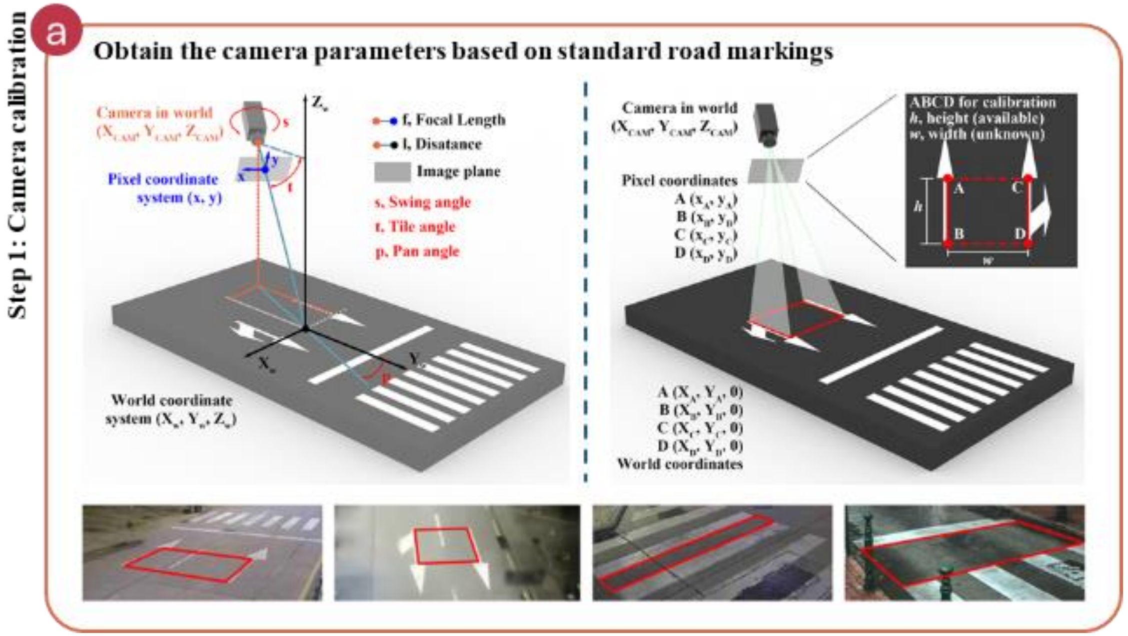


Figure 5. Workflow of the proposed methodology. (a) Calibration of traffic camera parameters using standardized road markings.

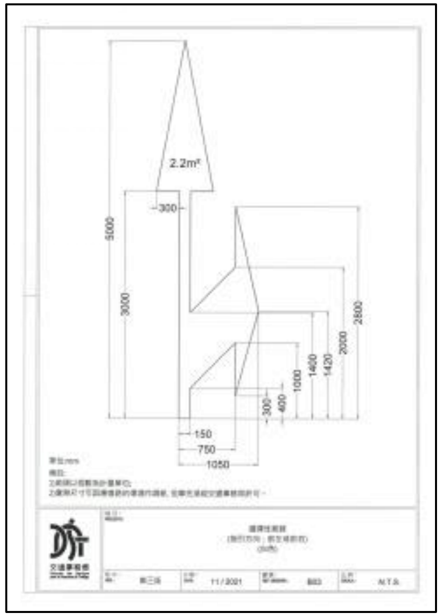
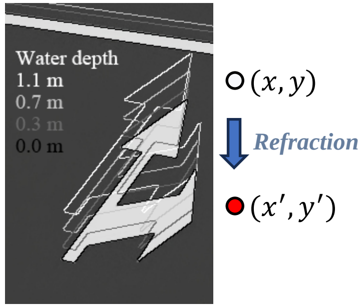


Figure 6. Standard road marking example.

Transparent: Methodology

1 Methodology

➢ Obtain the world coordinates from pixel coordinates



$$
\begin{cases}
X_w = \dfrac{\begin{bmatrix} \sin p \cdot (l + Z_w \cdot \sin t)(x \cdot \sin s + y \cdot \cos s) \\ + \cos p \cdot (l \cdot \sin t + Z_w)(x \cdot \cos s - y \cdot \sin s) \\ - Z_w \cdot f \cdot \cos t \cdot \sin p \end{bmatrix}}{x \cdot \cos t \cdot \sin s + y \cdot \cos t \cdot \cos s + f \cdot \sin t} \\
Y_w = \dfrac{\begin{bmatrix} - \cos p \cdot (l + Z_w \cdot \sin t)(x \cdot \sin s + y \cdot \cos s) \\ + \sin p \cdot (l \cdot \sin t + Z_w)(x \cdot \cos s - y \cdot \sin s) \\ + Z_w \cdot f \cdot \cos t \cdot \cos p \end{bmatrix}}{x \cdot \cos t \cdot \sin s + y \cdot \cos t \cdot \cos s + f \cdot \sin t} \\
Z_w = 0
\end{cases}
$$

