中文題目: 將無人機與AI影像辨識應用在橋樑檢測

英文題目: UAV and AI image recognition application in bridge inspection

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可行性：

1. 無人機的優勢

- **高效性與靈活性**：無人機能夠快速、靈活地飛行，並且可在各種天氣條件下運行，適合進行大範圍的檢查，特別是在地面無法輕易到達的地方。
- **降低人員風險**：傳統的橋樑檢測可能需要攀爬、吊掛等危險操作，而無人機能夠在無需派遣人員進入危險區域的情況下進行檢測。
- **即時數據回傳**：無人機可配備高清攝像頭、紅外線攝影機或激光掃描儀等設備，並且能夠實時將影像或數據回傳至地面，便於及時分析。

2. AI 影像辨識的優勢

- **高精度檢測**：AI 影像辨識技術（如深度學習、計算機視覺等）可以準確識別出橋樑表面的裂縫、腐蝕、磨損、結構損壞等問題，並根據圖像特徵進行自動標註和分析。
- **大數據分析與預測**：AI 可以對大量的歷史檢測數據進行學習，進而預測橋樑的未來狀況，幫助管理者做出更科學的維修和養護決策。
- **減少人工錯誤**：傳統檢測方法依賴人工目視檢查，容易受到疲勞或疏忽的影響，AI 則可以在持續運行下保持高精度，並且能夠處理大量數據，從中發現微小的異常。

3. 具體應用場景

- **橋樑結構的定期檢查**：無人機可以定期對橋樑進行全方位檢查，AI 影像辨識可以自動檢測出結構性損壞或劣化，並給出具體的損壞部位與嚴重

程度，供維修人員參考。

- **高危區域檢查**：對於一些設計較為特殊或處於難以接近的橋樑（如高架橋、懸索橋等），無人機可以進行更為全面的檢測，尤其是那些無法用傳統設備完成的檢查任務。
- **災後損害評估**：在地震、颱風、洪水等自然災害後，無人機能夠快速對橋樑進行檢查，AI 影像辨識技術可以及時識別出損壞區域，協助快速決策。

4. 技術挑戰與應對

- **數據質量與處理**：影像質量會受限於無人機的拍攝設備和飛行條件。對此，可以選擇高解析度相機，並通過多角度拍攝和低空飛行來提高影像質量。
- **AI 模型的訓練與準確性**：AI 影像辨識模型需要大量標註數據來訓練，這可能需要專業技術人員進行數據標註與模型優化。隨著數據量的增長，AI 的準確性和識別能力會逐步提高。
- **飛行管制與安全問題**：無人機在飛行過程中可能會遇到禁飛區、天氣限制、電池壽命等問題。為解決這些問題，需要有合適的飛行計劃與電池管理系統，並確保飛行過程中的安全。

5. 未來發展方向

- **無人機與 AI 技術的融合**：隨著無人機和 AI 技術的持續進步，未來可能會有更多專門為橋樑檢測設計的無人機與 AI 系統，這些系統將更加智能化、精確和高效。
- **自動化檢測流程**：未來，無人機和 AI 的結合可能實現完全自動化的檢測流程，從無人機拍攝、數據處理到報告生成都能實現無人化操作，進一步提升檢測的速度和精度。
- **多傳感器融合技術**：無人機可以搭載多種感測器（如雷達、紅外、激光掃描等），進行綜合性檢測，AI 則負責綜合數據分析，提升檢測結果的準確性和可靠性。

結論

無人機搭配 AI 影像辨識技術在橋樑檢測中的應用具有很大的可行性，不僅能提高檢測效率，減少人員風險，還能提升檢測精度，及時發現結構問題並提供預警。

隨著技術的進步，這種智能檢測系統將在橋樑維護與管理中發揮越來越重要的作用。

一、問題描述

1.傳統檢測方法的局限性

- 觀性問題：目視檢測依賴檢測人員的專業經驗，可能導致主觀判斷偏差。不同檢測人員的結果差異較大。
- 環境影響：傳統方法（如吊掛檢測、橡皮艇作業等）容易受到天候和現場條件的限制。 效率與成本：傳統方法作業時間長，成本高，且存在安全風險。

2.數據處理的挑戰

- 資料清洗問題：橋梁管理系統中的影像資料可能存在錯置、標註不一致、重複或誤差等問題，導致模型訓練數據質量不足。
- 影像質量問題：植被遮蔽、背光拍攝、主體全黑或非橋梁相關影像等因素，影響檢測準確度。

