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Application of Train Intelligent Detection System (TIDS)

列車智能障礙物檢測系統技術與應用

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Contents

目 录

1. INTRODUCTION 3

背景和必要性 3

2. SYSTEM FUNCTION AND PERFORMANCE REQUIREMENT 4

系統功能與性能要求 4

2.1FUNCTIONAL REQUIREMENT 4

功能要求 4

2.2PERFORMANCE REQUIREMENT 5

性能要求 5

3. SYSTEM ARCHITECTURE AND KEY TECHNOLOGIES 7

系統組成及關鍵技術 7

3.1SYSTEM ARCHITECTURE 7

系統組成 7

3.2TRACK RECOGNITION 8

軌道識別關鍵技術 8

3.3OBSTACLE DETECTION 9

障礙物識別關鍵技術 9

3.4FUNDAMENTAL PRINCIPLES OF FUSION PERCEPTION 11

融合感知關鍵技術 11

4. TEST IN HONG KONG TSUEN WAN LINE 12

香港荃灣線實驗情況 12

4.1ACTUAL INSTALLATION OF PRODUCTS 12

安裝情況 12

4.2PRODUCT PERFORMANCE ANALYSIS 14

測試結果 14

5. FUTURE PRODUCT PLAN 16

展望 16

Preface

前言

As one of the most important public transportation, urban rail transit bears great operational pressure and relies completely on signaling system to maintain its safety and efficiency. Once the signaling system fails, the assurance on safety and operational efficiency will be affected, and it is required to switch to manual driving mode under reduced train speed.

軌道交通作為公共交通領域的最大運力交通工具，擔負了極大的運營壓力，依賴於信號系統維持其安全、高效運行。信號系統一旦故障，需要降级到人工驾驶模式低速运行，完全依賴於人工保證安全，系統安全性和運營效率陡降。

Today's rapid technical development on artificial intelligence, sensor, and autonomous driving provide us a feasible solution to overcome this challenge. By using Train Intelligent Detection System (TIDS), we can detect any abnormal obstacles during operation, and lead the driver to take the emergency actions.

目前快速發展的人工智能技術、傳感器技術以及無人駕駛技術為解決上述問題提供了可行的方向，通過列車自主智能障礙物感知判斷前方線路情況，進而指導司機行車以及採取防護措施。

This White Paper is specially complied to illustrate the requirements, usage and testing result of Train Intelligent Detection System (TIDS).

為說明列車智能障礙物檢測系統的要求、使用場景及測試效果，特編制本白皮書。

This white paper is jointly organized and prepared by Innovation Research Institute for Hong Kong Railway and **National Engineering Laboratory for Urban Rail Transit Communication and Operation Control.**

本導則由香港軌道交通創新研究院與城市軌道交通列車通信與運行控制國家工程實驗室聯合組織編寫。

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1. Introduction

背景和必要性

The efficiency and safety of rail transit operation are mainly ensured by the signaling system. Once the signaling system is failure, the operation would be completely depending on driver's visual operation. In this case, the dispatcher and the driver would be under great pressure, which often causes serious delays and shutdowns. To solve the above problem, many companies and research institutions around the world have conducted relevant research on it for long, but there are still many technical deficiencies and it has not been applied to actual system.

軌道交通運營效率和安全主要由信號系統保證，信號系統一旦故障車輛運行完全依賴於駕駛員目視前向運行環境，調度和司機面臨巨大壓力，往往會造成嚴重晚點和停運。針對上述問題，世界各國相關企業及研究機構進行了長時間的探索，但技術上仍存在許多不足，並未應用到實際系統。

Under this circumstance, Hong Kong MTR and Traffic Control Technology Co., Ltd jointly started the research of TIDS in early 2018 and carried out a comprehensive real train test on Tsuen Wan Line. The test result is promising for further development into application level and target to achieve SIL2 level safety certificate. Once the system is completed, it will provide effective services for operation and become the most advanced rail transit intelligent obstacle detection system in the world.

在此背景下，香港地鐵與交控科技聯合於 2018 年初開始 TIDS 技術的研究，並在荃灣線開展了全面的實車測試，測試數據表明相關研究已基本達到實際應用水平，將实现 SIL2 安全等級目标。本系統建成後將真正為運營提供有效服務，成為世界上最先進的軌道交通智能障礙物檢測系統。

2. System Function and Performance Requirement

系統功能與性能要求

2.1 Functional Requirement

功能要求

TIDS can detect and alarm the sudden intrusion obstacles in front of the train，and implements braking if necessary. At the same time, the information of the train location will be reported to the train operation control center as needed.

