Augmented reality approach for mobile multi-robotic system development and integration

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Abstract

In the following paper we introduced new idea for mobile multi-robotic system development and integration based on augmented reality techniques (AR). We showed the concept of the combination of real-world and computer-generated data that can be used for multi robotic system design, where computer graphics objects are blended into the real environment in real time. We introduced a comprehensive toolkit to connect the physical and virtual world within AR using NVIDIA PhysX simulation. The advantage of our approach is not only live video images that are augmented by additional computer generated graphics, but also construction of the virtual environment based on real sensor data, that is used for virtual robots simulation and feedback into real robot sensing. For this reason we expect that real robots can interact with virtual one. The result is: the AR-system that combines real and virtual robots, therefore the cost and the time of integration is going to be decreased. The result demonstrates the AR-system combined by real autonomous mobile robot equipped with 3Dmap sensors and camera video and virtual teleoperated caterpillar robot with 5DOF arm which is simulated in the virtual environment built from real sensor data. The mobile robotic system is controlled from the real base station, from where all robots (real and virtual) are available to be controlled and interact each other.

Introduction

The mobile robotic system development and integration tasks need a lot of effort because of its complexity. The problem appears when robotic system is being designed and developed by international consortium. The difficulty is determined by the need of transportation each part of the system to the place of the integration. For this reason we propose new approach that combines virtual robots with real robotic system. In our opinion it can improve the process of multi robotic system development and integration. Due to the framework for AR mobile multi-robotic system design is a new concept we developed some necessary components to build such system. We designed the communication layer based on CORBA TAO which allows communication with robot based on Player/Stage. The 3D map building procedure is adapted to build 3D virtual environment for virtual robot with sensors simulation. New 3D obstacle avoidance system based on IFM PMD cameras is used for local mobile robot navigation. The simulation component based on NVIDIA PhysX is integrated with AR system. In our expectation AR approach should improve mobile multi-robotic system development and integration.

Our proposed system has two objectives: to develop multi robotic system starting form design using simulation tools, afterwards the real components are integrated with simulation using AR techniques, in the final all virtual components should be replaced by real one, therefore final system should be created. Second objective is to deliver methodology for multi robotic system integration and evaluation using AR techniques. For this reason we introduce AR approach combining real base station, real autonomous mobile robot equipped with 3D map building system, and virtual teleoperated robot simulated in NVIDIA PhysX engine. All needed information from robots is available in the base station, also the interaction between real and virtual components is modeled.

Related work

Augmented Reality approach applied for mobile robotics is a combination of real and virtual world. The representative developments where described in [1][2] with overviews of tracking, overlays and applications. The AR applications are typically related with augmented human robot collaboration to evaluate robot plan by usage of combination video from robot with graphical models, that represent additional information for robot operator. Various techniques for the registration of real and virtual content was proposed in [1]. The motivation for Photorealistic rendering versus Non-Photorealistic rendering in Augmented Reality applications was discussed in [3]. Numerous of AR approaches related to the interaction with mobile platforms are described in[4]. The development and experimentation of humanoid robot using AR approach was discussed in [5], where the recent advances in speed and accuracy of optical motion capture to localize the robot, track environment objects, and extract extrinsic parameters for moving cameras in real-time was described. The system enables safe, decoupled testing of component algorithms for vision, motion planning and control. The results of successful online applications in the development of an autonomous humanoid robot are also described in[5].

Development of the multi robotic systems is challenging task and requires a lot of effort concerning robot design and system integration. The program development environment for multiple robot-multiple application system was introduced in[6]. Due to the field of distributed mobile robotics has grown dramatically, several papers are focused on the topics of multi-robot systems[7][8][9][10]. Additional open research issues in distributed mobile robotic systems was described in [11]. Numerous multi-robot frameworks[12][13] are available for multi-robot system development [14][15][16].

In this paper the new idea of combination of Augmented Reality approach with mobile multi-robotic system development is introduced, also new research issues are described. We believe that our results can improve the robotic system development and testing.

