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AUTOMATIC DRIVING OF AN OUTDOOR VEHICULAR PLATFORM USING GPS AND PHOTONIC MIXER DEVICE (PMD) CAMERAS

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ABSTRACT

Extensive research has been conducted in mobile robotics so far. The main difficulty lies in the correct perception of the environment. Various sensors are available for this task, e.g. camera, radar, lidar, sonar. Combination of these sensors in terms of sensor fusion may lead to a more detailed awareness of the environment. This paper presents a method for controlling a mobile platform on basis of the combination of information provided by GPS and information derived from vehicle sensory. The task defined for the vehicle is to automatically drive from a starting point to a goal position (both stated in WGS84 coordinate system) while circumnavigating obstacles. For this purpose, the control of the vehicle relies on the following inputs. First on the position information of a GPS sensor. Second on the sensor data of two photonic mixer device (PMD) cameras. Signal loss and multipath propagation of the GPS are problems and therefore have to be handled appropriately. The control of the vehicle is done by extracting road boundaries from the PMD data as additional information. Furthermore the PMD cameras are used for detecting obstacles. Test drives are made for evaluation of the control algorithm.

Index Terms— Mobile Systems, Robotics, Navigation, Intelligent Systems

1. INTRODUCTION

Intelligent mobile systems facilitate a variety of applications. First for indoor use, e.g. service robots for interaction with humans like in shopping malls [1], museums [2] or in the rehabilitation and care domain [3]. Second in road traffic, leading to so called intelligent vehicles [4] [5]. Third, mobile systems may be used in industrial and security/ defense applications, e.g. logistics, inspection, surveillance, reconnaissance and manipulation. Prerequisite for the successful application of mobile systems is the ability for sufficient environment perception and action planning. The Fraunhofer IOSB-AST is developing a technology demonstrator system further with the aim of achieving the necessary abilities for a variety of such applications by using state of the art technology. However cost-effective components are preferred, so transforming technology in real world applications is feasible. Many application scenarios require the ability to retrieve global position information by the mobile system. Therefore in a previous project step a Kalman-Filter based localization module was developed [6] which provides enhanced position information under short-time signal loss or in signal multipropagation situations. In the current project described herein, the goal was to design and implement an automatic driving controller using the localization module and cost-effective photonic mixer device (PMD) cameras. Since navigating in fully unknown terrain is still far away in the robotics community, some restrictions were applied for the environment or the infrastructure, the system operates in respectively. First the mobile platform is supposed to act within structured environments, e.g. a street-like environment. Second obstacles do exist which force the mobile system to dynamically replan its path. Third the boundaries of the tracks are detectable by a vision system (markings) or by evaluation of 3D environment data (road curbs). The first case is tackled in this paper. The challenges solved in this paper are the special characteristics of the PMD sensors (limited resolution, sampling time and range) and moreover the ambiguity problem arising from the sensor technology. The rest of this paper is structured as follows. The next section contains information about the vehicular platform which was developed and used for the work herein. Section 3 gives a short overview on the PMD sensor technology as it affects their application for outdoor mobile systems. An overview of the control concept is given in section 4, followed by a detailed view on specific aspects of this concept in the next two sections. Experimental results and a conclusion / outlook are given in sections 7 and 8.

2. DESCRIPTION OF THE PLATFORM

The mobile robot Quanjo TDS, as shown in figure 1 was developed by Fraunhofer IOSB Application Center System Technology (IOSB-AST) over the last years. It is a technology demonstration system that provides a robust platform for testing and research of various kind of robotic matters. Due to the complex and variable site of operation in outdoor environment the demands to the system under different aspects are very high. The robot has four independent electrically driven wheels with two interdependent steerable axles which allows a small turn radius. It has a hybrid power concept consisting of batteries, being charged stationary or by an onboard combustion engine combined with a generator enabling a cruising range of 100 km or an operational time of ten hours.

