ISMCR 2018

21th International Symposium on Measurement and Control in Robotics

26-28 September 2018 – International CBRNE Institute, MONS, Belgium

ROBOTICS FOR THE CHANGING WORLD

www.imeko.org – TC 17

European Society for Defense	Hainaut Sécurité	Belgian Royal Higher Institute of Defense	Climbing and Walking Robots Association	

PROGRAM

SESSION 1. WELCOME and INTRODUCTION TO THE MOBILE ROBOTICS
26 September (Room 1)

CHAIR: Professor L.Van Biesen (VUB/BEMEKO)n Prof Dr Ir Dehombreux (FPMs) Dr Zafar Taqvi (Srt IMEKO/TC17), Professor Y.Baudoin (ICI)

10.00-10.30H	Welcome, Military Robotics, ELROB Status, ICI aims	Madame Vanwijnsberghe (Director Hainaut Sécurité), Dr F.Schneider (Fraunhofer, Germany), M.Y.Dubucq (Director ICI), Prof dr Ir H. Christensen,
10.30-11.00H	KEY-NOTE Autonomous Robot for Gas and Oil Sites (ARGOS): Total's Lessons Learnt and Next Steps	Kris KYDD Head of Robotics Total ARGOS Challenge
11.00-11.30H	KEY-NOTE Robotics and civilian emergency response : how lessons learned enpower Incident command systems organization	LtCol JP Monet (BDFRD, France), Maj E.Rodriguez (BDFRD), Capt S.Mozziconacci (BDFRD), E.Dombre (Emeritus CNRS Research Director, Montpellier University
11.30-12.00H	Robotics for facing CBRNE risks	Dr J.Galatas (KEMEA, Greece, CBRN-KC)m Y.Baudoin (E-KC)
13.30-17.00H	Robotics competition and Exhibition	(ELROB, ICI)
19.30-22.00H	**GET TOGETHER ISMCR at the Hotel MONS**	

SESSION 2/1 IMPROVEMENT of ROBOTICS
27 September (Room 1)

CHAIR : Professor EM Y.Baudoin (ICI/RMA)

10.00-10.30H	KEY-NOTE Unmanned vehicle systems in unstructured environments : challenges and current status	Prof V.Gradetsky (IPMNET, Moscou, Russia)
10.30-10.50H	*IMU based gesture recognition for mobile robot control using Online Lazy Neighborhood Graph search*	*Padmaja Kulkarni (Fraunhofer-Institute, Germany), B. Illing, B. Gaspers, B. Brüggemann, D. Schulz*
10.50-11.10H	*A Novel Data Fusion architecture for Unmanned vehicles*	*I. L. Ermolov, Institute for Problems in Mechanics of the Russian Academy of Sciences, Russia.*
11.10-11.30H	*Coverage Path Planning by swarm;- of UAV by swarm of UGV for traversability analysis*	*L. Cantelli, D.C. Guastella, D. Longo, C.D. Melita, G. Muscato University of Catania*
11.30-11.50H	*Robot control based on human motion analysis with IMU measurements*	*Robin Pellois, Laura Joris and Olivier Bruls Multibody and Mechatronic Systems Laboratory University of Liege, Belgium*
11.50-12.10H	*Development of the Modular Platform for Educational Robotics.*	*A.G. Semenyaka, Moscow State Technological University "STANKIN"*

SESSION 2/2 MEASUREMENT and CONTROL in ROBOTICS
27 September (Room 2)

CHAIR: Professor B. Kiss (BME/Hungary)

10.00-10.30H	KEY-NOTE: JIZAI Body Design of ultra-body fit for super smart society	Prof Masahiko Inami, , Japan)
10.30-10.50H	*Enhancing Bodily Expression and communication Capacity of Tele-existence Robot with augmented reality*	*Yasuyuki Inoue (University of Tokyo, MHD YamenSaraiji (Keio University, Japan), Fumihiro Kato and Susumu Tachi (University of Tokyo)*
10.50-11.00H	*Semantic Grid Mapping based on Surface Classification with Supervised Learning*	*Torsten Engler (Universität der Bundeswehr München Institut für Technik Autonomer Systeme (TAS)*
11.00-11.20H	*Pre-filter to robustify the exact linearization based tracking controller of a SCARA type robot*	*Na Wang, Balint Kiss Budapest Universityof Technology and Economics, , Hungary*
11.00-11.20H	*Feedforward command computation of a3D flexible robot*	*Arthur Lismonde and Olivier Bruls Department of Aerospace and Mechanical Engineering, University of Liege,Belgium*
11.20-11.40H	*Effectiveness test of simulator for e-training in carrying out missions with use of tele-operated vehicles*	*Igor Ostrowski, Andrzej Masłowski NASK Governmental Research Institute Digital Mobile Robotics Department Warsaw, Poland*
11.40-12.00H	*Training of robots' operators with use of multirobot simulators*	*Marek Kacprzak, IMMSF, Warsaw, Poland*

SESSION 3/1 ROBOTICS for DEFENSE and SECURITY - STATUS
27 septembre (Room 1)

CHAIR: Professor Y.Baudoin (ICI-RMA) – Dr Ir F.Schneider (Fraunhofer)

13.15-13.40H	UGV-UAV Growing Market for the Defense	Prof EM Y.Baudoin (ICI/RMA)
13.40-14.10H	In-flight launch of unmanned aerial vehicles Qualitative and quantitative validation of drone detection systems	Dr Ir Geert De Cubber (Royal Military Academy Belgium)
14.10-17.00H	*Competition/Exhibition EOD/IED trials*	

SESSION 3/2. CONTROL and SENSOR SYSTEMS in ROBOTICS
27 September (Room 1)

CHAIR: Prof A.Maslowski (NASK/Poland)

14.10-14.40H	KEY NOTE: Measurements for the Forthcoming Future .	Dr Zafar Taqvin Scientific Secretary IMEKO TC 17 (USA)
14.40-15.00H	*Dedicated simulator for e-training of demining robot "Dromader" operators.*	*Igor Ostrowski, Andrzej Masłowski NASK Governmental Research Institute Digital Mobile Robotics Department Warsaw, Poland*
15.00-15.20H	*An active beacon-based Tracking System to be used for Mobile Robot Convoying*	*Stanislaw Goll, Elena Zakharova, LLC KB Avrora/Ryazan State radio Engineering University, Ryazan, Russia*
15.20-15.40H	*RADAR-based Through-Wall Mapping*	*Sedat Dogru, Lino Marques, ISR-University Coimbra, Portugal*
15.40-16.00H	*Ultrasonic Rangefinder with submillimeter resolution as part of the Rescue Robot's sensor system*	*Stanislaw Goll, Julia Maximova, LLC KB Avrora/Ryazan State radio Engineering University, Ryazan, Russia*

SESSION 4. TECHNICAL PRESENTATIONS and MODELING
26-27 September (Exhibition Site)
Demos in competition 24-27 Sep
IMEKO TC17 meeting
And Room 2 (schedule later adapted, depending on the scenarios)

CHAIRS: Dr F.Schneider (Fraunhofer/Germany), Dr Z.Taqvi, Y.Baudoin
In RED: exhibitors (updated 15 July)

14.00-14.20H	*ELROB 2018. Convoy and Mule of Team MuCAR*	*Thorsten Luettel, University of the Bunderswehr, Munich, Germany* *F. Ebert, P. Berthold, P. Burger, T. Engler, A. Frericks, B. C. Heinrich, J. Kallwies, M. Kusenbach, K. Metzger, M. Michaelis, B. Naujoks, A. Sticht, and H.-J. Wuensche*
14.20- 14.40H	*Standard Test Methods for Mobile Robots*	*Andreas Ciossek, Produkt Manager, TELEROB, Germany*
14.40-15.00H	*Automated Magnetic Field reproducing Stand for Debugging Algorithms Navigation of Mobile Robots.which use on board Magnetometer Sensor*	*Stanislaw Goll, Alexander Borisov, LLC KB Avrora/Ryazan State radio Engineering University, Ryazan, Russia*
15.00-15.20H	*Robsim Software for Mobile Robots modeling*	*O.P. Goidin, S.A. Sobolnikov* *FSUE VNIIA, Moscow*
10.00-17.00H	The ZEUS robot	Steve Wisbey NIC Instruments Ltd
15.30H MEETING IMEKO TC17		
10.00-17.00H	The MSAS vehicle	Janusz Bedkowski, Manadal, Poland
10.00-17.00H	Telemax PRO, Hybrid, PLUS	Andreas Ciossek, Telerob, Germany
10.00-17.00H	The Mörri robot	Antti Tikanmäki, BISG Oulu ,

		University of Oulu Finland
10.00-17.00H	The SR-120D System	Patrik Bylin, Brokk AB, Sweden
10.00-17.00H	The Packbot 510 EOD/Kobra 710	Colin Weiss, ELP GmbH, Germany
10.00-17.00H	Tulf/StrAsRob, smart military vehicles	Dr Alexander Wolf, Diehl Defense GmbH, Germany
10.00-17.00H	Milrem THeMIS	Dr Alexandre Wolf, Diehl Defense GmbH&CoKG
10.00-17.00H	Patria AMV, SLO-IFV	Matti Saarikko, Patria land Systems Oy, Finland
10.00-17.00H	The Wombat Leader-Wombatt Follower	Gol Stanislav, LLC KB Avrora, Russia
10.00-17.00H	The robot LongCross	Bastian Gaspers, Fraunhofer, Germany
10.00-17.00H	TAUT	Reinhard stocker, Guenther Tratting, Austria

NOTE: a SHUTTLE BUS is foreseen during the symposium for transportation of participants to the ELROB stand (standing lunch and competition)

ELROB 2018 – Convoy and Mule of Team MuCAR

F. Ebert, P. Berthold, P. Burger, T. Engler, A. Frericks, B. C. Heinrich, J. Kallwies, M. Kusenbach, T. Luettel, K. Metzger, M. Michaelis, B. Naujoks, A. Sticht, and H.-J. Wuensche

***Abstract*— We present the hard- and software components of team MuCAR's fully autonomous vehicles to participate at the ELROB 2018 in the convoy and mule scenarios.**

For the convoy scenario, different tracking approaches are applied to track the leading vehicle. Data association of the tracking results is done in a PHD filter framework. Given the resulting estimate, an optimization-based planning module computes kinematically feasible trajectories to follow the leading vehicle's path as close as possible with a velocity-dependent lateral distance.

In the mule scenario, the leading guide is tracked either with a LiDAR-based Greedy Dirichlet Process Filter (GDPF) approach or in a vision-only approach by segmenting the disparity image and reprojection into 3D space to match the existing track. During the shuttling phase, two environment modeling algorithms were implemented. Again, one mapping approach is based on LiDAR and the second is based on vision only. The LiDAR mapping approach includes besides occupancy, color information, heights and terrain slopes. In the vision-only mapping approach a dense disparity image with a tri-focal camera is generated and back-projected to create a virtual 3D scene.

Finally, a high-level mission planning module and a local trajectory planner are used for GPS-based autonomous shuttling. The local trajectory planner based on a hybrid A* approach incorporates data from the environment mapping modules for goal-oriented navigation and local obstacle avoidance.

I. Robotic Platforms

Team MuCAR consists of 13 research assistants working at "Autonomous Systems Technology" institute at the University of the Bundeswehr Munich, whose chair is Prof. Dr.-Ing. H.-J. Wuensche. We participated with large success in various competitions such as ELROB 2007–2010, 2012, 2016 and euRathlon 2013, where we took 1st place in the "Autonomous Navigation" scenario. Further, together with TU Karlsruhe and TU München, we competed as part of Team AnnieWAY in the DARPA Urban Challenge 2007, where we were one of only 11 teams which made it into the finals.

Our institute has two autonomous vehicles with full drive-by-wire capabilities, named MuCAR-3 and MuCAR-4 (Munich Cognitive Autonomous Robot Car, see Figure 1). MuCAR-3 is based on a stock VW Touareg with a V6 TDI engine, modified to allow computer control of the steering, brake, throttle and automatic gearbox. Full body skid plates allow for testing in rough terrain. MuCAR-4 is based on a VW Tiguan and equipped with a custom-made drive-by-wire system as well. Since the hardware is either mounted inside the vehicle or protected with an appropriate housing, the vehicles are able to act in fog or rain.

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(a) MuCAR-3. (b) MuCAR-4.

Fig. 1: The 3rd and 4th generation of the Munich Cognitive Autonomous Robot Car (MuCAR).

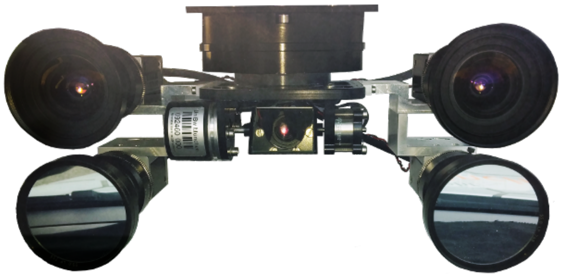
A detailed description of the vehicles' hard- and software follows in the next sections.

A. Sensors

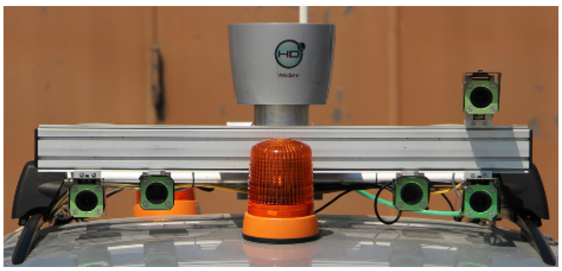
Basic sensors for e.g. the steering-wheel angle or the wheel speed are available in the stock car and can be used for autonomous driving. The sensing of the vehicle was extended with the following three main components:

1) LiDAR: MuCAR-3 and MuCAR-4 are equipped with a Velodyne HDL-64E S2 LiDAR, which is mounted on the roof of each vehicle. It consists of 64 single laser beams rotating around a common axis at 10 Hz. This commercially available sensor provides a horizontal field of view (FOV) of 360° and a vertical FOV of 26.8°. Its horizontal and vertical resolutions are 0.09° and 0.4°, respectively. Additionaly, MuCAR-3 is equipped with a forward-looking, close-to-production 110°-LiDAR from Ibeo which provides raw 3D points and tracked objects.

2) Vision System: MuCAR-3 and MuCAR-4 use MarVEye-8 [1], a multifocal active/reactive vision system, which is mounted between the windshield and the rearview mirror of each vehicle (see Figure 2). MuCAR-3's platform is equipped with a stereo pair of GigE Basler Ace color cameras and a Basler Ace near-infrared (NIR) camera, MuCAR-4's platform is equipped with a stereo pair of GigE Point Grey color cameras. All those cameras are equipped with wide angle lenses. For a wide field of view, MuCAR-4 is equipped with a custom-made forward-looking tri-focal stereo camera system on the roof, a Vislab stereo camera covers the rear area (see Figure 2). The tri-focal stereo system is operated by a self-developed algorithm optimizing a residual over all three images simultaneously. To extend the range of application, MuCAR-3 is equipped with a



(a) Camera platform of MuCAR-3.



(b) Custom tri-focal camera platform of MuCAR-4. The outmost cameras are used for matching.

Fig. 2: The camera platforms MarVEye-8 of MuCAR-3 and MuCAR-4 are equipped with two color cameras (upper row) and a third color camera which is mounted into the hollow shaft. In addition, MuCAR-3 has a near-infrared camera. MuCAR-4 is equipped with a roof rack and a custom made tri-focal wide baseline stereo system.

thermal camera operating in the far-infrared (FIR) spectrum and with a low light (LL) color camera.

3) Inertial Sensors: The main sensor for localization and estimation of motion is an inertial navigation system by Oxford Technical Solutions. Three acceleration sensors and gyros allow estimating vehicle motion in six degrees of freedom. The inertial measurement unit is coupled with a GNSS (Global Navigation Satellite Systems) satellite receiver (GPS, GLONASS).

By combining the information of the inertial navigation system and that of stock sensors, such as wheel-speed sensors, MuCAR-3 and MuCAR-4 are able to perform robust ego-motion estimation, which compensates for short losses of the satellite link.

