International CBRNE Institute

ISMCR 2018

21th International Symposium on Measurement and Control in Robotics
26-27 September 2018 – International CBRNE Institute, MONS, Belgium

ROBOTICS FOR THE CHANGING WORLD

ABSTRACTS

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ELROB	fnrs LA LIBERTÉ DE CHERCHER	fwo	Vrije Universiteit Brussel

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

1. Robot coordination system based on ROS and LabVIEW

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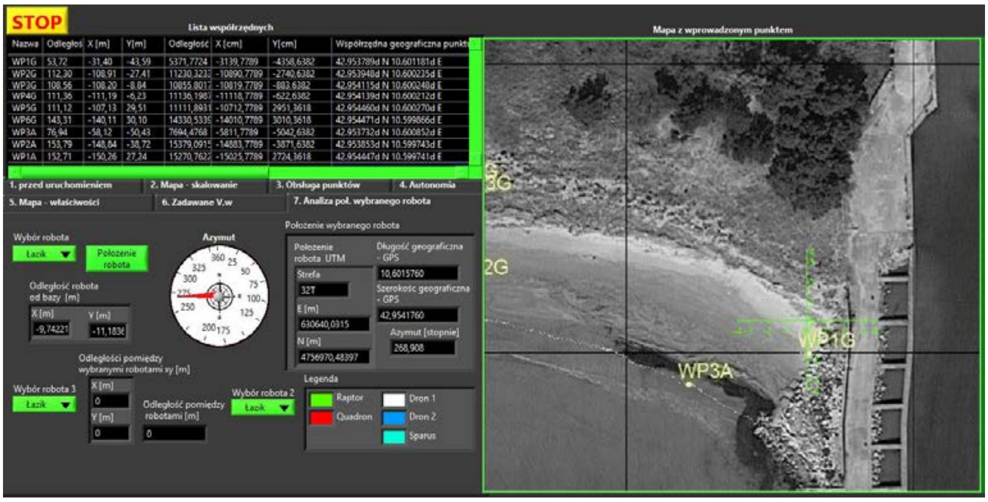
The paper presents a concept of a software system for managing robots co-ordination, and its realization by Raptors team at contests ERL Emergency robots and University Rover Challenge (URC).

Several robotic contests require advanced mission management and coordination of robots' actions. More and more often robots have heterogeneous nature and missions have to be autonomous or semi-autonomous, therefore, operators require computer systems to configure, monitor and/or control robots' activities, and report the mission results. The first version of presented software was specially created for the ERL Emergency Robots 2017 competition and is based on the LabVIEW technology and the Robot Operating System (ROS). It was the first time Raptors team took part in the contest of heterogeneous robots namely: land, air, and sea unmanned vehicles having a variety of joint action to perform in teleoperated, semi-autonomous or autonomous manner. The Raptors team has only UGVs and UAVs robot, therefore, second team joined the group before contest to fulfill requirements. Such scenario forced us to prepare the application in very flexible way based on two technologies, LabVIEW and ROS. It consists of a communication module, coordination of a common mission and location of robots on the terrain map. The use of a graphical interface and selection of information from the available list allows operator to shorten the time needed to enter and send messages to specific robots.

Participation in the ERL Emergency Robots 2017 competition required the teams to provide the mission data in kml / kmz format, which allows the analysis of collected data over time. We present an example of kml / kmz file structure for displaying the route of robots, statuses of successively reported tasks and objects of potential interest (OPI) found during the mission together with a photo and description. In addition, using this data one can display the location of waypoints and a marker containing aggregated information on the final status of each task for the mission.



Another dedicated version of the application was created for the URC 2018 competition. In this case only one robot performs the mission which stages can be realized in different way (i.e. manually, semi- or fully autonomously). To support the operator, the main task of the system is to supervise the time of performing particular task and to inform about delays in relation to the assumed plan. The user can create a mission by entering the name of subsequent tasks, saving and uploading the mission scenario from the file, changing the order of tasks performed during the mission, converting the collected data to the kml / kmz format, previewing the robot's location on the terrain map in offline mode. Results of using application at URC in June 2018 will be presented in full paper.

The next stage of our project is to create a distributed mission planning system that will work stably even after losing communication with any device (station or robot). The operator can create a mission scenario based on the task selection list. A single task requires defining the following information: selection of the task to be carried out, operating mode, type and required equipment of the robot, task priority, the start time and duration of the task. For tasks related to scanning or searching, it is necessary to define the area in which the activity is to take place. Each robot cooperating with the system provides the following information: robot type, equipment, operations performed with their mode (autonomous, semi-autonomous, manual). Based on the planned mission scenario and robot configuration, it is possible to automatically assign them. The robot should be able to dynamically create a task based on the analysis of the environment (e.g. planner can make a dynamic reconfiguration of the plan in case the robot reports an emergency situation), but the commands and changes introduced by the operator have the overriding priority. The software for the user should ensure tracking of current progress and mission time, displaying basic information about the robot, views from selected cameras, saving and reading mission configuration data to/from the file, ability to report non-autonomous tasks by the user, displaying robot locations and OPI on the terrain map, data conversion to kml / kmz format. At startup, the software is responsible for synchronizing times and sending out mission configurations to all devices.

2. Effectiveness test of simulator for e-training in carrying out missions with use of tele-operated vehicles

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This paper describes results of effectiveness test of the simulator for operators of tele-operated vehicles e-training. The test has been conducted with 20 participants (Warsaw Military University of Technology students) divided into two groups. First group, numbering 11 persons, operated Dromader robot without previous training on the simulator. Members of the second 9-persons group went through simulator training before operating the robot.

The trial was composed of two exercises. First of them was devoted to test driving abilities of the operators. The task for operator it was to cover the distance in a short time and not making errors (such as deviations from the route or collisions with obstacles) that was scored negatively. The second exercise was devoted to test manipulation abilities, and manipulation concrete blocks with robot's manipulator was its substance.

3. Dedicated simulator for e-training of demining robot "Dromader" operators.

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This paper discusses results of using tools for 3D modelling and building physical models for simulator dedicated to e-training of demining robot "Dromader" operators**.** Graphical models are developed using 3dsMax software from CAD model. It is possible to perform straight conversion from the CAD model to a graphical game-ready model, but results are poor. The most serious issues were performance, and texturing. Graphical models had to be created from scratch. Mechanical part was developed with Vortex Editor. Vortex Editor is tool which allows creating mechanical system for Vortex physics universe. It is CAD like software, which allows creating project, running test simulation, and tuning parameters without exporting model to simulation framework.