Fig. 1. Quanjo TDS - developed by the Fraunhofer IOSB-AST

The microcontroller unit (MCU) based onboard computer allows full access to all internal sensors and actors of the robot platform, which are linked via CAN.

3. SENSOR WORKING PRINCIPLE

The PMD sensor used in this work allows the direct pixel-wise measurement of the distance of objects in the field of view of the sensor together with its grey-intensity. We used the PMD[vision] O3 from ifm electronics gmbh, which has a resolution of 64x48 pixel and a field of view of 40 horizontal and 30 vertical. In general the sensor works according to the Time-of-Flight (TOF) principle, which means measuring the period of active light travelling to the measured object and being reflected to the sensor chip. However this time is not measured directly which would require extreme accurate measurement in the range of picoseconds and high-quality HF-components. The time is measured indirectly by determination of the phase shift between outgoing and incoming wave directly by the related pixel on the sensor chip through realizing implicitly an autocorrelation. The pixel can be seen as balanced mixer, which effectively eliminates the influence of ambient light. Figure 2 shows the sensor which was integrated twice at the left and right front of the vehicle platform.

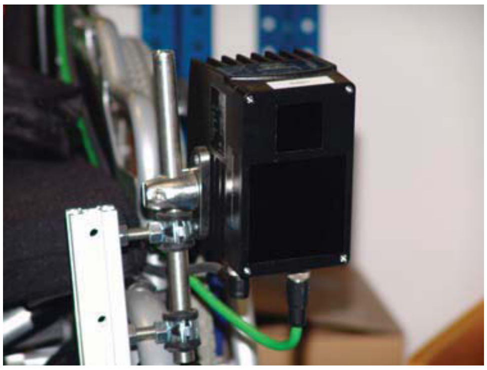

Fig. 2. PMD sensor used for perception

Although the acquisition range depends from environment and also highly from the object (material, color) to be measured, there is a fix ambiguity range of 7.5 m resulting from the frequency used for the light pulse.

4. SYSTEM OVERVIEW

Figure 3 shows the principle information flow of the automatic driving system. As perceptive sensors, two photonic mixer device (PMD) cameras are used, which are integrated into the vehicle system in such a way, that they are forward looking at the left and the right side of the vehicle respectively. The sensors are interfaced via a special protocol which uses a TCP/IP connection. The sensors are interfaced by a Matlab/ Simulink S-function DLL. This allows easy integration into a Simulink model. The model implementing the perceptive processing step runs on a commercial PC for development purposes and will be transferred into an embedded processing system later. The perceptive processing is for extracting relevant information from the sensor data and consists of the parts preprocessing and obstacle detection and is explained in the next section in more detail.

The actual path planning is done by the so called robot-multicontroller (ROMUC). This is realized by a special purpose real-time machine (Speedgoat) based on a 80x86 PC-system. This system is equipped with standard PC-interfaces, with analog/digital IO and a CAN interface card. Rapid prototyping is possible with the help of the xPC Target toolbox of Matlab/ Simulink. Obstacle information is sent to the ROMUC via UDP connection. The information scheme is cyclic, which means that obstacle information is sent to the ROMUC system in fixed intervals. For the purpose of the task