B. *System Architecture*

The overall system architecture is depicted in Figure 3, [2]. The main computing system is a multi-CPU system equipped with a dual-CPU octa-core Intel Xeon, 64 GByte memory, a Nvidia GPU and shock resistant solid-state drives. It has several interfaces for Gigabit Ethernet, CAN and RS-232 to communicate with the sensors. Real-time computer systems from dSPACE are responsible for low-level control of the vehicle and MarVEye-8 camera platform. Additionally, they provide data from stock vehicle sensors to the main computing system. Interprocess communication between the distinct applications on the main computing system is provided by the KogniMobil Real Time Data Base (KogMo-RTDB). MuCAR-4's setup is similar.

II. Convoying Scenario

This section describes our autonomous following system for the convoying scenario of the ELROB competition.

We want to participate with MuCAR-3 as an autonomous and MuCAR-4 as a manually-driven vehicle. The driver of MuCAR-4 receives a map with UTM coordinates that specify the waypoints which have to be traversed in the given order. While a safety driver will be monitoring MuCAR-3's software and hardware system, it will follow the leading vehicle completely autonomously based on sensor data.

The following sections describe the mission planning, vehicle tracking and path generation modules used during autonomous following.

A. *Mission Planning*

The human machine interface module of MuCAR-3 enables an operator to configure a mission, which contains the type of the convoy leader, the maximum allowed velocity and the desired velocity-dependent convoy distance.

B. *Vehicle Tracking*

The fundamental task for autonomous following of another vehicle is the tracking system, which is described in the following two subsections.

1) Sensors and Systems: For that task our vehicles are equipped with several sensors as already outlined in Section I-A. On the one hand, we use a close-to-production Ibeo LiDAR and a radar sensor, which both perform internal object tracking. The output data of these sensors can be used directly.

On the other hand, we have developed two tracking algorithms which use raw sensor data from cameras and a 360°-LiDAR sensor.

For the LiDAR-only tracking, the Greedy Dirichlet Process Filter (GDPF) as described in [3] is used. The measurements for the filter are determined by first separating the ground plane from obstacle points with [4]. Second, the remaining obstacle points are clustered to coherent objects with the method of [5] and a bounding box is fitted [6] to estimate the dimension of the remaining object instances.

Another model-based method uses a manually generated 3D feature model for detection of a specific vehicle in vision and/or LiDAR data [7], [8]. It is capable of estimating the relative 3D position and orientation, the velocity and the steering angle of a convoy leader precisely. Each 3D feature model consists of significant image and LiDAR features such as vertices, edges, colored/thermal regions and occupied/non-occupied ground-plane cells. The algorithm estimates the vehicle pose of the convoy leader with a multidimensional particle filter. This particle filter generates and maintains numerous hypotheses of the convoy leader's 3D position and orientation. Then, the features of the 3D feature model are used to evaluate the hypotheses. During evaluation, hypotheses are weighted based on the feature congruency. Finally, the result of this model-based tracking approach is the particle with the highest weight which is used as an input to the object-based fusion.

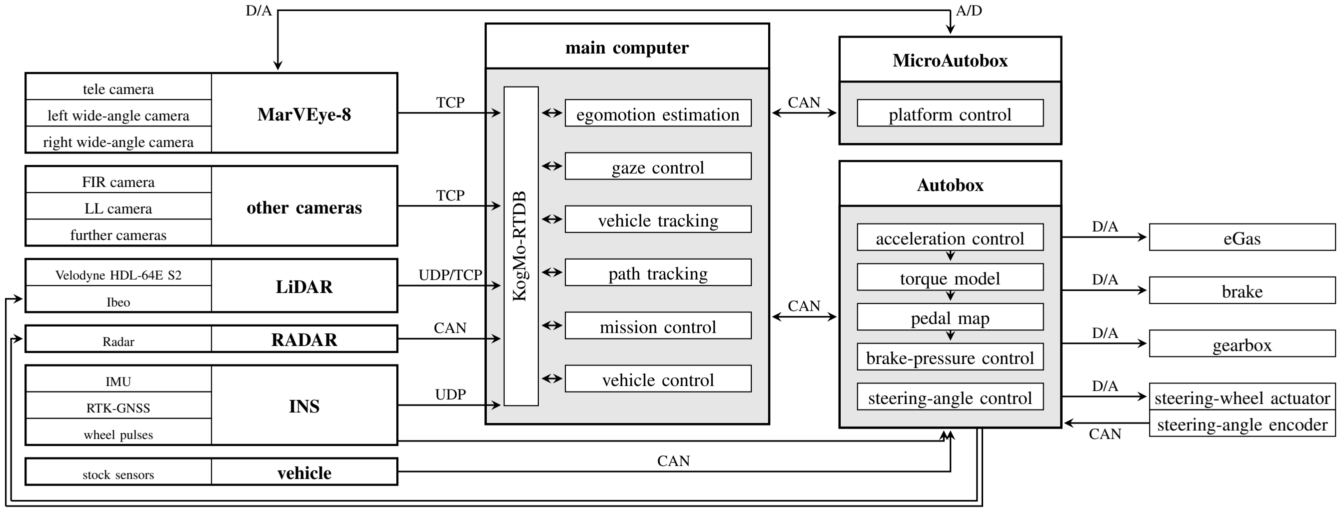


Fig. 3: Hardware architecture of Munich Cognitive Autonomous Robot Car (MuCAR) 3 and 4, taken and modified from [2].

2) Multi-Sensor Data Fusion at Object Level: In order to achieve better robustness and higher accuracy we have implemented a module which fuses the measurement data of all sensors and tracking modules at object level. Thus, it estimates the position, orientation, velocity and curvature of the leading vehicle based on a kinematic single-track model as a motion model.

Due to the huge number of detected objects which are used as input for the object-fusion module, data association is a central problem here. To solve that challenge in an elegant way, we use a Probability Hypothesis Density (PHD) filter [9], which performs data association implicitly.

The resulting output of the fusion module is an estimate for the position, orientation and velocity of the leading vehicle which can afterwards be used for path planning and vehicle control.

C. Trajectory Generation

This section describes the generation of the trajectory for the following vehicle. The trajectory generation application uses the egomotion information [10] and the object-fusion module's output (see Section II-B.2) to generate a kinematically feasible trajectory. The resulting trajectory consists of a series of concatenated clothoid arcs combined with a set of desired velocities and accelerations for each of these segments. The planning algorithm is based on numerical optimization of the trajectories' parameters. The parameters are optimized such that the resulting clothoid path tracks the estimated poses of the leader vehicle as close as possible. Additionally, the velocities and accelerations are computed such that the following vehicle maintains a desired lateral distance to the leader vehicle (see [11]).

III. Mule Scenario

The Mule scenario is comprised of two phases. During the teach-in phase, the vehicle should autonomously follow a human guide to learn the route between two endpoints. Given the learned route, the vehicle then shuttles repeatedly during the second phase between the endpoints along the learned route.

In contrast to the convoy scenario, the vehicle must provide local obstacle avoidance during shuttling. Furthermore, it should be able to recover from complete path blockages by finding an alternative path to the current route endpoint.

High-level decision making, fault detection and global replanning is implemented as a hierarchical state machine. During the teach-in phase, it records and stores the path taken by the vehicle. In the shuttle phase, the path is provided as the reference path to the trajectory planning module. More details can be found in [12].

A. Teach-In

At the beginning of the mule scenario the robot follows a human guide to the first camp. Here, the same LiDAR-based tracking system as described in II-B, with a human-based prior for the GDPF, is used. In a vision-only approach, the human leader is detected and tracked based on the movable stereo platform. The resulting disparity image is segmented to extract potential tracking targets. Afterwards, the potential targets' disparities are reprojected into 3D space and matched to previously existing tracking targets. Additionally, monocular methods, such as optical flow estimation and feature-based tracking, are employed for increased robustness in the tracking stage. The result of the tracking pipeline is a path of the tracked object and shown in Figure 4.

Subsequently, the vehicle can follow the human's path. The path is stored for later use in the second part of the mule scenario, where the robot begins to repeatedly shuttle and exchange cargo between the two camps.

B. Shuttling

1) Environment Mapping: The major prerequisite – enabling a mobile robot to autonomously navigate in unknown terrain – is its ability to perceive the local environment.

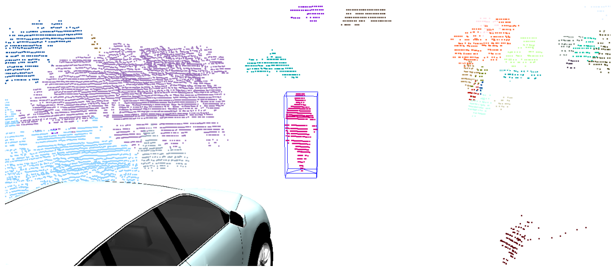


Fig. 4: Result of the LiDAR tracking system of the mule scenario. The ground plane is removed and object instances are used as measurements for the filter. Furthermore, colors of the LiDAR points correspond to the track id. The blue bounding-box denotes the sole active track, which is the human guide.

Creating some sort of environment map using its perceptual abilities thus has become a common task for nearly every robot.

For autonomous vehicles operating in outdoor environments, possibly off-road, the flat-world assumption underlying many mapping techniques is no longer valid. The approach used by MuCAR in this context is the usage of elevation maps, which store the surface of the terrain over a regularly spaced metric grid [13]. Such maps are commonly classified as $2\frac{1}{2}$D models, as every cell of the grid only stores one height value and the third dimension is only partially modeled. A high degree of detail is reached by accumulating the data from multiple complementary sensors in a single map as the vehicle moves. This way, a comprehensive, dense environment representation, including geo-referenced heights, obstacle probabilities, colors, infrared reflectivities and terrain slopes, is obtained.

Maintaining the map is efficient enough to allow building the maps online on-board our autonomous vehicle. This is achieved by an efficient method to manage the map's memory in case the robot moves, that does not need to reorganize or copy any data already stored in the map. Given all position, image and depth sensors, the aim of mapping is to produce a dense local representation of the environment, making use of all data the sensors provide. Considering the limited FOV of a (rigid) camera and the limited angular resolution of even the most advanced LiDAR sensors, a dense representation can only be achieved by accumulating data as the robot moves. For maps of limited physical size, this necessitates managing the map's data, removing data that gets out of scope and adding free map space for areas that just entered the FOV of any sensor.

Currently, each cell of the maps we build contains information about obstacles, geospatial height (both from local LiDAR sensing and from publicly available GIS-data, making use of the high-grade GPS sensor on-board), infrared reflectivity, color (from vision) and slope. Due to the different nature of sensor data, we first update the obstacle information, heights, slopes and reflectivity in parallel before updating the colors. This is because we need up-to-date heights to decide which cells are visible to the camera before updating their colors.

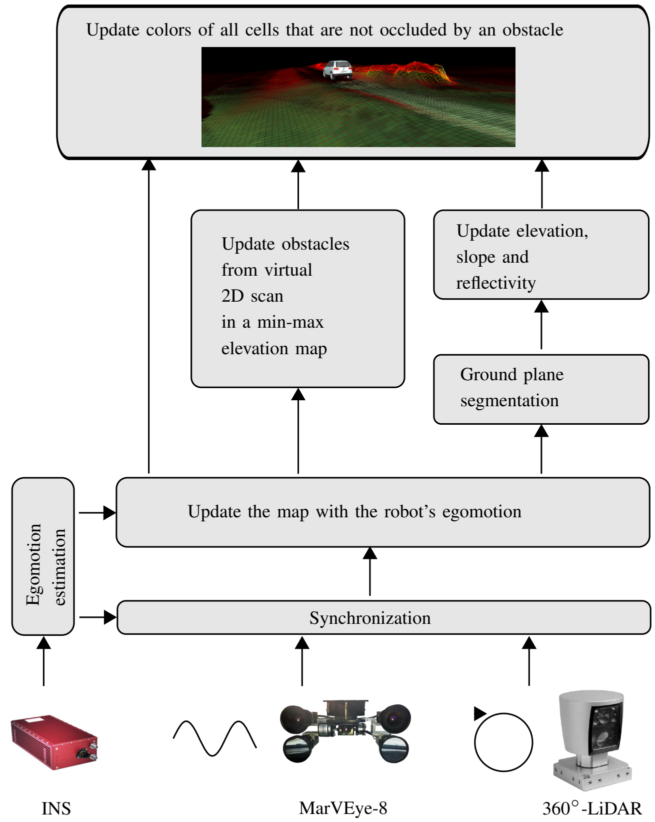


Fig. 5: Overview of the mapping architecture and the sensors involved.

In contrast to the sensor fusion based approach with camera colored LiDAR information, camera only environment mapping becomes feasible. While LiDAR provides many advantages and robust measurements, it is quite expensive. Additionally, it has an active measurement principle which may prevent usage in certain situations. In a vision-only approach, the custom tri-focal camera of MuCAR-4 is employed to create a dense disparity measurement image. The pixels of the disparity image are back-projected to create a virtual 3D scene. Each timestamp the virtual scene is rendered with a GPU to create an expected disparity measurement image. The position of the structures in the virtual scene are filtered over time to minimize the difference between expected disparity image and measured one. Afterwards, the virtual scene is used to create an obstacle grid similar to the one described by the LiDAR section.

Based on this map, a trajectory planning algorithm ensures the robot avoids obstacles and drives along the given path between the camps.

2) Trajectory Planning: The trajectory planning algorithm is described in detail in [14]. It is a variant of Hybrid A* that constructs continuous-curvature trajectories from fixed-length clothoid arcs.

Given a goal pose around 25 meters ahead of the vehicle on the global reference path, the planner attempts to find a trajectory that takes it close to the goal without necessarily reaching it exactly, which makes it robust against GPS errors. The cost function considers features such as curvature, change of curvature, proximity to obstacles, slopes, road probabilities and vegetation probabilities. As the clothoid arcs' curvatures and change of curvature are limited based on the vehicle's speed, its current and maximum steering angles as well as the maximum admissible lateral acceleration, all paths are guaranteed to be drivable.

Once the least-cost path has been found, the planner computes a piecewise-linear velocity profile (constant acceleration along each arc) which respects the vehicle's constraints w.r.t. lateral and longitudinal acceleration.

3) Global Replanning: According to the scenario definition the current route can be blocked completely. In order to find an alternative route, a digital road network of the environment in the OpenStreetMap (OSM) format is used. After a blockage is detected, Dijkstra's shortest path search is applied to find an alternative path through a graph derived from the road network. In this graph, edges correspond to roads and vertices to intersections of the roads.

IV. Summary

This paper first described the hard- and software system of the two autonomous vehicles of Team MuCAR. Then the methods implemented to accomplish the convoy and mule scenario of the ELROB 2018 robotic trials were covered. In the case of the convoy scenario, we presented the vehicle tracking system which adopts fusion at object level by applying a PHD filter. Input to the fusion algorithm comes, among others, from a LiDAR-only tracking algorithm and a model-based tracking approach. This single estimate of the leading vehicle is then used to generate a kinematically feasible trajectory to autonomously follow the leading object. For the mule scenario, we apply either a LiDAR-only based tracking algorithm or a stereo vision approach to track the leading person and store the recorded path between two camps. Given this path, the vehicle is able to shuttle between these two camps by adopting a trajectory planner which generates drivable trajectories and performs local obstacle avoidance. Finally, replanning capabilities upon complete path blockages were covered.

ACKNOWLEDGMENT

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References

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RPAS -UGV: a growing market for military and civilian applications.

