PROJECT PERIODIC REPORT

Grant Agreement number: **FP 7-610603**
Project acronym: **EUROPA2**
Project title: European Robotic Pedestrian Assistant 2.0
Funding Scheme: STREP

Date of latest version of Annex I against which the assessment will be made: 25 June 2013

Periodic report: **1st**
Period covered: **from 01 October 2013 to 30 September 2014**

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1 Publishable Summary

1.1 Project objectives

Over the last five years there is a growing interest in robots operating in urban environments such as city centres. Such urban areas are highly dynamic and complex environments which introduce numerous challenges to autonomous robots. This, for example, includes aspects of representing the environment including semantics as the vehicle needs to be able to effectively store and extend maps of its environment, to plan its actions, and to localize itself in a highly accurate way even if GPS signals are missing. Furthermore, reliable navigation requires solutions to several complex problems regarding the perception of the environment, state estimation, and interpretation of the gathered information including the uncertainty associated to the data and thus the resulting decisions. In addition to the task of estimating their own position in the environment, robots deployed in urban areas need to identify and estimate the positions and velocities of other relevant agents in their vicinity such as those of potential users, but also those of other pedestrians and even cars.

The objective of EUROPA2 are:

- Online semantic scene interpretation for more efficient navigation.
- Investigate a new means to combining publicly available prior map models with the robot's perceptions, enabling the system to maintain and exploit map knowledge without having mapped a city beforehand.
- Bootstrapping the navigation system with publicly available maps to avoid requiring to map the environment with the robot in advance.
- Life-Long operation of the whole robotic system, including map management, navigation, and calibration.
- Perception under different weather conditions and seasons.
- Introspective classification for robust decision making, i.e., considering the certainty of classification results appropriately.
- Extend and improve existing online methods for detecting and tracking dynamic objects towards close-range and partially visible pedestrians and other traffic participants.

- Develop the foundations for representations of dynamic urban environments for autonomous robots. This includes better models for the interaction between people and the robot as well as with other traffic participants such as cars.

To achieve these goals, the EUROPA2 Consortium consists of leading researchers in the fields of autonomous robots, autonomous cars, navigation, vision and perception, and mobile mapping. EUROPA2 is targeted at developing novel technologies that will open new perspectives for commercial applications of service robots in the future.

1.2 Description of the work performed since the beginning of the project and main results

The work progress was carried out according to the Annex I. All deliverables that were due during the first period have been submitted to the commission. All milestones have been achieved.

WP1 deals with the specification setup of the hardware modifications and software components to be developed in this project as well as with building a prototype of a commercial indoor mapping system and professional data collection by GeoAutomation. In this first year, a number of specifications have been set forward on the level of software and hardware to create the robot platform. GeoAutomation has started the recording of the partner's cities based on their typical workflow. Further, the first tests have started to create a reduced recording setup to deal with indoor environments.

In WP2, the problem of exploiting semantic information for navigation has been addressed. This is en essential aspect for intelligent navigation strategies. Especially online techniques are needed here as the robot has to make decisions on the fly while navigating in order to decide where to go. Several topics regarding this problem have been investigated. The first steps are taken towards semantic analysis of layout of the scene, based on 3D input. A first module for traffic sign recognition has been implemented. With respect to workspace acquisition, accurate confidence estimates have been proposed to create a perception pipeline to deal with the uncertainty of classifiers, which allows to make proper decisions such as narrowing the search space to tune recognition and navigation.

We investigated local navigation approaches in WP3. Extensive research was made into state-of-the-art interaction model learning and interaction-aware motion planning methods. We developed a maximum-entropy reinforcement learning approach to model the behaviour of cooperative agents such as pedestrians. We further implemented interacting Gaussian processes and reciprocal velocity obstacles methods and tested them together with the maximum entropy model in simulated scenarios. A fast collision detection technique for EUROPA's state-lattice planner was developed to properly treat dynamic objects in the scene and thus enable this planner to serve as a baseline comparison for EUROPA2's upcoming planner. A fast and robust image-based pedestrian detector was developed in order to detect and track pedestrians at close range based on the Aggregated Channel Features framework. It runs at up to 20 Hz on a single CPU core and was tested on various public datasets to prove its state-of-the-art detection capabilities. A Navtech CTS350-X radar was mounted on one of the EUROPA2 platforms, and is currently being integrated. A driver to extract point cloud readings from the radar scanner was developed.