TIDS 對軌道前方列車、行人以及侵入障礙物，實時檢測與報警，乃至實施制動控制。另外根據需要可以實時報告列車位置給運營控制中心。

TIDS has the following functions:

TIDS 應具備如下功能：

a) Intelligent obstacle detection function: Obstacles on the track ahead of the train (such as vehicles, people, cabinet, etc.) can be actively identified and the distance for obstacles can be accurately perceived. It can also warn the driver (in the case of human driving) and take emergency measurements to apply a brake.

   障礙物智能檢測:對列車運行前方軌道內的障礙物（如車輛、人、機箱等）進行主動識別同時精准感知障礙物距離，並具備向駕駛員預警（在有人駕駛情況下）以及施加制動採取防護措施的能力。

b) Fully independent environmental perception: Obstacle distance measurement and self-speed measurement can be achieved by collecting the physical characteristics of the environment without the need to install supporting equipment and no external input from the train or signaling system.

   完全獨立的環境感知能力:通過自身對環境物理特徵的採集實現障礙物距離測量和自身速度測量，無需被檢測對象安裝配套設備以及其他來自車輛、信號系統的外部輸入。

c) Rail transit multi-scenes detection: TIDS can detect straight track, ramp, curve and other scenes. It can adapt to weather conditions such as daytime, night, sunny, cloudy, rainy

days, etc. It applies to the ground, tunnel, elevated and other operating environments.

軌道交通多場景檢測能力:在全線直道、彎道、道岔區域準確識別運行前方障礙物，不受相鄰軌道障礙物或軌旁障礙物（軌旁圍牆、信號機等）的影響。能適應白天、夜晚、晴天、陰天、雨天等天氣狀態，適用於地面、隧道、高架等運行環境。

d) Train position and abnormal status report: TIDS can upload train position and the image data with the abnormal status to operation control center through 4G.

列車位置及異常狀態彙報：基於環境感知技術實現定位，並將定位結果以及異常狀態的圖像數據通過 4G 等網絡上傳至地面設備顯示。

2.2 Performance Requirement

性能要求

TIDS shall meet the following performance index:

TIDS 應滿足以下性能指標：

Table 1 TIDS Performance Index

表 1 TIDS 檢測距離

Obstacle types 障礙物類型	Obstacle sizes 障礙物典型大小	Detection distance 檢測距離
Train 列車	2.8m*3.8m	≥280m
Person 行人	1.7m*0.4m	≥120m
Small obstacles (such as box) 小障礙物（如箱子）	0.4m*0.4m	≥50m

To meet the high-reliability requirements of rail transit, TIDS shall meet the following index:

為滿足軌道交通高可靠要求,TIDS 系統應滿足以下指標：

1. Rate of missing detection: ＜0.01%;

   漏報率：＜0.01%；

2. Rate of false detection: ＜0.01%;

   誤報率：＜0.01%；

3. Distance measurement error for obstacle <= 1 m;

   障礙物檢測測距誤差≤1m；

4. The error of system velocity measurement < 1 km/h;

   系統測速誤差<1km/h;

5. Safety Integration Level (SIL) is no less than level 2.

   安全完善度等級（SIL）不低於 2 級。

Notes:

Rate of missing detection = failure to report the number of frames for obstacles in the actual effective distance ahead / the total number of frames during the effective working period

注：

漏報率=實際前方有效距離內有障礙物而未能報出障礙物幀數/有效工作期間總幀數。

Rate of false detection = report the number of frames of non-existing obstacles in the actual effective distance ahead / the total number of frames during the effective working period

誤報率=實際前方有效距離內無障礙物而報出障礙物幀數/有效工作期間總幀數。

3. System Architecture and Key Technologies

系統組成及關鍵技術

3.1 System architecture

系統組成

TIDS system consists perception layer, cognitive layer, and decision-making layer. The perception layer is mainly used to receive data that comes from the visual sensor and radar sensor. The cognitive layer mainly processes and integrates the input from sensor data, combines the deep understanding of the driving scene to obtain the environmental information in front of the train. The decision-making layer further processes the data through the perception results of the cognitive layer and the vehicle status, calculates the allowable running distance and recommends driving speed, and judges whether the train is speeding or not according to the allowable running distance and the train speed, so as to give an alarm or brake the vehicle. The entire system is integrated through three key technologies: **track recognition, obstacle recognition,** and **data fusion perception.** TIDS architecture is shown in Figure 1.