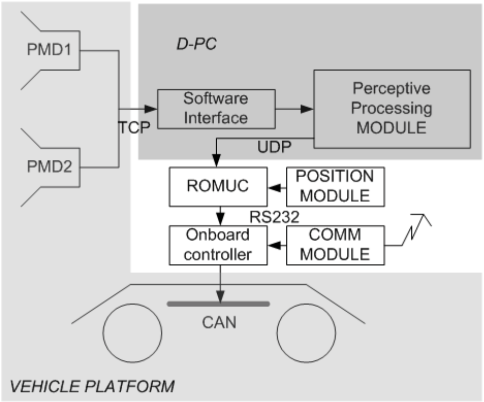

Fig. 3. Principle information flow

presented here, the ROMUC holds a path planner which detailed is described in section 6. In general the ROMUC system allows multiple controllers to work in parallel, e.g. object following, collision avoidance, wall following. The outputs of the ROMUC are the velocity target value and the steering target value. These values are given by a RS232 connection to the onboard controller in fixed time intervals. The onboard computer itself is the direct interfacing unit to the platform CAN bus and also implements safety mechanisms. The onboard computer is awaiting the control messages from the ROMUC and is stopping the vehicle if they are missing. Furthermore a remote communication link which is directly connected to the onboard computer allows an emergency stop. The ROMUC needs in extension to the obstacle information provided by the perceptive processing module the global position in every processing step. This information is provided by a Kalman-Filter based localization module, utilizing GPS, speed and inertial sensor data [6]. The target track is given by succeeding waypoints in global GPS WGS84 format in prior to mission start. For this purpose the ROMUC is configurable by a software application running on an external computer, which is connected to the ROMUC via RS232.

5. PERCEPTIVE PROCESSING

PMD cameras do measure distances according to the principle of time-of-flight (tof). Due to light does only take 6.6 ps for one millimeter, accurate measurement of distances is difficult. Therefore the method used within the PMD camera, is to modulate the light before emitting it. Also it is possible to assign a distance value to every single pixel of the 2D-Matrix of the PMD chip. In the end the time of flight isn't measured directly, but the elapsed time of the modulated light wave. This method brings the disadvantage, that it gets impossible to measure distances greater than a critical ambiguity distance d_{amb}. A non-ambiguous measurement of distances from phase shift is only possible for distances between zero and d_{amb}. The distance d_{amb} yields from the modulation frequency f_{mod} used by the sensor in the following way:

$$d_{amb} := \frac{c}{2 \cdot f_{mod}}. \tag{1}$$

where c is the speed of light. As f_{mod} equals 24 Mhz for the sensor used in this project, the resulting ambiguity distance is 6.2 m. It is important to mention that light is reflected in many cases by objects that are located outside of d_{amb}, depending on their material and color. In this cases the measured distance is not the real distance. For example it may happen, that an object at a real distance of 9 m is measured with a false distance of 2.8 m and causes an emergency stop of the vehicle. Therefore it is important to handle this problem by an intelligent data processing step discussed in the following, according to the processing scheme depicted in figure 4.

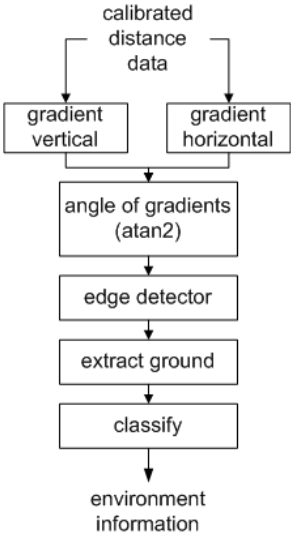

Fig. 4. Scheme of perceptive processing of PMD camera data

As the PMD camera like standard CCD-cameras has optic components, related error effects, like lens distortion, have to be compensated in a calibration step. However in our case this is done by the PMD camera itself by an internal calibration. The output of the camera interface are the x, y, z- coordinates of the measured distance values in relation to the camera frame. These values are transformed to get the direct distance related to each pixel. Furthermore, in case multiple PMD cameras are used, they have to get synchronized since they are active sensors. This can be made by software or on hardware level with the help of a special trigger signal. However in our assembly this was not necessary, since the fields of view of both used cameras were disjunctive. In order to determine the distance to obstacles, although the present ambiguity problem, another criterion is evaluated in the processing. Therefore it is assumed that obstacles are connected to the ground in a way, that there are no overhangings. In this way an obstacle is an interruption of the ground. To detect this, first the ground is separated from the rest of the distance image. For successful application additional assumptions must hold: the ground has to be in the field of view of the PMD camera; an obstacle may not occlude the field of view of the camera completely (otherwise the obstacle may be detected as ground). The processing starts with calculating the gradients of the entire distance image in vertical and horizontal direction. The resulting two values are used for calculation of the resulting angle for each pixel. This angle is assumed to be distributed homogeneous for planar objects or the ground. To actually extract the ground an edge detector (Sobel filter) is applied and afterwards the ground is separated with a threshold value. The threshold was found empirically. Applying the assumptions made so far, all pixels beneath the lowest edge are accounted to the ground level. Since in the case no obstacle is present, the ground level is apparent up to the vertical maximum of the lowest edge, all pixels significant beneath this level are assessed as obstacles. Hereby a safety zone considering the measurement noise is implemented. Once these potential obstacle pixels are identified, position and heading can be determined from the original distance image. In addition to the processing described above, also walls or road curbs can be detected using the intensity image data and are used within the control algorithm by interpreting them as line-like obstacles analogous to obstacles detected in regard to the description above. To achieve this, a lane detection algorithm on basis of hough transform [7] was implemented.