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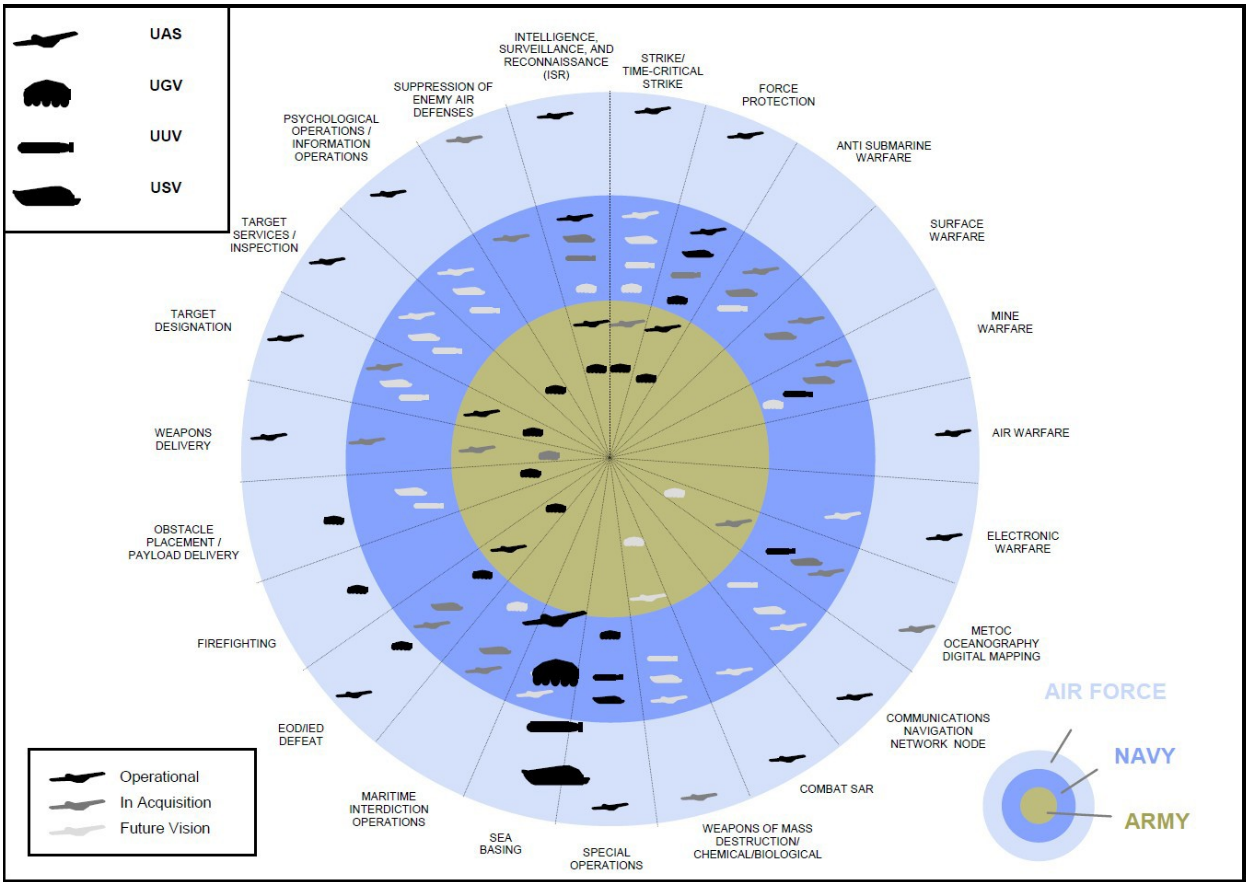
1. Introduction

The Royal Military Academy was coordinating two European Projects , one focusing on Humanitarian Demining, the other one on Search and Rescue Operations, both projects intending to exploit the improved performances of Robotics Systems, Unmanned Aerial Vehicles (UAV) or, better said, Remotely Piloted Aircraft Systems (RPAS) in particular and Unmanned Land-vehicles or UGV
The RPAS are characterized by an increasing development and use in the military sector for combat, combat support and logistic missions, as well as in the civilian sphere, essentially focusing on Environmental Surveillance and Security missions: The well-known acronym RSTA summarizes those missions: RECONNAISSANCE, SURVEILLANCE, TARGET ACQUISITION
The UGV are still prototypes and regularly tested through competitions like ELROB (www.elrob.org)

From a recent Roadmap 2007-2032 developed by the US Department of Defense[1], the following picture highlights the most urgent mission needs that are supported both technologically and operationally by various unmanned systems



Depending on the mission, UGV (Unmanned ground Vehicles), USV (Unmanned Sea Vehicles) or RPAS may be required. A combination of UVS may also depend on the strategic or tactical nature of the tasks entrusted to them. Those tasks may be summarized as follows:

1. **Reconnaissance and Surveillance**. Some form of reconnaissance (electronic and visual) is the number one Combat Commander priority applicable to unmanned systems. Being able to survey areas of interest while maintaining a degree of covertness is highly desirable. The reconnaissance mission that is currently conducted by unmanned systems needs to increase

[1] First Edition of the Integrated Office of the Secretary of Defense Unmanned Systems Roadmap – Dec 2007

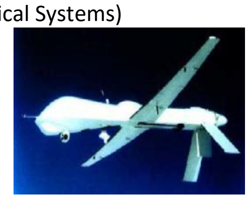
standardization and interoperability to better support the broad range of NATO DoD users.

2. **Target Identification and Designation**. The ability to positively identify and precisely locate military targets in real-time is still a current shortfall with RPAS. Reducing latency and increasing precision for GPS guided weapons is required. The ability to operate in high-threat environments without putting warfighters at risk is not only safer but potentially more effective than the use of current manned systems

3. **Counter-Mine Warfare.** Sea mines may cause damage to ships and obviously warships. Improvised Explosive Devices (IEDs were/ are the number one cause of of coalition casualties in Operation Iraqi and Afghanistan Freedom. A significant amount of effort is already being expended to improve the military's ability to find, tag, and destroy both land and sea mines. Unmanned Systems are a natural fit for this dangerous mission.

4. **Chemical, Biological, Radiological, Nuclear, Explosive (CBRNE) Reconnaissance.** The ability to find chemical and biologic agents and to survey the extent of affected areas is a crucial effort.

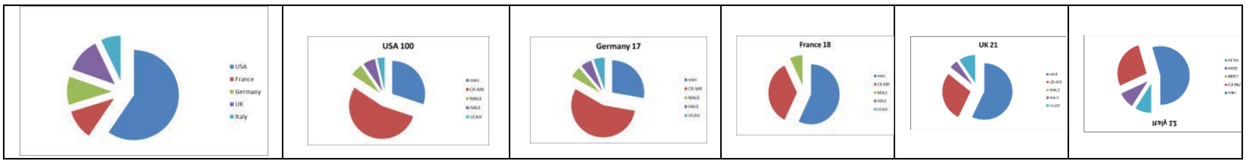
Depending on those missions (limiting the study to RPAS), the endurance, altitude and payload of the used RPAS play a crucial role: several categories of RPAS may be considered. The following table includes some statistical information on the most involved categories[2]

RPAS Category-Acronym	Range-Payload	Flight Altitude/ Endurance	Example
Microdroneµ AV	<10km < 1kg	250m / 1 h	ORBIT Geospatial technologies 
Minidrones MAV	<10km < 10kg	300m / 2 h	
Close Range (CR), Short Range (SR), Medium Range (MR)	10 km <250 km >10kg	>1000m / << 24h	FPASS (Locheed Martin – USA) 
Medium Altitude Long Endurance MALE	>500km > 100kg	>10000m >24 h	SIDMHarfang (EADS France) HERON TP (Israël) PREDATOR A/B (USA General atomics Aeronautical Systems) 
High Altitude Long Endurance HALE	>2000km	20000m >24h	Global Hawk USA (Northrop Grumman) EuroHawk USA-Germany (EADS) 
Unmanned Combat aerial Vehicle UCAV	>1000km >500kg	>10000m >1h	X-47B demonstrator (Northrop Grumann) 

Let us add that the NATO also considers two categories of RPAS, the LOS (Guidance from a Groud Station – Line of Sight) and the BLOS (Beyond Line of Sight) or Satellite Guided Drones (MALE and HALE)

2 For a detailed information see RPAS The Global Perspective, Blyenburgh&Co © www.uvs-info.com

Referring to the USA production (100%) without giving precise (evolving) produced quantities, the following picture underlines the current status of the major RPAS producers/actors from the NATO Countries (status 2014)



2. National – International Programmes

Thanks our participation to several NATO STO (Science and Technology Organisation) AVT (Applied Vehicle Technology) Panel working groups (the more recent being the AVT 175 focusing on Unmanned Systems Platform Technologies and Performances for Autonomous Operations, the AVT 174 focusing on Qualification and Structural Design Guidelines for Military Unmanned Air Vehicles), the following National and/or International still evolving programmes, figures and cooperation (limited to the 2014/15 references) may be underlined.

1. The United States

The United States have the most important RPAS fleet covering all categories and characterized by a high interoperability thanks to their system ROVER allowing all Land, Sea, Air Forces to get in real time all necessary information for filling their missions. As an example, PREDATOR B have been deployed by the Navy for struggling against the sea piracy.
Even if categorized MALE, the MQ1 PREDATOR (General Atomics Aeronautical Systems, Inc), equipped with a Laser designator and precision-guided munitions, is now a multi-mission vector engaged for 80% in Combat missions. The MQ-9 Reaper is the new version, a medium- to high-altitude, long-endurance UAS. Its primary mission is to act as a persistent hunter-killer for critical time-sensitive targets and secondarily to act as an intelligence collection asset. The integrated sensor suite includes a SAR/MTI (Moving Target Indicator) capability and a turret containing electro-optical and midwave IR sensors, a laser rangefinder, and a laser target designator. Let us also remind the Combat mission support entrusted to the MQ-5B HUNTER (Northrop Grumman Corporation) in the Balkans and in Irak, the RQ-7 Shadow 200 at disposal of the US Army in Afghanistan, the MQ-8 Fire Scout chosen by the US Navy.
The 2013/14 investment reached about 500M$ for UGV, 3000M$ for RPAS and 170M$ for USV

2. The United Kingdom

The UK has acquired the PREDATOR B Reaper and was developing a MALE system through the program MANTIS entrusted to the Society BAE Systems (Rolls Royce – QinetiQ – GE Aviation - Meggit – Selex Galileo) and in close cooperation with the program WATCHKEEPER related to the development of Tactical Drones developed by Thales UK for an investment evaluated to 1 Milliard Euro. An UCAV system was also in development, namely the TARANIS.
Let us also remind the operational use of the HERMES 450 (from the Society Elbit Systems in Israël) in Irak and Afghanistan.
Beside those MALE vectors, a lot of mini-RPAS as well as CR, MR drones, like the PHOENIX and the VIGILANT are operational.

3. Germany

Germany considers the drones as an important military tool and owns many tactical drones like the Short Range LUNA or the mini ALADIN. But Germany, in favor of International or European cooperation in the domain of HALE or MALE drones, and recently engaged in Afghanistan, focused on the development of the EuroHawk system (inspired by the US Global Hawk).The Bundeswehr favors the Reconnaissance Systems, equipping the drones with cameras, IR sensors and SAR and oriented its choice to the MALE offered by the Reintmetal society, based on the HERON platform from Israël
About 2 Milliards Euros have been foreseen over the periode 2010-2015, about 900M€ for the EuroHawk, but also about 450M€ for the NATO Program called Alliance Ground Surveillance (AGS)

4. Italy

Italy invested in HALE drones with the program MOLYNX (Selex ES&Thales Aliena Space), in UCAV with the SKY- X (Alenia Aeronautica) and above all in MALE drones, the PREDATOR A and B involved in reconnaissance missions in Afghanistan. The PREDATOR are also used for border and maritime surveillance missions.

5. France

The French capacities include MALE and tactical drones. The SIDM-Harfang acquired by the Air Force in 2008, based on the Israeli platform HERON, was developed by EADS DS France and IAI-Malat Israël. It was foreseen with the SAR/MTI (Ground Moving Target Indicator) and has been involved in Afghanistan. Such MALE induces a total cost of about 50 M€/year
The Army has used tactical MR drones Patroller, developed by SAGEM, for close reconnaissance missions (to 12 km), involved in KOSOVO and Afghanistan while new or renewed SPERWERs are now equipping the Armed Forces. Mini-drones are also equipping the French army, for example the DRAC developed by EADS with SMEs like Survey Copter, while the SKYLARK 1 from Israël, with similar performances had completed their Arsenal.

6. The NATO objectives

The previously mentioned program AGS concerns the acquisition of Global Hawk Drones essentially devoted to Surveillance missions. The program, with a participation of 15 Countries and estimated to about 1.5 Milliards euros is funded by Canada, Italy and Germany for about 70%. The partners France, UK and the Netherlands, not directly involved in this program, are focusing on the MAJIIC project (Multi-sensor Aerospace/Ground Joint ISR Interoperability Coalition), a multinational program where to Germany, Canada, Spain and the USA are the major contributors .

Summarized:

The advantages offered by RPAS to the Defense are numerous and essentially focusing on the so-called dull, dirty, and dangerous areas. This refers to missions which would generally be long, tiring, and in some cases boring for aircraft pilots, and which would present a high risk factor for them[3]
In order to decrease the force sizes and the danger of specific activities, RPAS are force multipliers that can increase the Unit effectiveness. Let us mention the threat of NBC attacks on Military Forces abroad or, less critical but even dangerous, the detection of IED actions in countries affected by civilian conflicts. As suggested in the US Roadmap[4] , in a climate more demanding of lossless engagement, UAVs can assume the riskier missions and prosecute the most heavily defended targets. Unaccompanied combat UCAVs could perform the high-risk suppression of enemy air defenses (SEAD) missions currently flown by accompanied F-16 In such a role, RPAS would be potent force multipliers, directly releasing aircraft for other sorties.

3. UGV

During a NATO workshop organized in September 2004 in Bonn, over 70 participants from the military, industry, research and ministries of 16 different countries defined a roadmap for Multi-robotics systems. The military users generated a large number of tasks that might or might not be supported by robots. The five most relevant missions according to the military are:

Reconnaissance and surveillance for tactical support of the forces on the ground including CBRN.
De-mining: tactical and post-conflict – clearing roads and fields from AP and AT mines
Convoying: transports of goods
Checking vehicles and people from explosive and weapons at checkpoints
Carry equipment for dismounted soldier

The mission requiring the most intelligence of the robots working as a team is clearly the first listed task, namely reconnaissance and surveillance. Other tasks rely more on the capability of tasks oriented sensors, like mine and chemical detectors of hardware capabilities like size and payload.
This mission definition is however too wide and should actually be split in 3 different ones:

- Reconnaissance of a totally or partially unknown area
- Surveillance of a known area like a camp or an airfield.
- Military Mine clearance and CBRN-Threat

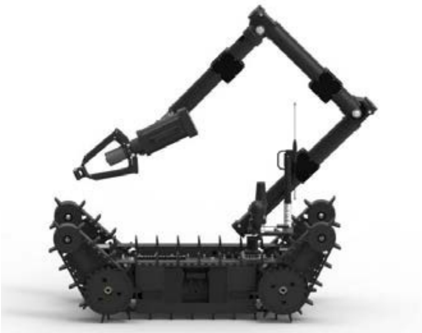
An analysis of Military user requirements (LCG-2 NATO Group on Land Capability) suggests that 4 classes of vehicles may be needed:

1. Small Wheeled Robot (SWR)
2. Medium Wheeled Robot (MWR)
3. Medium Tracked Robot (MTR)
4. Large Wheeled Robot (LWR)

The LWR is designed for extended patrol missions, following a planned route with the autonomous capability to face obstacles not present in the map. It has high mobility, heavy payload, and self- transportability. It has large dimensions that affect its own explorative/patrolling capability, so it brings inside ("marsupial") MWR (medium size, high speed), MTR (medium size, higher mobility) and SWR (small size) that can be deployed on the field. When some kind of abnormal condition (i.e., presence of intruder or security breach) is detected by the sensor suite, a first alarm is sent to the remote control station. If the sensors of the larger robots provide enough situation awareness, the remote operator can decide the next action (i.e., send an alarm to the crew or neglect the robotic alarm). If there is a need for further analysis, the larger robot deploys a swarm of medium and small robots, performing a coordinated analysis of the situation. The medium and small robots have limited energy autonomy due to their limited dimensions, so they can use the larger robot as energy-charge base. Each vehicle should be equipped with a suite of sensors and a supervised-autonomy intelligent controller so as to be capable of successfully executing its assigned mission with, or without, direct communication with a human supervisor.

Some pictures from the ELROB'2018 competition (more information on www.elrob.org/elrob-2018 and catalogue on request by the author of this paper)












4. Legality, Safety, Interoperability, Ethics

Military Robots (UGV) should be capable of protecting assets, providing information and reporting alarm messages to a remote control station. Extensive use of Unmanned Ground Vehicle systems should enable to completely substitute human operators in surveillance tasks. Robots should be capable of being deployed individually, or in groups. The overall system should be capable of:

1. being sent on extended patrolling missions up to 7/24 hours, with the ability to follow a planned route, avoid obstacles, reach a designated destination, observe and report sensitive area assessment, and return to base. They should also be able to operate in close proximity to manned vehicles, for example to serve as lead vehicles on a patrol.
2. carrying RSTA packages and performing a full range of RSTA activities when in position, and limited RSTA capabilities while in motion.
3. operating through smoke.
4. autonomous obstacle avoidance navigation to deal with unforeseen objects.
5. to relay communications so as to coordinate with each other.
6. to detect intruders and security breaches.
7. operating either independently or in groups.
8. following a planned path on a map to an accuracy of 1 m to 5 m over a distance of 1 km using on-board navigation systems and fixed beacons.
9. day or night operation in limited adverse weather (rain/dust). Night operations are extremelyimportant.