TIDS 系統包含有感知層、認知層和決策層組成。感知層主要用於接收視覺傳感器數據以及雷達傳感器數據數據；認知層主要對輸入的各傳感器數據進行處理並融合，結合對軌道交通駕駛場景的理解，得出列車前方的環境信息；決策層通過認知層的感知結果結合列車自身狀態進一步對數據進行處理，計算出列車可行駛距離，建議速度、並根據可行駛距離和列車速度判斷是否超速進行報警或對車輛進行制動。整個系統通過**軌道識別**、**障礙物識別**以及**數據融合感知**三項關鍵技術集成實現。TIDS 系統結構如圖 1 所示。

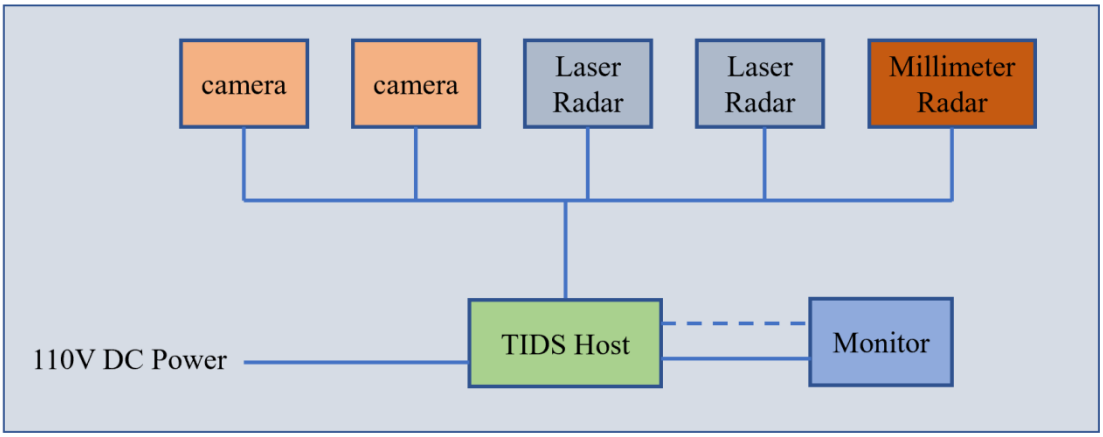


Fig. 1 TIDS Architecture

圖 1 TIDS 架構圖

TIDS consists the following equipment:

具體的 TIDS 包含如下設備：

a) TIDS host;

TIDS 主處理器；

b) Cameras (The detection distance≥300m, supporting illumination intensity: 0.001lux);

工業相機（檢測距離≥300m，支持光照強度：0.001lux）；

c) 3D lidars (The detection distance≥300m, or 80 line and above, angular resolution is less than 0.2 °);

3D 激光雷達（檢測距離≥300m，80 線及以上，角分辨率小於 0.2°）；

e) A millimeter wave radar;

毫米波雷達；

f) Wireless module (Transmission of train location and status from the train to control center);

通信模塊（用於下發列車位置、狀態）；

g) MMI(Optional)

人機交互設備（根據現場情況選配或集成）。

3.2 Track recognition

軌道識別關鍵技術

The cognitive layer of TIDS uses deep learning algorithm, by constructing a deep convolutional neural network (CNN), applying convolution-deconvolution network, designing

feature extraction operators such as sparse convolution and cascade down sampling, extraction of global feature and local feature of the tracks, the acquired sensor data are processed. It can also obtain end-to-end track information, so as to achieve accurate track line recognition.

TIDS 認知層中通過對獲取的傳感器數據進行處理，採用深度學習算法，通過搭建深層次卷積神經網絡，應用卷積-反卷積網絡架構，設計稀疏卷積、級聯下採樣等特徵提取算子，對軌道進行全局特徵和局部特徵提取，獲取端到端的軌道信息，實現精准的軌道線識別。

The performance of TIDS track recognition is shown in Figure 2. At the present stage, the following track types can be identified: straight track, ramp, curve, turnouts, etc., TIDS can also be applied to tunnel, elevated road and other scenes. The recognition effect is satisfactory in daytime, night, sunny day, rainy day, cloudy day and other weather conditions.

