Feature Article

特集論文

Towards Autonomous Vehicles:
Developing Highly Automated Vehicles for Structured and Unstructured Environments

自動運転車に向けて：
構造化環境および非構造化環境のための高度に自動化された車両の開発

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In this paper some of the latest HORIBA MIRA developments on systems for the simulation and development of automated vehicles are introduced. For the structured environment case the emphasis is on the longer term research challenge of developing systems for cooperative automated driving allowing the benefits in both safety and efficiency to be realised in the future. This includes developments on traffic simulations and management systems since these will also be key to reaching the longer term vision of cooperative autonomous driving. For the unstructured environment case the emphasis is on the shorter term development challenge of engineering unmanned vehicles that can be safely and reliably deployed in demanding customer specific off-road environments. Finally, some conclusions and a selection of future works are presented.

本稿では，自動運転車のシミュレーションと開発のためのシステムに関してHORIBA MIRA社の最新開発事例のいくつかを紹介する。構造化環境*1を対象とする場合は，安全性・効率性の双方の実現に有効な協調型自動運転システムの開発という長期的な研究課題を重視している。開発対象には，交通量および交通管制シミュレーションや，管理システムも含まれる。いずれも協調型自動運転の長期ビジョンに到達するための鍵となるからである。非構造化環境*2の場合は，顧客が指定するオフロード環境に安全確実に対応できる無人車の開発という短期的課題が重要である。最後には，まとめと今後の取り組みにもふれる。

＊1：構造化環境（structured environment）：ネットワークに接続できるいわゆる「コネクテッドカー」の無人運転制御のために，データ通信などのインフラが整備された環境のこと。

＊2：非構造化環境（unstructured environment）：上のような専用インフラが整備されておらず，個々の自動運転車が自律的に無人運転を制御する必要のある環境のこと。

Introduction

Automobiles have become essential to our life and so will higher levels of automated driving. Automated Driving is, for the European Road Transport Research Advisory Council (ERTRAC), one of the major technological

はじめに

自動運転とは，欧州道路輸送調査諮問委員会（ERTRAC）によれば，将来の私たちのモビリティ社会と生活の質を向上させる大きな技術進歩のひとつである[1]。安全性（ヒューマンエラーに起因する事故の低減），効率性（輸送システムの効率を高めて自動車の排出ガスを低減），快適性（自動化システムの作動中は利用者が運転から解放され，他の活動を行える），社会的包摂（すべての人にモビリティを確保），およびアクセス性（都市の中心部へ容易にアクセス可能）などがある。欧州での協調型高度道路交通システム（C-ITS）の共通な共有ビジョンを業界代表と公的機関が合意して，C-ITSプラットフォームが制定された[2]。

将来の自動車と交通システムの技術の進歩に関して HORIBA MIRA 社[4]は，高度自動化機能を組み込んだ車両の普及の実現に向け，必要な信頼できる設備を提供する。

無人陸上車両（UGV）は自動運転車両の一種であり，通常人間が制御ループに組み込まれ（マン・イン・ザ・ループ：man in the loop），監督や監視を人間が行えるようになっている。

advancements shaping our mobility and quality of life in the future.[1] Amongst the main drivers for higher levels of automated driving are: safety, reducing accidents caused by human errors; efficiency, increasing transport system efficiency, reduced emissions of vehicles; comfort, freeing the user for other activities when automated systems are engaged; social inclusion, ensuring mobility for all; and accessibility, facilitating access to city centres. Furthermore the importance of cooperative automated driving has been recognised by the European Commission who have coordinated the establishment of the C-ITS Platform where industry representatives and public authorities have agreed on a shared vision for the coordinated deployment of Cooperative Intelligent Transport Systems (C-ITS) in Europe.[2] This is an important step towards connected and cooperative cars as C-ITS enable vehicles to communicate with each other and with the infrastructure, an essential step to enable efficient highly automated driving. The impact of the advancement in Connected and Autonomous Vehicles (CAV), will reach many adjacent sectors including insurance, telecommunications, electronics, technology, IT, transportation, logistics, advertising, digital and retail.[3]

The HORIBA MIRA offering[4] on the advancement of future vehicle and systems technology is helping in the development and testing of reliable technology, required to eventually achieve a deep penetration level of vehicles with high-automation features integrated. There is an active programme of research and development in Autonomous Vehicles and their related technologies carried out for both on-road structured environments and off-road unstructured environments.

