Scalable Location Prediction of Miners using Hierarchical Temporal Graph Attention Model in Underground Mine

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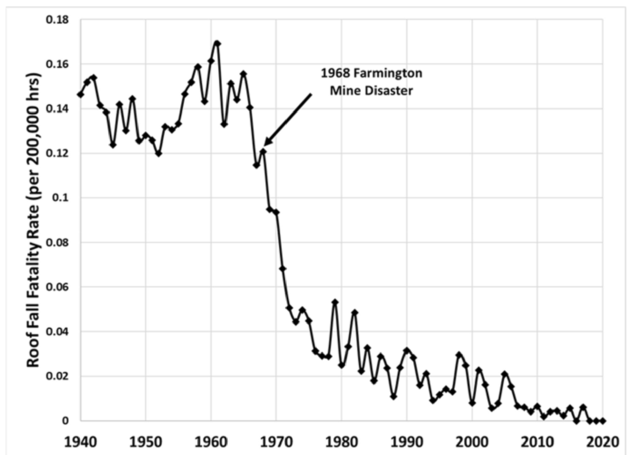
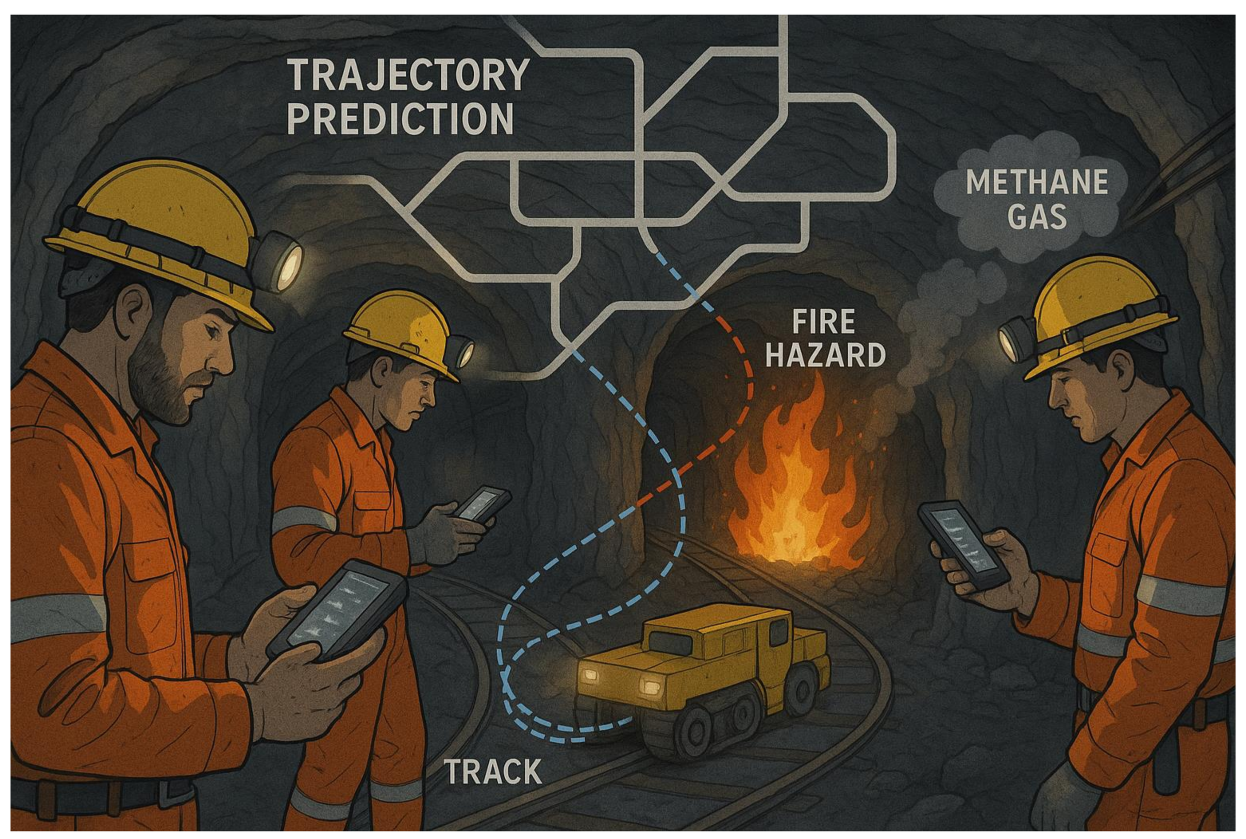
Motivation