WP4 addresses the problem of leveraging publicly available maps for navigation and loop closing to improve mapping quality. In the context of loop closing, we developed a novel approach to visual re-localization of mobile robots, which is able to deal with substantial changes in the appearance or illumination. We investigated how sequence information can be exploited in order to improve data association, i.e., a decision is not based in individual imaged but based on a *sequence of images*. We also improved the workflow of GeoAutomation by inserting proper correspondences between difference passes in the bundling scheme. We compute those correspondences in an automated way, by exploiting SURF features extracted from the camera and taking into account possible changes due to weather or illumination. We also investigated two approaches to make use of publicly available maps for localization. The first method leverages laser measurements and exploits the road network information available in OpenStreetMaps. We modified the Monte-Carlo localization (MCL) to include a road classification step that, during the update step, we use to evaluate the likelihood of the perceived road profile with respect to the road network of OpenStreetMap. The second method leverages camera data and exploit the panoramic images available in Google Street View. We model the problem as a non-linear least squares estimation in two phases. The first estimates the 3D position of tracked feature points from short camera sequences. The second computes the rigid body transformation between the panoramic Street View images and the estimated points. We finally developed a method to reduce the energy consumption of a robot while following a predefined trajectory by turning off exteroceptive sensors at appropriate times. We formulated the problem as a probabilistic belief planning problem and solved it using dynamic programming to obtain optimal plans.

We addressed life-long operations in urban environments in WP5. In the first task, we developed a plan for the calibration of the full sensor setup and implemented some sensor specific modules. For the online calibration we have an operational module that supports extrinsic calibration for the 3D and 2D LiDaR sensors, the Inertial Measurement Unit (IMU) and the wheel odometer. We also developed a calibration techniques for the remission values of the different laser scanners mounted on the robot. Regarding long-term navigation using vision, we have developed an implementation of a stereo vision localisation system able to detect loop closing events in order to establish links between experiences. In addition, we have also introduced a new algorithm that ranks the relevance of previous experiences reducing the computational cost. In order to consistently add relations between a prior map and new observations an accurate localisation system is required. In this period we have developed a global optimization approach that estimates the maximum likelihood configuration of the position of the platform with respect to a road network obtained from a publicly available map using 3D laser and GPS measurements. This method allows us to construct consistent models from the robot's sensor data and at the same time is able to relate the information with a prior map with a high accuracy. We have also developed a method for the sparsification of a pose graph, in the context of simultaneous localization and mapping, making informed decisions of what relations perceived by the robot can be safely removed.

WP6 focuses on integration of the software components and their evaluation. We set up a subversion repository for administrative purposes and a git repository for software development. An integration plan for the first integration phase of the project has been established and the first integration week was successfully planned for M13 to be held in Freiburg in

October 2014. The updated hardware specifications agreed during the Kick-off meeting have been successfully applied to all the platforms. We have successfully captured log files with the new setup and are able to navigate autonomously based on the adapted EUROPA software.

Finally, WP7 addresses innovation-related activities and especially dissemination and exploitation actions. A nicely designed website is fully operational since the second month of the project. Already in the first twelve months, the consortium published 6 papers and submitted twelve. In addition to that, we organized a workshop at a major conference.

In sum, the developments in EUROPA2 are on track and the consortium works jointly towards the common goal. No conflicts exist between consortium members and no substantial deviations from the Description of Work.

1.3 Expected final results and their potential impact and use

In brief, the development and research within the EUROPA2 project will enable robots to navigate safely in city-scale urban environments, populated by people, for long durations without the constant supervision of experts. We expect our technology to

- Bootstrap navigation using publicly or commercially available maps. This will reduce setup time and allow the robot to navigate outside previously visited places.
- Enhance and augment existing maps using the percepts of the robot with the goal that the robot can improve its navigation capabilities over time.
- Provide online self calibration tools that allow service robots to remain autonomous for long durations without the need for re-calibration.
- Describe complex three-dimensional urban areas, with the goal of automatically generating road network descriptions (RNDs) similar to those available in commercial maps.
- Allow online perception, scene understanding, and partial motion planning for safe navigation in dynamic urban environments in the presence of pedestrians and cars.