The research scope for both environments are complementary. For the on-road structured environment, the ever-increasing complexity of vehicle's systems and the incorporation of newer Advanced Driver Assistance Systems (ADAS),[5] is making the process of comprehensive validation and implementation of system design increasingly challenging. The high number of different subsystems, use cases, environmental conditions and driver profiles, among many other factors, makes the testing and validation of all the vehicle's automated systems under all possible combination of factors unfeasible. Intelligent, configurable test protocols and specialized simulation and test facilities dealing with this validation process complexity are required. Additionally, as CAVs come to rely on external information for planning of safety related functions, any corruption or misuse of these communication channels could compromise vehicle safety. Added to the challenges for CAVs is the inter-operability and market penetration.

Off-road environments are largely unstructured. Unmanned Ground vehicles (UGVs) are a class of autonomous vehicles that are typically designed to be used instead of manned vehicles particularly in dull, dirty or dangerous applications. Although these vehicles are unmanned they still normally have a "man in the loop", i.e. in a supervisory or monitoring capacity. However, navigating complex terrain at speed with minimal human supervision represents a major challenge for UGVs. For example, this requires advanced on-board perception systems featuring innovative algorithms for interpreting challenging environments such as mountains, deserts, woodland and wetland. Key challenges are the sensor suites and sensor fusion needed to provide perception information to the automation control systems to enable the vehicle to operate in off-road terrains and in harsh environmental conditions. This combined with addressing key engineering requirements such as reliability, safety and operational integration with other systems means that advanced algorithms coupled with appropriate test and validation tools are also required.

In this paper some of the latest HORIBA MIRA developments on systems for the simulation and development of automated vehicles are introduced. For the structured environment case the emphasis is on the longer term research challenge of developing systems for cooperative automated driving allowing the benefits in both safety and efficiency to be realised in the future. This includes developments on traffic simulations and management systems since these will also be key to reaching the longer term vision of cooperative autonomous driving. For the

構造化環境における自動運転

高度な自動化[6]を広く運用できる前に自動車業界が取りくむべき課題は多い。HORIBA MIRA社は，車両エンジニアリング，機能安全，試験，検証などの多くの重要分野の専門知識を有している。

協調型運転シミュレーションとロボティクスのテストベッドは，協調型自動運転アルゴリズムの素早い反復とベンチマーキングを可能にする。

協調型運転シミュレーションとロボティクス

このテストベッド（Figure 1参照）は，道路網全体とすべての車両のリアルタイム状態を認識し，各車両制御に必要な信号を供給している。環境マネージャは，新しいETSI協調型認識メッセージ（Cooperative Awareness Message：CAM）を受信した時にメッセージの受信範囲内に位置する車両を特定し，それらの制御装置にのみCAMを転送する。

実際にこのシミュレーションを走らせることによってビークル・ハードウェア・イン・ザ・ループ（VeHIL）が可能になる。これは，

unstructured environment case the emphasis is on the shorter term development challenge of engineering unmanned vehicles that can be safely and reliably deployed in demanding customer specific off-road environments. Finally, some conclusions and a selection of future works are presented.

Automated Driving in Structured Environments

Automation in passenger vehicles and public transport systems offers many societal benefits but there are significant challenges for the industry to address before high levels of autonomy[6] can be deployed widely. HORIBA MIRA has expertise in many of these crucial areas such as vehicle engineering, functional safety, test and verification. Furthermore, a number of strategic research themes have been identified which are supported by internally funded and collaborative research and development activities. These themes include autonomy in complex urban environments, cooperative driving algorithms, simulation, safety and cyber security. Current collaborative programmes include UK Autodrive which is trialling different levels of automation for private road vehicles and public transport "pods" in two UK cites, and UK CITE which is exploring hybrid-connectivity approaches to connected vehicles on highways and urban roads.

The need for a scalable approach to component and vehicle testing, and to support the development of CAVs, has led HORIBA MIRA to develop a set of simulation tools. The Cooperative Driving Simulation and Robotics testbed allows for rapid iterations and benchmarking of cooperative and automated driving algorithms. The Cloud based Traffic Management System (CTMS) simulation system[7] allows integrated simulation of vehicles and traffic management systems in a scalable, and hierarchical, distributed cloud-based computing architecture. These tools have all been designed for real-time simulation to support advanced hardware-in-the-loop (HIL) testing.