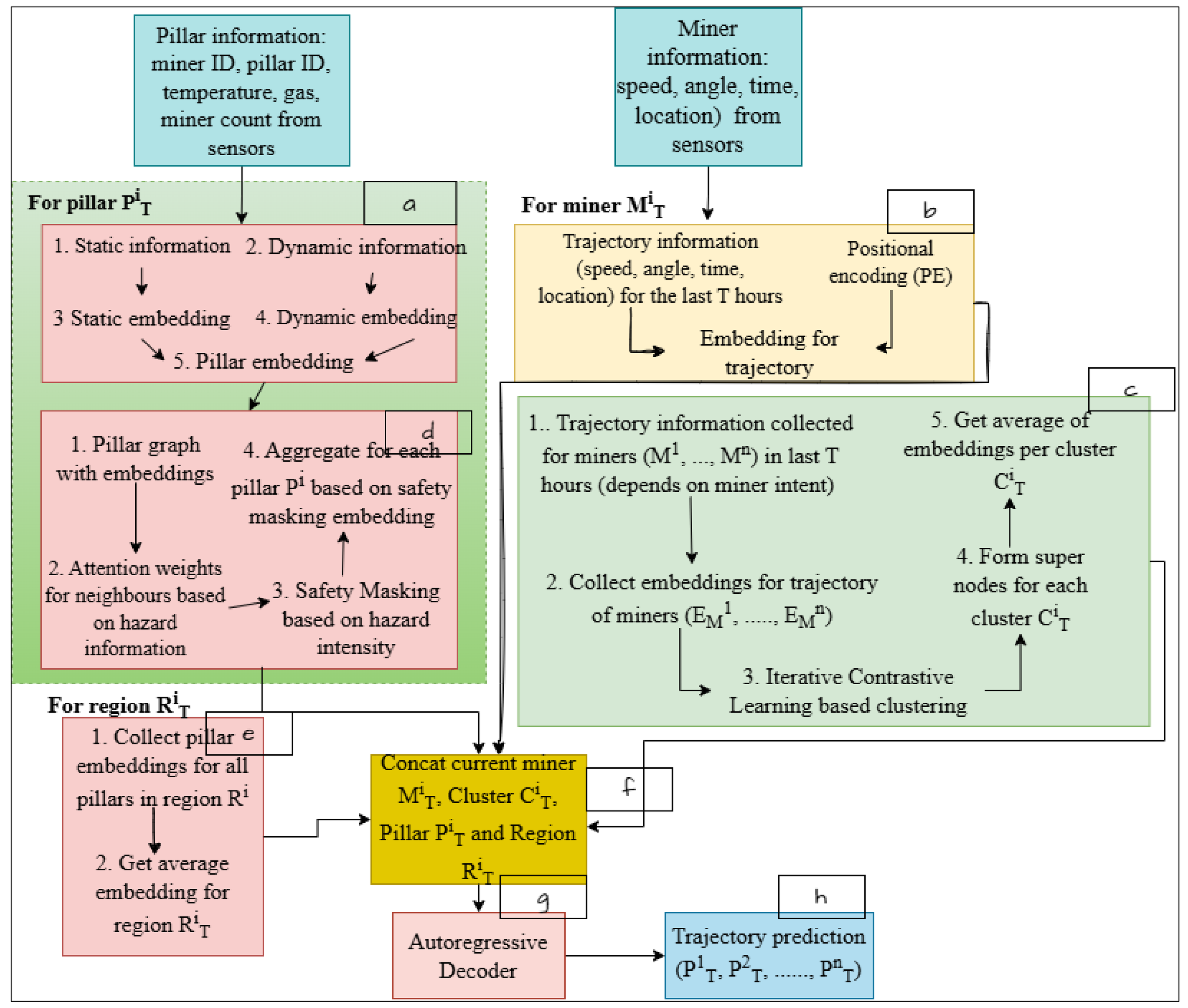


- Sago mine disaster[1], 6 died despite efforts, decentralized communication for scalable location prediction
- Situational awareness for navigating miner to safety
- Scalable trajectory prediction