When considering combined military missions devoted to UGV, USV and UAV/RPAS, let us say UXV, the minimum operational requirement for UXV or UXS is interference-free compatibility. The optimum synergy among the various national Systems deployed requires close co-ordination and the ability to quickly task available assets, the ability to mutually control the UXS (including their payloads), as well as rapid dissemination of the resultant information at different command echelons. This requires the employed UXS to be more than just compatible, i.e. interoperable, in order to be of any meaningful operational utility for the commanders, particularly in a very fluid/dynamic mixed and non-segregated operational environment.
Currently, many UXS are not fully inter-operable, some are not even operationally compatible. Current or "legacy" UXS have been designed and procured nationally and contain system elements that are generally unique and system-specific. They do not have standard interfaces between the system elements. This results in a variety of non-interoperable/non-compatible systems. Although commonality of hardware and software would be a solution

Furthermore, RPAS systems must comply with rigorous certification and airworthiness procedures, including communications, flight controls and ground stations, they also have to demonstrate safety in relation to loss of communication with air vehicle, resistance to jamming & correct failure-mode recovery; Sense-and-avoid technology/architecture will almost certainly be required, in particular for micro- and mini UAV. We strongly suggest the readers to consult the ' RPAS global Perspective' edited by Peter Van Blyenburgh, President UVS International[3]: the use of RPAS is recognized by the International Civil Aviation Organization (ICAO), a policy for the airworthiness of light RPAS (less than 150kg) has been introduced by the European Aviation Safety Agency while the European Commission launched a European Steering Group (ERSG) focusing on the coordination of the European RPAS Market: this ERSG includes the JARUS[5] group which aims to develop operational requirements and certification specifications.

3 P.Van Blyenburgh, The Global Perspective 2013/2014, www.uvs-info.com
4 USA DoD Roadmap 2000-2025 (Office of the Secretary of Defense, D.R.Oliver, A.L.Money)
5 www.jarus-rpas.org

Last but not least, ethical considerations are discussed not only in the context of military combat/combat support missions but also in civilian applications.
While remotely piloted aircraft systems are very useful to several applications and may even become a tool of choice (for instance in Demining Technical Survey or Search and Rescue Operations in affected Countries or Areas, they also create some strong opposition. The main concerns include the protection of human rights such as privacy or life and the negative connotations attached to these tools are due to being used as weapon carriers in military conflicts.
The development of a technology, including robotics, takes account of a number of factors. These include social, economic, application and environmental implications and associated issues. In this context the design of the technology is constrained and thus dictated by associated national and international standards and regulations. From the standards perspective the developer of the technology is required to carry out proper risk assessment so that the technology complies with safety requirements as emphasized in the standard.
The UK Robot Ethics (UKRE)[6] group formed as part of the BSI AMT/00-/02 (Robots and Robotic Devices) committee has identified various ethical issues of robotics, and has classified these into four main categories, namely societal, application, commercial/financial and environment.
Some of the fundamental societal robot ethics issues include among others the Privacy and confidentiality, the respect for human dignity and human rights, the respect for cultural diversity and pluralism, the De-humanization of humans in the relationship with robot, the responsibility and legal issues. Concerning the Application issues, let us limit them to the military applications: The development of robots for military applications, especially for combat is a matter of serious discussion and debate. Concerns are shown over the use of robots in combat scenarios, and these include how combatants and innocents may be discriminated from one another in close-contact encounter. Although, many of the ethical questions in this respect have been contained into the military command and control framework (by keeping human in the loop), i.e. where commanders are responsible for issuing orders and the soldiers are for carrying out those orders, the system becomes very complex as the number of robots deployed in combat scenarios increases.

3. Conclusion

Let us give a first conclusion to Christian Bréant, former Director of the Research&Technology of the European Defense Agency: civil and military resources are today combined to achieve societal acceptance of using RPAS in airspace. The EDA tries to clearly define the necessary cooperation between both sectors: the military missions and the civilian missions for overcoming the Security challenges of our Societies and a sustainable Economic policy.

A second conclusion has been expressed by Major André Haider[7] from the joint Air power Competence Centre (JAPCC) of the NATO: facing future unexpected adversaries empowered by the growing development of the modern technologies, UAS involvement in future operations, including offensive ones, is expected to escalate and mission planning and execution will be even more dependent on unmanned support than today: we must thus prepare ourselves for all aspects of automated RSTA

6 www.robotethics.org.uk
7 UAS Operations in Contested Environments, Major A.Haider, RPAS The Global Perspective 2013/2014 www.uvs-info.com

“Unmanned vehicle systems in unstructured environments: challenge and current status”

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Abstract

The scientific and applied interest to Unmanned vehicle systems (UVS) or Unmanned guided vehicles (UGV) is growing every year and a lot of world-known universities and companies are working very hard in R&D of UVS. The fully autonomous vehicles or ones with different degrees of autonomy vehicles are used on the land, in the air, and in the sea for broad range of technologies including hazardous waste cleanup, agriculture crops processing, transportation, underwater monitoring, nuclear power station repair, as well as security, inspection, demining, military operations.The new uses for these systems may be found every day.

Real UVS has to understand control commands fast and without mistakes. They have to possess logically thinking, have possibilities of learning and training, produce decision making by themselves, to move in unknown environment without operator. However, today in practice the situation may arise when operator forced to intervene in teleoperated control because of unsufficient reliability of robot behaviour. High level of artificial intelligence and mind as well as data base and special software are required for real UVS.

Introduction

As a rule UVS includes following systems: mechanical, sensory, control, drive, transdusers of external information, technology. The systems are acting in accordance with solving tasks, algorithms, programming trajectory of motion, what may be proofread automatically depending on environmental situation changing.

The brain of UVS is intelligent cooperation of environment by means detective sensors and multilevel feedback control, working under special software and algorithms.

Software is used for such functions like communications, data links, vehicle sensory control, and data management. Various UVS software challenges are illustrated as example of company development, including software architecture and data collection, transfer, integration and decision-making [1-3].

Flexibility, configurability, reliability and availability are important for UVS software.

Artificial intelligent planning, logical kernels based on "Multidimensional Information Variable Adaptive Reality System" presented by several companies may serve as an example of robot software. Several types of UVS including Wall Climbing Machine, illustrate their possibility for various functions and tasks [4-7], depends of areas applications (Fig. 1).

Dron quadrocopter

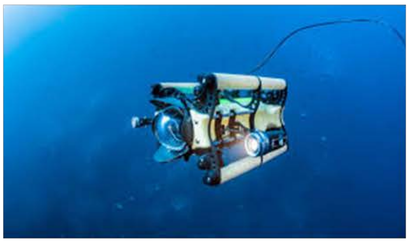
Autonomous Systems, Control and Optimization (ASCO) Lab

Ground robot

MAARS: The MAARS (Modular Advanced Armed Robotic System)

Caterpillar robot

CFP Robotic Group - CFP Company



Underwater robot

Pure Advantage

Robot car

Google car

Wall Climbing robot

IPMeh RAS

Fig. 1 Air, ground, underwater, fields Robots.

Sensory and navigation systems are rather important for UVS; among these it is necessary to mention laser scanner, vision and stereo vision, optical zoom cameras, GPS/GLONASS, etc., that are used for trajectory planning, obstacle avoidance, recognition of objects, 3D vision, design of maps [8-14].

Different control methods for UVS, strategies of autonomous wheeled mobile robot motion in unstructured environments, including fuzzy system, neural computation are analyzed and conditions for performing tasks realization are considered. Groups of mobile robots motion are based on artificial intelligent application.

Creation of artificial brain in machine areas permits to increase reliability of multiagent motion for robot interaction. Information and data transmission is important for providing the required direction of motion for every agent. Information of motion and map correction data are storing in the memory of every robot. To know mutual agent position, all robots have wireless radiofrequency sensors. Multiagent systems have possibility for adaptation to environment.

The future R&D will improve main peculiarities of UVS and multiagent group. Among the noticed characteristics there are reliability, maneuvrability, accuracy, stability, and increase functional possibilities.

Future aspects of UVS innovation technologies, their application, improving of people live are taken into consideration.

UVS Structure

The main peculiarity of UVS is that their can perform intelligent motion in unstructured environment with possibility to fulfill decision making. Mobile robot motion is accomplish automatically by means intelligent control without people or with minimal participation of man-operator on the highest level of control structure.Degree of autonomy are determined on possible participation and role of man-operator. UVS is acting (Fig. 2) under sensory control based on special software and algorithms using such functions as artificial intelligence, decision making, obstacle avoidance that is realised by application fuzzy logic, neural computation that could satisfy such qualities like reliability, manoeuvrability, easy connection, stable motion on undetermine environments. UVS may be equipped by ultrasonic sensors and stereovision system. The autonomous mobile robot has groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle that the model of the mobile robot has two or four driving wheels and the angular velocities of the wheels are independently controlled.

The proposed methods have been implemented on the sensory-based control strategy. UVS for use on land can solve various goals (Fig. 3) and trajectory planning has important significance for motion design.

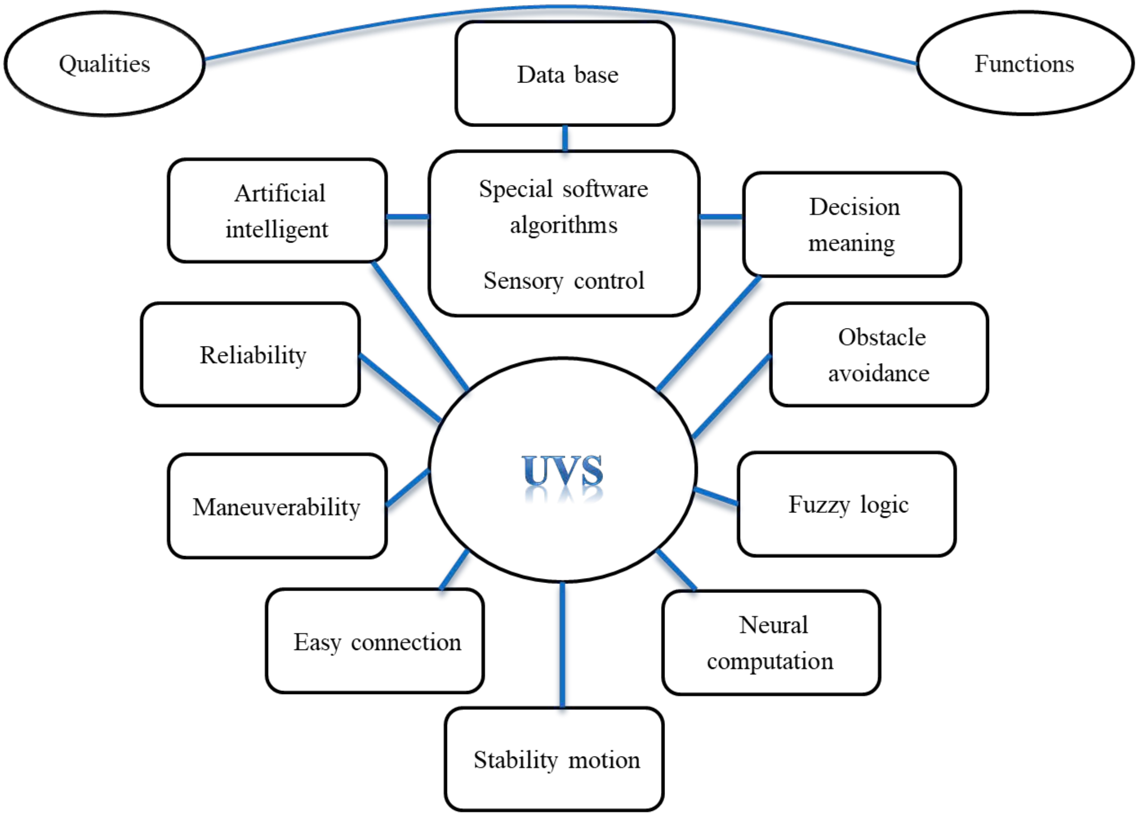


Fig. 2 Unmanned Vehicle System (UVS) Structure.

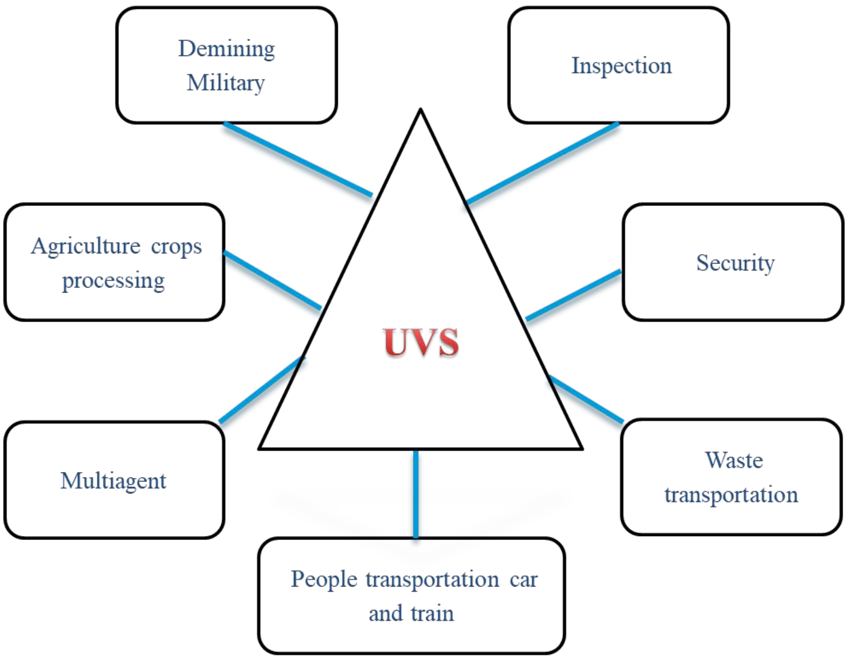
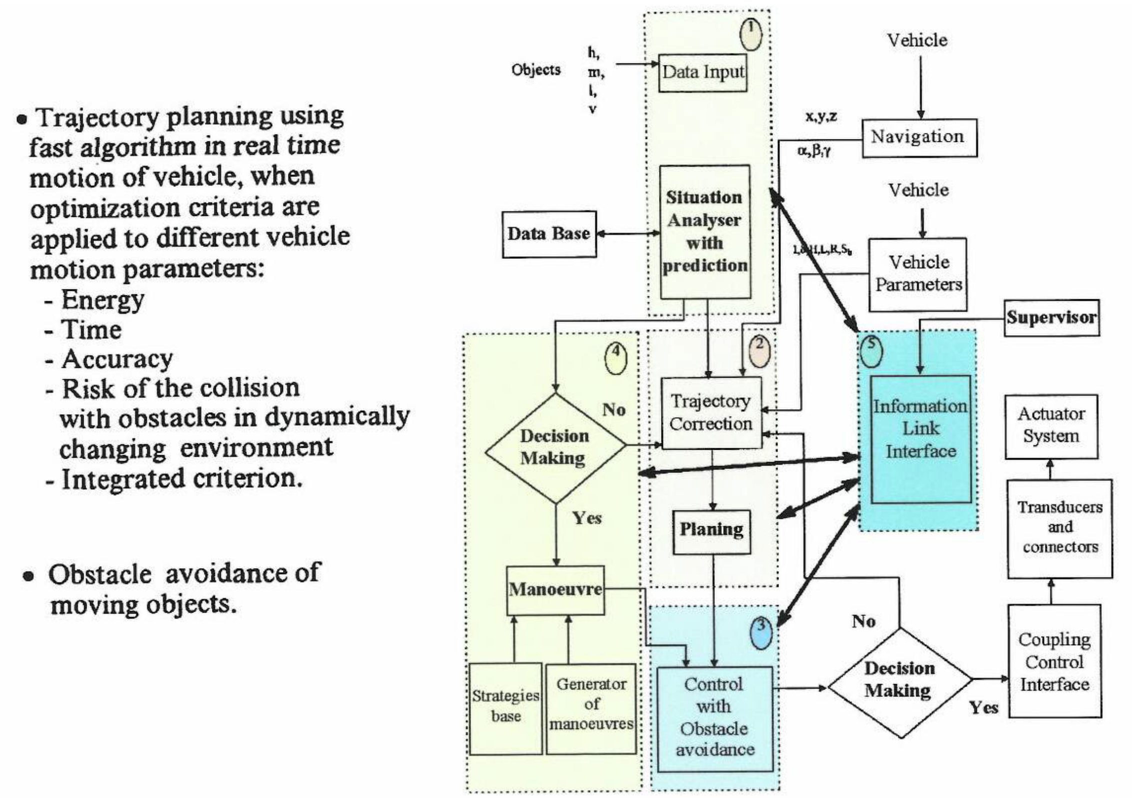


Fig. 3 UVS for use on land.