TIDS 軌道識別效果如圖 2 所示，現階段已具備直道、彎道、道岔等軌道類型識別，且可適用於隧道、高架等場景，在白天、夜晚、晴天、雨天、陰天等天氣狀態下均有較好的識別效果。

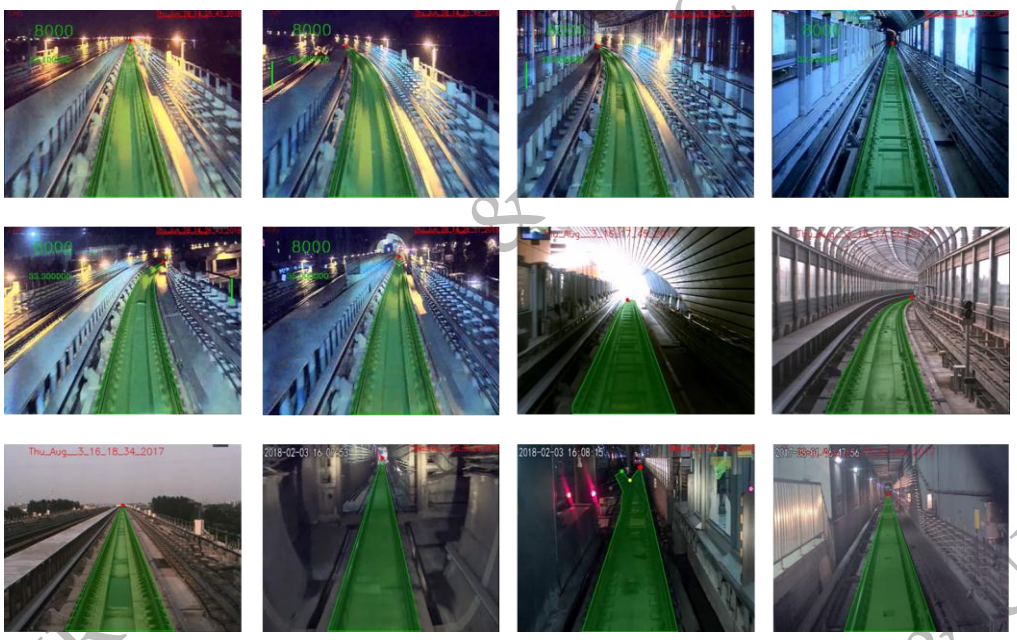


Fig. 2 Performance of track recognition
圖 2 軌道識別效果

3.3 Obstacle detection

障礙物識別關鍵技術

The TIDS adopts convolutional neural network (CNN) to realize obstacle recognition in the forward track, by setting a particular detection criterion for obstacle, using the depth separable

convolution, applying the residual network structure and combining the multi-layer feature layer for predicting results. The obstacle detection results can be further regressed to obtain the final obstacle output.

TIDS 應用卷積神經網絡實現前向軌道中障礙物識別，具體的通過設置障礙物檢測先驗框，採用深度可分離卷積，並應用殘差網絡結構，通過對多層特徵層輸出進行融合對檢測結果進行預測，進一步的對障礙物檢測結果進行回歸，從而得到最終障礙物輸出。

The performance of TIDS obstacles detection is shown in Figure 3. At this stage, TIDS can achieve identification of trains, pedestrians, and signal, it is suitable for obstacle recognition up to 300m in different weather conditions.

TIDS 障礙物效果如圖 3 所示，現階段具備多種類型障礙物識別能力，具體包括列車、行人、信號燈等識別，且適用於不同的天氣狀況下，實現最遠 300m 的遠距離障礙物識別。