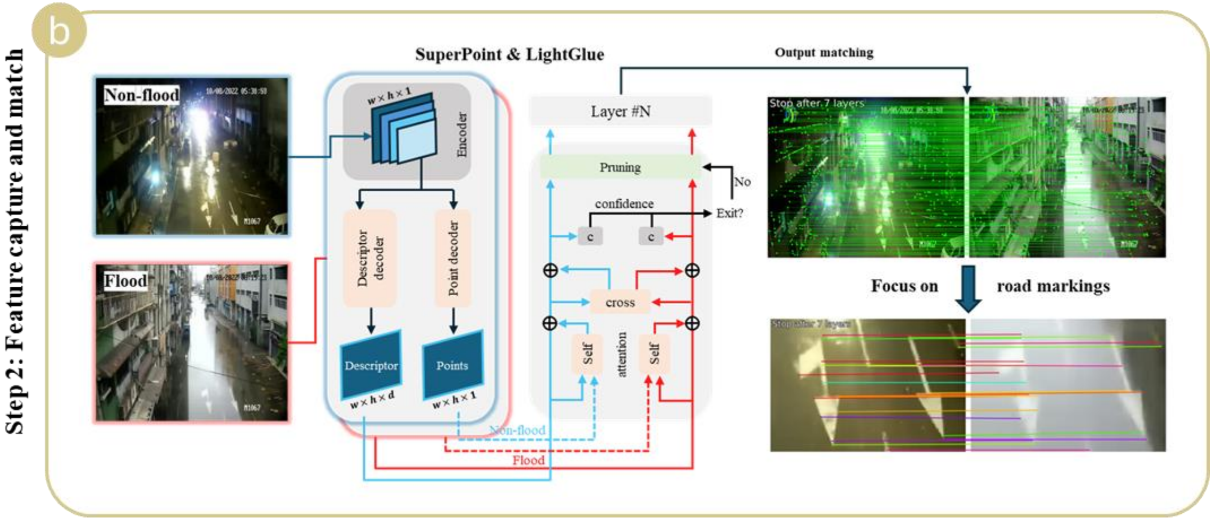


Figure 18. Workflow of the proposed methodology. (b) feature matching steps.

Transparent: Methodology

1 Methodology

- The water logging depth (WL) can be calculated based on the displacement of feature points.

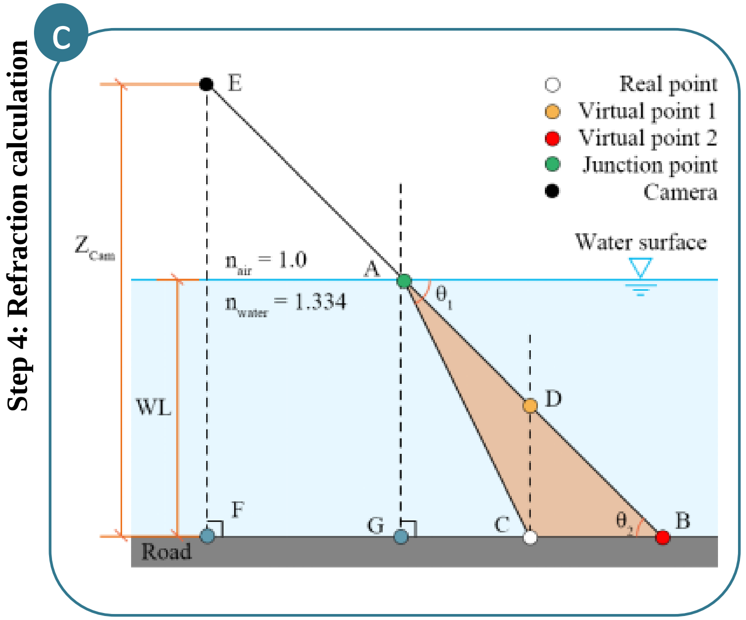


Figure 19. Workflow of the proposed methodology. (c) Schematic of the refraction-based waterlogging depth measurement method