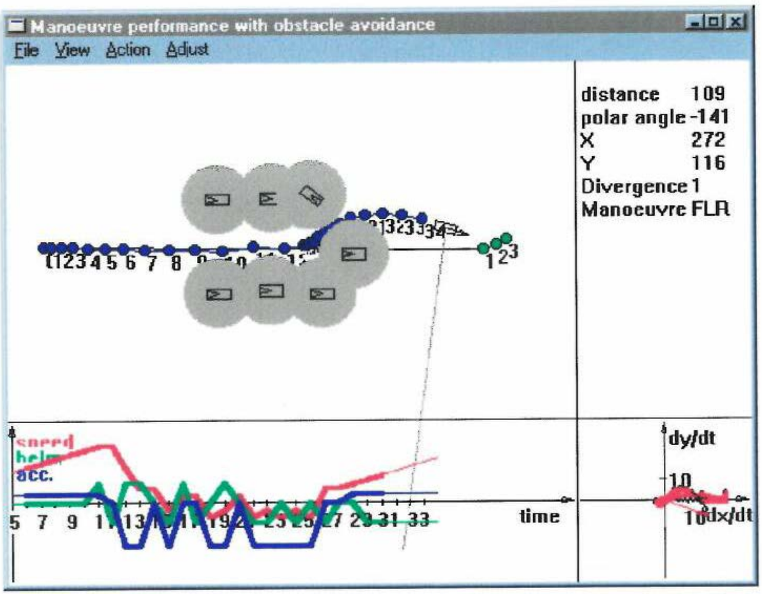
Trajectory planning.Fuzzy logic.Decision making.

In common case structure of the trajectory planning with obstacle avoidance is presented in Fig. 4 and it includes 5 blocks:

1 – situation analyzer with prediction, 2 – trajectory correction and planning, 3 – fuzzy control with obstacle avoidance, 4 – decision making and manoeuvre producing, 5 – information link interface.



Structure of the trajectory planning with obstacle avoidance



Computer simulation of obstacle avoidance manoeuvre in trajectory planning.

Fig. 4Trajectory planning and obstacle avoidance.

Example of computer simulation is showing obstacle avoidance with manoeuvre in trajectory planning processes (Fig. 5).

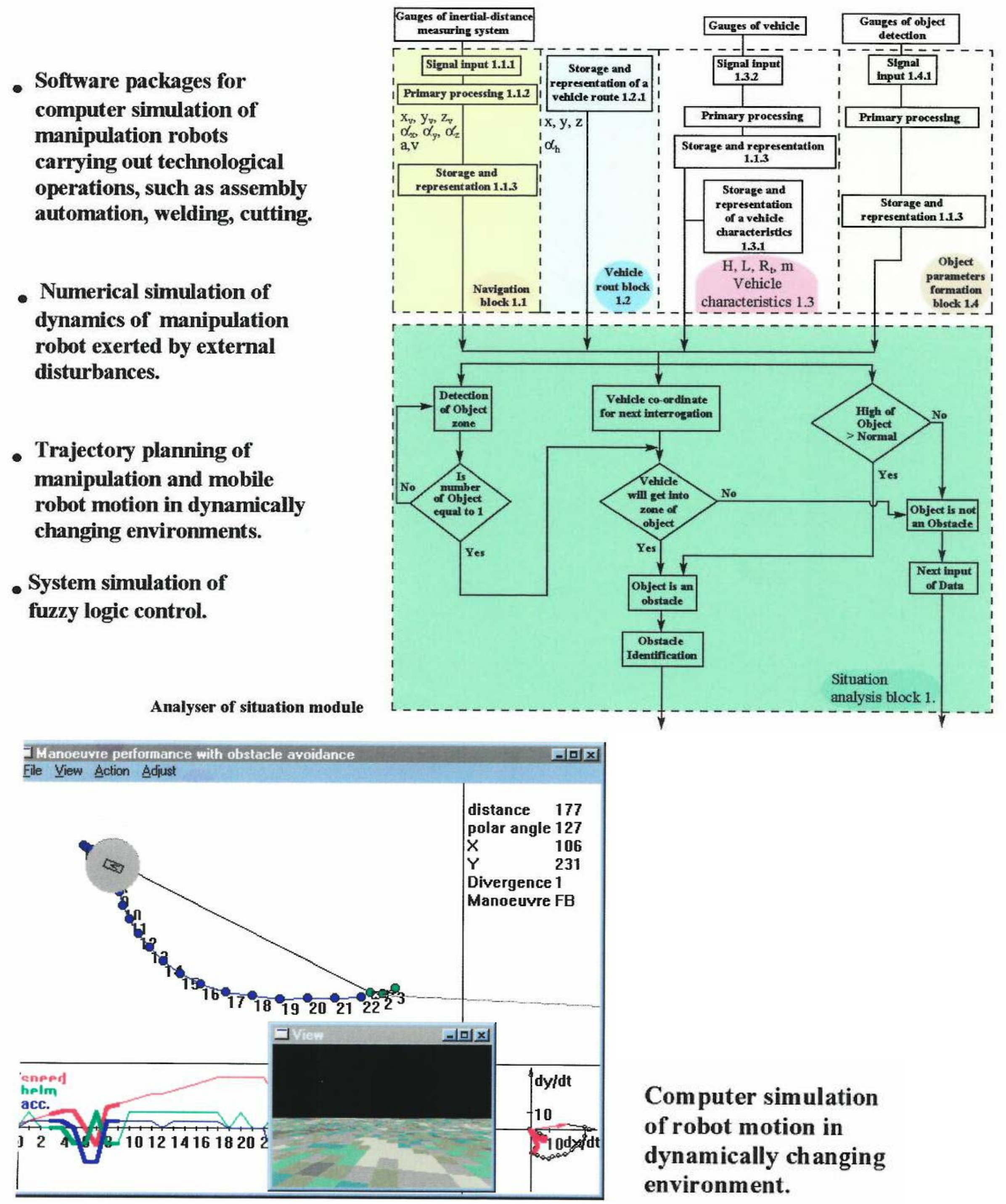


Fig. 5Computer simulation of robot dynamics.

Fuzzy logic for decision making was suggested in paper [1] and was applied for car algorithmic control of a model car by oral instruction [2] and for design control system [3]. Fuzzy systems on the base of Weight Associative Rule Processor WARP were created and methods of realization of such system was delivered [4-7].

Currently much research in robotics deals with different problems of the motion of wheeled mobile robots and the motion control of wheeled mobile robots in unstructured environments. Fuzzy logic approaches to mobile robot navigation and obstacle avoidance have been investigated by several researchers. Many application works of fuzzy logic in the mobile robot field have given promising results.

Strategy was presented in paper [11] for the autonomous navigation of field mobile robots on hazardous natural terrain using a fuzzy logic approach and a novel measure of terrain traversability. The navigation strategy is comprised of three simple, independent behaviours: seek-goal, traverse-terrain, and avoid obstacles. This navigation strategy requires no a priori information about the environment.

The sensor-based navigation of a mobile robot in an indoor environment is very well presented in [12]. The paper deals with the problem of the navigation of a mobile robot either in an unknown indoor environment or in a partially-known one. Fuzzy controllers are created for the navigation of the real robot. The good results obtained illustrate the robustness of a fuzzy logic approach with regardto sensor imperfections.

The fuzzy reactive control of a mobile robot incorporating a real/virtual target-switching strategy has been made in [13]. Real-time fuzzy reactive control is investigated for automatic navigation of an intelligent mobile robot in unknown and changing environments. The reactive rule base governing the robot behavior is synthesized corresponding to the various situations defined by instant mobile robot motion, environment and target information.

Paper [14-17] presents a control method for the formation on nonholomic mobile robots. Robots track desired trajectories in the environment with static convex-shaped obstacles. The algorithm includes collision-avoidance between robots and obstacles.

In many papers, for example [18-23] fuzzy control and the other methods are applied to the navigation or reliable motion of the autonomous mobile robot or wall climbing robot in unstructuredenvironments over surfaces with obstacles and slopes.

On the base of fuzzy logic and neurone network theory the algorithms for fuzzy control and decision making are developed to promote the vehicle motion in unstructured environments. Mathematical models of fuzzy control are studying to represent he real dynamic scene motion, using cognitive graphics. In the simulation process the optimum motion parameters are chose under different requirements, restrictions, forming environment scenes and adequate information about environment and vehicle motion. The problems of modelling and control are solved for different customer demands.

On the base of fuzzy logic approach the trajectoryplanning system is developed for the vehicle motion on dynamically changing environment with obstacle avoidance, when the obstacles could move independently. Thedirection of the vehicle motion may be changed automatically depending on surrounding situation. The pattern recognition of the obstacles is produced under robot motion. Software packages for computer simulation are carried out.

Interactions between man, robot, machine and environment are studying and various intelligent interfaces are created for interactions between man and environment, such as: “man-robot”, “man-environment”. For example, “man-robot” computer interface provides a friendly co-operation between people and robots. Situation analysis is provided the decision making process, robot teaching, trying and errors method.

The fast and sophisticated algorithms were created for trajectory planning problem solving for a mobile vehicle in real time motion. The numerical calculated optimised vehicle motion was considered under satisfaction of main motion parameter criteria, such as minimum energy, minimum time, minimum risk (maximum safety), maximum accuracy and integrated criterion. Trajectory planning considered to avoid the obstacles, to produce the manoeuvres, to avoid the collision, to realise the requirement task under motion on dynamically changing environments and on nonpredicted situations in advanced. Special control algorithms are suggested for correction the programming motion depended on suddenly situation changing. Fuzzy control method developed for these kinds of tasks with the possibility to produce the primitive decision making in the motion with maximum permitted velocity.

Examples of UVS

Examples of air robot and micro robot for space presented in Fig. 6 and Fig. 7.

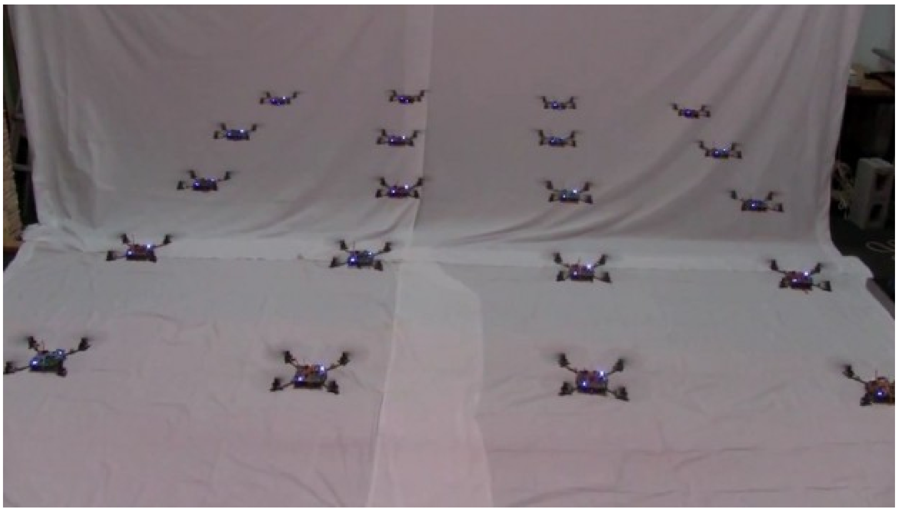


Fig. 6 Air robots.

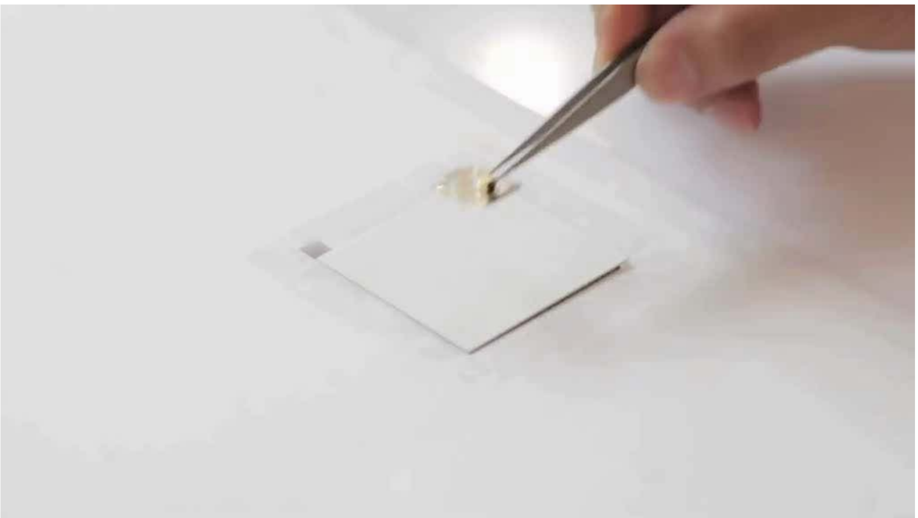


Fig. 7Micro robot for space.

UVS for use on the land may accomplish various functions. Mainly there are intended for transportation people and payloads as usually cars or train. Another part includes special UVS application for special purposes like security, patrol, multiagent system, inspection, agriculture, demining, military andextremeconditions as nuclear power station service and repair.

Many companies (Google, BMW, Toyota and others) are presented autonomous cars moving without drivers, as example may be presented Toyota Prius, Lexus (Google), Piaggio Porter (UK), TerraMax (Oshkosh Corporation and VisCab). In 2011 Airport Hitrow made announce about using ULTra UVS for transportation passengers between terminals.

In March, 2012, (Nevada, USA), stepped in law that permitted riding along highway or main road for cars using artificial brain, sensors and global positioner system for motion independently without active intervention of man-driver. Driver is called as operator in this case, for possibility to control namely the robot but not car. Laser on the roof of Toyota UVS car intended for navigation instead of eyes. Specialists from “Google” consider that intelligent cars will move along roads after 4-5 years. Approximately 20 years ago was start for intelligent cars R&D.

Such optimism is rather excessive but success is sensitive because cars without drivers were moving many thousand miles along roads of Europe, America, Asia. Data about road situation contain in power board computer where decision making and control of car are produce. At the same time more than ten microprocessors intended for engine, breake and other system of local control.Sensors about pressure in the wheels, temperature of oil and cool systems, and other parameters. The problem with parking is solved also by help of multipurpose technology “drive me” (Google Piaggio Porter Companies, Vislab Labs, Darpa cars Terra Max, MIG) (Fig. 8, 9).

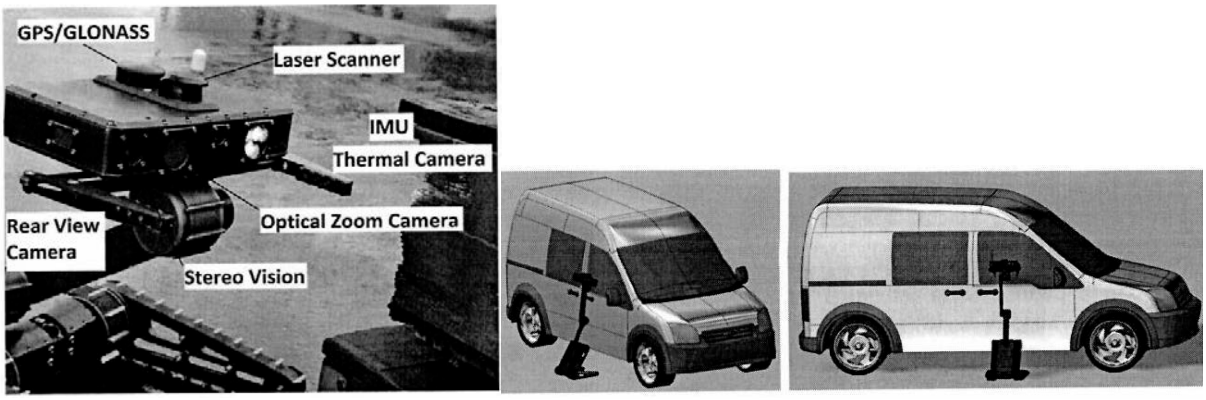


Fig. 8Sensors on board the robots.