6. PATH PLANNING

The automatic path finding is divided into two steps - advance planning and reactive control - as can be seen in figure 5.

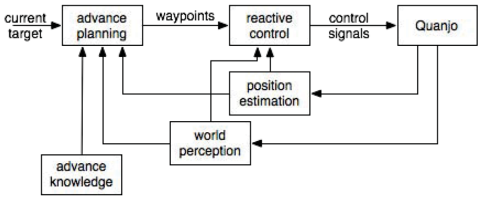

Fig. 5. Control system for path planning

In the first step, the advance planner calculates a path to the current target position. This path, represented by a number of waypoints, will then be used as base path for the reactive control. In order to avoid collisions, the obstacle information calculated by the world perception module is used along with the obstacles entered by the vehicle operator prior to the start of the mission. Additionally, the user can feed the vehicle with preferential paths that will be taken into account by the advance planner. In order to calculate the waypoints, representing a safe path to the target position, the advance planning module builds up a graph from a set of potential waypoints. All edges that are obstructed by known obstacles are deleted from the graph and the remaining edges are weighted with the Euclidian distance of the respective points. In order to incorporate the preferential paths, the corresponding edges are weighted lower than the Euclidian distance. Since the aim of the path planning is to find a short but safe path, the resulting waypoints are calculated using a shortest path algorithm on the created graph. Even though an optimized version of the A*-algorithm [8] has been used for the shortest path search, the calculation still takes a significant amount of time due to the high number of potential waypoints and the extensive edge checking needed while setting up the graph. In order to be able to operate the vehicle with a reasonable speed, the advance planner is only used when absolutely necessary and is triggered by the reactive control module. The actual generation of control signals handed to the internal engine control is conducted by the reactive control module. Inputs for this module are the waypoints calculated by the advance planner as well as the estimated current position and the obstacles detected by the world perception module. The reactive control system does not make use of the a-priori knowledge about obstacles, as these might not be consistent with the sensor information. The control signals calculated by this module are the desired steering angle and the vehicle speed. The reactive controller begins its work by searching the sensor information for obstacles that obstruct the direct connection to the waypoint currently aimed for. In the case of obstructing obstacles a temporary waypoint is calculated, as shown in figure 6. The planner picks the obstructing obstacle that is closest to the vehicle and finds the shorter of the two directions around the obstacle. Then the temporary target point is placed in a way that the obstacle is no longer obstructing the direct connection to this temporary point but still close to the obstacle to keep the path as short as possible.

