Multi-Task Classification of Sewer Pipe Defects and Properties using a Cross-Task Graph Neural Network Decoder

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Introduction

- The **sewerage** infrastructure is essential in modern societies.
- Primarily focus on the important **sewer defect classification** task.
- Little research on pipe material, shape, or water level classification.
- All tasks are needed for determining sewer pipe deterioration.
- The **CT-GNN Decoder** is a **multi-task classification** network for simultaneously inferring all four tasks.
- A Graph Neural Network (GNN) refines the per-class embeddings through the cross-task relationships encoded in an adjacency matrix.
- We investigate using Graph Convolutional Networks (GCN) and Graph Attention Networks (GAT).

Adjacency Matrix

- Graphs are represented using an adjacency matrix.
- Adjacency matrices can be dynamically inferred or given a priori.
- We determine the adjacency matrix based on conditional probabilities of classes in each pair of tasks.
- The adjacency matrix is thresholded at τ and re-weighted with p.
- The final weighted and directed adjacency matrix is denoted $\mathcal{A}$.

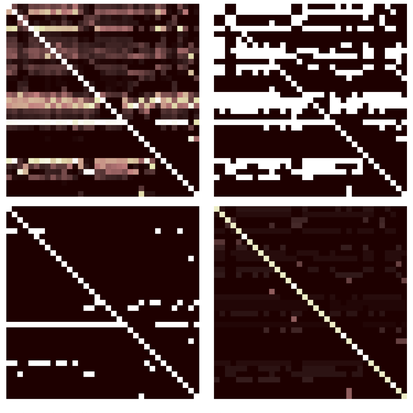

Fig. 1: Conditional probability matrix, binary adjacency matrices for $\tau = 0.05$ and $\tau = 0.65$, and the re-weighted adjacency matrix for $\tau = 0.05$ and $p = 0.2$, for the Sewer-ML dataset.

Cross-Task Graph Neural Network (CT-GNN) Decoder

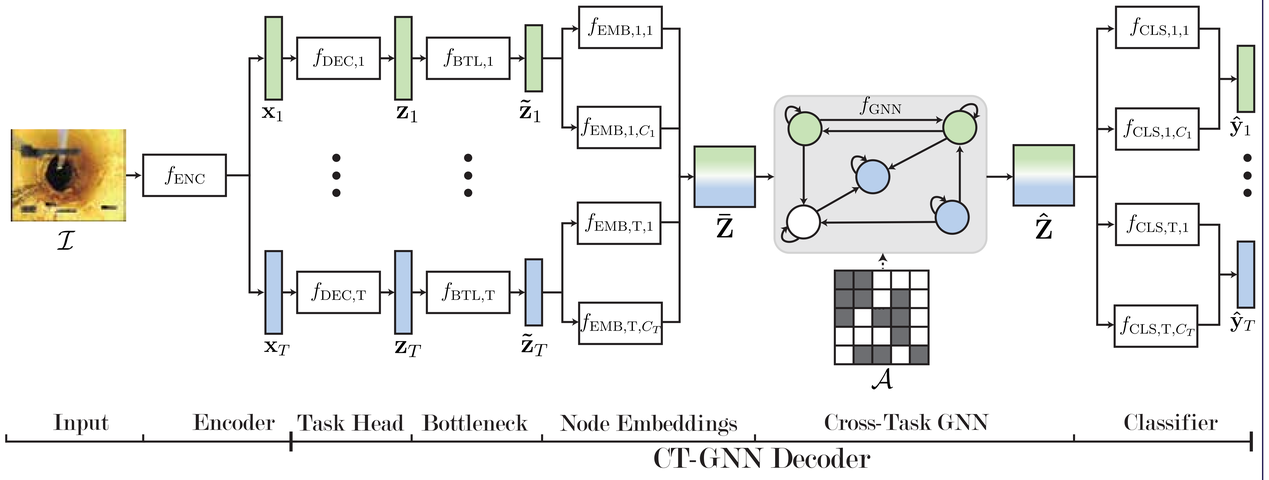

Fig. 2: Model overview of the Cross-Task Graph Neural Network (CT-GNN) Decoder. The CT-GNN refines the class features based on dynamically or a priori defined class relationships.