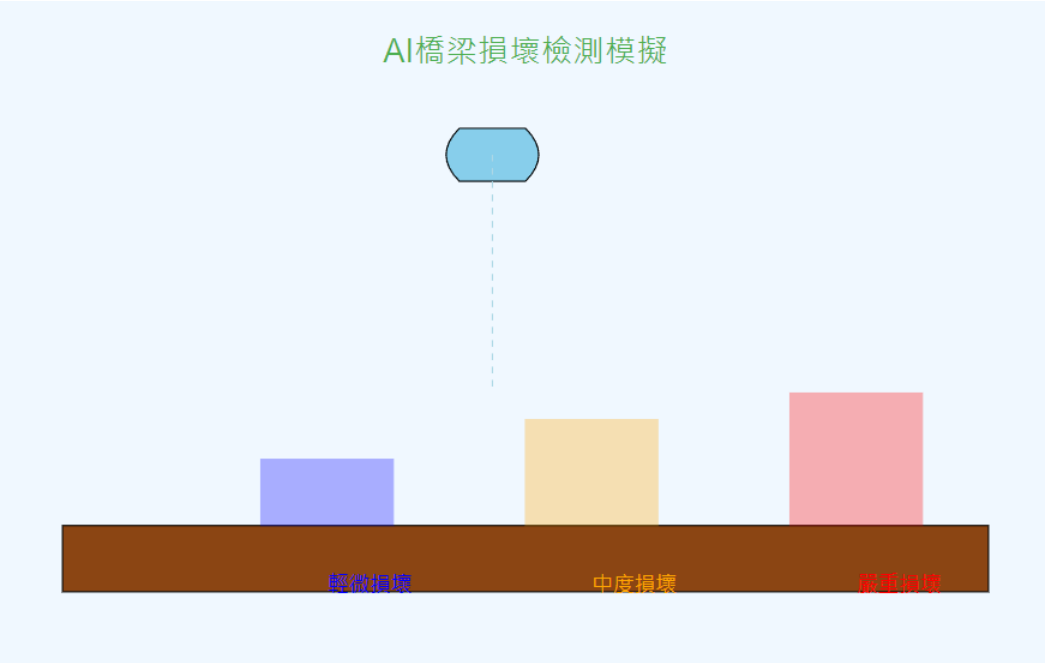
3.技術難點

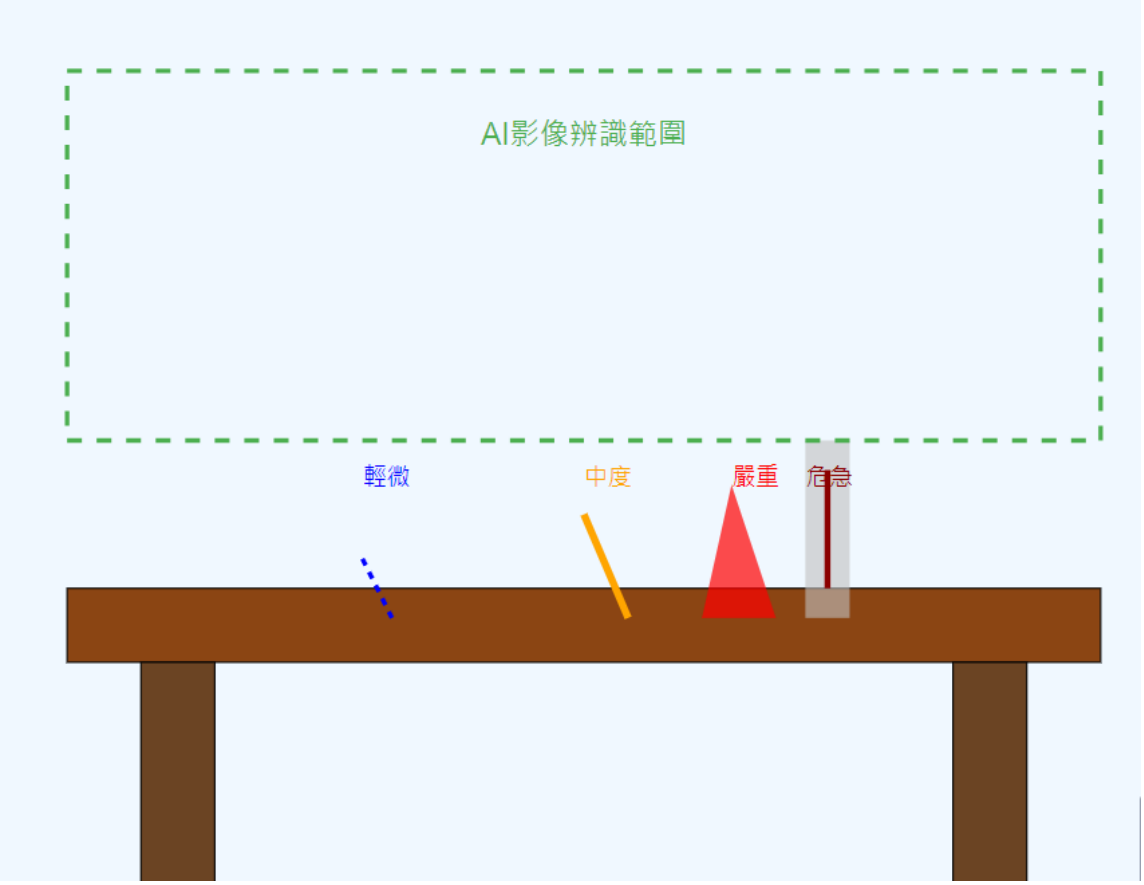
- 無人機導航與定位：橋下環境缺乏GPS信號，無人機定位與飛行控制面臨挑戰。
- AI模型精度與適用性：深度學習模型需在多種橋梁構件和不同劣化類型上保持高準確率，且模型推估的結果需與實際劣化情況吻合。
- 影像處理與整合：需要將無人機拍攝的高解析度影像與3D模型有效結合，用於量化劣化程度。