Fig. 9Sensors on board the car.

Ground UVS special type

As example of special robot type, it is possible to note Mobile robot for extinguishing fires (Fig. 10).

Fig. 10 Mobile robots for extinguishing fires.

Robot Tral Patrol (SMP Robotics) intended for guard various unfrequented territories and dangerous objects by means of automatically moving using program trajectory. It can ptotect such objects like stores, plants, works, parkings, etc. by moving on day and night time.

A lot of designed mobile robot has dufferent degree of autonomy, when majority of operations are realized without man but final decision formulate man-operator.

Mobile robots easy, middle and heavy classes are intended for fire-fighting purposes, dangerous situations, underground applications (Fig. 11- 13). Robot can be used in dust, snowing, rain conditions. Robots are equipped with sensory systems.

Fig. 11 Multifunctional vehicle of fast response for fire-and-saving operations with the use of the mobile robotized complex of the easy class.

Fig. 12 Mobile robotic complex of the middle class "EL- 4".

Fig. 13Mobile robotic complex of heavy class "EL-10".

These are many examples of effective UVS application with possibility to partially control of man-operator. Examples of such system may be mobile robot “All-Terrain TM5” (Vezdehod TM5) (Fig. 14).

Fig. 14Mobile robotic engineering complex
«VEHICLE TM5».

The robot intended for inspection of sparsely populated environment, detection of mines dangerously explosive loading in containers. Technical characteristics: mass – 50 kg, working time – 2 hours, distance – up to 600 m, velocity – up to 1,0 m/s.

“Berloga R” robot intended for radiation and chemical inspection of undetermined environments. Find decision andremote control of such system is produced by radio (Fig. 15).

Fig. 15Remote controlled robotechnical complex of radiation and chemical intelligence «BERLOGA-P».

Inspection machines for work at nuclear power plants (NIKIMT, Russia) is presented in Fig. 16.

Fig. 16Inspection mobile robot for work at nuclear power plants (NIKIMT ITUTSR, RosatomStroy).

Wall climbing robots (WCR) contain determine type of UVS with limited area of autonomy. There are used in such extreme conditions asdesactivation inspection and repair in nuclear power station (Fig. 17, 18) Another WCR application is fire-fighting operations on the inner surfaces of big reservoirs with petroleum. Main motion and manoeuvring of such mashines are realized automatically but final decision-making is controlling by man-operator. Decision making and strategy of underwater wall climbing robot is shown in Fig.19.

Fig. 17Wall climbing robot.

Inspection robot for nondestructive testing

Technological robot for cutting

Fig. 18 Wall climbing robots for deactivation, inspection and repair in nuclear power station.

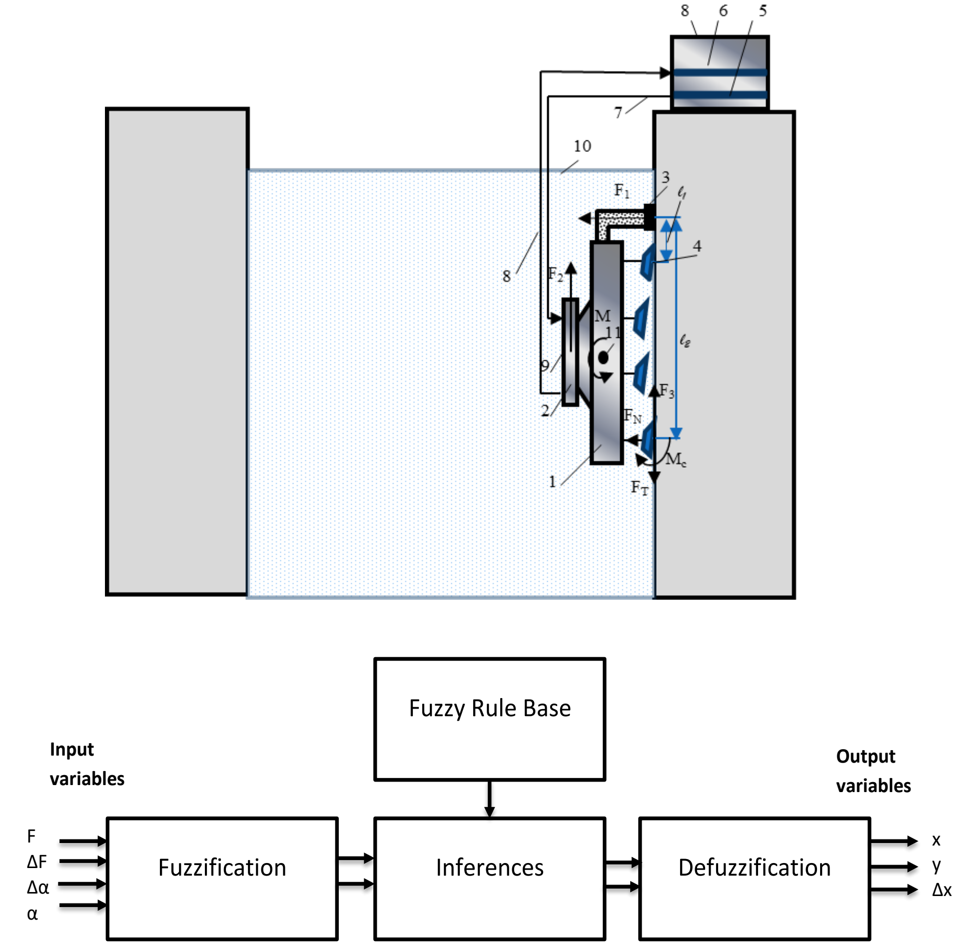


Fig. 19 Decision making and strategy of underwater wall climbing robot.

Multi – agent system.

UVS may be used as agent in multi-agent systems that forms wireless communication (Fig. 20).

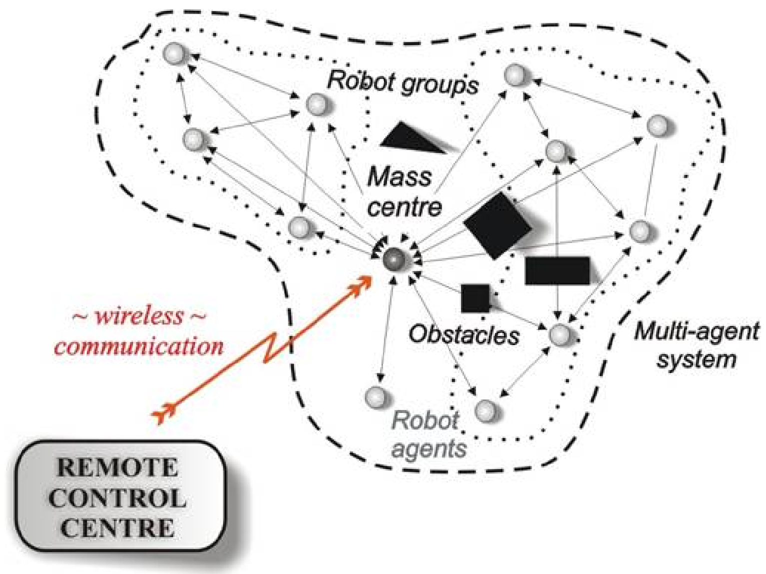


Fig. 20Multi-agent systems.

Robot agents are communicated between in undetermined environments with obstacles to solve predicted tasks. Another example is multi agent robot retro transmitter system, when command data may transmitted by parallel – sequences means.

UVS Software Challenges (Fig. 21) permit to satisfy connections between ground station – use GPS – airborne communication to find unmanned systems.

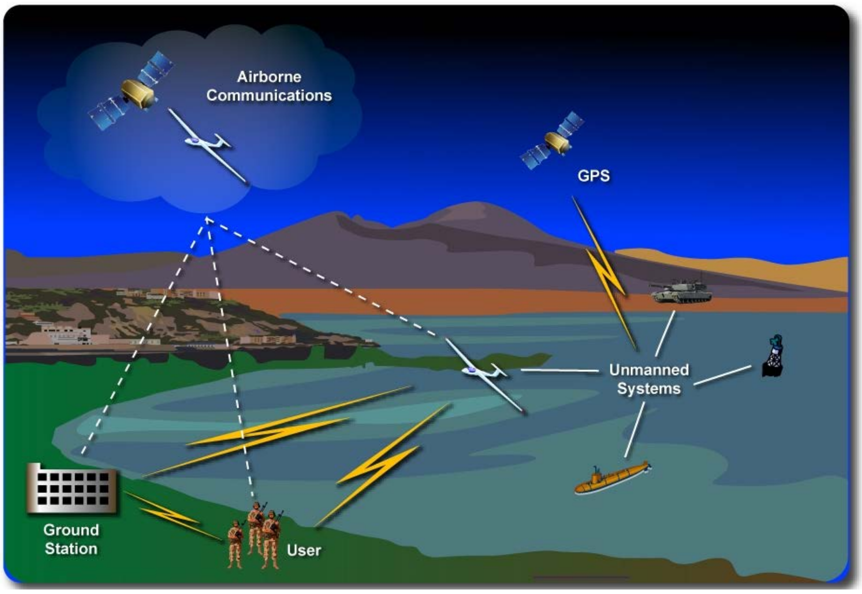


Fig. 21 UGV Software Challenges.

Fig. 22Control system for future artificial intelligence unmanned robot.

The problem of artificial intelligence creation in robotics.

Intellectual robots creation is one of important tendency in robotics. This is prolongation of UVS development in the part of thinking capabilities increasing of robots like human inteligence. Intelligent robot and artificial robot intelligence are the first next steps in the technical realization of human intelligence produced by human brain [24]. Physiological and psychologic features of human mind, its verbal and imagery components – the basis of intelligent and creative abilities. Verbal (symbols) mind of left semisphere of human brain based on formalized knowledge and creative abilities of right semisphere of human brain based on pattern minds (pattern recognition).

Control system includes two information channels – verbal intellectual control channel and pattern information control channel and it intended for design artificial intelligent robot of future as analogy of human brain.

Block module scheme of one version for future possible design for artificial intelligence robot is presented in Fig. 22. Every module includes local neuronnetworks, forming necessary information for control intelligence algorithms.

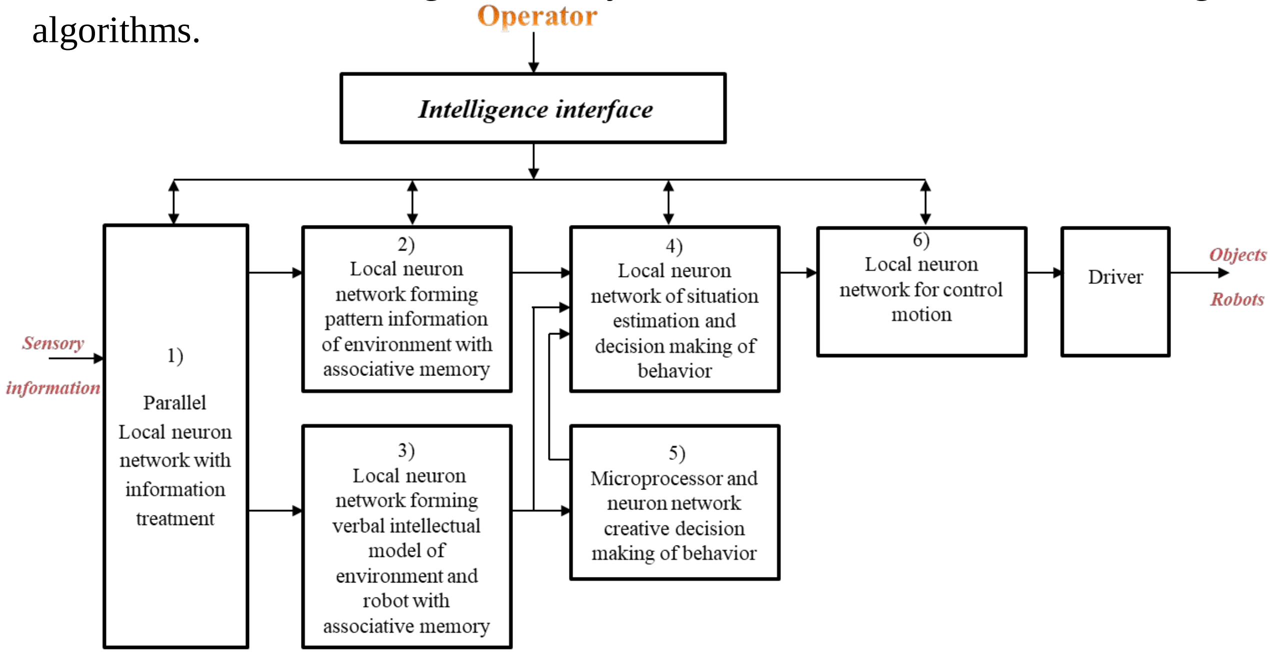


Fig. 22Control system for future artificial intelligence unmanned robot.

Neuron networks may be various type: cognitron or neocognitron types (modul 1), dynamic neurological and neuromorfological (modul 2), multymodules (modul 3), dynamic neurological (modul 4), genetic and evolution algorithms (modul 5), piramidal (6). Interaction between modules is shown in Fig. 22.

Smart City and UVS

“Smart City” is look in the future conception of information and communication technologies, including transport, for city estate and materials control. This intended for improve significantly human life, increase service quality and decrease resources.

Prof. McKinsey considers that up to 2020 years will be about 600 smart cities in the world, among those Tiandsin (cooperation China and Singapore, Masdar (UAE), and others.

“Smart City” is characterised by Smart Government, Smart Transportation, Smart Water, Smart Energy, Smart Buildings.

Smart transportation includes intelligence transport and logistic systems, trafic monitoring and contrl, fast reaction on extreme situations, intellectual parking, design of intellectual networks for logistic (Fig. 23).

Fig. 23 Smart Transportation in Smart City.

UVS public transportation is one of basic idea of smart city and smart transportation. All possibilities of UVS will apply in smart cities of the future. Many problems related with improving characteristics of new existing UVS will be solved in the future to adequate demands of Smart City traffic. Such behaviour of UVS like reliability, manoeuvrability, security, fast reaction on situation changing and so on have to be solved for future smart city transportation.

Acknowledgments.

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Conclusion.

Brief Review was presented to show UAS and UGV application and development. One of important goal of such kind of systems is the improvement of people life in all over the world. Especially when extreme conditions, undetermined environment, rugged terrain, dangerous conditions are existing.

Look in the future is discussed on more reliable fully autonomous smart system.

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ELROB 2018 - Team Diehl THeMIS participating in Mule Scenario

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Abstract

The team Diehl THeMIS Vehicle is the tracked THeMIS platform developed and produced by Milrem Robotics (EST). Milrem has participated with the THeMIS in several competitions in the last couples of years like SMET (US) and Last Mile (UK).

For the mule scenario the THeMIS will use a local terrain based grid map generated based on two LiDAR systems in combination with a waypoint navigation algorithm that has been developed and optimized continuously in the last five years. Both, map and navigation algorithm has been developed by Diehl Defence and Hentschel System.

I. Introduction

In the team Diehl Defence THeMIS Diehl Defence and Hentschel System joined to equip the THeMIS UGV developed and produced by Milem Robotics (EST) with unmanned capabilities. Both players participated in several ELROB competitions before while the THeMIS platform is presented on an ELROB for the first time.

II. Robotic Platforms

The Milrem THeMIS shown in Figure 1 is a Diesel-electric hybrid vehcile with rubber tracks a modular design. It is developed and produced by the estonian company Milrem Robotics.

Figure 1: Milrem THeMIS

The specifications of the platform are

- Payload: 750 kg
- Weight: 1450 kg
- Length: 240 cm
- Width: 215 cm
- Height: 111 cm
- Max speed: 22,4 km/h
- Operating time: 12 hours

The THeMIS is based on a modular concept as one can see in Figure 2 where the mechanical architecture is shown. All components are located within the tracks. Between the track-modules there is a empty center platform for wide variety of payloads. During the development the use of as many COTS components as possible was a key criterion. An Open system architecture with ROS node simplifies the integration of unmanned capabilities.