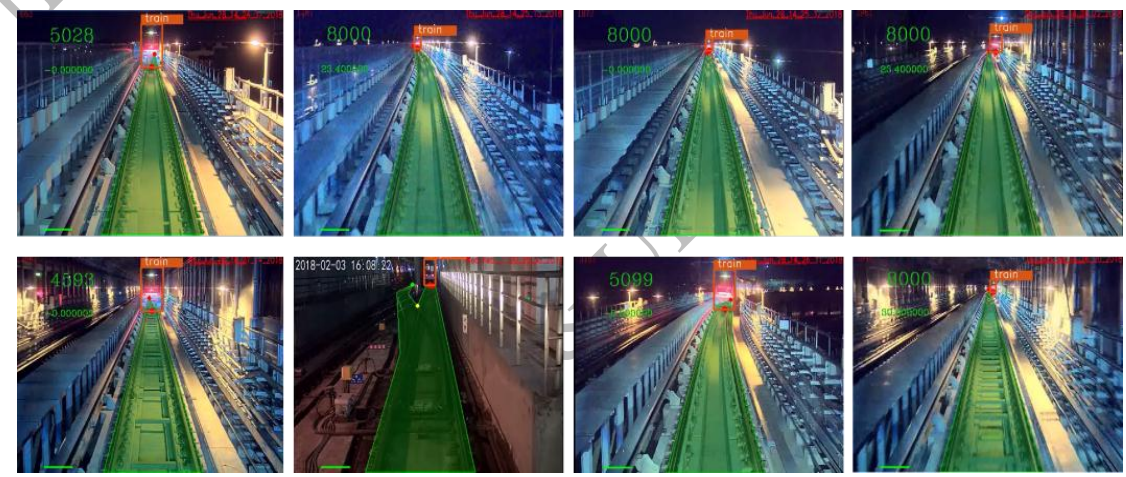


Fig. 3 Performance of obstacle recognition

圖 3 障礙物識別效果

3.4 Fundamental principles of fusion perception

融合感知關鍵技術

TIDS further combines the rich image information from camera and the radar's accurate 3D measurements, to achieve a deeper understanding of the environment. Firstly, the system builds model for the track environment. It acquires visual information and radar information based on this model, by using information matching and space-time unification, and applying multi-level vision and radar fusion algorithm to obtain obstacle distance and type, combining pre-verified knowledge to re-verify, then, finally obtain the perception output.

進一步的融合圖像和雷達傳感器的信息, 發揮圖像信息量豐富以及雷達對於三維環境精確測量優勢，實現更深層次的環境理解。系統首先對軌道環境進行建模，在此基礎上通過獲取視覺信息與雷達信息，通過信息匹配與時空統一，並進一步應用多層次視覺與雷達融合算法獲取障礙物的距離和類型信息，並結合先驗知識對結果進行再校驗，從而得到最終的感知輸出。

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4. Test in Hong Kong Tsuen Wan Line

香港荃灣線實驗情況

A comprehensive test of TIDS was commenced in Hong Kong Tsuen Wan Line in mid-2018. The test data has accumulated over 2TB in eight months testing. Systematic and comprehensive functional test and system capability analysis for typical application has been carried out in Tsuen Wan Line with its rich scenes, including straight track, curves, tunnels, elevated, and tunnels with low illumination.

TIDS 系統於 2018 年中開始在香港荃灣線進行全面測試，測試時間約 8 個月，測試數據超過 2TB。香港荃灣線由於其豐富的場景，包含有直道、彎道、隧道、高架，同時隧道具有低照度等特性，有效支撐系統全面的功能和性能測試。

4.1 Actual installation of products

安裝情況

TIDS shall be easily built and installed. With highly flexible design, the actual installation space for different train types can be customized.

應便於現場施工和車輛實際安裝，由於 TIDS 高柔性化設計，可針對每款車型實際安裝空間，定制化安裝方案。

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Fig.4 Actual Sensor Installation on Site (Driving Cab Installation Scheme)

圖 4 傳感器安裝實際效果（駕駛室安裝)



Fig. 5 Actual Sensor Installation on Site (Roof Compartment Installation Scheme)