4.制度與應用推廣的限制

- 現有橋梁檢測規範和操作流程可能不完全適應新技術的應用，需進行調整。
- 技術普及和推廣需要解決資金、政策和技術標準化等問題。

二、解決方案提案：





1.傳統檢測方法局限性的解決方案

使用無人機取代人力檢測

- 目標：解決傳統檢測中人工操作耗時、危險性高、主觀性強的問題。
- 方法：透過無人機（UAV）進行高空或難以接近的橋梁部位的檢測。無人機拍攝影像涵蓋橋梁主梁、橋墩、橫隔梁等構件，能快速收集大量影像數據，取代人工目視檢測。
- 效果：無人機搭載高解析度相機，能在不同角度取得精細影像，大幅降低人員安全風險及檢測時間。

結合AI影像辨識技術提升檢測效率

- 目標：降低主觀判斷帶來的偏差，提高檢測準確性和效率。
- 方法：使用AI影像辨識技術，將無人機拍攝的影像進行深度學習模型分

析，辨識劣化區域，如裂縫、剝落、滲水等損傷。這樣可以實現自動化檢測，避免因人員判斷差異而帶來的誤差。

- 效果：AI模型可以標準化檢測結果，提升檢測的一致性。自動化辨識功能讓檢測結果更準確、可重複，減少了人工成本和偏差。

2.數據處理挑戰的解決方案

建立數據清洗流程

- 目標：解決橋梁管理系統中數據質量不佳的問題，提升模型訓練數據的準確性。
- 方法：設計TBMS2（Taiwan Bridge Management System 2）數據清洗流程，去除錯誤、標註不一致、重複的資料，並針對無效影像（如背景過暗或植被遮蔽）進行篩選與校正。
- 效果：保證訓練數據的高質量，讓AI模型的訓練過程更有效率，進一步提高影像辨識的準確性。

改善影像質量

- 目標：解決植被遮蔽、背光等影響影像品質的問題。
- 方法：設計無人機的照相補光系統，增加光源以減少陰影或反光問題，確保影像的清晰度和完整度。針對遮蔽部分，使用不同的飛行角度和距離進行多角度拍攝，避免因單一視角遮蔽劣化區域。
- 效果：確保影像清晰度，提升後續AI辨識的準確性，讓損傷部位顯示更明確。

3.技術難點的解決方案

提升無人機導航技術以適應橋梁下環境

- 目標：解決橋下無GPS信號時無人機的定位難題。
- 方法：結合視覺感測（VIO）、慣性導航（IMU）和超寬頻定位技術（UWB），實現無人機在橋梁下方或無信號環境下的精準定位。這樣可以讓無人機在橋下環境中自主飛行，避免碰撞或偏移。
- 效果：提升無人機導航與定位精度，讓其能在複雜的橋梁環境中自主完成檢測，避免了人工操控的局限。

提高深度學習模型的辨識精度

- 目標：讓AI模型能準確辨識各種劣化類型。
- 方法：採用多階段模型訓練流程，先使用預訓練模型進行基本辨識，再針對橋梁劣化特徵進行專項微調，提升AI模型在裂縫、剝落等細微損傷的辨識精度。同時，利用多層次數據增強技術，如CutMix，模擬不同損傷情境，提高模型的泛化能力。
- 效果：提高AI模型的準確度和穩定性，使其能適應不同橋梁類型和劣化特徵，準確判定劣化區域。

建立3D建模結合影像辨識系統

- 目標：有效整合無人機影像與橋梁3D模型，量化劣化區域。
- 方法：基於無人機拍攝的影像，建置橋梁3D模型，並透過AI辨識的劣化結果與3D模型匹配，生成劣化區域的2D/3D向量資料（如Shapefile或OBJ）。該資料可提供劣化位置、面積及損傷大小，並與橋梁結構尺寸進行比對，從而準確計算DERU（劣化程度、影響範圍、影響性、急迫性）指標。
- 效果：能以3D視角呈現損傷部位，輔助橋梁檢測人員直觀地判斷劣化情況，進一步量化損傷數據，提高養護決策的準確性。