4. A NOVEL DATA FUSION ARCHITECTURE FOR UNMANNED VEHICLES

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Abstract. An effective functioning of unmanned vehicles demands to process large amounts of various data. Therefore date fusion technology becomes one of key-technologies for autonomous vehicles and systems. In order to systemize such data processing special so-called data fusion architectures are used (e.g. JDL, Waterfall, Boyd etc.). However some of those have a list of shortages restricting their wide usage. A goal of this paper is to present a novel data fusion architecture which could be used on board of unmanned vehicles. This architecture consists of 5 basic layers: parameters identification, state identification, (object type identification), situation identification and task implementation identification (see fig.).

Each level of this architecture can be described mathematically which is important for automatic UVs' programming systems. All the data is fused in bottom-up direction. However it's obvious that some simple or primitive systems may omit some of the higher levels. However highly autonomous systems will involve all the levels.

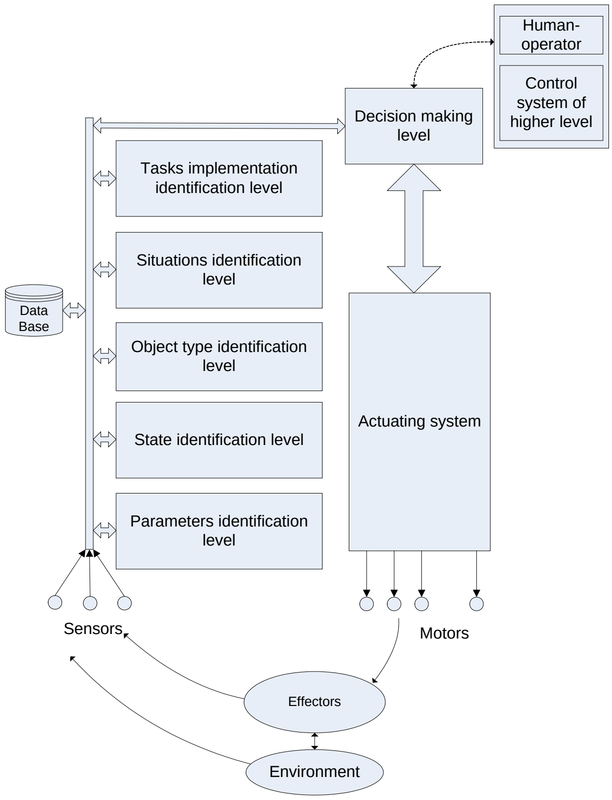

Figure 1. Hierarchical Data Fusion Architecture

The proposed architecture has some advantages in comparison to those already in use. Author considers that presented architecture has good visibility, intuitive understanding, possibility for deep feedback usage and good potenia for automatic reconfirguration and self-learning. The developed data fusion architecture can be used for building complex data fusion systems on board of unmanned vehicles as well as of group of vehicles and even of systems of higher hierarchy.

Keywords: Data Fusion, Sensor Fusion, Unmanned Vehicles, Robotic systems.

5. Pre-filter to robustify the exact linearization based tracking controller of a SCARA type robot

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EXTENDED ABSTRACT

Robustness against parameter uncertainties is an important requirement for robot controllers to achieve high precision and fast tracking. Considering robotic arms, the set of uncertain parameters comprises the inertia of the segments (including the load) and the friction coefficients. In the sequel, it is assumed that there are N uncertain parameters $(p_1, p_2, \ldots, p_N)$ such that each parameter may take its value from a bounded set, i.e. $p_i \in Q_i$.

Robot dynamics are nonlinear, hence the robust design techniques available for linear plants cannot be directly applied. Thanks to the computed torque method, however, the robot dynamics can be linearized by feedback. It is supposed that this holds true for all $p \in Q$, where $Q = Q_1 \times Q_2 \ldots Q_N$. This technique is also known as exact linearization as it requires no approximation but the knowledge of the nonlinear model and its parameters. The linearizing feedback can be complemented by a tracking feedback to ensure the exponential decay of the tracking error. Due to the uncertainty of the parameters, the nominal values p^0 used in the linearizing feedback may be different of their real values. This parameter misfit implies that the resulting closed-loop dynamics may still include nonlinearities.

The paper proposes a procedure to cover the uncertainties remaining after the exact linearization and to design a linear compensator $K(s)$ to ensure robust performance and stability. The design of $K(s)$ involves standard $\mathcal{H}_\infty$ techniques.

The scheme of the exact linearization and the robustifying controller is shown in Figure 1 where q is the vector of joint

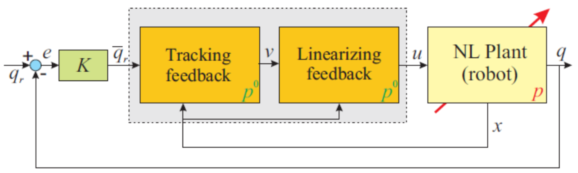

Fig. 1. Block diagram of the closed-loop system with exact linearization and the robustifying compensator

variables, q_r is the vector of joint reference trajectories and $\bar{q}_r$ is the pre-filtered reference trajectory using the compensator $K(s)$.

The robustifying compensator $K(s)$ is designed by replacing the robot and its linearizing feedback by an output multiplicative structure as shown in Figure 2. An augmented plant is used to design $K(s)$ with weighting transfer functions $M(s)$, $W_e(s)$ and $W_u(s)$.

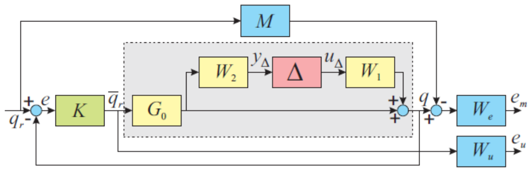

Fig. 2. The controller $K(s)$ with the uncertainty structure and the performance weighting functions

The proposed technique is illustrated using the model of a 4 DOF SCARA type robot manipulator. Such manipulators are widely used for pick and place tasks in the industry. The uncertainty parameters are the inertia of each segment, the mass of the load and the friction in the joints. A grid is chosen to cover the uncertainty range of these parameters Q. For each vertex p^i of the grid, a linear transfer $G^i(s)$ is obtained between the signals $\bar{y}_r$ and y (see Figure 1) by linearization. The weighting matrices $W_1(s)$ and $W_2(s)$ of the output multiplicative structure are chosen so that

$$G^i(s) = (1 + W_1(s)\Delta^i(s)W_2(s))G_0(s) \qquad (1)$$

holds true for some $\|\Delta^i(s)\|_\infty \leq 1$. These weighting functions are numerically determined using Matlab. The mixed sensitivity $\mathcal{H}_\infty$ design problem is also solved with the help of Matlab.