Cooperative Driving Simulation and Robotics

This testbed (see Figure 1) was created to allow rapid evaluation of new control algorithms in a controlled and repeatable way. Within this simulated environment any number of real vehicle controllers can be run with an accompanying plant model to replicate the real-time effects of control decisions. Central to this is the powerful concept of an "Environment Manager". The Environment Manager has an awareness of the full road network, and the real time status of all the vehicles, allowing it to feed each vehicle controller with a realistic set of sensor inputs. This starts with parameters such as speed, heading and position but can be extended to include more complex aspects such as wireless communications data or object tracks from ADAS sensors. For example in a cooperative driving scenario the individual vehicle controllers each send out periodic beacon messages, based on the ETSI Cooperative Awareness Message (CAM)[8]. When the Environment Manager receives a new CAM it decides which vehicles would be in range to receive that message and it rebroadcasts it to those controllers only.

Figure 1 Cooperative Driving Simulation and Robotics demonstrator. Real moving Robots interact with simulated Tracks and Vehicles.

Running the simulation in real-time allows physical vehicles to interact with simulated vehicles and events, known as Vehicle Hardware-In-the-Loop (VeHIL). This demonstrates the validity of the simulation and models and can be used as an initial demonstration of high risk functions such as automated overtaking and merging at junctions. As an interim step HORIBA MIRA have built a fleet of small robot vehicles to allow engineers to quickly check

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シミュレーションとモデルの妥当性を実証し，自動運転による追い越しや高速道路での合流といった高リスク機能の初期実証として使うことができる。

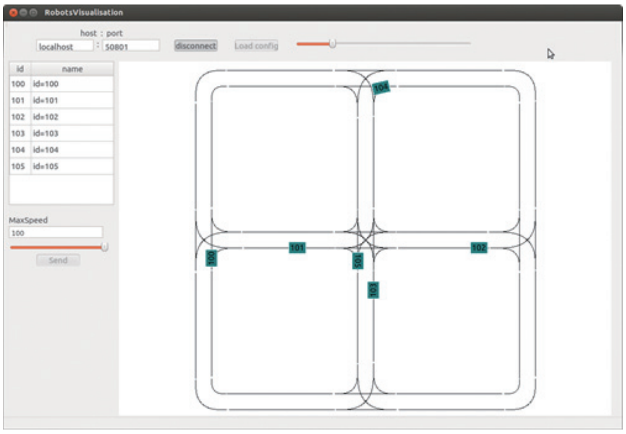
HORIBA MIRA社のネットワーク誘導車両（Network Guided Vehicle：NGV，**Figure 2**参照）[9, 10]は，高度自動運転機能の安全と制御のために協調型的な車車間（V2V）および路車間／道路車両間（V2I/I2V）システムを使用する研究・実証車両プラットフォームである。

クラウドベースの交通管理システム

HORIBA MIRA社のクラウドベースの交通管理システムは，複雑な都市交通の管理ソリューションであり，車両と交通信号制御装置の連携によって交通の流れを最適化することを目指している。

交通管理システム（Cloud based Traffic Management System：CTMS）と連携するために微視的交通シミュレーションツール[11]が開発され，実装された交通管理戦略の評価に使われている。シミュレータの最大の目標は，複雑な交通条件を微視的スケールでシミュレートするための普遍的で拡張可能なプラットフォームを

Figure 2 UGV System Architecture – Perception/Reasoning/Motion



host : port
localhost : 50801

id	name
100	id=100
101	id=101
102	id=102
103	id=103
104	id=104
105	id=105

MaxSpeed
100

Figure 3 Configuration tool of the Cooperative Driving Simulation and Robotics tested

the validity of simulation by introducing physical vehicles in the laboratory.

HORIBA MIRA's Network Guided Vehicle (NGV, see Figure 2)[9] [10] is a research and demonstration vehicle platform which utilises cooperative Vehicle-to-Vehicle (V2V) and V2I/I2V systems for both safety and control of highly automated driving functions. The latest automation software being developed at HORIBA MIRA is written in a modular way which allows algorithms developed in simulation to be directly ported to robots, and then to the full size vehicle. Most recently this approach has been employed to demonstrate multiple vehicles operating independent automated driving controllers in scenarios such as platooning, intersection priority management and merging with traffic at slip roads. The controllers can process complex road maps and derive situation awareness from V2x messages received from surrounding vehicles, which may be real or simulated.