4.制度與推廣挑戰的解決方案

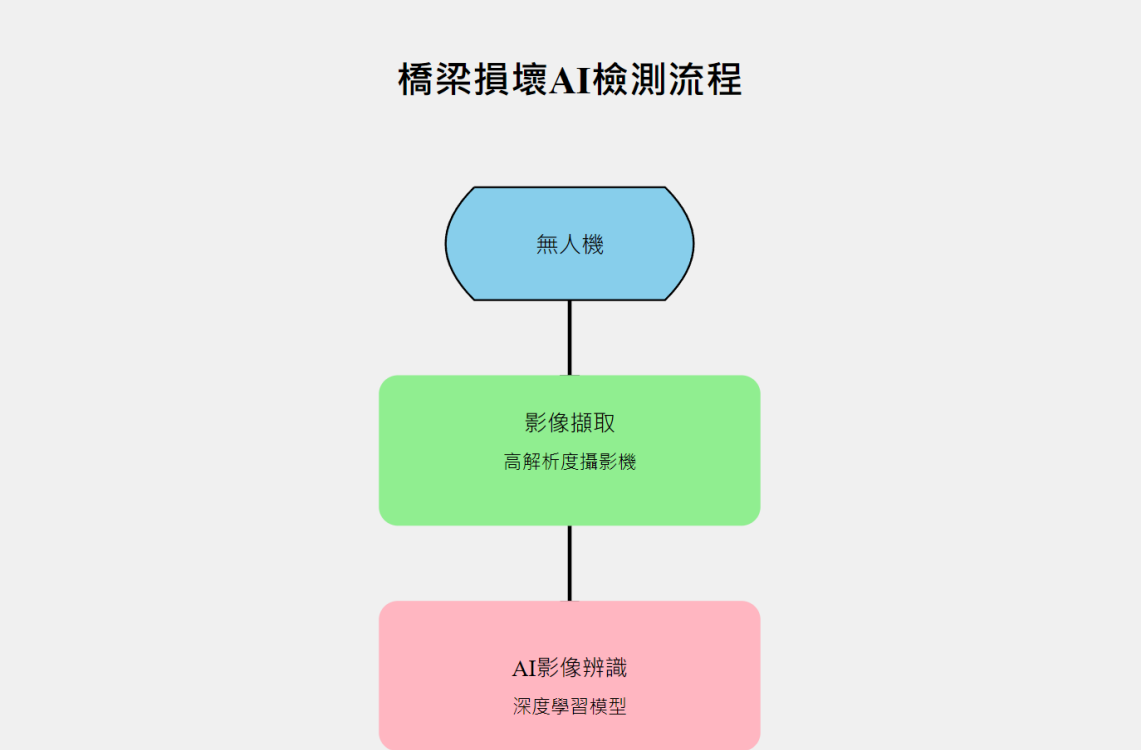
制定無人機檢測技術的標準化流程

- 目標：讓無人機與AI技術能無縫融入現有的橋梁檢測流程。
- 方法：依據交通部制定的「公路橋梁檢測及補強規範」，訂立無人機拍攝標準，包括拍攝角度、影像解析度、亮度、構件識別等具體指標。並開發自動飛行與拍攝路徑，使無人機依照標準流程運行，實現檢測數據的標準化和規範化。
- 效果：讓無人機檢測成為標準化檢測流程的一部分，使得新技術能夠被橋梁管理機關廣泛採用。

加強技術推廣與普及

- 目標：加快無人機搭配AI影像辨識技術的應用普及。
- 方法：透過技術發表會、研討會、技術轉移和技術專利等方式推廣。並對公路管理單位、維修單位進行技術培訓，讓更多人了解並掌握無人機檢測和AI辨識技術。
- 效果：推廣技術應用，讓橋梁管理機關和施工單位更快接納此新技術，促進橋梁檢測的數位化、智能化轉型。 這些解決方案針對各方面的挑戰進行了全面考量，從技術開發、標準流程建立、數據品質提升等方面全方位提高橋梁檢測的準確性和效率，減少檢測過程中的人為干擾，讓無人機與AI技術成為有效的檢測手段。

三、如何使用生成式人工智慧解決選定的問題：



1.改善數據質量與增強影像資料

生成合成影像數據

- 目標：在資料有限或品質欠佳時，生成式AI可以創造出大量擬真影像，模擬橋梁的不同劣化狀況，補充訓練數據。
- 方法：使用生成對抗網絡（GANs）或擴散模型，根據已有影像生成劣化情境的擬真圖像，例如不同程度的裂縫、剝落和滲水等劣化影像。這些生成影像可以標註相應的劣化類型和範圍，作為訓練資料來增強AI模型。
- 效果：生成式AI生成的數據能豐富訓練數據庫，改善AI模型對劣化特徵的識別能力，使模型適應更多樣的情境，提升辨識準確率，並減少因數據質量不足而帶來的準確性問題。

增強影像品質

- 目標：解決因拍攝環境問題導致的影像質量下降。
- 方法：生成式AI可以修復影像中的模糊、背光、陰影或對比不足的部分。使用超分辨率技術將低解析度影像放大、強化，並增強影像的清晰度。

同時，可以應用去噪和亮度增強技術，使橋梁構件劣化特徵更加明顯。

- 效果：提高影像清晰度，有助於AI模型更精確地辨識出裂縫、滲水等劣化特徵，使後續檢測結果更可靠。

2.提升AI影像辨識模型的準確性

生成多樣化訓練樣本

- 目標：使AI模型能在多樣化情境中準確辨識橋梁劣化。
- 方法：生成式AI可以擴充原始訓練資料的多樣性。例如，生成不同視角、光線條件、橋梁材料和損傷程度的影像，模擬現實中無人機可能遇到的各種情況，強化模型的泛化能力。
- 效果：生成的多樣化資料使AI模型更具適應性，有助於在實際橋梁檢測中應對不同情境下的劣化識別。

使用生成式AI進行模型調優與增強

- 目標：優化影像辨識模型在橋梁劣化檢測的準確度。
- 方法：通過生成式AI生成的資料進行數據增強，並使用生成的合成影像進行模型預訓練。此方法可以讓模型提取到更具代表性的特徵。在模型開發過程中，使用生成式AI模擬實際場景，讓模型在有更多樣化數據的情況下訓練和測試。
- 效果：生成式AI輔助的數據增強可以提升模型的辨識效果，使其更準確地判定裂縫、剝落等損傷類型，並提高在橋梁結構多樣性中的應用效果。

