Multi-Modal Prompt Learning for Hydrogen Storage Composite Inspection

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Abstract: High-pressure hydrogen storage relies on composite overwrapped pressure vessels with zero tolerance for missed defects. Filament winding introduces variations in tension, fiber angle, and stage transitions that yield subtle, evolving flaws beyond conventional inline inspection. We propose Multi-Modal Prompt Learning (MMPL), a language-guided inspection framework that jointly learns coupled prompts in the vision and language branches to enforce tight cross-modal alignment and avoid uni-modal shortcuts. MMPL also injects stage-specific prompts into early backbone layers to encode winding context (tow placement, tension/angle, texture, layup history). The system enables open-vocabulary, text-driven defect detection (gaps, overlaps, fuzz, broken tows, resin-rich regions) from inline RGB imagery, supports free-form operator queries, and generalizes to unseen conditions without retraining. We release a filament-winding dataset with synchronized RGB frames and natural-language descriptions and define open-vocabulary and phrase-grounded evaluation protocols. Across these settings, MMPL improves alignment and localization over single-branch or decoupled baselines while integrating seamlessly with existing QA workflows providing an explainable, automation-ready capability for safer hydrogen storage.

References

[1] Tunukovic, V., McKnight, S., Hifi, A., Mohseni, E., Pierce, S. G., Vithanage, R. K., ... & O'Hare, T. (2025). Human-machine collaborative automation strategies for ultrasonic phased array data analysis of carbon fibre reinforced plastics. NDT & E International, 154, 103392.
[2] Gu, Z., Zhu, B., Zhu, G., Chen, Y., Tang, M., & Wang, J. (2024, March). Anomalygpt: Detecting industrial anomalies using large vision-language models. In Proceedings of the AAAI conference on artificial intelligence (Vol. 38, No. 3, pp. 1932-1940).

Figures

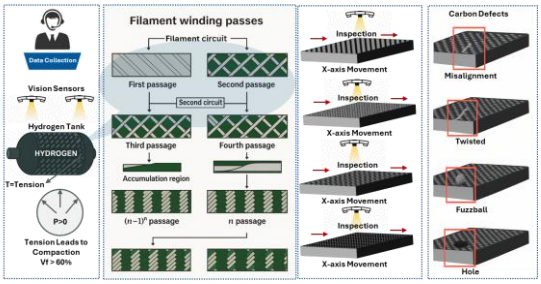

Figure 1: Data collection process during filament winding process.

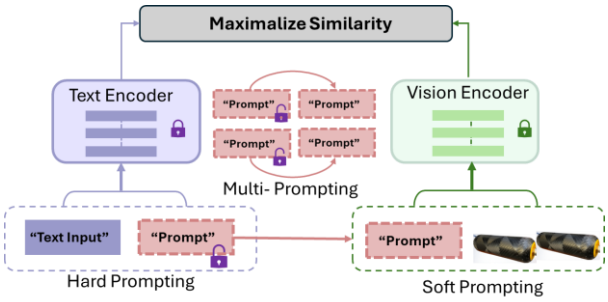

Figure 2: Multi-prompt learning framework for the inspection of carbon fiber in hydrogen tanks manufacturing process.