Cloud based Traffic Management System

HORIBA MIRA's Cloud based Traffic Management System is a complex urban traffic management solution aiming to optimise traffic flow by means of coordinated cooperation between the vehicles and traffic signal controllers. The system is realised as a collection of cloud services deployed on the ITS-Cloud platform. Such a design ensures scalability and reliability of the system, and provides an abstraction layer between the traffic control algorithm and the sensing/actuating equipment.
A microscopic traffic simulation tool[11] has been developed to cooperate with the CTMS and is used to evaluate the traffic management strategies implemented. The main goal of the simulator is to provide a universal and extensible platform for simulating complex traffic conditions on a microscopic scale (see Figure 3). It has been designed as a tool to support research on traffic control and its impact on general vehicle flow and individual vehicle behaviour. Each vehicle in the simulation is a semi-independent agent that can have its behaviour customised. Vehicles equipped with wireless communications can communicate with the infrastructure using V2I communications enabling them to receive intersection approach advice and dynamic routing information. Vehicles can also engage in cooperative driving such as platooning.

Using this simulator it has been demonstrated that both traffic throughput, expressed in terms of travel time and energy expenditure, can be optimised using adaptive and cooperative intersection and vehicle management methods such as Cooperative Adaptive Cruise Control (CACC). Current research includes the simulation and modelling of real urban and strategic highways along with their ITS features required for CAVs. In the short term modelling will be used to inform some of the first use cases in the

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提供することである（Figure 3参照）。

協調型アダプティブクルーズコントロール（Cooperative Adaptive Cruise Control：CACC）などの適応・協調型の交差点・車両管理手法を用いれば，移動時間とエネルギー消費量で表現される両方の交通スループットを最適化できることが，このシミュレーションを用いて実証されている。現在研究されているのは，実際の市街地と戦略的幹線道路について，CAV に必要なITS機能とあわせてシミュレーションとモデリングを行うことである。短期的には，英国の初期の使用事例は，CACC，安定プラトゥーニング[12, 13]，協調交差点などの車車間・路車間通信（Vehicle-to-All Communications：V2X）と自動化技術によって実現され，それらを特徴づけるのにモデリングが使われるであろう。

試験施設と設備

HORIBA MIRA社のCity Circuitは，コネクテッド自動運転車両と関連ITS技術に特化した試験コースである。試験施設は，十字路，T字路，坂道などを含む都市道路網を再現し，さまざまな種類の路面，路面標識，路側設備を備えている。安全で制御された現実的な物理的環境に，同じく制御された代表的な無線環境が組み合わされていることが，この施設の特徴である。携帯電話網を含む

UK enabled by the Vehicle-to-All Communications (V2X) and automation technologies, for example CACC, stable platooning[12] [13] and cooperative intersections.

Test Facilities and Equipment

The HORIBA MIRA City Circuit is a proving ground specifically for automated and connected vehicles, and related ITS technologies. The test facility features a network of urban roads including cross roads, T-junctions, and hill sections, and it features different types of road surface, road markings, and roadside equipment. What makes this facility unique is that this safe, controlled, and realistic physical environment is coupled with an equally controlled and representative wireless environment. Wireless communications including cellular networks, Global Navigation Satellite System (GNSS), Wi-Fi and Dedicated Short Range Communications (DSRC/V2x) all increasingly play a role in how cooperative automated vehicles will perform. The City Circuit can provision, and deny in a controlled way, the availability of each of these networks. This allows the creation of a wide range of test scenarios ranging from ideal conditions, through to intermittent network coverage, and congested networks. Furthermore, real-time GNSS denial is available based on simulated City infrastructure configured for individual vehicles, replicating the effects of features such as tall buildings, tunnels and GPS jammers.[14]

City Circuit monitoring systems allow the facility to operate as an outdoor laboratory. RTK-GPS reference stations allow vehicles to be tracked with +/− 1 cm accuracy, and an always-on Mesh network connects test vehicles with the facility infrastructure for data collection and the triggering of synchronised events. A novel prototype 3D motion capture system is installed at a large intersection that can track objects, such as pedestrian dummies, with high precision and at a fast frame rate.