3.支援無人機定位和導航

生成虛擬環境進行模擬訓練

- 目標：解決無GPS信號環境下無人機定位導航問題。
- 方法：使用生成式AI生成的虛擬橋梁3D模型和橋下環境，模擬無人機在橋下巡航、定位的情境。可以利用這些虛擬環境來模擬無人機的飛行行為和導航場景，為無人機模型提供視覺-慣性融合（VIO）的訓練數據。
- 效果：生成式AI創建的虛擬場景幫助無人機在真實環境中運行，提升其導航和避障能力，有助於在橋梁下方和GPS信號不穩定的區域穩定巡檢。

增強視覺導航模型

- 目標：提升無人機在複雜橋梁環境中的導航能力。
- 方法：生成式AI可以生成無人機在橋梁內部、外部的影像資料，以此訓練視覺導航模型。這些數據可以包括無人機巡航時的多視角橋梁影像，生成遮擋、光線變化等複雜場景，提升無人機的視覺導航算法。
- 效果：無人機的視覺導航模型可以更好地理解橋梁環境的結構，提高定位精度，並在無法依賴GPS的情況下進行精確巡檢。

4.加速標準化流程建立與應用推廣

協助建立標準化資料集

- 目標：為橋梁檢測的AI模型和無人機操作建立通用的標準流程。
- 方法：利用生成式AI構建標準化橋梁檢測影像數據庫，包含不同橋型、劣化狀況、光線等多種條件的合成影像，作為業界參考的標準數據集。這樣的數據集可以幫助不同機構統一模型訓練的基礎數據，促成標準化的AI檢測流程。
- 效果：讓無人機和AI檢測流程有標準可循，推動技術的行業應用，有助於減少實施過程中的數據質量不一致問題。

開發生成式AI支持的可視化工具

- 目標：通過直觀的可視化工具加速技術推廣。
- 方法：利用生成式AI開發可視化工具，比如將劣化部位和3D模型進行可視化重疊，讓用戶可以通過3D視角查看損傷部位，並用簡單的操作界面完成檢測報告。這些工具可以讓橋梁管理單位和檢測人員更直觀地理解AI檢測結果，提升使用便捷性。
- 效果：生成式AI支持的可視化工具促進技術應用，讓不同單位快速上手，進而擴大AI和無人機檢測技術的使用範圍。

總結

生成式AI可以通過增強數據質量、提升影像辨識準確度、支持無人機導航及標準化流程等多方面的應用，來解決橋梁檢測中的各項挑戰。通過生成影像、增強模型和優化導航，生成式AI能大大提高橋梁檢測的自動化、準確性和效率，並促進該技術在行業中的廣泛應用。

中文題目: 將無人機與AI影像辨識應用在橋樑檢測

英文題目: UAV and AI image recognition application in bridge inspection

專題成員：張浩語、許家誠

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Feasibility:

1. Advantages of Drones

- **Efficiency and Flexibility:** Drones can fly quickly and flexibly, operating under various weather conditions, suitable for large-scale inspections, especially in areas difficult to access on the ground.
- **Reduced Personnel Risk**: Traditional bridge inspections may require climbing

or hanging operations, while drones can perform inspections without sending personnel into dangerous areas.

- **Real-time Data Transmission**: Drones can be equipped with high-definition cameras, infrared cameras, or laser scanners, capable of transmitting images or data to the ground in real-time for immediate analysis.

2. Advantages of AI Image Recognition

- **High-Precision Detection**: AI image recognition technologies (such as deep learning, computer vision) can accurately identify surface issues like cracks, corrosion, wear, and structural damage on bridges, automatically annotating and analyzing image features.
- **Big Data Analysis and Prediction**: AI can learn from large amounts of historical inspection data, thereby predicting the future condition of bridges, helping managers make more scientific maintenance and repair decisions.
- **Reduction of Human Errors**: Traditional inspection methods rely on manual visual checks, which can be affected by fatigue or oversight. AI can maintain high precision during continuous operation and process large amounts of data to discover tiny anomalies.

3. Specific Application Scenarios

- **Periodic Bridge Structure Inspections**: Drones can perform comprehensive checks on bridges periodically. AI image recognition can automatically detect structural damage or deterioration, providing specific damage locations and severity for maintenance personnel.
- **High-Risk Area Inspections**: For bridges with special designs or difficult to approach (such as elevated or suspension bridges), drones can conduct more comprehensive inspections, especially for tasks that cannot be completed with traditional equipment.
- **Post-Disaster Damage Assessment**: After natural disasters like earthquakes,

typhoons, or floods, drones can quickly inspect bridges. AI image recognition can promptly identify damaged areas, assisting in rapid decision-making.

4. Technical Challenges and Responses

- **Data Quality and Processing**: Image quality can be limited by drone shooting equipment and flight conditions. To address this, high-resolution cameras can be selected, and image quality improved through multi-angle shooting and low-altitude flights.
- **AI Model Training and Accuracy**: AI image recognition models require large amounts of annotated data for training, which may need professional technicians for data annotation and model optimization. As data volume grows, AI accuracy and recognition capabilities will gradually improve.
- **Flight Control and Safety Issues**: Drones may encounter no-fly zones, weather restrictions, battery life issues during flight. To solve these problems, suitable flight plans and battery management systems are needed, ensuring flight safety.