Within EUROPA2, we will design a complete, integrated system for robust autonomous navigation in densely populated urban environments. The evaluation of the EUROPA2 robot in real urban environments will demonstrate that the developed technologies are mature enough to be brought to the market. Demonstrating system operation within real urban settings – such as downtown Freiburg or Zurich city center – forces the system and its components to be highly robust. Consequently, future applications will directly gain from findings in EUROPA2.

The technologies developed within EUROPA2 all aim at an intuitively usable robot operating in challenging scenarios. Such systems have a large number of possible applications in widely-varying areas such as inspection operations, surveillance, and service robotics. In the following, we highlight several areas where the EUROPA2 technologies could directly be applied.

- Automated delivery: The task of package delivery within urban centres is a technically challenging problem with a multitude of applications for both users and companies. To realize robust delivery tasks, delivery companies can use the localization, path planning, and collision avoidance developed in EUROPA2. If the delivery tasks are carried out in populated environments, pedestrian tracking and prediction developed in EUROPA2 will be essential.
- Guidance: The maps created automatically by the robotic platform could be augmented with informational tags to offer guided tours. To this end, technologies for pedestrian tracking and prediction, scene modelling and street sign identification are required. Finally, the map curating and maintenance techniques developed in EUROPA2 will be necessary to ensure that the mobile robot can do its work continuously in a changing environment.
- Autonomous Driving: The current state-of-the-art in autonomous driving uses hand-curated maps to enable robust operation within these maps. The mapping technology generated by EUROPA2 will make it possible to automate parts of the mapping process and to allow feedback from vehicles to improve the maps over time. Algorithms for navigation within publicly available maps would extend the workspace of these vehicles to all previously mapped areas. Pedestrian tracking and prediction algorithms could increase the safety of autonomous driving. Furthermore, the online self calibration algorithms will ensure that vehicles stay well calibrated and operational over the lifetime of the vehicle.
- Personal service robotics: The capacity to navigate in densely populated urban environments will enable new possibilities for personal service robotics. In the simplest case, the robot would be accompanying the user as some kind of advanced “drudge” to assist in carrying purchases. While this would definitely be a convenient way for stressed people to regain some precious free time, it is extremely helpful for elderly or handicapped people, who might have considerable trouble moving through crowded streets while carrying their purchases. An autonomous robot would not only free them from this cumbersome burden, but allow them to stay independent for a longer time.
- Automation of Urban Mapping: Online maps have changed the way we plan, walk, and drive within our urban spaces. The current generation of maps are largely maintained by hand. The results of EUROPA2 could be used to automate the generation and maintenance of these maps. With our partner GeoAutomation, we have a commercial map provider that will directly exploit results from EUROPA2.
- Mine Automation: Parts of the technology produced by EUROPA2 has the possibility of enabling mine automation. The mapping algorithms developed in the project could be adapted to produce continuously updated detailed three-dimensional models of a worksite. The models could then be used for project planning or resource allocation. Furthermore, the pedestrian detection and tracking algorithms developed in the project could increase safety of mine operation by acting as a safety system for mining vehicles.
- Industrial Inspection: The capability of generating maps of an environment, then tracking the changes in these maps over time could be directly utilized in an indus-

trial inspection context. The EUROPA2 research in long-term vision based maps and information-driven perception selection could be used to maintain compact maps of industrial facilities such as boilers or power plants, then automatically detect structural changes, passing on this information to human operators. The automatic long-term calibration algorithms developed in EUROPA2 would allow the inspection robots to stay active for long durations without servicing. This has the potential to reduce the load of dull inspection tasks while increasing the frequency of inspections.

- Surveillance: The base technology of EUROPA2 is also highly suited for surveillance tasks. As the system includes the tracking of dynamically moving objects, logging or alarms can be triggered as soon as a new agent enters the static scene, keeping only the interesting, non-static footage. Furthermore, the solutions to robust navigation in difficult settings developed in EUROPA2 can be used to realize a mobile surveillance platform. Project research into energy management could enable fewer mobile surveillance robots to cover more ground, thus reducing costs to the end user. Automated calibration techniques developed in the project could reduce the amount of servicing needed by robots, further reducing the cost of deployment.

1.4 Project website and contact details

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