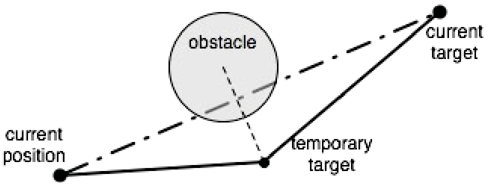

Fig. 6. Temporary target points to avoid obstacle collision

However, because the obstacles are taken into account one by one, the reactive control module has to make a set of local decisions and can therefore not guarantee for a globally optimal path, at the moment. After placing a temporary target point that is no longer obstructed by any obstacles, the vehicle aims straight for this point. Now the current yaw-angle of the vehicle, as measured by the position estimation, is compared with the angle straight to the temporary target and an error is calculated. This error is now applied to a standard PID-controller in order to generate the desired steering angle and velocity of the vehicle. The control parameters for this PID-controller were generated with the help of simulations using a model of the Quanjo TDS system in Matlab/ Simulink [9]. The calculated control signals then are transmitted to the internal engine control system, and eventually to the engines that control steering and vehicle speed. In order to allow a stable run of the vehicle during outdoor missions, some special cases have to be considered. First, due to sensor problems or non-static obstacles, it is possible that the vehicle finds itself within a very close range to an obstacle. In this case the controller has to signal an immediate emergency stop to have the situation observed by the operator or to slowly drive away from the obstacle until it can be safely circumnavigated. In this case the reactive controller also triggers the advance planner to calculate a path using the newly found obstacle information. A replanning is also required if the controller cannot safely calculate a temporary target and hence avoid collision. A second possibly hazardous situation is the loss of radio communication to the operator, as the vehicle could get out of control. In this case the reactive control module lets the vehicle drive back to the position of last contact until the communication is working. Again, a new path has to be calculated in order to avoid another loss of radio signal.

7. EXPERIMENTAL RESULTS

To test the implemented automatic driving controller experiments were conducted at module level and for the entire system. Some qualitative results are given here. First the localization module [6] was tested.

Shown in figure 7 are the position signals as presented from the GPS receiver as well as the filtered positions as output from the Kalman-Filter based localization module. The short-time disturbances do result from multipropagation effects while driving in shadowed environment and are compensated well by the filter. Next the perceptive processing module was tested. For results see figure 8 and figure 9. In figure 9 the detected obstacle (person standing in front of vehicle) and the road boundary (road curb) are shown overlayed in white in the original gray-scale image of the PMD cameras. In figure 8 the corresponding situation is pictured.

Finally the entire automatic driving control system was tested by stating a set of goal waypoint in WGS84 format. The vehicle was supposed to generate a path for reaching the waypoints in sequence. In addition the vehicle should keep a minimum distance to the road boundary and should circumnavigate obstacles. For the work so far, static obstacles were used. The road boundary was measured in global WGS84 coordinates in beforehand. Figure 10 shows the path driven by the system, the road boundary and the obstacles from the test in direct environment of the research lab.

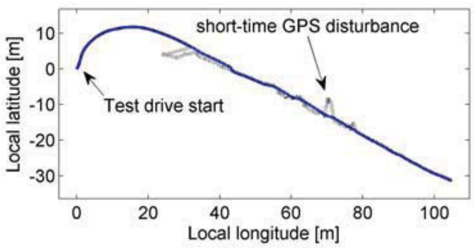

Fig. 7. Experimental results of localization test drive: Although at the driven track DGPS signal quality was available, short-time disturbances occured due to shadowing from an urban building. However after beeing detected by the position filter, these were handled well

Fig. 8. Static scenario for evaluation of the perceptive processing module

Despite for this test only GPS quality was available in conjuction with the position filter, obstacle detection and road curb detection, the vehicle successfully completed its mission. Average speed was about 0.5 m/s with a mission time of 246.5 s.

8. CONCLUSION AND OUTLOOK

This paper presents an automatic driving controller for an outdoor vehicular platform. This driving controller adds on to the existing work in building up a technology demonstrator platform by the Fraunhofer IOSB-AST. Specific restrictions were applied to the environment the vehicle platform may operate in. So, road like tracks with detectable boundaries are a prerequisite for the operation. Challenges related to the sensor technology of TOF camera used for this work were addressed