5. Future Development Directions

- **Integration of Drone and AI Technologies**: With continuous advances in drone and AI technologies, more drones and AI systems specifically designed for bridge inspections may emerge, becoming more intelligent, precise, and efficient.
- **Automated Inspection Processes**: In the future, the combination of drones and AI might achieve fully automated inspection processes, from image capture to data processing and report generation, further improving inspection speed and precision.
- **Multi-Sensor Fusion Technology**: Drones can be equipped with multiple sensors (such as radar, infrared, laser scanning), conducting comprehensive inspections, with AI responsible for integrated data analysis, enhancing the

accuracy and reliability of inspection results.

Conclusion

The application of drones with AI image recognition in bridge inspections is highly feasible. It not only improves inspection efficiency and reduces personnel risks but also enhances inspection precision, enabling timely detection of structural issues and providing early warnings. With technological advancement, these intelligent inspection systems will play an increasingly important role in bridge maintenance and management.

I. Problem Description

1. Limitations of Traditional Inspection Methods

- Subjectivity Issues: Visual inspections rely on inspectors' professional experience, potentially leading to subjective judgment bias. Results can vary significantly between different inspectors.
- Environmental Constraints: Traditional methods (such as suspended inspections or rubber boat operations) are easily affected by weather and on-site conditions. · Efficiency and Cost: Traditional methods are time-consuming, expensive, and involve safety risks.

2. Data Processing Challenges

- Data Cleaning Issues: Image data in bridge management systems may have

problems such as misplacement, inconsistent annotations, duplications, or errors, resulting in insufficient model training data quality.

- Image Quality Problems: Factors like vegetation obstruction, backlighting, completely dark subjects, or non-bridge-related images can affect detection accuracy.

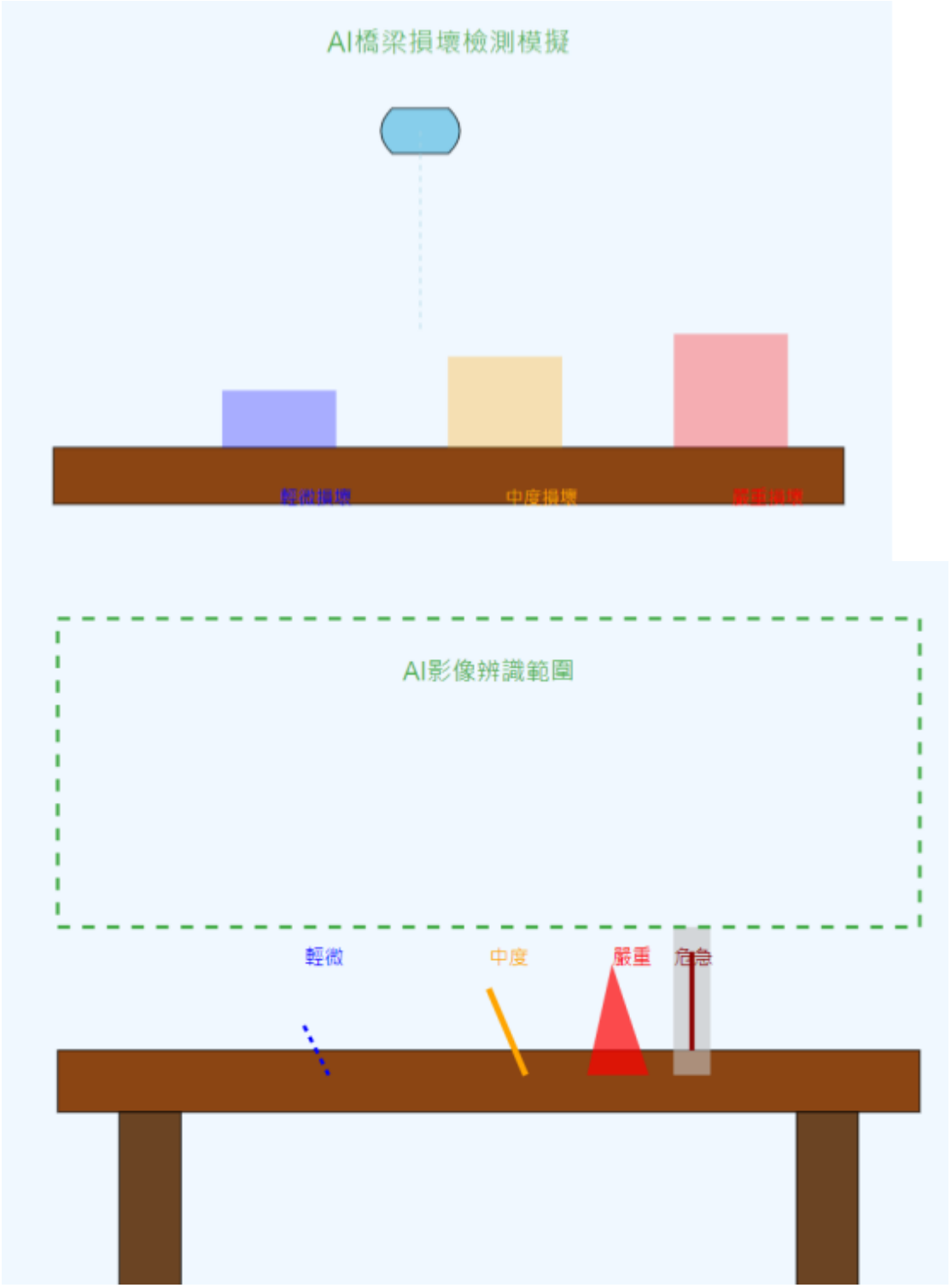
3. Technical Difficulties

- Drone Navigation and Positioning: Lack of GPS signals underneath bridges poses challenges for drone positioning and flight control.
- AI Model Precision and Applicability: Deep learning models need to maintain high accuracy across various bridge components and different types of deterioration, with model estimates closely matching actual degradation conditions.
- Image Processing and Integration: There's a need to effectively combine high-resolution images taken by drones with 3D models to quantify degradation levels.