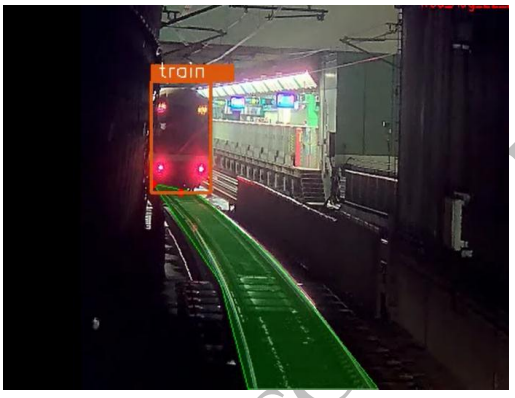
圖 5 傳感器安裝實際效果（車頂安裝）

4.2 Product performance analysis

測試結果

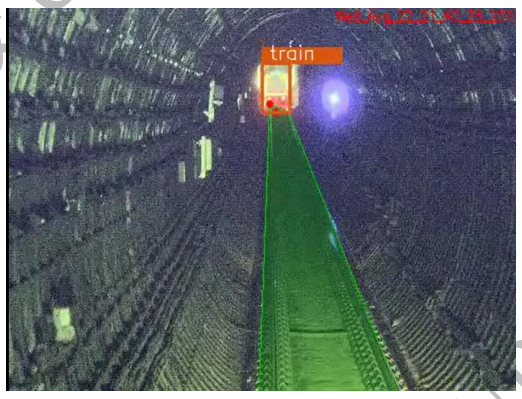
As of March 13th, 2019, TIDS has been running for test for 2,160 hours in Tsuen Wan Line, with accumulative data volume of 2.42T. The collected data includes various weather scenes such as sunny, cloudy, rainy, daytime and night, covering straight track, curve, turnout, elevated track, and tunnels and covers all track and running conditions under normal train operation. A detailed performance analysis was carried out for the test of TIDS in Tsuen Wan Line. The main performance indexes included obstacle missing detection rate, false report rate, and farthest recognition distance. In addition, detail statistics has been carried out on the test performance of straight tracks, ramps and curves. The statistical data includes 864 hours of data, which are cross-validated by automatic analysis tools combined with manual supervision, and through multiple rounds. The test results show that the TIDS can meet the functional requirements and is promising for achieving the performance indexes in near future.

截至 2019 年 3 月 13 日，TIDS 系統已在荃灣線全線運行 2160 小時，累計數據量達 2.42T，採集的數據包含晴天、陰天、雨天、白天、夜晚等多種天氣場景，涵蓋直道、彎道、道岔、高架、隧道等多種場景，涵蓋了列車正常運行所面臨的所有場景和路況。針對荃灣線 TIDS 系統運行情況做了具體性能分析，主要指標包括障礙物漏識別率、誤識別率、最遠識別距離等，此外本系統針對直道、坡道、彎道對測試性能進行了詳細統計，統計數據包括 864 小時數據，通過自動化分析工具結合人工監督方式多轮交叉驗證，實驗結果表明，TIDS 系統各項功能指標均滿足要求，性能參數將滿足运营指标要求。



Curve scene

彎道場景



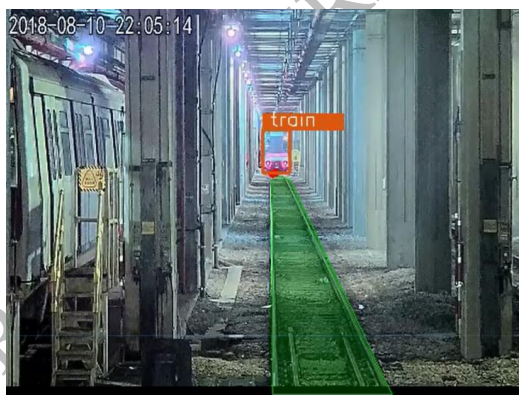
Ramp scene

坡道場景



Curve + ramp scene

彎道+坡道場景



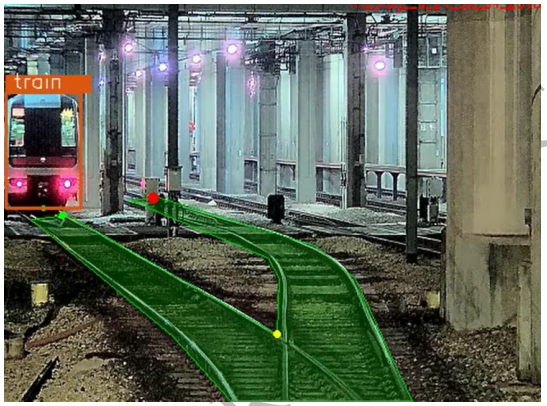
Straight track scene

直道場景



More than one train recognition in turnout scene

道岔場景下多車識別



Side track recognition

道岔反位識別

Fig. 6 Sample of Recognition Effect of Statistical Data in Tsuen Wan Line

圖 6 荃灣線統計數據部分識別效果示例

5. Future Product Plan

展望

TIDS will become an indispensable product for improving the safety and efficiency of operation, reducing the time for recovery operation, and improving the operational service level under signaling system failure or unequipped signaling system scenarios. In addition, with the further development of AI technology, the performance and safety level of TIDS will be further enhanced and will definitely have a greater impact to railway industry.

TIDS 將成為在軌道交通信號系統故障或未裝備信號系統場景下，提升車輛運行安全和效率，縮短運營恢復正常過程時間，提升運行服務水平的必備產品。同時隨著 AI 技術的進壹步發展，TIDS 將進壹步提升其性能及安全水平，必將對軌道交通產業產生更大影響。

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