The AR - system overview

The proposed AR system is multi agent system composed by AR-agents and R-agents that interact each other. The NVIDIA PhysX engine is used to perform AR-agents simulation. The fundamental assumption is that the position of each agent is known, therefore data fusion from real sensors and simulated is possible. In the global localization of the real robot the SLAM algorithm[17][18] based on LMS SICK 200 and odometry data is used. The global position of AR-agent is given from simulation. To simulate laser range finder the environment 3D model build from 3D data acquisition system has to be transferred into simulation engine. Figure 1 shows general idea of proposed AR approach.

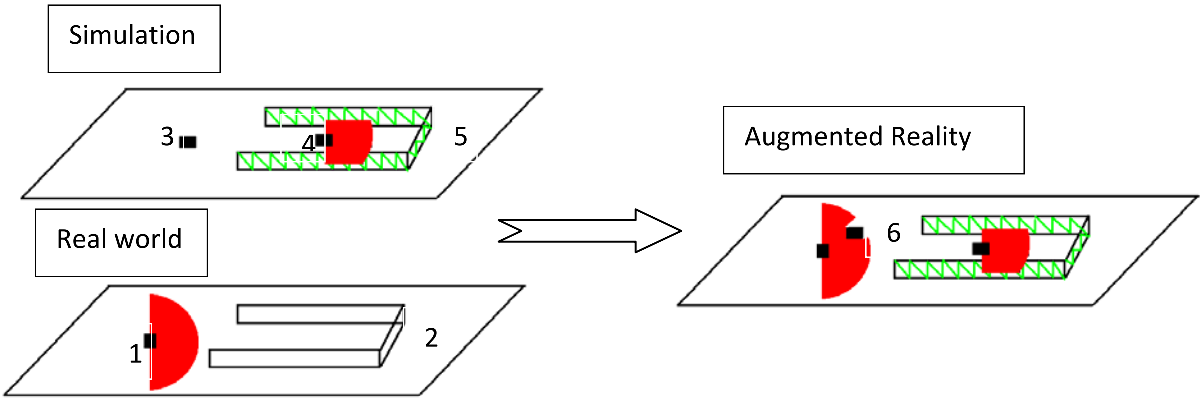

Figure 1: General idea of AR approach. 1 – real robot equipped with laser range finder, 2 – real obstacles, 3 – virtual robot, 4 – virtual robot equipped with simulated laser range finder, 5 – virtual 3D model of the real obstacles obtained by real robot, 6 – augmented real laser range finder measurement with additional virtual measurement of virtual robot chassis (1+3).

Real robot

For the experiment purpose we equipped ATRVJr robot with several devices such as 3D PMD cameras, laser range finder LMS SICK 200 for localization and LMS LD 1000 for 3D map reconstruction. For the 3D local navigation purpose we built 3D PMD sensor system compound from 4 PMD cameras. Each camera has 64x48 pixel array – in which each pixel represents a time of flight measurement defines the field of view for the sensor. Figures 2,3 show the 3D local map sensor system. The advantage of this approach is that the 3D local map situated in front of mobile platform is available each 100ms. The local map is represented by 4 x 64 x 48 pixels array that project 12288 points of reference, capturing the entire image in three dimensions.

Figure 2: 3D local navigation sensor system based on 4 3D PMD sensors.