4. Institutional and Application Promotion Limitations

- Existing bridge inspection standards and operational procedures may not fully accommodate the application of new technologies and require adjustments.
- Technology proliferation and promotion need to address issues related to funding, policies, and technical standardization.

II. Proposed Solutions:



1. Solutions to Traditional Inspection Method Limitations

Using Drones to Replace Manual Inspection

- Objective: Address issues of time-consuming, high-risk, and subjective traditional inspections.
- Method: Conduct inspections of high or hard-to-reach bridge parts using Unmanned Aerial Vehicles (UAVs). Drone-captured images cover main beams, bridge piers, cross-beams, and other components, quickly collecting large amounts of image data, replacing manual visual inspections.
- Effect: Drones equipped with high-resolution cameras can obtain detailed images from different angles, significantly reducing personnel safety risks and inspection time.

Combining AI Image Recognition to Enhance Inspection Efficiency

- Objective: Reduce subjective judgment bias and improve inspection accuracy and efficiency.
- Method: Utilize AI image recognition technologies to analyze drone-captured images through deep learning models, identifying deterioration areas such as cracks, peeling, water seepage, etc. This enables automated detection, avoiding errors from personnel judgment differences.
- Effect: AI models can standardize inspection results, improving consistency. Automated recognition capabilities make inspections more accurate and repeatable, reducing human costs and biases.

2. Solutions to Data Processing Challenges

Establishing Data Cleaning Processes

- Objective: Address poor data quality in bridge management systems and improve training data accuracy.

- Method: Design TBMS2 (Taiwan Bridge Management System 2) data cleaning process to remove erroneous, inconsistently annotated, or duplicate data, and filter and correct invalid images (such as overly dark backgrounds or vegetation obstruction).
- Effect: Ensure high-quality training data, making AI model training more efficient and further improving image recognition accuracy.

Improving Image Quality

- Objective: Solve problems of vegetation obstruction, backlighting, etc.
- Method: Design drone photography supplementary lighting systems to reduce shadows or reflections and ensure image clarity and completeness. For obstructed areas, use different flight angles and distances for multi-angle shooting to avoid obscuring deterioration areas from a single perspective.
- Effect: Ensure image clarity, improve subsequent AI recognition accuracy, and make damage areas more evident.

3. Technical Difficulty Solutions

Enhancing Drone Navigation Technology for Bridge Environments

- Objective: Solve drone positioning challenges in GPS-absent bridge environments.
- Method: Combine Visual-Inertial Odometry (VIO), Inertial Measurement Unit (IMU), and Ultra-Wideband (UWB) positioning technologies to achieve precise drone positioning in bridge subsurface or signal-free environments, enabling autonomous flight and avoiding collisions or deviations.
- Effect: Improve drone navigation and positioning accuracy, allowing autonomous inspection in complex bridge environments, overcoming manual operation limitations.

Improving Deep Learning Model Recognition Accuracy

- Objective: Enable AI models to accurately identify various deterioration types.
- Method: Adopt a multi-stage model training process, starting with pre-trained models for basic recognition, then fine-tuning for bridge deterioration features to enhance AI model accuracy in detecting subtle damages like cracks and peeling. Utilize multi-level data augmentation techniques like CutMix to simulate different damage scenarios and improve model generalization.
- Effect: Increase AI model accuracy and stability, enabling adaptation to different bridge types and deterioration characteristics, accurately identifying deterioration areas.

Establishing 3D Modeling and Image Recognition Integration System

- Objective: Effectively integrate drone images with bridge 3D models to quantify deterioration areas.
- Method: Based on drone-captured images, construct bridge 3D models and match AI-recognized deterioration results with 3D models to generate 2D/3D vector data (like Shapefile or OBJ). This data provides deterioration location, area, and damage size, allowing comparison with bridge structural dimensions to accurately calculate DERU (Deterioration degree, Extent, Relevance, Urgency) indicators.
- Effect: Provide a 3D perspective of damage areas, assisting bridge inspection personnel in intuitively assessing deterioration, further quantifying damage data, and improving maintenance decision accuracy.

4. Institutional and Promotion Challenge Solutions

Establishing Standardized Drone Inspection Technical Processes

- Objective: Seamlessly integrate drone and AI technologies into existing

bridge inspection processes.

- Method: Based on the Ministry of Transportation's "Highway Bridge Inspection and Reinforcement Specifications," establish drone shooting standards, including specific indicators for shooting angles, image resolution, brightness, and component identification. Develop automatic flight and shooting paths to ensure drones operate according to standard procedures, achieving standardized and normalized inspection data.
- Effect: Make drone inspections a part of standardized inspection processes, enabling broader adoption by bridge management authorities.