Simulations allow to compare the robust tracking performance of the closed-loop systems with and without the robustifying pre-compensator for high speed trajectories where the quadratic effects and the coupling inertia are not negligible. It is also possible to check that the robustifying filter does not increase the input torques produced by the motors.

The method can be generalized to other types of robotic arms as well and more complex (e.g. two degree of freedom) robustifying structures can be also considered.

6. Automated Magnetic Field Reproducing Stand For Debugging Algorithms Navigation Of A Mobile Robots Which Use Onboard Magnetometer Sensor

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Mapping, localization and navigation are still the widest area for research in mobile robotics despite significant progress over the past decades. Common SLAM methods based on lidars and video sensors data fused with data from global navigation systems and the inertial measurement unit aren't suitable for some off-road application conditions.

An important addition to the inertial navigation system are single- or multi-axis magnetometers, which allow to determine the orientation of a mobile robot using magnetic field of the Earth. There are areas with magnetic field anomalies on the path of the robot sometimes, which identification can serve to determine the reference points. The magnetometers installed on the mobile robot are subject to significant influence from both the electrical equipment of the robot itself and its current configuration: the relative positioning of the robot's component parts like articulated platforms, manipulators and other equipment. Compensation of the robot's self-influence on the readings of the magnetometers is carried out by computer tools, and today intensive research is being carried out in this direction. However, in order to obtain the initial data, live experiments are required in a natural enviroment. In addition, manufacturers of magnetometers often don't report the frequency characteristics of the sensors in the technical documentation, limited only by the data output rate. This information is one of the most important for developers of mobile robots control algorithms, which determ the constraints imposed on the angular velocities of the robot.

For simplifying data acquisition about the behavior of magnetometric systems of a mobile robot an experimental test bench is used, which allow to compensate the local magnetic field of the Earth in a certain working volume and to create an artificial magnetic field that varies according to a predetermined algorithm and simulates a magnetic field in the intended environment of application of the mobile robot. The algorithm of variation of the magnetic field can be specified in a specialized software tool or recorded using a precision three-component magnetic induction sensor that traverses the route of the mobile robot.

The basic element of the stand is the three-channel orthogonal system of Helmholtz coils. The main technical tasks solved during the creation of the experimental stand were:

- providing a working volume with a high degree of homogeneity of the magnetic field, sufficient to place the mobile robot,
- temperature drift correction of coil resistance,
- providing the uniformity of the frequency response of the system in the operating frequency range,
- providing the compensation of technogenic disturbances of the natural magnetic field and, first of all, the pickup of industrial frequency currents,
- alignment of magnetic induction reproduction channels,
- compensation of rotation between the coordinate systems of the three-component magnetic induction sensor and Helmholtz coils.
- a technique for identifying the frequency characteristics of magnetometers in mobile robots

Control of magnetic field reproduction is carried out using three feedback loops. The first compensates the background magnetic field in the stand area according to the data of the reference magnetic induction sensor. The second compensates temperature drifts of the coils using the measured current values in them. The third circuit introduces an adaptively adjustable amplitude and phase correction into current signals to reproduce a given magnetic field in order to compensate for man-made noise.

Keywords: orthogonal system of Helmholtz coils; magnetic field; adaptive control; mobile robot.

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7.An Active Beacon-Based Tracking System To Be Used For Mobile Robot Convoying

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One of the most required tasks of mobile robotics is a convoy scenario: an autonomous robot following a leader, which can be human as well as robot. This can be used at the fields of agriculture, transportation, military operations, which is proved by the well-known international trials, such as ELROB, who choose it to be one of the main scenarios during the tests.

The scenario is focused on the mobile robot autonomously following some human leader or another vehicle, which can be fully autonomous or remotely controlled. To detect the leader different systems can be used, including GNSS systems, video sensors, infrared cameras, lidars, radars and ultrasonic rangefinders. There are, however, some complications reasoned by the nature of the mentioned systems. GNSS systems perform poorly in the urban canyons and inside of the buildings. Lidars and radars can be used to measure distance between the vehicle and the surrounding objects, but it is hard to estimate if the given object is the leader the robot has to follow. Cameras, both video and infrared, can be used for leader detection, but the acquired data depend highly on the environmental conditions. Moreover, the accuracy of estimate of these two objects' relative positions can be severely decreased due to an obstacle placed between them.

The mathematical methods used for localization, obstacle detection and occupancy grid mapping techniques are not reliable enough. Moreover, such algorithms usually need redundant sensor data gathered from sensors of different nature. The lidar, radar or video sensors based leader detection suffers from the same restrains and can be made an even more difficult task due to rough weather conditions, dense vegetation, smoke and other factors.

The paper presents a different approach to the leader detection problem. The leader is equipped with an active beacon transmitting ultrasonic pulses, which are received by the receiver array in the robot's sensor system. This system is proposed to be the main leader tracking system for the task of convoying.

The system on nonlinear equations is used to calculate the relative position of the beacon. The observable values, which are the timespans taken by the ultrasonic waves to reach the corresponding receivers, is used to calculate the squared distances from each of the receivers to the beacon. The receivers' coordinates in the robot frame are used as a structural parameters of the equations system. The trilateration of beacon's position is complicated due to the nonlinearity of the model, bilateral exponential distribution of the observable values and the nonstationary variance increasing as does the distance of the beacon to the receiver array. The system of nonlinear equations can be transformed into the system on linear equations without the Taylor's series-based linearization due to usage of additional observable values representing the differences of the squared distances for all the combinations of the receivers. As all the observable values are normally distributed it is possible to implement the real-time beacon tracking via the classical Kalman Filter. The covariance matrix of the measurement vector is nonstationary and is formed according to the distances measured. However, under the rough environmental conditions the beacon's position estimate is still unsatisfying and influencing severely the trajectory of the mobile robot. The situation becomes more difficult with the increasing distance between the leader and the robot while moving, as the variances are comparatively high.