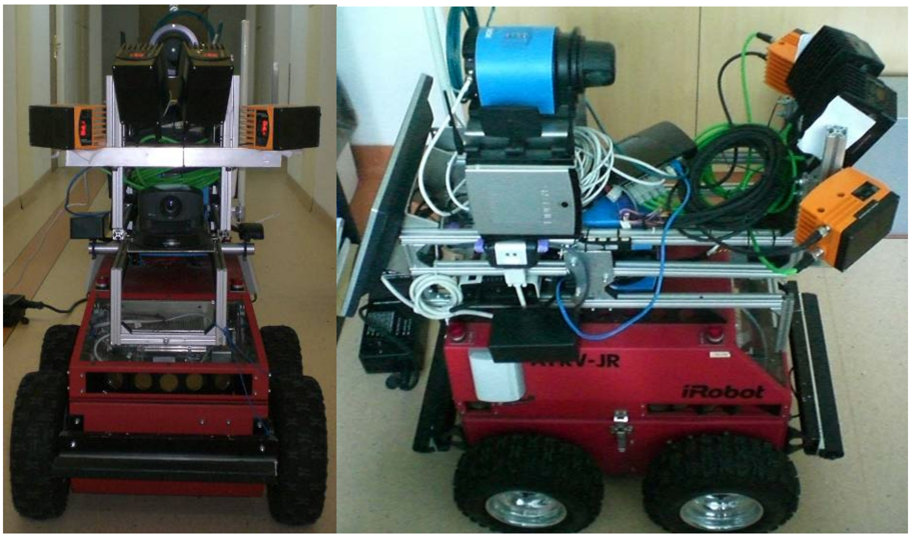

Figure 3: Autonomous mobile robot equipped with 3D sensors for local navigation and 3D map building.

Environment model

The 3D map is built based on the data delivered by SICK LD1000 laser mounted vertically on the robot chassis. The 3D map is constructed during robot motion. The accuracy of the map is strongly determined by SLAM algorithm which delivers robot global position. Figure 4 shows the visualization of the mobile robot and 3D environment.

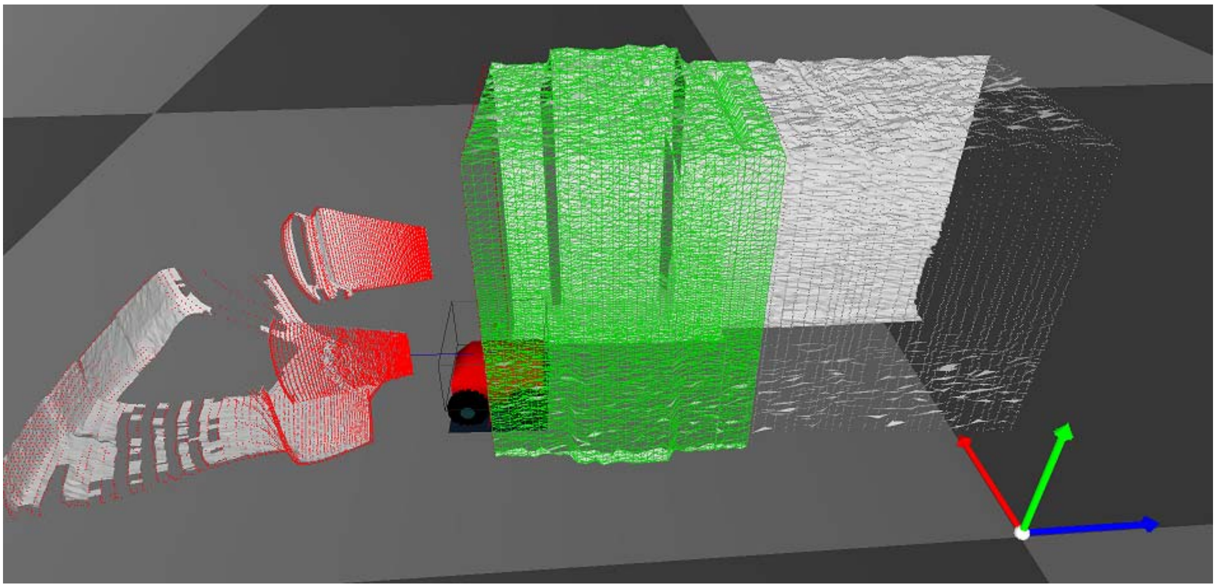

Figure 4: Visualization of the mobile robot and 3D environment. Red points correspond to PMD 3D camera measurement, green triangles – local 3D map, gray triangles – saved model of the environment.

Virtual robot

The virtual model of robot INSPECTOR is compound from rigid bodies connected via joints with angular and linear motors. Therefore it is possible to manipulate all DOFs using control panel. The caterpillars are modeled by numerous wheel shapes in NVIDIA PhysX, therefore the behavior of robot motion is similar to real one. Figure 5 shows visualization of geometrical model of described robot that is used for HMI purposes.