Developing Unmanned Ground Vehicle Systems for Unstructured Environments

HORIBA MIRA has extensive experience in the development of autonomous unmanned and tele-operated vehicles for both civil and defence applications. Since 2002, HORIBA MIRA have led the way in the development and delivery of advanced UGVs featuring the proven and award winning MIRA Autonomous Control Equipment (MACE) technology - the system which provides the basis for all HORIBA MIRA's UGV vehicle conversions.

Further enhancements to this UGV technology continue to be made through HORIBA MIRA's Autonomy Development Programme (ADP). New technologies, software and algorithms are integrated and tested on the third-generation off-highway research vehicle MACE III which is based on a Land Rover Defender chassis using in-house designed actuators to convert the vehicle to Drive-by-Wire (DBW). It is fitted with three forward and one rearward facing driving camera to allow monitoring and real time tele-operation. The platform is also equipped with an integrated Global Positioning System (GPS) and Inertial Navigation System (INS) with wheel

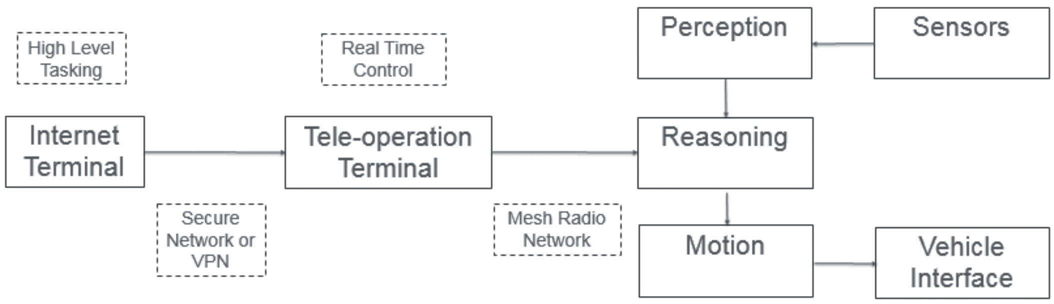

Figure 4 NGV at the Master Intersection in the City Circuit Proving Ground

無線通信，全地球航法衛星システム（Global Navigation Satellite System：GNSS），Wi-Fi，および専用狭域通信（Dedicated Short Range Communications：DSRC/V2x）は，いずれも協調型自動運転車両の動作においてますます大きな役割を果たすようになっている。

非構造化環境のための無人陸上車両システムの開発

HORIBA MIRA社は，民生用および国防用の自動無人・遠隔操作車両の開発において豊富な経験を有している。2002年以来，HORIBA MIRA社は，MIRA自動制御装置（Autonomous Control Equipment：MACE）技術を採用した先進的UGVの開発と供給を主導してきた。MACEは，HORIBA MIRA社で行うすべてのUGV改造の基礎となる。

MACEは，認知／判断／操作アーキテクチャを採用している（**Figure 4**参照）。各要素は，基本的にそれぞれのコンピュータプラットフォームにホストされている。認識コンピュータは，LIDAR（Light Detection And Ranging），GNSS，ホイールエンコーダ，カメラなどの車両センサからの入力を受け取り，車両の周囲の環境情報を認知する。この軌跡は，次に判断コンピュータに転送され，判断コンピュータは車両DBWシステムの制御要求を生成

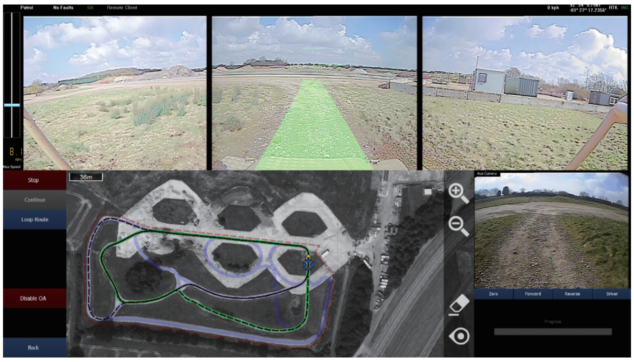

Figure 5 Operator Control Station primary display. The predicted path of the vehicle is shown as a green path in the centre monitor.

angular position encoder input. A mesh network radio system provides communications with the vehicle and an E-Stop system provides a safe and high-integrity way of remotely stopping the vehicle in an emergency.