The beacon's trajectory, which robot must follow, is critical to the autonomous system and should not suffer from the incorrect measurements. Luckily, it can be smoothed via the Rauch-Tung-Striebel Smoother due to the fact that the history of the beacon position estimates can be remembered.

The experiments were conducted to compare the accuracy and performance of the described method to the such methods as Non-linear Least Squares, extended Kalman Filter, Unscented Kalman Filter and Particle Filter. Two separate measurement channels with auto gain tuning used in the each of receivers as well as interpolation of the lost data and the outliers removal are the reasons that made the system presented in the paper usable to form a movement trajectory for a autonomous robot without data from the other expansive sensor in some special cases when the leader leads the robot, skirting the obstacles.

Keywords: autonomous robot following; convoy; active ultrasonic beacon; Kalman Filter

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8.Ultrasonic Rangefinder With The Submillimeter Resolution As a Part Of The Rescue Robot's Sensor System

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Search and Rescue operations caused by industrial disasters and military conflicts become very dangerous for the SAR crews, making the telemetry containing victims' locations and vital signals extremely valuable. That kind of information can be used to plan and execute the rescue operation the best way possible, including the SAR crew members' efforts and the rescue robots, both autonomous and remote controlled. The importance of such operations is proved by various field tests and world-class robot trials, such as ELROB, choosing the SAR scenarios to be one of the main tasks in their programme.

Detection of the injured person's vital signals, mainly pulse and respiratory rates, poses a difficult task for a rescue robot regardless of it being autonomous or remotely controlled. Video and thermal cameras are the sensors primarily used for that kind of task. Due to amount of data broadcasting by these sensors, they require wired connection (e.g., LAN) between the robot and the human operator or the broadband wireless connection in case the former is not possible. However, the radio wave-based data transmission can lead to detection mistakes due to interferences and non-line-of-sight (NLOS) and near-line-of-sight transmissions. Moreover, the usage of thermal camera to detect the body temperature can sometimes lead to the dead body being mistaken for the living person.

Another way to measure the human vitals is to make contact measurements. In that case the robot must place the electrodes on the particular parts of the injured person's body, which leads to a handful of problems like the process of electrodes placement or detection and recognition of the body parts where the electrodes should be placed. Clearly, these can be quite dangerous operations to be performed on a injured person.

To perform the noncontact measurements of the pulse and respiratory rates the short-range radars can be used, but the data gathered that way can be affected due to electromagnetic interference and other interfering factors. We propose to increase the robustness of these measurements by the means of the secondary noncontact measurement channel based on the ultrasonic sensors. The resolution of ultrasonic range finders is currently the subject of more than one research, focusing primarily on linear-frequency or composite signal modulation. The common problem of these methods is the hardware cost as they require broadband ultrasonic receivers and transmitters.

The solution presented in the paper is focused on the data processing algorithm instead of the hardware development. The sensor used in research is a standard for the automotive industry ultrasonic hardware used in some of ADAS systems

(e.g., parking systems, collision avoidance systems). Such sensors commonly provide the time-of-flight distance measurements with the maximum resolution of one fourth of the ultrasonic wavelength. However, the resolution needed to detect the human's vitals lies in the submillimeter range, and can be achieved using the combined method presented in the paper.

The presented method is used to sum the two measurements: the rough TOF-based measurement and the precise measurement, based on the tracking of the relevant components of echo signal's envelope phase spectrum. The echo signal is obtained by transmitting the probing pulse burst. The output rate of the measurements collected that way is the same as for the TOF-based measurements and the measurement resolution is of one hundredth of the ultrasonic wavelength.

The proposed method was implemented in the breadboard model, which underwent laboratory testing.

To estimate the relevant components in the echo signal's envelope an experimental setup was created to change the relative position of the probe pulse source and the reflecting surface in the predetermined manner. As a result of experiments conducted the relevant components were estimated in the echo signals phase spectrum. To prove these results another experiments were made, where the breadboard model was used to detect respiration and heartbeat of a volunteer researcher.

According to the results mentioned above, the breadboard model can be developed into the fully-fledged device, which can be used as a part of the rescue robot's sensor system.

Keywords: ultrasound distance measurements; echo signal envelope; phase spectrum; mobile robot.

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9.Semantic Grid Mapping based on Surface Classification with Supervised Learning

Torsten Engler, Felix Ebert, Kai Metzger, and Hans-Joachim Wuensche

Classic occupancy grid approaches often are too conserva- tive in offroad szenarios.

While most obstacle avoidance systems and techniques perform well in highly structured environments, e.g. urban scenarios, those systems often lead to misclassified grid cells in offroad driving scenarios. This is especially the case for rural road driving, because most dirt roads commonly comprise vegetation between the lanes which might be classified as obstacles. Further, many of the cells containing vegetation next to the road, e.g. high grass, are marked occupied and thus not considered for path planning despite being driveable. Additionally, hanging branches and roadside vegetation may prevent the vehicle from finding a driveable path.

Hence, we extend our driveability analysis by semantic grid mapping. A better semantic understanding of the scene is necessary to lower the misclassification rate. We apply the classification results to distinguish between areas that are classified as occupied but actually are driveable (e.g. high grass) and those that are correctly classified as non-driveable (e.g. tree, hedge, stones covered with grass). To this end, we augment our current grid cells with environment attributes classified from fused sensor data.

Our current environment representation is a multi-modal local terrain map obtained from Vision and LiDAR data. It consists of several distinct layers where each layer corre- sponds to a specific environmental feature such as obstacle probabilities, colors and heights. The sensors used are a Velodyne HDL-64 LiDAR with 360° field of view, a front- facing color camera and a high precision inertial navigation system. The resulting terrain map is obtained by spatiotem- poral fusion of depth measurements, color information and motion estimation. Due to temporal accumulation, outliers are effectively filtered.

While this terrain map provides a conservative basis for obstacle-free path planning, we observe a high false positive rate of cell occupancy classification. Therefore, we propose a classification based approach to semantically distinguish be- tween different surfaces and driveabilities. The classification is performed on two different data representations. Firstly, we classify each pixel directly in the image and use the same ray-tracing and accumulation algorithm to obtain a 2D grid result. Secondly, we use the preprocessed accumulated color grid and classify each grid cell.