Strengthening Technology Promotion and Popularization

- Objective: Accelerate the application and popularization of drone-assisted AI image recognition technologies.
- Method: Promote through technical conferences, symposiums, technology transfer, and technical patents. Conduct technical training for highway management and maintenance units to increase understanding and mastery of drone inspection and AI recognition technologies.
- Effect: Promote technology application, helping bridge management authorities and construction units more quickly accept this new technology, driving digitalization and intelligent transformation of bridge inspections. These solutions comprehensively address various challenges, improving bridge inspection accuracy and efficiency from multiple angles including technical development, standard process establishment, and data quality enhancement. They reduce human interference in the inspection process, making drone and AI technologies an effective inspection method.

III. How to Use Generative Artificial Intelligence to Solve Selected Problems

IV.

1. Improving Data Quality and Enhancing Image Data

Generating Synthetic Image Data

- Objective: When data is limited or of poor quality, generative AI can create a large number of realistic images that simulate different deterioration conditions of bridges, supplementing training data.
- Method: Using Generative Adversarial Networks (GANs) or diffusion models, generate realistic images of deterioration scenarios based on existing images, such as images with cracks, spalling, and water seepage at different severity levels. These generated images can be annotated with corresponding deterioration types and ranges, serving as training data to enhance AI models.
- Effect: Data generated by generative AI can enrich the training database, improve the AI model's ability to identify deterioration features, enable the model to adapt to more diverse scenarios, increase recognition accuracy, and reduce accuracy issues caused by insufficient data quality.

Enhancing Image Quality

- Objective: Address image quality degradation due to shooting environment problems.
- Method: Generative AI can repair blurry, backlit, shadowy, or low-contrast parts of images. Using super-resolution techniques to enlarge and enhance low-resolution images, and improve image clarity. Additionally, denoising and brightness enhancement techniques can be applied to make bridge component deterioration features more apparent.
- Effect: Improving image clarity helps AI models more precisely identify deterioration features such as cracks and water seepage, making subsequent detection results more reliable.

2. Improving the Accuracy of AI Image Recognition Models

Generating Diverse Training Samples

- Objective: Enable AI models to accurately identify bridge deterioration in diverse scenarios.
- Method: Generative AI can expand the diversity of original training data. For example, generate images from different angles, lighting conditions, bridge materials, and damage levels, simulating various situations drones might encounter in reality, thereby enhancing the model's generalization capabilities.
- Effect: The generated diverse data makes AI models more adaptable, helping to identify deterioration in different scenarios during actual bridge inspections.

Using Generative AI for Model Optimization and Enhancement

- Objective: Optimize the accuracy of image recognition models in bridge deterioration detection.

- Method: Perform data augmentation using generative AI-generated data, and use synthetic images for model pre-training. This approach allows the model to extract more representative features. During model development, use generative AI to simulate actual scenes, enabling the model to train and test with more diverse data.
- Effect: Generative AI-assisted data augmentation can improve the model's recognition performance, making it more accurately identify damage types such as cracks and spalling, and enhance its effectiveness across diverse bridge structures.

3. Supporting Drone Positioning and Navigation

Generating Virtual Environments for Simulation Training

- Objective: Solve drone positioning and navigation problems in environments without GPS signals.
- Method: Use generative AI to create virtual 3D bridge models and under-bridge environments, simulating drone cruising and positioning scenarios. These virtual environments can be used to simulate drone flight behaviors and navigation scenes, providing visual-inertial fusion (VIO) training data for drone models.
- Effect: Virtual scenes created by generative AI help drones operate in real environments, enhancing their navigation and obstacle avoidance capabilities, and assist in stable inspections in areas under bridges and with unstable GPS signals.

Enhancing Visual Navigation Models

- Objective: Improve drone navigation capabilities in complex bridge environments.
- Method: Generative AI can generate image data of drones inside and outside bridges, used to train visual navigation models. This data can

include multi-angle bridge images during drone cruising, generating scenarios with occlusions, light variations, and other complex conditions to improve drone visual navigation algorithms.

- Effect: Drone visual navigation models can better understand bridge environment structures, improve positioning accuracy, and perform precise inspections when GPS cannot be relied upon.

4. Accelerating Standardization Process and Application Promotion

Assisting in Establishing Standardized Datasets

- Objective: Establish universal standard processes for AI models in bridge inspection and drone operations.
- Method: Use generative AI to construct a standardized bridge inspection image database, including synthetic images under various conditions such as different bridge types, deterioration states, and lighting. This dataset can help different organizations unify basic model training data and promote standardized AI detection processes.
- Effect: Provide standards for drone and AI inspection processes, promote technological industry applications, and help reduce data quality inconsistencies during implementation.

Developing Generative AI-Supported Visualization Tools

- Objective: Accelerate technology promotion through intuitive visualization tools.
- Method: Develop visualization tools using generative AI, such as overlaying deterioration areas on 3D models, allowing users to view damage locations from 3D perspectives and complete inspection reports through simple interface operations. These tools can help bridge management units and inspection personnel more intuitively understand

AI detection results and improve user-friendliness.

- Effect: Generative AI-supported visualization tools promote technological applications, enabling different units to quickly get started and thereby expanding the use of AI and drone inspection technologies.

Conclusion

Generative AI can address various challenges in bridge inspection by enhancing data quality, improving image recognition accuracy, supporting drone navigation, and standardizing processes. By generating images, enhancing models, and optimizing navigation, generative AI can significantly improve the automation, accuracy, and efficiency of bridge inspections, and promote widespread application of this technology in the industry.