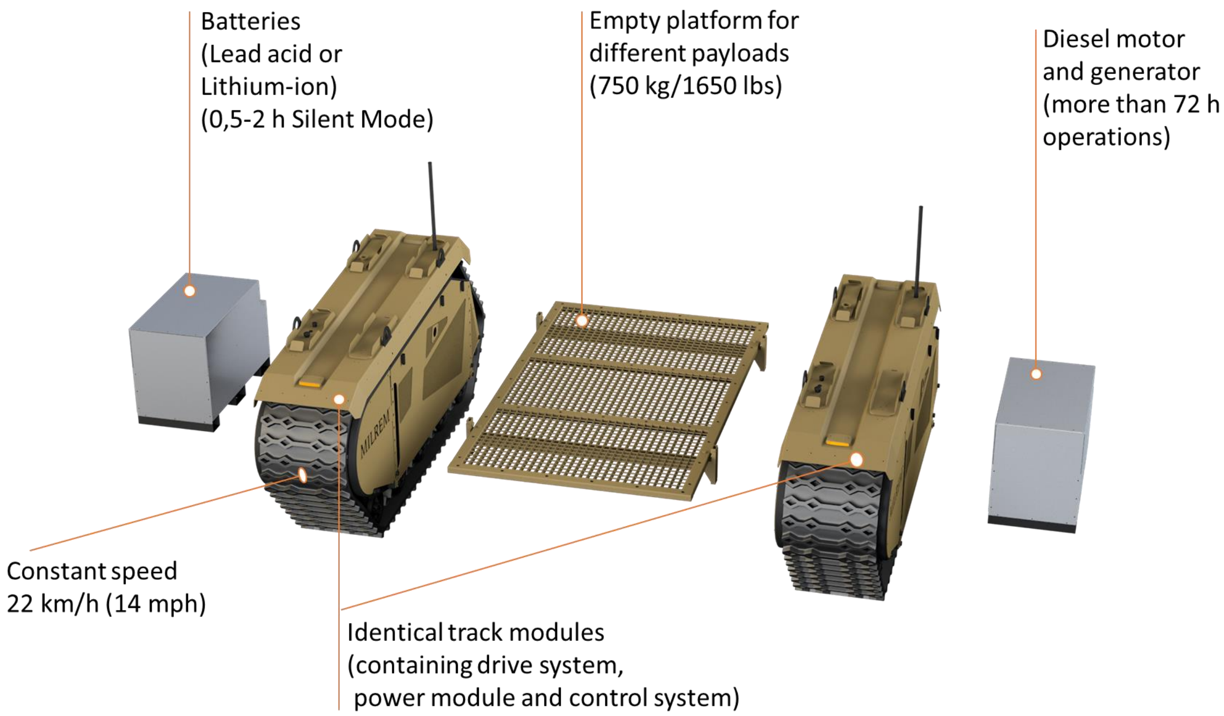

Figure 2: THeMIS mechanical architecture

A. Sensors

For the ELROB trials the THeMIS is equipped with an inertial navigation system by Oxford Technical Solutions. With this sensor setup a robust ego-motion estimation, which compensates even short losses of satellite link.

As active sensors for the environment detection the THeMIS has two Velodynes VLP 16 placed on the track modules. Additionally a camera is placed on the vehicle. This is used for OPI detection and for documentation.

Furthermore a PLATON Kit (ruggedized PC + Algorithms) and a radio system is placed on the center plate of the platform.

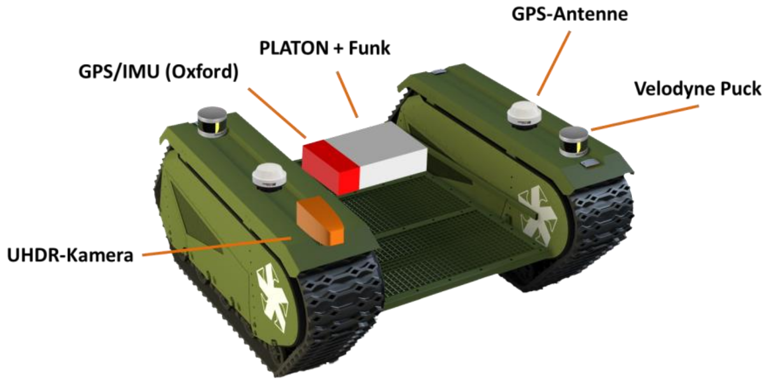

Figure 3: Sensor Setup

B. Hardware Architecture

For the processing hardware standard equipment can be used. The following hardware is used:

CPU:

Intel Core i7-3612QE, Quad Core, 2.1 GHz, 6 MB Cache, 35 W

Memory:

- System RAM
  - Soldered DDR3, ECC support
  - 8GB
- Boot Flash
  - 64 Mbits

Graphics;

- Integrated in QM77 chipset
- 650 MHz graphics base frequency

- 1.2 GHz graphics maximum dynamic frequency
- Simultaneous connection of two monitors

Interfaces

- Video
  - One VGA connector
  - DisplayPort/HDMI
  - HD Audio
- USB
  - USB 2.0 (480 Mbit/s)
- Ethernet
  - RJ45 connectors, 1000BASE-T (1 Gbit/s), or
  - 9-pin D-Sub connector, two 100BASE-T (100 Mbit/s), or
- PCI Express
  - 1 links (500 MB/s per link), PCIe 2.x (5 Gbit/s per lane)
- SATA
  - Two channels, SATA Revision 3.x (6 Gbit/s), RAID level 0/1/5/10 support
- Compatible with PICMG 2.30 CompactPCI PlusIO
  - 1PCI33/4PCIE5/2SATA3/2SATA6/4USB2/1ETH1G

Supervision & Control

- Board controller
- Watchdog timer
- Temperature measurement
- Real-time clock with supercapacitor or battery backup
- Intel Active Management Technology

Environmental Conditions

- Temperature range (operation)
  - -40°C to +85°C (model 02F022P00)
  - Airflow 1.5 m/s
  - Temperature range (storage): -40°C to +85°C
- Cooling concept
  - Conduction-cooled
- Relative humidity (operation): max. 95% non-condensing
- Relative humidity (storage): max. 95% non-condensing
- Altitude: -300 m to +2000 m
- Shock: 50 m/s², 30 ms
- Vibration (Function): 1 m/s², 5 Hz to 150 Hz
- Vibration (Lifetime): 7.9 m/s², 5 Hz to 150 H

The above described hardware configurations is an excellent and robust baseline for the use within a UGV AI-Kit.

C. Software Architecture

The R&D vehicles THeMIS and TULF are using a similar software architecture. In both systems, the software is split into dozens of individual small programs with dedicated tasks. All this small programs are communicating using ROS with each other. Some of them are reading sensor data (one individual program or one individual instance of a program for each sensor) others are processing the data for object tracking or generation of local maps. Finally, the movement commands are generated by a sequence of path planning, high-level platform controller and platform interface software modules before executed by the platform itself. This structure allows it to individually scale the developed software to the available CPU power and to shift whenever during R&D tests required one software component from on CPU board to another.

III. Mule / Transport Scenario

The mule scenario will be performed with the THeMIS. Due to the small size of the vehicle no safety driver will be onboard. The engineer, who will walk in front of the vehicle will have a remote emergency system. Therefore he will also accompanying the platform during the complete MULE mission.

A. Mission planning

The operator control station (OCS) for the mule scenario is depicted in Fig. 6.

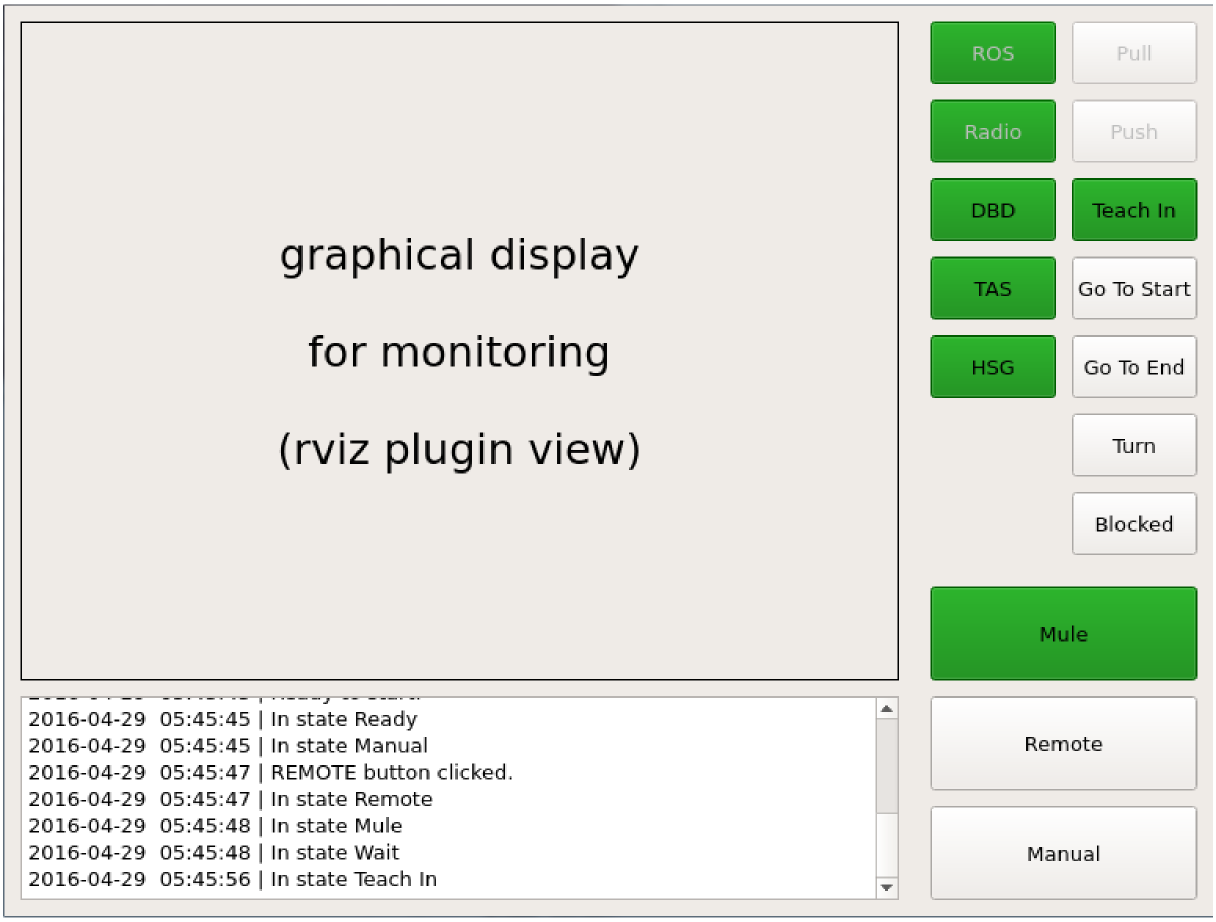

Figure 4 : Operator Control Station for Mule Scenario

The OCS is divided into three sections:

- The command pane on the right side

  The text output on the lower left side.

- The monitoring pane on the upper left side

The general behavior of the OCS is similar to the one in the convoying scenario with the difference that in mule mode the operator is able to switch between manual operation, remote piloting and automatic mule operation. The OCS further offers possibilities to mark the actual position as blocked for mule. In mule mode, the operator can separately command teach-in, mule operation in both directions and 180° turns to be able to handle difficult U-turn situations in close connection with the operator.

B. Waypoint Navigation

The UTM waypoints provided at mission start are used for waypoint navigation. With the provided waypoints, a global path planning is performed using a database which includes all available (and mapped) routes and tracks. From the set of available routes, the optimal (e.g. shortest) path is computed which leads from the current position of the THeMIS to the mission waypoint. The planned path is presented to the operator which may modify the path or set additional waypoints. The final planned path is executed by the waypoint following algorithm autonomously. This algorithm uses the planned path, the current position and orientation of the THEMIS and the environmental information of both Velodyne 3D LiDAR sensors as sensory input. From the input, the algorithm computes the optimal velocity and steering angle to maintain roughly the planned path and avoid any obstacle interference. While following, the planned path, a map of the environment is created which includes the static obstacles in the environment. This map is used by the waypoint following algorithm for vehicle control. Furthermore, this map is used for global path replanning, in case an obstacle is reactively unavoidable. When the vehicle reaches the mission waypoint, the vehicle is turned automatically to shuttle back to the first mission waypoint.

IV. Summary

This paper gives first an overview of the vehicles used by the team Diehl THeMIS at the ELROB 2018 regarding the systems itself and its hardware and software architecture. In addition the operation modes for the ELROB scenario mule are described including information of the mission planning and some of the most important algorithms which are used to perform the desired tasks.

ELROB 2018 - Team Patria participating in Convoy Scenario

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Abstract

The team Patria consists of three project partners with different focus in research and development. The Patria AMV vehicles used in the scenario are both R&D platforms, which have been developed in a cooperation of Patria and Diehl Defence. The platforms are used by the team in the convoy competition at the ELROB 2018. While one of the vehicles (called AMV 2) is equipped with a Drive-by-Wire system developed by Patria and with a sensor package to track a leading vehicle the other AMV (AMV 1) is a vehicle with standard configuration. Only a LTB (Leader Tracking Box) developed by Diehl Defence is installed on this vehicle. The LTB consists of a GPS/IMU system and radio. Therefore, the LTB is able to determine its position and to send it to the following AMV 2 vehicle. The AMV 2 additionally has a Continental automotive RADAR which is used for tracking. Both, sensor data from the RADAR, and the LTB position estimation, are fused to achieve a robust and accurate tracking of the leading vehicle.

I. Introduction

In the team Patria three project partners are joint. Two partners are Diehl Defence in cooperation with Hentschel System GmbH, who successfully integrated the PLATON convoy capability into the Patria AMV vehicle. The third partner Patria provides the AMV platform equipped with an own-developed Drive-by-Wire system. The individual partners have different experiences gathered during the last decade. Diehl Defence GmbH & Co. KG and Hentschel System GmbH have participated in the ELROB 2006, 2008 and 2016. Patria has no experience with ELROB so far.

II. Robotic Platforms

The development of Patria AMV Demonstrator (AMV 2) started in 2017 when Patria began to implement the Drive-by-Wire system (DbW). In parallel Diehl Defence and Hentschel System GmbH adapted the convoy functionalities of the PLATON system so that they are suitable for the environmental conditions in Finland (low temperature, snow). For this, the convoy algorithm which was based on LiDAR and GPS was modified in a way that radar data was used instead of LiDAR.

Beginning of 2018 the implementation of the DbW and the modification of the convoy algorithm was complete and Diehl Defence started the integration on the platform. This was done during a one week integration campaign which already included first test driving. Robustness and accuracy were improved in 2018 during two more test campaigns in Finland.

PLATON developed by Diehl Defence is a conversion kit which includes several functionalities for unmanned driving. It is also used in the platforms TULF, StrAsRob, MILREM THeMIS, HyMUP and Mustang. To support the open architecture, the middleware ROS is used for the data exchange between all software components.

The Patria AMV (Armored Modular Vehicle) platform itself is an 8×8 multi-role military vehicle. The main feature of the AMV is its modular design, which allows the incorporation of different turrets, weapons, sensors, or communications systems on the same carriage. The velocity in manual operation mode is limited to 100 km/h. All robotic modifications and extensions have been performed in a manner that the vehicle can operate in manual operation mode without any specific limitation on public roads. The vehicle as an unmanned platform has been developed in an industrial cooperation between Patria and Diehl Defence.

Figure 1: Patria AMV (AMV 2)

A. *Sensors*

For the self-localization the following sensor set is integrated into the AMV 1: a XSens MTi-G as inertial measurement unit and GPS based sensor system combined with a KVH DSP-3000 optical gyro. The AMV 2 is equipped with an inertial navigation system by Oxford Technical Solutions. With this sensor setup both vehicles allow a robust ego-motion estimation, which compensates even short losses of satellite link.

As active sensors for the tracking of the leading vehicle, the AMV 2 has a commercial distance radar. For documentation and to improve the situational awareness of the UGV operator (driver of the leading vehicle AMV 1) a front and rear camera are installed on the AMV 2. The picture of the rear camera is send via radio to the control station of the UGV operator.

B. Hardware Architecture

The AMV 2 has 2 conduction-cooled quadcore CPUs, each with 4 GB of memory and two 1 GBit Ethernet interfaces. As operating system Ubuntu 14.04 LTS 64 bit is used and the communication between the CPU boards is realized using ROS.