MACE adopts a Perception / Reasoning / Motion Architecture (see Figure 4). Each element is typically hosted on its own computer platform. The Perception computer takes input from the vehicle sensors such as Light Detection And Ranging (LIDAR), GNSS, wheel encoders and cameras, and builds an understanding of the world around the vehicle. The virtual world is made available to the reasoning computer which also takes inputs from the operator control station and combines this with on-board mission plans and known route networks to decide on a vehicle trajectory. The trajectory is then passed to the motion computer which in turn generates control demands for the vehicle DBW systems. The vehicle can be tele-operated from a local operator control station (see Figure 5) over a radio link or placed into an autonomous mode where it can be tasked from anywhere in the world over a secure internet connection.

The tele-operation terminal or Operator Control Station (OCS) is hosted either on a PC or rugged laptop. For tele-operation either a hand controller with joysticks or a steering wheel and pedals are connected to the computer. The OCS also interfaces to an E-Stop button and a mesh radio network node for communications with the vehicle. Live camera views allow the UGV to be monitored or controlled in real-time. A user-configurable speed profile allows maximum autonomous driving speed to be set, an overhead map view allows the position of the vehicle to be shown and routes to be created or selected for autonomous operation. A “tentacle” shows the predicted path of the vehicle (see Figure 6) and if any obstacles are detected then the system can take appropriate action. The obstacle detection system makes it virtually impossible for the vehicle to collide with any object or drive onto any untraversable terrain either when it is being tele-operated or autonomously driven.

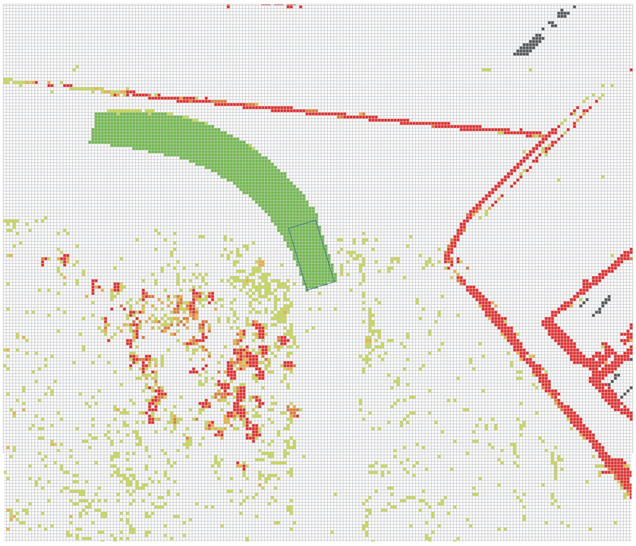

Figure 6 Snapshot from the Obstacle Map showing the MACE III Vehicle (Blue Rectangle) predicted trajectory (Green Tentacle), traversable terrain (White, Yellow and Orange) and obstacles (Red).

A system of LIDARs is used to map the terrain around the vehicle and to detect and avoid obstacles in real time. There is a horizontal LIDAR mounted on the front and rear bumpers providing a safety skirt around the vehicle and a “push broom” LIDAR mounted on the roll cage which is able to generate 3D terrain information as the vehicle moves forward. The primary sensor mounted on top of the vehicle’s roll cage is a Velodyne HDL 32 spinning LIDAR which has a range of 70 m around the vehicle.

The LIDARs produce a huge amount of information

する。現場の操作員制御端末から無線リンクで車両を遠隔操作することができる（Figure 5参照）ほか，自動運転モードに設定すると，世界のどこからでもセキュアなインターネットによって，自動運転の最高速度の設定を可能にする。地図の俯瞰表示は，車両の位置を表示して，自動運転で走行するルートの作成または選択を可能にする。「触手」は，予測される車両の進路を表示し（Figure 6参照），障害物が検知された場合には，システムが適切な行動をとることができる。

LIDARのシステムは，車両周囲の地形図を作成し，障害物をリアルタイムに検知して回避するのに使われる。LIDARが生み出す大量の時間同期情報は，時間同期ハブにおいて他の車両センサと結合される。ハブは同期されたデータを認知コンピュータに提供し，認知コンピュータはソフトウェアアルゴリズムを実行して，大量のLIDARデータからスクロール表示の障害物地図を作成する。障害物地図は，通常，0.2 m四方の三次元ボクセルを表すセルで構成される。

次にシステムは，車両の予測軌跡を見て，進路上に障害物がないか確認する。障害物地図ディスプレイでは，障害物が赤に，全速で通過可能な地形が白に着色される。黄とオレンジのセルは，通過可能だが速度を落とす必要がある地形を表す。

which is time-synchronised and fused with the other vehicle sensors in a time synchronisation hub. The hub makes the synchronised data available to the Perception computer which runs software algorithms to turn the huge amount of LIDAR data into a scrolling obstacle map used to navigate the vehicle through the terrain.