Challenges & Objectives



- Challenge 1- LOS communication needed
- Challenge 2- No GPS signal
- Challenge 3- Low battery power devices
- Centralized to decentralized, collect data using DTNs[2] for robust communication in disasters [3]
- Leverage sensed information for prediction
- Pillars for localization, no need for GPS
- Trajectory prediction crucial for navigating miners to safety in evolving disasters



a. Pillar information (static + dynamic)
b. Miner trajectory embedding
c. Iterative contrastive mobility clustering
d. Temporal hazard-based attention
e. Region attention information
f. Concatenate embeddings
g. Autoregressive decoder
h. Trajectory prediction

- Combine static information (IDs, location of pillar w.r.t. mine etc) and dynamic information (miner count, hazard kind, hazard intensity etc).
- Using neighbouring pillars hazard and embedding, calculate attention scores for each neighboring pillar based on intensity. M_{safe} masking for serious hazards low intensity hazards for example low intensity toxic gases

$$\alpha_{vu} = \mathrm{softmax}(a^T \mathrm{LeakyRelu}(W[h_v \oplus h_u \oplus \phi(t_v)]) - \lambda hazard_u)$$

- Region information used to guide miners on high granularity, hierarchical information used to predict trajectory

$$h_v^{agg} = \sum_{u \in \mathcal{N}(v)} \alpha_{vu} \cdot h_u \odot M_{\text{safe}}$$

$$M_{safe}[u] = \begin{cases} 1, & \text{if hazard}_u \leq 0.7 \\ 0, & \text{otherwise} \end{cases}$$

$$h_r = \frac{1}{|V_r|} \sum_{v \in V_r} h_v^{agg}$$

- Miner trajectory information, from sensors (speed, angle, time, location), embed each component and concatenate to get miner trajectory embedding, location based on pillars
- Iterative contrastive learning (CL) for cluster embeddings, negative pairs are contrasted for clustering -> supernodes.

- Supernodes, similar miners mobility together
- Four components concatenated for miner trajectory (trajectory, pillar, region, cluster)
- Loss combines all 4 components

$$\mathcal{L}_{traj} = -\sum_{t=1}^{T} \log P(v_{true}^t | v_{true}^1, \cdots, v_{true}^{t-1})$$

$$\mathcal{L}_{pillar} = \sum_{t=1}^{T} \sum_{v} hazard_v \mathbb{I}(v = v_t^{pred})$$

$$\mathcal{L}_{region} = \sum_{r} ||h_r - AvgPool(h_v^{agg})||^2$$

$$\mathcal{L}_{cluster} = \sum_{m \in S_k} ||Z_m - h_{S_k}||^2$$

$$\mathcal{L} = \lambda_1 \mathcal{L}_{traj} + \lambda_2 \mathcal{L}_{pillar} + \lambda_3 \mathcal{L}_{region} + \lambda_4 \mathcal{L}_{cluster}$$

- Autoregressive decoder for location prediction
- Trajectory for next time horizon (t+1)

Future work & Conclusion

- Scalable trajectory prediction to guide miners to safety
- Spatial-temporal hazard attention method, pillar & region based
- Attention based on intensity, masking for hazard, hierarchical model
- Iterative CL clustering giving supernodes based on trajectory, scalability

References

[1] https://blog.dol.gov/2023/01/18/the-legacy-of-the-sago-and-aracoma-mine-disasters
[2] https://www.msha.gov/miner-act
[3] Abhay Goyal, Sanjay Madria, and Samuel Frimpong. 2022. MinerFinder: a GAE-LSTM method for predicting location of miners in underground mines. In Proceedings of the 30th International Conference on Advances in Geographic Information Systems (SIGSPATIAL '22). Association for Computing Machinery, New York, NY, USA,