All authors are with the Institute for Autonomous Systems Technology (TAS) of the University of the Bundeswehr Munich, Neubiberg, Germany. Contact author email: torsten.engler@unibw.deAcquiring datasets of sufficient size poses the main chal- lenge for supervised machine learning algorithms. Moreover, most readily available datasets for autonomous driving are designed for urban scenarios and therefore not directly applicable. It is necessary to create a distinct dataset for the situations and vegetations we encounter during offroad driving. Due to the high effort of manually creating large datasets, our dataset is comparably small. While deep neural networks perform very well in pixel-wise semantic classification, their performance degrades when trained with insufficient training data. In order to achieve good classification results, it is necessary to artificially increase the training data size by augmentation and/or transfer learning. In addition to neural networks, we evaluate random forests which don't require large data sets and compare their classification performance to neural networks.

10.ComplianceControlforSub-crawlerRotationAngleof Crawler Mobile Robot

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When accidents occur due to the occurrence of natural disasters due to earth- quakes, storm and flood damage, etc., in order to prevent secondary disasters such as ambulance crew who conduct survey of the afflicted site and human life explo- ration, remotely controlled mobile robots are effective. The mobile environment after the occurrence of a disaster is unknown on its road surface condition and collapses due to movement, so its mobile environment is also fluid. Not only are the operator and the robot another place but also work in the narrow or dark place space requires a lot of degrees of freedom in order to adapt to the unknown road surface depending on the limited information. Therefore, control is complicated, its control depends strongly on the operator.

Therefore, a semi-autonomous control problem on a crawler robot having a

sub-crawler (an adaptive crawler robot) is a research task. Therefore, a semi- autonomous control system for crawler robots has been studied to realize both high mobility and simple operation. On the other hand, there are no reportson why the mobility mechanisms are effective in ground adaptability. In previous studies, wehaveinvestigatedthecharacteristicsofpassiveadaptivecrawlerrobot making use of the passivity of the sub-crawler rotation axis and tried to solve its mobility on rough terrain.

The ground adaptability means that the robot's behavior is flexible and ro- bustness to the rough and uneven terrain. Ground adaptability is evaluated by "Traversing Performance ", " Movement Energy Efficiency", "Smoothness ", "Di- versity ", and "Tumble Stability". We have been trying to the quasi-static analysis of a crawler robot with passive rotational joints of the sub-crawler (called passive adaptive crawler robot) by considering the results of experiments and simulations. Especially, when a robot is driving a certain moving velocity, the body attitude angle and the moment of the robot change by depending on the rotation of the sub-crawler, and then these greatly affect the ground adaptability. In addition, the moment generated by the robot affects the contact pressure (area and distri- bution) between the robot and the obstacle. On the other hand, since the attitude angle of the robot influences the change of the center of gravity, the fall stability is affected.

The authors found that passive adaptive crawler robots have easy maneuverabil-itydue to high ground adaptabilitytoanunknownroughterrainenvironment. In this paper, thecrawlerrobotwithsub-crawleris controlled, andthecrawlerrobot 's ground adaptability is shown. Furthermore, I think that there is an important relationship between the contact pressure between ground adaptability and obsta- cles. Therefore, paying attention to the contact pressure which the crawler robot applies to obstacles, we clarify the relationship between the contact pressure and the ground adaptability from the balance of the moment of the crawler robot by experiment and simulation. Byclarifyingusingsuchatechnique, crawlerrobotis expected that the crawler robot will be able to run even more smoothly.

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11.Enhancing Bodily Expression and Communication Capacity of Telexistence Robot with Augmented Reality

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This research focuses on realization of embodied remote communication via a telexistence robot with augmented reality (AR). The conceptual core of telexistence explains that a robot with multiple devices to substitute human communication function (camera, microphone, speaker, and so on) can be used for the surrogate body of a remote operator. The telexistence robot allows us to act in a remote place spontaneously as if we were actually there and to communicate with people who are not physically accessible. By using a telexistence robot, people in remote places can establish face-to-face communication with each other, in which bodily expression such as nod and glance plays important role for natural conversation. Therefore, a telexistence robot is required to perform these actions as abundantly as possible.

Effective replication of human action is achieved by a surrogate robot having a human-like form and a large number of DOF embedded in the body to duplicate various postures and gestures performed by actual human body. However, the surrogate robot as telexistence platform needs high-responsive sensors and motors, at a high cost, to minimize delay in sensori-motor feedback in order to keep natural sensory experience during operation. According to the purpose and application, therefore, it is conceivable that several models of the telexistence robots in different configuration (i.e., entry model and high-end model) can be provided. Whereas a maximum configuration of telexistence robot is realized as highly expensive humanoid robot, a minimum configuration of telexistence robot needs only to have 3DOF head rotation function to enable the operator to look around and perform head gestures.

Although a 3DOF telexistence robot can make satisfactory face-to-face communication just using head gestures integrated with verbal information, the function is still insufficient to realize an equivalent quality of real conversation particularly due to the absence of arm/hand display. The lack of expression ways may cause difficulties in mutual understanding between users. To compensate for the bodily expression impossible to be performed by 3DOF robot, we propose an AR-based presentation system visualizing additional body-parts of the robot to allow an operator and an interlocutor to establish embodied communication.

The developed system consists of the following components: (1) a head-mounted display (Oculus CV2, Oculus VR) worn by an operator to measure head movements of the operator to apply duplicated actions to a 3DOF robot (TXtoolkit, JST-ACCEL) and to present stereoscopic camera images from the robot to the operator; (2) a pair of position sensor (Oculus touch, Oculus VR) held by the operator’s hands to obtain the hand movements; (3) a see-through AR glasses (HoloLens, Microsoft) worn by an interlocutor who faces the robot to communicate with the operator. During conversation, the system generates the 3D-CG image of 7DOF virtual arms which copies the same action of the operator’s arms, and presents the virtual arms to both the operator’s HMD and the interlocutor’s glasses simultaneously. Consequently, even though the robot does not have actual arms or hands, the operator can show his/her arm gestures to the interlocutor, resulting in natural embodied interaction equivalent to the communication attained by using a high-grade telexistence robot equipped with limbs.