The obstacle map is made up of cells which represent three dimensional voxels typically 0.2m square. An algorithm is run on the LIDAR data corresponding to each cell and the result is a value per cell representing the traversability of the terrain. The system then looks ahead at the vehicles predicted trajectory and checks to see that there are no obstacles in the path. In the obstacle map display obstacles are coloured red and terrain that can be traversed at full speed is coloured white. Yellow and orange cells represent terrain that can be driven but at a reduced speed.

The usual UGV operating environment is challenging for radio links. Tele-operation of the UGVs requires robust data links, with relatively high bandwidth in order to provide sufficient video resolution, frame rate, and low latency in order to reduce operator work load and to enable control at relatively high speeds. ADP research has developed a system which can deliver the equivalent of 4 PAL (720 × 576) video camera streams over a mesh network with a glass-to-glass latency of approximately 100ms. Glass-to-glass latency refers to the amount of time it takes between something being seen at the vehicle cameras lens (glass) and appearing on the operator control station screen (glass). A mesh network approach allows the communications data link to achieve coverage beyond the line of sight by hopping across radio nodes in the network. Each additional hop the video and control signals have to make adds only 10ms additional latency. The radio data link uses Forward Error Encoding (FEC) and Coded Orthogonal Frequency Division Multiplexing (COFDM) to achieve a robust link between the vehicle and control station. The FEC essentially provides an efficient way of sending the same data more than once and the COFDM transmits that data across different frequencies in order to maximise the chance of the data being received.

Current UGV research being carried out includes work on machine perception and image processing to allow the UGVs to navigate and operate without being reliant on Global Navigation Satellite System (GNSS). The work includes road edge detection and tracking in unstructured environments where computer vision cameras look ahead of the vehicle and using image processing techniques to look for edges of an off-road track. The approach uses an image processing pipeline to identify off-road track edge candidates and assigns the candidates to a particle filter which then tracks the road edge. The goal is to be able to follow a track network without using GNSS. Other new research being performed includes using convolutional neural networks and deep learning techniques with computer vision to recognise landmarks for navigation and also identify traversable terrain.

The range of application areas for UGV technology is continuing to expand. For example, HORIBA MIRA is leading research into Intelligent Autonomous Digital Construction Machines through a UK government funded project collaborative research project. The purpose of the project is to research future construction techniques involving a combination of automation, information technology and machine guidance.

The UGV Proving Ground

The purposed-built UGV proving ground at HORIBA MIRA's main site is used extensively for UGV systems development for off-road environments. The facility includes approximately 4 km of off-road test tracks with various features designed to allow engineers to push these vehicles to their limits. Key features include: test hills, positive and negative obstacles, complex bend radii, non-line of sight testing and a fully integrated, elevated control room with line of sight of the whole UGV proving ground.

Conclusions

Achieving autonomous driving and the encompassing

ADP研究は，グラス・トゥ・グラス遅延が約100 msのメッシュネットワーク上で4PAL（720×576）相当のビデオカメラストリームを提供できるシステムを開発した。グラス・トゥ・グラス遅延とは，何かが車載カメラのレンズ（グラス）で見えてから操作員制御端末の画面（グラス）に表示されるまでにかかる時間のことである。現在実施されているUGV研究には，UGVが全地球航法衛星システム（Global Navigation Satellite System：GNSS）に頼らずに航法と動作を行えるようにする機械知覚と画像処理に関する取り組みが含まれる。

UGV試験コース

HORIBA MIRA社の本拠地に作られたUGV専用試験コースは，オフロード環境でのUGVシステムの開発に広く使われている。施設には，エンジニアが車両を限界まで試すことができるように設計された約4 kmのオフロード試験コースがある。主な特徴として，登坂路，上方および下方障害物，複合曲率コーナー，見通し不良環境に加え，UGV試験コース全体を見渡せる高い位置に完全に統合された制御室が設けられている。

C-ITS will bring remarkable benefits. The complexity of such vehicles as well as the foreseeable growth in the number of interconnected subsystems in ITS-enabled vehicles calls for developments in procedures, tools and facilities to test and assess the vehicles and ITS infrastructure under a sufficiently comprehensive set of conditions. The HORIBA MIRA R&D portfolio addresses some of the key development and testing challenges required to eventually achieve a deep penetration level of vehicles with high-automation features and the supporting ITS technologies.