$$X_B = \frac{[l \cdot \mathrm{sinp} \cdot (x_B \cdot \mathrm{sins} + y_B \cdot \mathrm{coss}) + l \cdot \mathrm{sint} \cdot \mathrm{cosp} \cdot (x_B \cdot \mathrm{coss} - y_B \cdot \mathrm{sins})]}{x_B \cdot \mathrm{cost} \cdot \mathrm{sins} + y_B \cdot \mathrm{cost} \cdot \mathrm{coss} + f \cdot \mathrm{sint}}$$

$$Y_B = \frac{[-l \cdot \mathrm{cosp} \cdot (x_B \cdot \mathrm{sins} + y_B \cdot \mathrm{coss}) + l \cdot \mathrm{sinp} \cdot \mathrm{sint} \cdot (x_B \cdot \mathrm{coss} - y_B \cdot \mathrm{sins})]}{x_B \cdot \mathrm{cost} \cdot \mathrm{sins} + y_B \cdot \mathrm{cost} \cdot \mathrm{coss} + f \cdot \mathrm{sint}}$$

$$X_C = \frac{[l \cdot \mathrm{sinp} \cdot (x_C \cdot \mathrm{sins} + y_C \cdot \mathrm{coss}) + l \cdot \mathrm{sint} \cdot \mathrm{cosp} \cdot (x_C \cdot \mathrm{coss} - y_C \cdot \mathrm{sins})]}{x_B \cdot \mathrm{cost} \cdot \mathrm{sins} + y_B \cdot \mathrm{cost} \cdot \mathrm{coss} + f \cdot \mathrm{sint}}$$

$$Y_C = \frac{[-l \cdot \mathrm{cosp} \cdot (x_C \cdot \mathrm{sins} + y_C \cdot \mathrm{coss}) + l \cdot \mathrm{sinp} \cdot \mathrm{sint} \cdot (x_C \cdot \mathrm{coss} - y_C \cdot \mathrm{sins})]}{x_B \cdot \mathrm{cost} \cdot \mathrm{sins} + y_B \cdot \mathrm{cost} \cdot \mathrm{coss} + f \cdot \mathrm{sint}}$$

$$X_{Cam} = l \cdot \mathrm{sinp} \cdot \mathrm{cost}$$

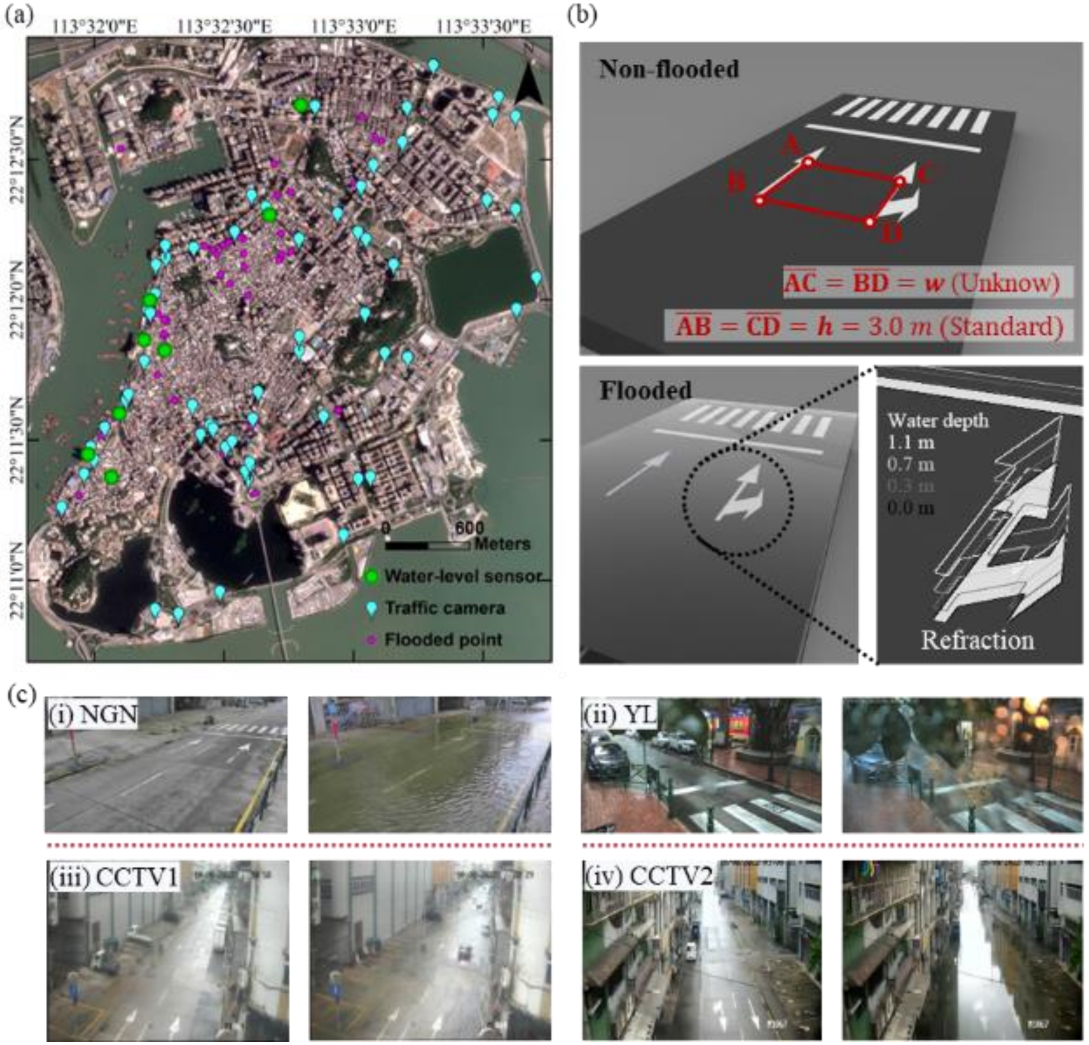
$$Y_{Cam} = -l \cdot \mathrm{cosp} \cdot \mathrm{cost}$$