C. Software Architecture

The Patria uses a software architecture which is similar to that of the R&D vehicles TULF and StrAsRob, as both use the PLATON Kit developed by Diehl Defence. The software is split into dozens of individual small programs with dedicated tasks. All this small programs are communicating using ROS with each other. Some of them are reading sensor data (one individual program or one individual instance of a program for each sensor) others are processing the data for object tracking. Finally, the movement commands are generated by a sequence of path planning, high-level platform controller and platform interface software modules before executed by the platform itself. This structure allows it to individually scale the developed software to the available CPU power and to shift whenever during R&D tests required one software component from on CPU board to another.

III. Convoying / Movements Scenario

This section describes how the Patria AMV 2 will be able to follow the Patria AMV 1 in the convoying / movement scenario of the ELROB 2018. Therefore AMV 1 will be manually driven as lead vehicle while the AMV 2 is used as autonomous vehicle. Due to safety issues, a safety driver will be onboard the AMV 2 permanently to allow quick and secure reactions in case of an emergency. The plan is that AMV 2 is following autonomously AMV 1during the complete trial. In the beginning of the scenario, the mission planning for the convoy task will be performed either in AMV 1 or AMV 2 vehicle with automated data exchange to the other vehicle.

A. Mission planning

The operator control station (OCS) for the convoying scenario is depicted in Fig. 2. It is mainly divided into three sections:

The command pane on the right side: This pane allows for pulling mission data from the WebDAV server prior to mission start, pushing logged vehicle data back to the server after mission end and switching between manual operation, remote piloting and automatic leader following. It further offers possibilities to reset the leader follow algorithm or to restart specific modules on the vehicle in case errors occur. Moreover, it is possible to command the vehicle to a closer follow distance for difficult situations.

The text output on the lower left side: This pane provides a textual output of useful information for the operator. Particularly, error messages and warnings will be displayed here.

The monitoring pane on the upper left side: This pane provides graphical display of important information like own vehicle state, distance to leader vehicle etc.

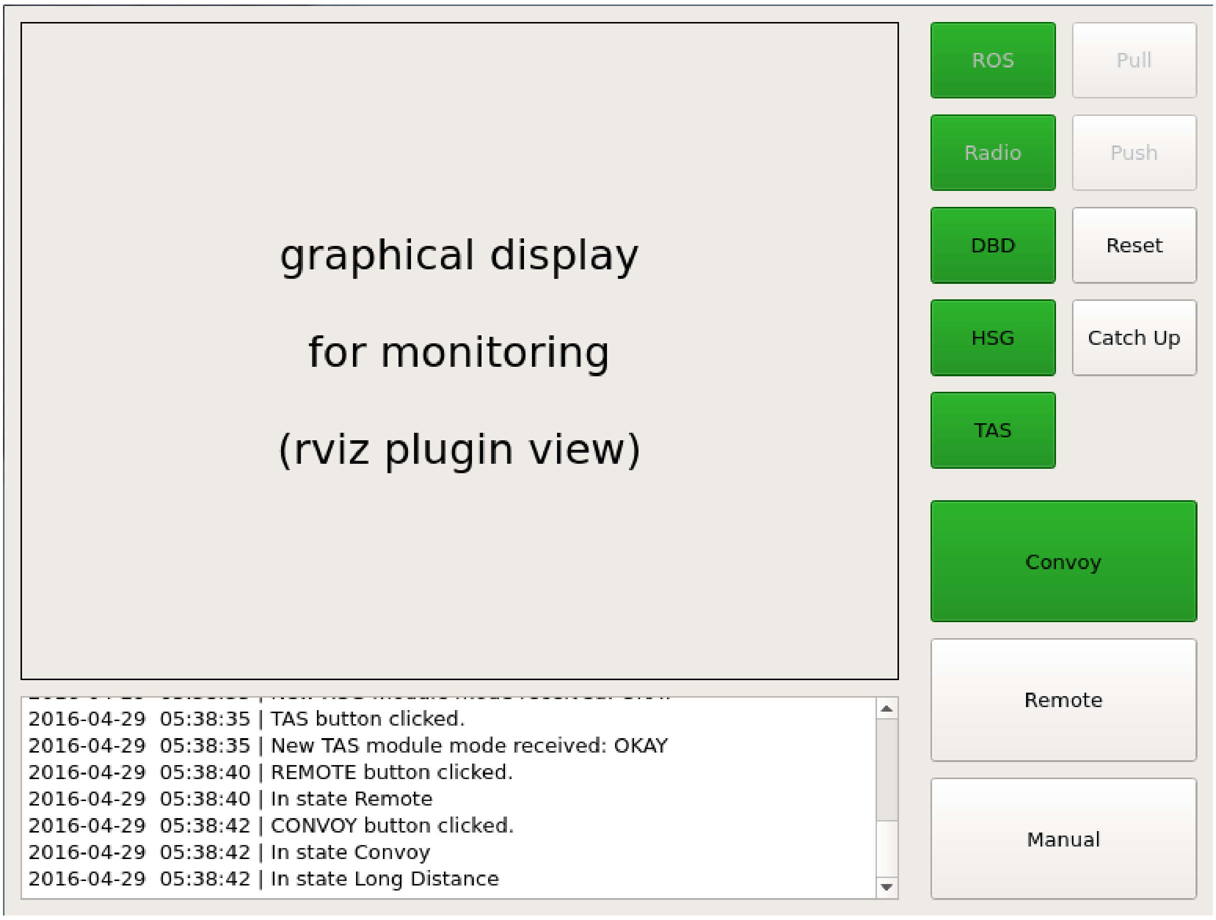

Fig. 2: Operator Control Station for Convoying Scenario

At startup, the OCS is in STANDBY as shown in Fig. 3. Only the pull button is enabled. By clicking the pull button, a mission startup procedure is initiated (see Fig. 4). First, the mission data are fetched from the WebDAV server. Then these data are internally processed in order to provide an automatically planned mission to the operator and the driver of the leader vehicle. The planned mission is displayed on a map in the graphical display. Finally the Logging is started and the OCS switches to READY state. Now all mission operations are possible.

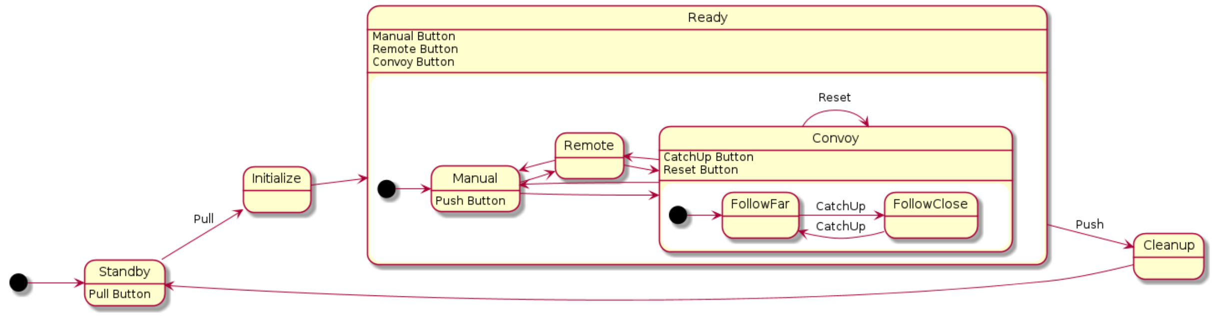

Fig. 3: Operational states in Convoying Scenario

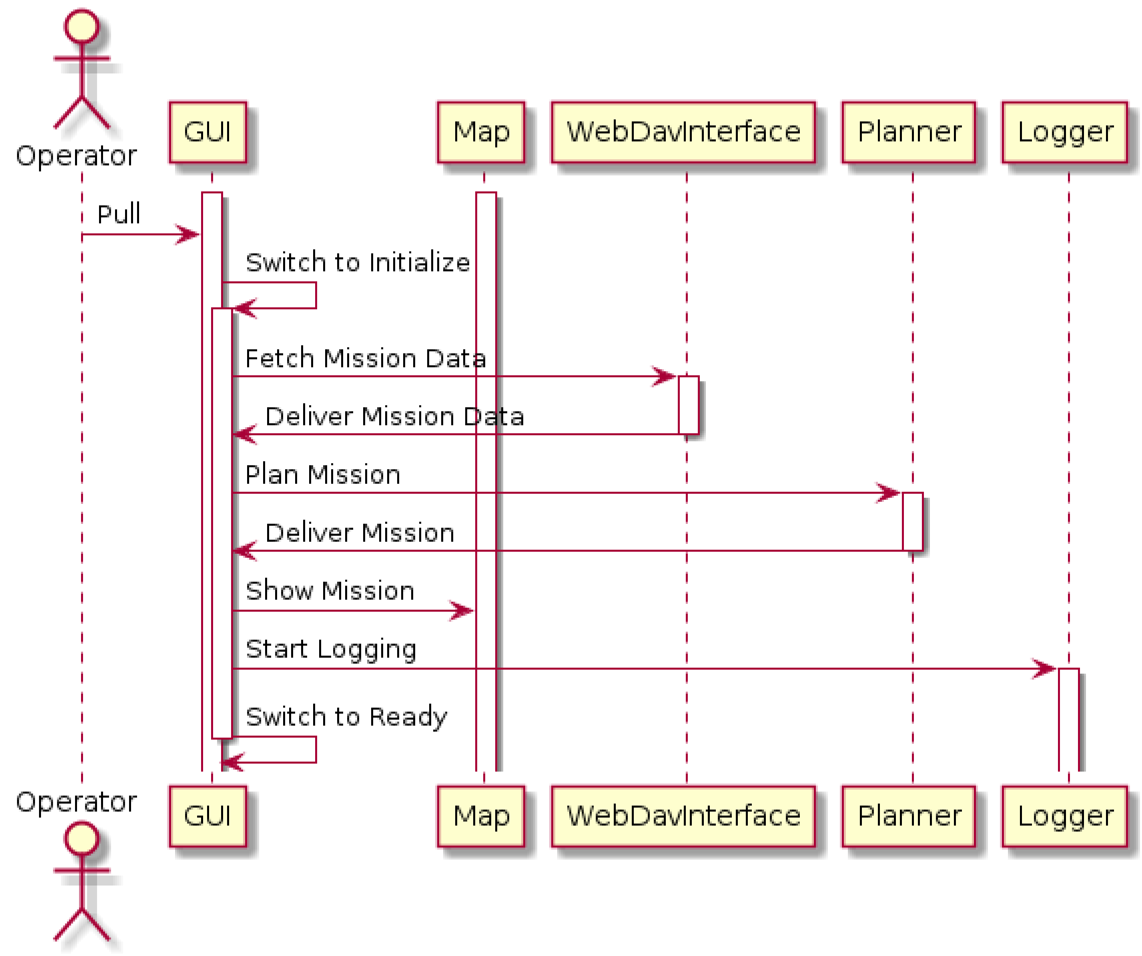

Fig. 4: Pull sequence

At the end of the mission, the operator must switch back to manual operation. Only in this state, the OCS allows for data collection and delivery on the WebDAV server. This is done by clicking the push button (see Fig. 5). The OCS then stops logging, fetches the log data from the vehicle and pushes vehicle and OCS log data to the WebDAV server before switching to STANDBY.

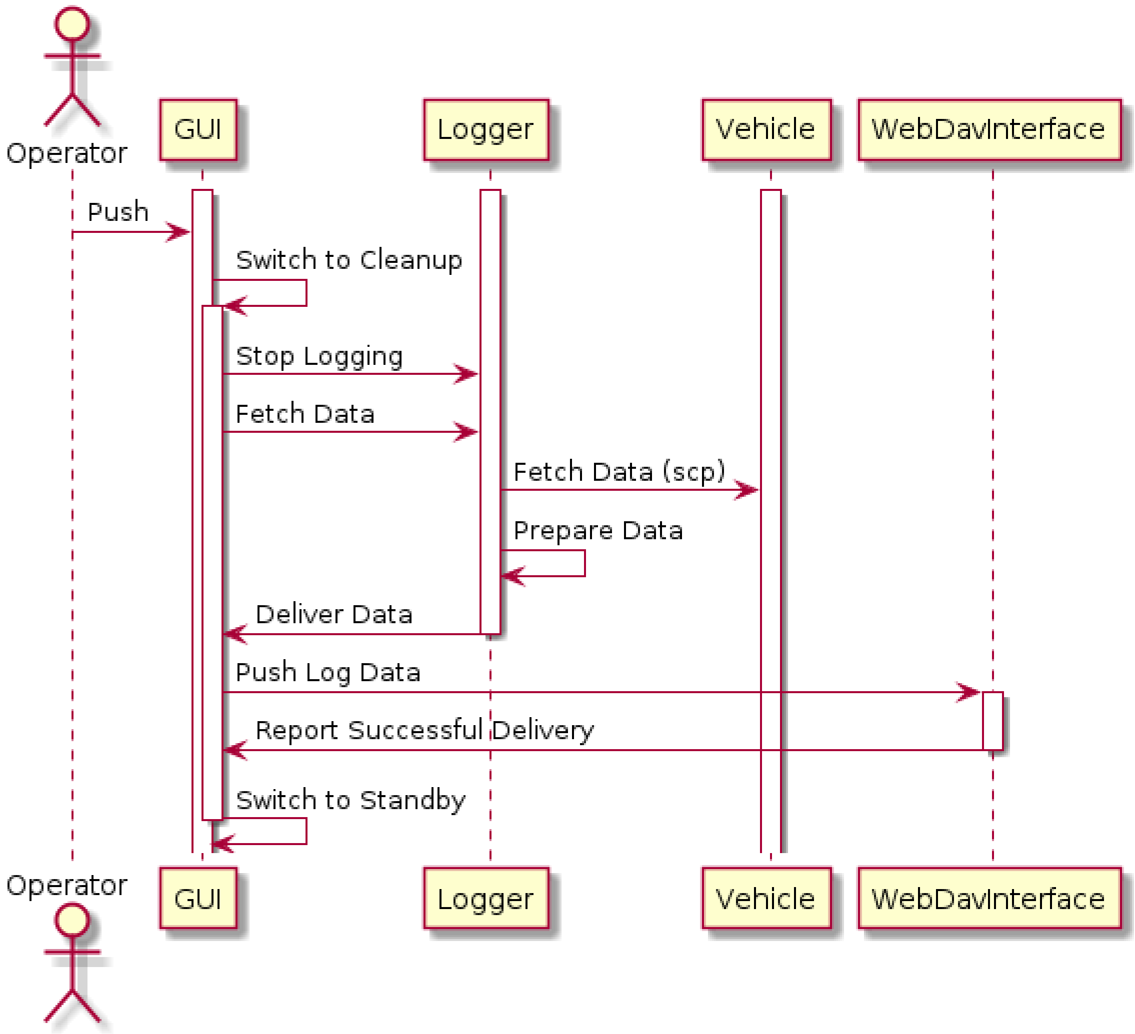

Fig. 5: Push sequence

B. Vehicle Tracking

In order to achieve robust vehicle tracking with high accuracy we have implemented a module which fuses the measurement data of all sensors and tracking modules at object-level. It thus estimates the position, orientation and velocity of the leading vehicle based on a kinematic single-track model as a motion model.

Another important input data for the filter is the absolute global position of the leading vehicle determined by GPS and received by car-to-car communication. The problem here is that measurement is often disturbed by a significant GPS offset of several meters.

In order to be able to use the information it is vital to estimate the GPS offset online using the mentioned inertial sensors. As soon as the GPS offset is estimated good enough, the corrected position measurement can be used during phases with poor or completely missing local measurements. The resulting output of the fusion module is an estimate for the position, orientation and velocity of the leading vehicle which can afterwards be used for path planning and vehicle control.

C. Leader Following

In this operational sequence there are two interdepend activities. One is the path planner, which is responsible for generating a trajectory between the leading and the following vehicle. Therefore it uses the UTM-positions of both vehicles from the data fusion algorithm and hence it plans an optimal chain of (aiming) points.

The second function within the modus is the controller or rather an interaction of different controller. After all the challenge to follow a vehicle can be divided into three different tasks. One is to keep a defined distance to the leading vehicle. The second condition is the desired velocity of the following vehicle with respect to the leading one. And finally the third task is to stay on the planned path.

IV. Summary

This paper gives first an overview of the vehicles used by the team Patria AMV at the ELROB 2018 regarding the systems itself and its hardware and software architecture. In addition the operation modes for the ELROB scenario convoy are described including information of the mission planning and some of the most important algorithms which are used to perform the desired tasks.