12. IMU based gesture recognition for mobile robot control using Online Lazy Neighborhood Graph search".

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For robots to be able to work in unstructured environments, areas dangerous to humans, or disaster sites, human intelligence is still vital. In such cases, teleoperation of robots could be one of the solutions. With recent advancements in robotics, the complexity of its usages has also increased. Despite this fact, currently used technology limits the majority of man-machine interfaces to text or GUI based interfaces and joysticks. Such types of control can become cumbersome in case of, for example, robots with a heavy control box or high degrees of freedom. Often working in disaster areas could be stressful for an operator. Hence, alternate and intuitive control paradigms need to be developed. Gesture-based control seems particularly useful as it can be very intuitive [1].

Vision-based gesture control is well researched but the setup time and dependency on controlled environmental conditions, like lighting, make it less suitable for teleoperation in disaster areas. On the other hand, Hoffmann et al. developed an IMU (Inertial Measurement Unit) based control for a robot manipulator [2], which does not need any infrastructure. They used five IMUs attached to the sleeve of a wearable-jacket and transferred human arm motions into corresponding robotic manipulator motions wirelessly. They showed that teleoperation performed in this way is very efficient and intuitive [3]. However, to trigger some predefined manipulator motion or to trigger robot base motions this direct control method cannot be used.

In this paper, we present and evaluate a framework for gesture recognition using four wearable IMUs to indirectly control a mobile robot. Six gestures involving different hand and arm motions are defined. A novel algorithm based on OLNG (Online Lazy Neighborhood Graph) search is used to recognize the gestures. Online Lazy Neighborhood Graph is a data structure based on kd-tree's n-nearest neighbors. Originally, OLNG was suggested and implemented for motion reconstruction from sparse accelerometer data in the field of computer graphics [4]. As it allows real-time similarity searches in big motion databases to a given input, we use this algorithm to classify the gestures online and trigger predefined behaviors.

To build up the database we ask the operators to perform defined gestures wearing the jacket equipped with the IMUs. Data from the IMUs is stored in a database during this training phase. In the recognition phase, an input in terms of orientation data is applied. We calculate its n nearest neighbors and use OLNG to find the best matching sequence. A best-matched gesture, if existing, is then returned and a predefined robot behavior corresponding to the gesture is triggered. Experiments are conducted to find and validate the best parameters for our algorithm. The database also offers the possibility to extend it online by saving input data for a matched gesture during recognition phase.

In experiments we show that the framework is able to correctly detect and classify six different gestures in real-time with an average success rate of 81%, while keeping the false positive rate low by design.

Keywords

Gesture recognition, teleoperation, IMU, manipulator control, mobile robotics

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13. Coverage Path Planning by swarm;- of UAV by swarm of UGV for traversability analysis

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ABSTRACT for ISMCR2018

In rough environments as in humanitarian demining or in other risky environments as landslides or volcanic eruptions, it is extremely complex to plan safe trajectories for a UGV robot. In fact, both vehicle stability and path execution feasibility must be guaranteed. In these scenarios, the adoption of one or more UAVs that can survey the area and reconstruct 3D models of the environment, can be really helpful.

In this paper we will present three different works that combined together can represent a complete solution to solve the problem of the autonomous navigation of a rover in unstructured environments.

The first work regards 3D coverage path planning and is concerning the optimization of UAV trajectories for photogrammetric aerial image acquisition. In particular, when a rough terrain with obstacles is present, it is important to generate trajectories that avoid obstacles and optimise coverage, in terms of time spent and path length. This can be achieved by a proper decomposition the whole area to be surveyed in many sub-regions.

A consequent relevant aspect is related to the use of a swarm of UAV to implement the aerial coverage in a parallel way. In this case it is crucial to assign the different regions among the flying vehicles. We will present a solution optimising the path length of the whole swarm, by taking into account the UAVs' starting positions and the desired target positions.

The last work is concerning the generation of optimised trajectories for a ground vehicle, once that the 3D model of the terrain has been derived. This is achieved by means of a traversability analysis performed on such model. The outcome of this analysis is a map including traversability costs which can be given as heuristic to classical grid-based path planning algorithms. In this manner the computed paths will be optimal in terms of difficulty of moving across the rough terrain.

Several results concerning the individual aspects will be presented and some examples of the overall approach will be shown.

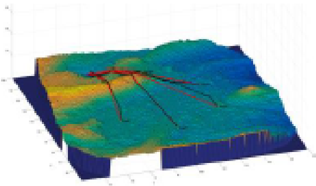

Fig. 1 Terrain 3D model and UAV target assignement

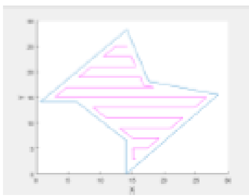

Fig.2 Coverage path planning

14. **Training of robots' operators with use of multirobot simulators**

Communication on the work in progress

Marek Kacprzak, Institute of Mathematical Machines Scientific Foundation

In critical situations (like CBRNE threads, terrorist attacks, natural disasters- hurricanes, earthquakes) different types of remote-controlled robots (UGVs, UAVs, USVs) are used on large scale. In many cases work to be done should be performed by set of cooperating robots. Thus, training of robots' operators acting together is a must. The training should be performed at three levels.

First level, introductory, is based on studies of robot's documentation, complemented with lectures, including computer presentations and video materials.

Second level is to be based on computer simulators. Virtual reality or even augmented reality technologies are applied. In general, training is performed on computer (mostly on PC-class desktops or laptops) with real robots' control consoles (usually – computer-based) attached. Model of virtual robot acting in virtual environment with virtual objects are presented on a computer screen. Only one operator may be trained on a simulator at the given moment.

An intelligent training is performed:

- program of training, elaborated by a trainer, consists of a set of training exercises,
- trainer assigns grades-points (usually different) to any exercise,
- trainee performs due operations controlling a robots' models with use of a control consoles,
- computer supervises the operation and evaluates the performance of a given exercise, taking into account precision, speed etc and grants grades (points),
- computer decides on whether to continue, repeat or finish a program of training,
- computer provides a final score

This type of training process may be the basis for operator's certification.

In case of tasks that have to be performed by cooperating robots, **third level** of training is necessary - with use of multirobot simulators. An implementation of mutirobot simulator is under way. At present, the simulator, designed in a server-client architecture, is based on PC-class desktop with up to ten control consoles attached via Ethernet. Thus, action performed by up to ten operators may be simultaneously simulated on a same screen. Intelligent training, as described for the simulator of the second level, is realised.

Typical scenario of a training exercise, performed by a set of UGVs, is the following: to search a specific object, excavate it from the ground, put into container and transport the object to the given place.