$$Z_{Cam} = -l \cdot \mathrm{sint}$$

$$\boldsymbol{WL = F(s, t, p, l, f, x_B, y_B, x_c, y_C)}$$

Transparent: Materials

2 Applications



Region: Macao

Flood zone > water-level sensors

Mostly Clear waterlogging

Cases:

1 simulation scenario

4 real flood scenarios

Figure 20. Research region and corresponding camera images. (a) Macao peninsula. (b) Non-flooded and flooded images of the simulated road model. (c) Non-flooded and flooded images of real cameras at (i) the NGN station, (ii) the YL station, (iii) CCTV1, (iv) CCTV2.

Transparent: Results

1 Verification: camera with water-level sensor

- ➢ Proposed method is feasible in simulation and real scenarios.

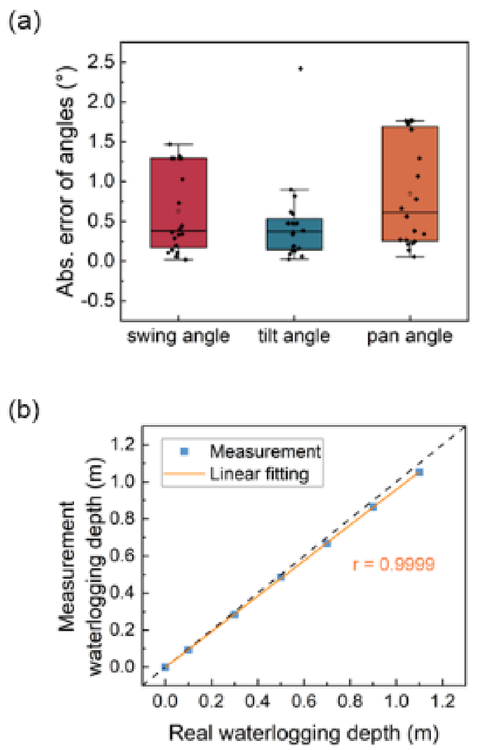


Figure 21. Results of the simulation scenario.