For the structured environment case the emphasis is on the longer term research challenge of developing systems for cooperative automated driving, whereas the emphasis for the unstructured environment case is on the shorter term development challenge of engineering unmanned vehicles that can be safely and reliably deployed in demanding off-road environments.

The development of the real-time simulation tools addresses the need for more virtual techniques for test and validation in the longer term. The development of the Cooperative Driving Simulation and Robotics testbed allows for rapid iterations and benchmarking of CAVs through Robot Hardware-in-the-loop. Vehicle Hardware-In-the-Loop simulations demonstrate the validity of the simulation and robot models through the use of the NGV and the City Circuit.

In the area of unstructured environment automated driving, the development and client use of advanced UGVs and vehicle conversions featuring the MACE technology demonstrates a proven HORIBA MIRA technology. Further enhancements continue to be made and new technologies, software and algorithms are typically integrated and tested on the latest-generation, off-highway research vehicle MACE III and the UGV proving ground.

Future Works

Building on the existing work outlined in this paper HORIBA MIRA is embarking on a number of routes to further expand the current scope of its research in autonomous vehicles.

More in-depth communications Simulation and Modelling capability is to be developed and integrated into the CTMS to better understand the effects of communications related issues in ITS application. New algorithms for cooperative driving and traffic management will also be the subject of future research. These will be developed and tested initially using the cooperative robots and then tested at full scale.

To cope with more complex and realistic conditions during automated vehicle system tests the availability of sensor models and automated vehicle features in the simulation platform will be further expanded.

For unstructured environments, improvements to the UGV operator control stations are planned to increase system productivity, for example in construction applications. Ultimately these will realise the goal of simultaneous multi-vehicle control from a single operator station. To facilitate this the system will be developed to allow the scheduling of autonomous vehicle tasks and the control of vehicles over the Internet.

Further work is also planned on UGV obstacle mapping and terrain classification systems to enable vehicles to be able to react appropriately to dynamic obstacles and to allow increased vehicle autonomy on more complex off-road routes.

まとめ

自動運転を実現し，C-ITSを取り入れることで，著しい便益がもたされるであろう。こうした車両の複雑さに加え，ITS対応車両の相互接続されたサブシステムの増加が予測されることから，十分に包括的な条件下で車両とITSインフラの試験と評価を行うための手順，ツール，および施設の開発が必要である。HORIBA MIRA社の研究開発ポートフォリオには，高度な自動化機能と支援ITS技術を備える車両を最終的に普及させるのに必要な開発と試験の主要課題が含まれている。構造化環境の場合は，協調型自動運転のシステム開発という長期的な研究課題が重視される。一方，非構造化環境の場合は，厳しいオフロード環境で安全確実に展開可能な無人車両の製作という短期的開発課題が重視される。非構造化環境分野では，自動運転，先進的UGVの開発と顧客利用，MACE技術を用いた車両改造が，定評あるHORIBA MIRA社の技術を実証している。

今後の取り組み

この論文で概説した現在の取り組みを基礎として，HORIBA MIRA社は，自動運転車両における現在の研究範囲をいっそう拡大するために多くの方法に着手している。

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ITSの適用における通信関連問題の影響をよりよく理解するには，さらに詳細な通信のシミュレーションとモデリングの能力を開発し，CTMSに組み込まなくてはならない。協調型運転と交通管理のための新しいアルゴリズムも，将来の研究対象になるであろう。

自動運転車両システムの試験中により複雑で現実的な条件に対応するため，シミュレーションプラットフォームにおいてセンサモデルと自動運転車両機能の可用性がさらに拡大するであろう。

非構造化環境では，建設用途などでのシステムの生産性を高めるためにUGV操作員制御端末の改善が計画されている。最終的には，1台の操作員端末から複数の車両を同時に制御するという目標が実現されるであろう。

UGVの障害物地図作成と地形分類のシステムについても，さらなる取り組みが計画されている。これによって，車両が動的な障害物に適切に対応できるようになり，より複雑なオフロードルートでの車両の自律性を高めることができる。

（抄訳 編集部）