15. Robot programming based on human motion analysis with IMU measurements

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Human-robot interactions (HRI) is a research field that receive more and more interest by combining the accuracy and repeatability of a robot and the versatility of the human. This idea involves many areas in robotics. For instance new control laws are developed to avoid collision with a human or to allow joint object manipulation by a human and a robot. HRI are also largely present in robot programming. The survey by G. Biggs and B. MacDonald opposes manual programming methods to automatic methods. Even if it is more and more easy and intuitive, the first method always involve the modification of the robot program directly by the operator, which requires special skills. In the second one the robot program is modified by the robot itself according to its environment and information received from the operator. Treating information from the operator in order to command the robot is a complete research field usually called Programming by Demonstration (PbD). This emerging way to program a robot is largely inspired from interaction between humans. Touching and manipulating the robot, talking or showing it a task and even face or voice expression can lead to machine programming. Basically, every verbal or non-verbal communication ways can be used to transmit commands to a robot. Following this idea, it is known that human arm motions are largely meaningful during an interaction between humans which can be to point something out as well as giving indirect information. Thus, being able to measure human arm motion, and using it with a robot, can lead to a more efficient way to program robot. In this work, Inertial Measurement Units (IMUs) sensors are used to measure human arm motion. Among the available technology, IMUs have the benefit of being easy to used, light, wireless and cheap compared to vision-based technologies for instance. In this paper we present the method to measure the human arm motion based on the orientation of the sensors modules and a simple kinematic model of the human arm. This orientation is computed with respect to a frame based on 3-axis accelerometer and gyroscopic signals. Magnetometer signals are not used here because of their too high sensitivity to electromagnetic disturbances typically encountered in industrial applications. Thereby, applying this orientation on a human arm kinematic model enable to compute the trajectory of the wrist with respect to the shoulder. In order to quantify the accuracy and the efficiency of developed methods, the measurement of the orientation of the module and the complete trajectory is compared to a robot arm data. Finally a simple example of the robot following the computed trajectory is presented as a first step toward a human-robot interaction programming application.

16.Feedforwardcommandcomputation ofa3Dflexiblerobot

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Robotic manipulators with a lightweight structure can present some interesting features. Thanks to their reduced weight and stiffness, lightweight robots could achieve high speed tasks while being safer and more efficient than traditional rigid robots. However, when designing the controller of such systems, elastic behaviors should be accounted for in order to prevent unwanted vibrations. Inordertohaveamotionofthemanipulatorwithreducedvibrations,thelattercanbefedbacktothecontroller so that proper compensation can be done [1]. By analysing the system, appropriate feedforward inputs can also be designed in such way that the resulting motion has decreased elastic deflections. Both feedforward and feedback action can be combined to achieve robust performances [2, 3]. This work focuses on the feedforward control of 3D flexible manipulators. Based on a model of such flexible multibody systems (MBS), the inverse dynamics is solved to compute the feedforward input of the manipulator. Different methods can be used to model flexible robotic arms. Lumped mass elements models are widely used to model robotic systems [4]. Indeed, to represent the manipulator and its flexibility, this modelling technique uses a limited number of parameters and is therefore quite suitable for control purposes [5]. On the other hand, the finite elementmodellingapproachisageneralwaytomodelMBS[6]thatisabletorepresentdistributedlinkflexibility. Here, a three actuated degree of freedom (dof) elastic robot, represented in Fig. 1, is considered. Flexibility in the robot is modelled using the above mentioned methods and the inverse dynamics of the system is solved using the optimizationapproach[7]extendedto3Dproblems. Thecomputationofthefeedforwardinputcommandforboth models is discussed. Questions arising from their implementation on a real system combined with some feedback action are also addressed.

(a) Finite element model with distributed link flexibility.

(b) Lumped mass element model with localized joint flexibility.

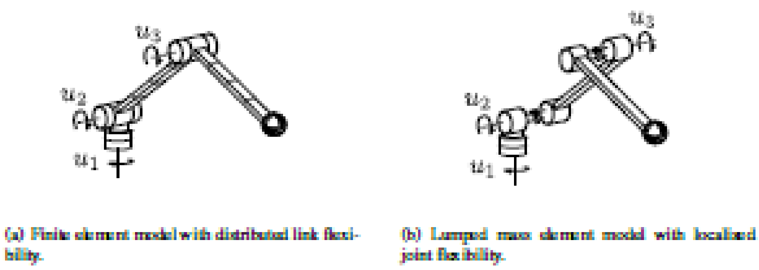

Fig. 1: Models of a 3 actuated dof elastic robot.

Acknowledgements

The first author would like to acknowledge the Belgian Fund for Research training in Industry and Agriculture for its financial support (FRIA grant).

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17. RADAR-based Through-Wall Mapping

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Indoor maps are useful tools both for robots and human operators, helping them to plan missions and prioritize actions in various situations, including emergency scenarios. Examples of such scenarios include rescuing victims in hostage situations as well as buildings under fire. In these situations, small robots can be deployed into the environment of interest and built maps with the relevant features of the environment in order to support operational decisions. However, traditional mapping approaches use optical sensors (Laser range finders and cameras) which require line-of-sight view for the robot, which may not be possible, especially in hostage situations. In order to address this problem, there is ongoing research in the field of through-wall mapping which would enable mapping a building or parts of it by remote sensing from the outside of the area of interest. Radio Frequency electromagnetic waves (RF) are known to be able to pass through various materials and structures that ordinary light cannot. It is well-known that walls containing iron, such as reinforced concreate walls, degrade significantly the pass-through capacity of RF.In this paper, we investigate the feasibility of using an off-the-shelf Short Range RADAR (SSR) working at 24GHz frequency, like the ones used in cars, for through-wall mapping of walls made of wood or plaster. For this purpose, an arena made by portable wood wall segments was constructed. The SSR was mounted on a scanning mechanism over a 2 wheel differential drive robot which was driven around the arena. The collected data was later processed in order to estimate the indoor maps of the testing arena. The SSR measurements were tagged with the robot position obtained from its localization system, and the map was constructed by merging the measurements using a probabilistic sensor model for the detections. The RADAR returns range and bearing information for a fixed number of obstacles in its field of view, similar to a LIDAR in terms of the reported data. However, in LIDAR mapping, all the space up to a detection is assumed to be empty, which is not a valid assumption in a through-wall SSR system. Additionally, the RADAR's probability of detection depends on various factors like the orientation of the target surface, its reflectivity, as well as existence of stronger reflectors in the environment. These issues required both scanning the testing area using a range of RADAR angles and a sensor model that does not update empty spaces, but instead just updates detections. In order to enhance the quality of the generated map, Hough transform was applied to the generated grid map so the walls of the environment were further highlighted. The approach was tested with multiple indoor configurations and it was shown the ability of the SSR to detect most wall segments hidden behind the outer wall, and the ability of the approach to reconstruct a 2D map of the environment with sufficient detail to perceive the existing indoor features.