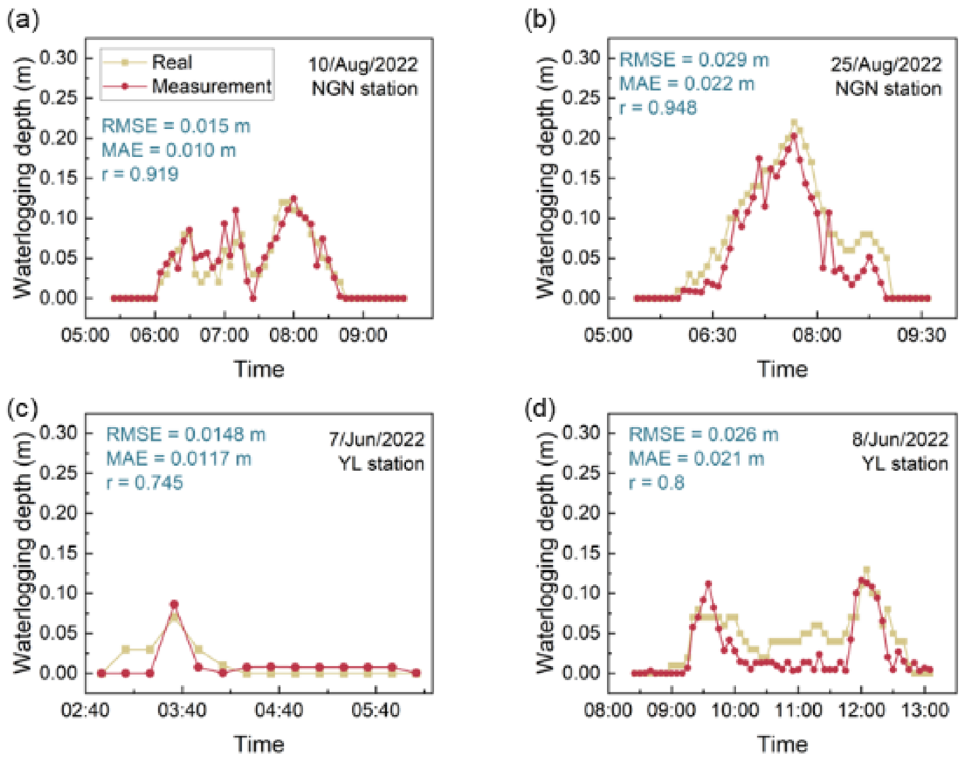


Figure 22. Results of traffic cameras with water-level sensors at the NGN station and YL station.

Transparent: Results

2 Application: camera without water-level sensor

- Manual determination flood periods are **highly overlap** with the algorithm-identified flood periods.

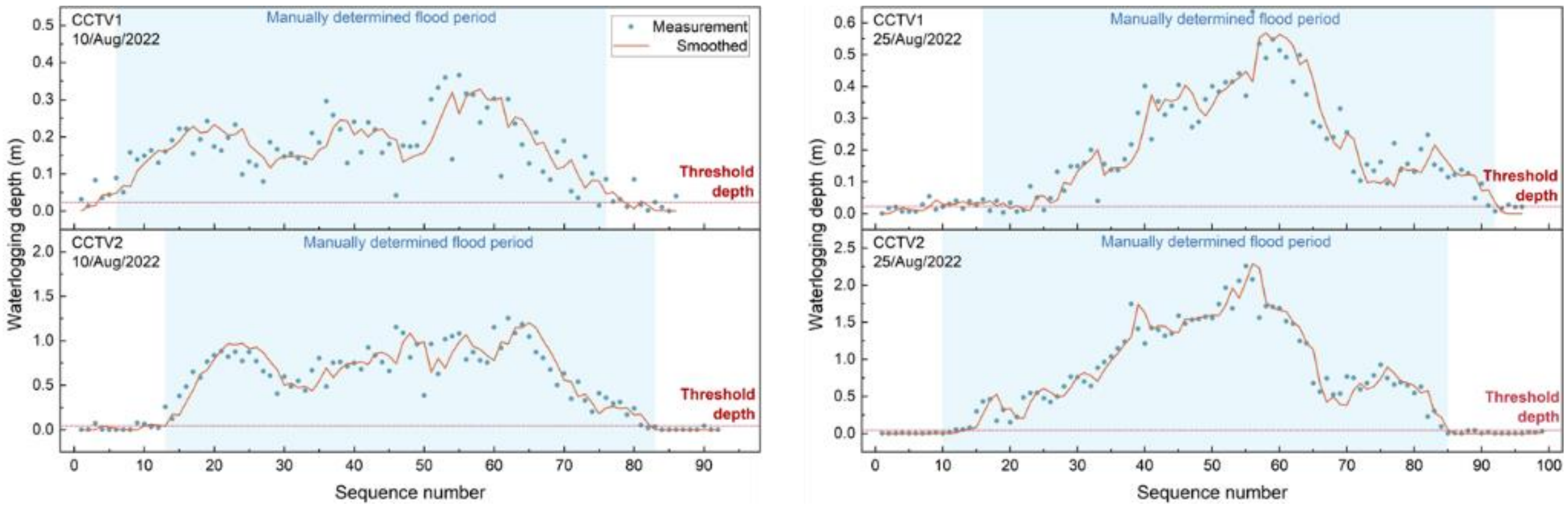


Figure 23. The waterlogging depth measurement results and analysis of traffic cameras without water-level sensors.

Summary

- Developed a flood monitoring system for both turbid and transparent water.
- Requires only traffic images with standard road markings, minimizing labor costs.
- Enables flexible turbidity measurement, broadening application scope.

Finally, the scalable and lightweight urban flood monitoring solution is built!

Thank you very much.

Research Gate