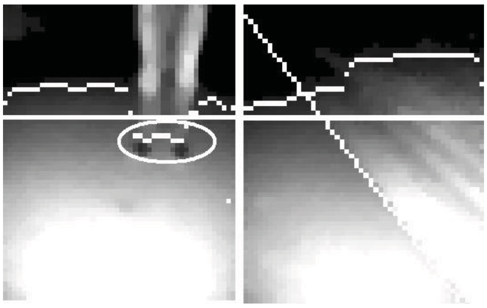

Fig. 9. Result of perceptive processing evaluation scenario: Detected obstacle in data of left PMD-camera (ellipse) and detected road curb in data of right PMD-camera (diagonal line)

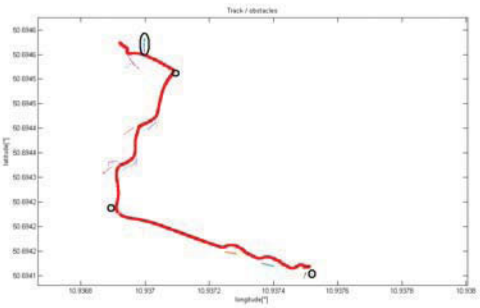

Fig. 10. Position of vehicle while test drive with three waypoints (black circles) while circumnavigating one obstacle (black ellipse); detected road curb sections are shown as lines

in this paper. This is especially the ambiguity problem. A method for obstacle detection under possible ambiguities was presented. It is clear from the presentation that backtracking isn't reasonable in present state, since no cameras are integrated as behind looking sensors. However with this as a possible future work the proposed system states a cost effective automatic driving system for a variety of possible applications. Maximum travel speed is still a problem which is limited by the PMD cameras range and sampling time. This will improve as the sensor technology evolves in the future.

9. REFERENCES

[1] Gross, H.-M., Boehme, H.-J., Schroeter, Ch., Mueller, St., Koenig, A., Martin, Ch., Merten, M., Bley, A. ShopBot: Progress in Developing an Interactive Mobile Shopping Assistant for Everyday Use. in: Proc. IEEE Int. Conf. on Systems, Man and Cybernetics (IEEE-SMC 2008), Singapore, pp. 3471-3478, IEEE 2008

[2] Hoch, Andreas; Simons, Florian; Haag, Matthias; Parlitz, Christopher; Reiser, Ulrich; Haegele, Martin: Care-O-bot 3 - Mobiler Serviceroboter mit ausgepraegter Manipulationsfaehigkeit. In: Kompetenznetzwerk Mechatronik BW: Intelligente mechatronische Systeme : Internationales Forum Mechatronik, begleitend zur MOTEK, 22.-23. September 2008, Stuttgart. Goeppingen, 2008, S. 360-371

[3] Graf, Birgit; Staab, Harald: Service Robots and Automation for the Disabled / Limited. In: Nof, Shimon Y. (Hrsg.): Springer Handbook of Automation. Berlin u.a. : Springer, 2009, S. 1485-1502

[4] Christoph Stiller, Jens Gayko: Kognitive Automobile. In: at - Automatisierungstechnik, 2008 Nov., 56, 551 - 553, Oldenbourg Verlag.

[5] Chris Urmson et. al. Autonomous Driving in Urban Environments: Boss and the Urban Challenge. In: Journal of Field Robotics 25(8), 425-466, 2008, Wiley Periodicals, Inc.

[6] Fabian Mueller, Andreas Wenzel, Achim Gehr, Christoph Ament. Embedded Control Design of a Mobile Robot System: Results on a robust localization module. In: Proceedings of IEEE Conference on Control Applications (CCA), 2010 (in press).

[7] V. Hardzeyeu, F. Klefenz. On using the hough transform for driving assistance applications. In Proc. 4th Int. Conf. Intell. Comput. Commun. Process., Shanghai, China, 2008, pp. 9198.

[8] Peter E. Hart, Nils J. Nilsson, and Bertram Raphael. A formal basis for the heuristic determination of minimum cost paths. IEEE Transactions of Systems Science and Cybernetics, 4(2):100107, July 1968.

[9] Achim Gehr. Entwicklung und Test dynamischer Modelle teilautonomer/autonomer mobiler Robotersysteme, TU Ilmenau, Diplomarbeit, 2009