18.Development of the Modular Platform for Educational Robotics.

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We live in an age of digital technology, where science and technology are the two key concepts for understanding the fundamentals of the various devices that people face every day. The robotization of various fields of science and technology is gaining momentum every year. For example, mobile robotics finds application in many areas of our life, such as medicine, military intelligence, service and so on. In addition to these areas, mobile robotics are also involved in education. Mobile robotics is an excellent area suitable for education, because it integrates mechanics, electronics, computer science and programming.

The trend of evolution of educational robotics increases every year. As a result, it is necessary to orient young people to study the foundations of the development of modern technologies.

There are many robotics construction kits on the market, such as Fischertechnik, Lego, Huna, MakeBlock and so on. But as statistic show, the above-mentioned construction kits and teaching methods have age limits.

We propose a new concept in the application of educational robotics, namely, we present the development of a prototype of a modular mobile platform and its software. It is planned to create a robotic stand that provides with the ability to visualize group algorithms, as well as a web interface for remote interaction with this stand for testing algorithms used in group robotics.
The main goal of this development is to expand the scope of training robotics and make it accessible not only for schoolchildren, but also for students.

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19.ROBSIM SOFTWARE FOR MOBILE ROBOTS MODELING

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Abstract

This paper discusses issues of Unmanned Vehicles' (UV) modeling at various stages of their life-cycle. It presents software system RobSim. RobSim has a capacity to develop models of UVs of high complicity and perform modeling of their functioning. The paper describes structure of RobSim software with basic developers' tools including high-level robotic languages programming and control.

Key words: mobile robot, unmanned vehicle, modeling, software, simulator.

21. In-flight launch of unmanned aerial vehicles

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As more and more unmanned aerial systems are entering our everyday lives, we also see more and more variety in the systems that are being developed, each towards a different application field. This variety should come as no surprise, at is impossible to create one system that would fit all user needs. Heterogeneous systems, all being used at the same time are therefore the way forward. However, this also leads to new problems in terms of interoperability and the search for optimal collaboration strategies between all these different systems. In this paper, we focus on the collaborative action between two unmanned aerial systems where one acts as a mothership / carrier / launch platform, capable of launching in-flight a smaller child system that can then be used for close-to-ground search and rescue missions.
The in-flight-launch of one aerial system by another is no easy problem and requires the careful consideration of the aerodynamics and control of the two systems. Indeed, in terms of aerodynamics and flight performance, the mothership and the child UAV impose important forces and constraints on one another that are very different when they are mechanically interlinked and from when they are separated from one another. The autonomous control concept – which is implemented for this research experiment on the child UAV – needs to be able to cope with these sudden changes in real-time at the moment of release in order to prevent a crash.
This paper will discuss how an optimal release mechanism was developed, taking into account the aerodynamics of one specific mother and child UAV. Furthermore, it will discuss the PID-based control concept that was introduced in order to autonomously stabilize the child UAV after being released from the mothership UAV. Finally, the paper will show how the concept of a mothership UAV + child UAV combination could be usefully taken into advantage in the context of a search and rescue operations.

22. Qualitative and quantitative validation of drone detection systems

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As drones are more and more entering our world, so comes the need to regulate the access to airspace for these systems. Regulators have taken actions accordingly, but it is hard for police services to enforce these rules, as they lack the means to automatically detect airspace infringements. Indeed, something like a car traffic speed camera for the air doesn't really exist yet. Numerous commercial and non-commercial parties have noted this gap in the market and have started the development of drone detection systems.
There are in general two main difficulties related to the detection of drones. First, the cross section / detection baseline for these systems is in general very limited, whatever sensing technology is used. Indeed, drones have a small RADAR cross section, a small acoustic signature (from a relevant distance), a small visual / infrared signature, they use common radio signal frequencies, Of course, it would be possible to make the detection methodologies extremely sensitive, but this then leads to the second difficulty: how to avoid false positives. Indeed, the signature of many drones is quite close to the one of birds, so it is really difficult to filter out these false positives.
Given these difficulties, the evaluation of the performance of drone detection systems is a delicate operation, which requires the careful consideration of all technical and non-technical aspects of the system under test. Indeed, weather conditions and small variations in the appearance of the targets can have a huge difference on the performance of the systems. In order to provide a fair evaluation and an honest comparison between systems, it is therefore paramount that a stringent validation procedure is followed. Moreover, the validation methodology needs to find a compromise between the often contrasting requirements of end users (who want tests to be performed in operational conditions) and platform developers (who want tests to be performed that are statistically relevant). Therefore, we propose in this paper a qualitative and quantitative validation methodology for drone detection systems. The proposed validation methodology seeks to find this

compromise between operationally relevant benchmarking (by providing qualitative benchmarking under varying environmental conditions) and statistically relevant evaluation (by providing quantitative score sheets under strictly described conditions).

22. 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

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 resultingestimate,anoptimization-basedplanningmodulecomputes 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

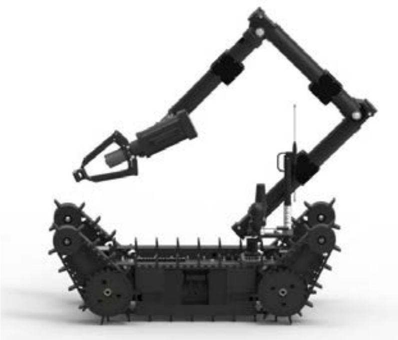
(a) MuCAR-3. (b) MuCAR-4.

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

23. TECHNICAL SESSION-EXHIBITION ELROB-ISMCR

Updated: july 15 2018

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ECA: https://www.ecagroup.com/en/defence-security
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MuCAR (GE) Robot MuCAR3-4 www.unibw.de/tas
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