Results

Table 1: Performance on Sewer-ML with a ResNet-50 encoder.

	Model		Overall	Defect		Water	Shape	Material
	Model	#P (M)	Δ_{MTL}	$F2_{CIW}$	$F1_{Normal}$	MF1	MF1	MF1
Validation Split	Benchmark [1]	62.8	-	55.36	91.32	-	-	-
	R50-FT [2]	23.5	-	-	-	62.53	-	-
	STL	94.0	+0.00	58.42	**92.42**	69.11	46.55	65.99
	R50-MTL	23.5	+10.36	59.73	91.87	70.51	71.64	80.28
	MTAN [3]	48.2	+10.40	61.21	92.10	70.06	68.34	83.48
	CT-GCN	25.2	+12.39	61.35	91.84	**70.57**	**76.17**	82.63
	CT-GAT	24.0	**+12.81**	**61.70**	91.94	**70.57**	74.53	**86.63**
Test Split	Benchmark [1]	62.8	-	55.11	90.94	-	-	-
	R50-FT [2]	23.5	-	-	-	62.88	-	-
	STL	94.0	+0.00	57.48	**92.16**	69.87	56.15	69.02
	R50-MTL	23.5	+7.39	58.29	91.57	71.17	79.48	**76.35**
	MTAN [3]	48.2	+6.83	59.91	91.72	70.61	78.50	72.73
	CT-GCN	25.2	+7.64	60.07	91.60	70.69	80.32	75.13
	CT-GAT	24.0	**+7.84**	**60.57**	91.61	**71.30**	**81.10**	73.95

Defect Task: In-Depth

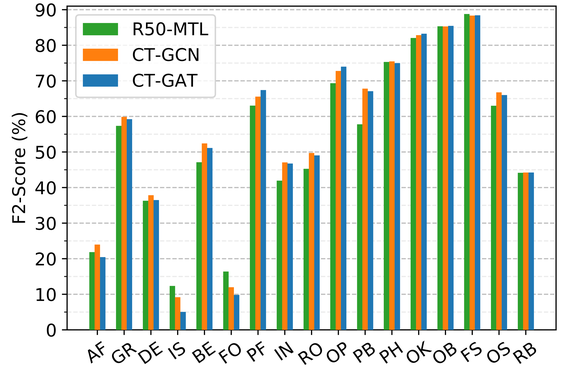

Table 2: Per-class performance on the defect task. Classes are sorted in ascending order according to their Class-Importance Weight (CIW).

Contributions

- The CT-GNN Decoder, a novel **graph-based decoder-focused** multi-task classification network.
- The **first** multi-task classification network for classifying sewer pipe defects and properties.
- A **data-driven** construction of the cross-task graph adjacency matrix.
- State-of-the-Art performance on **all four classification tasks** in the Sewer-ML dataset.

Qualitative Examples

Task	Ground Truth	R50-MTL	CT-GNN
Defect	FS, RO	FS	FS, RO
Water	[0%,5%)	[0%,5%)	[0%,5%)
Shape	Circular	Circular	Circular
Material	VC	VC	VC

Task	Ground Truth	R50-MTL	CT-GNN
Defect	OB, FS	FS	OB, FS
Water	[0%,5%)	[0%,5%)	[0%,5%)
Shape	Circular	Circular	Circular
Material	Conc.	VC	Conc.

Project Page

www.vap.aau.dk/ctgnn

References

[1] J. B. Haurum & T. B. Moeslund, *Sewer-ML: A Multi-Label Sewer Defect Classification Dataset and Benchmark*, CVPR 2021
[2] J. B. Haurum, M. Pedersen, C. H. Bahnsen & T. B. Moeslund, *Water Level Estimation in Sewer Pipes using Deep Convolutional Neural Networks*," Water 2021
[3] S. Liu, E. Johns & A. J. Davison, *End-to-End Multi-Task Learning with Attention*," CVPR 2019