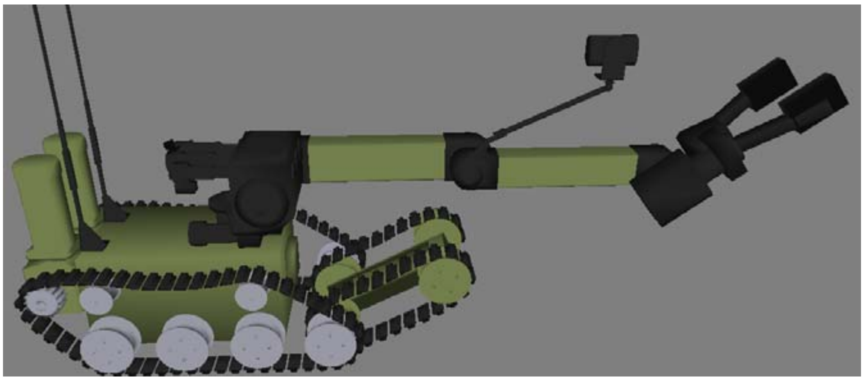

Figure 5: Geometrical model of robot Inspector used in HMI.

Virtual laser range finder

Figure 6 shows simulation of laser range finder that computes distance between laser range finder position and virtual objects such as reconstructed 3D map and virtual robots. To give an information about the real robot chassis into the simulation the additional rigid body has to be associated with it. The laser range finder simulation uses ray intersection mechanism to compute distances and additional noise to model physical parameters of real device.

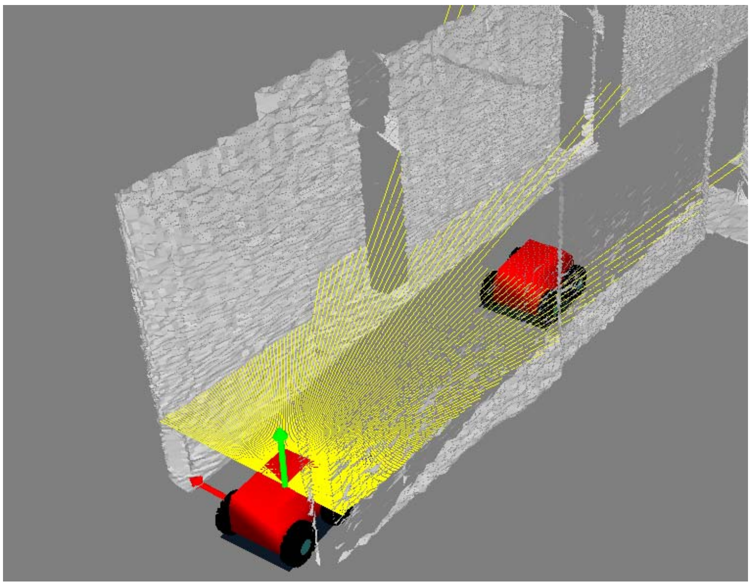

Figure 6: Simulation of virtual laser range finder LMS SICK 200 in reconstructed 3D environment.

Augmented reality system

The augmented reality system dedicated to multi robotic system development and integration is composed by real autonomous mobile robot ATRVJr equipped with 3D map sensors, real base station with robot Inspector console, simulation of teleported robot Inspector with simulation of laser range finder. The system for composition real video feedback from robot ATRVJr with simulation is developed using ARToolkit[19] for camera calibration and positioning purposes. Figure 7 shows control base station where operator can control each robot, real and virtual one. It is important to emphasize that virtual robot is visible in autonomous robot main camera view. Another advantage of proposed approach is the possibility of summarizing all system components in the main HMI program that visualizes robots position and sensor data.

Figure 7: The augmented reality system.

Discussion

Due to the simulation techniques used for multi robotic system development give a lot of advantages, the integration process should be done in real environment. It is obvious that simulation is not able to replace experiments in real environment. For this reason the multi robotic system augmented by simulated components is an alternative way and can potentially improve the process of testing and integration. AR techniques can be used as the middle layer between simulation and reality for multi mobile robotic system development and integration. Therefore more complex and sophisticated systems can be designed using low cost resources.

Conclusion

This paper introduced new AR approach for mobile multi-robotics system development and integration. The mobile robot ATRVJr equipped with 3D perception is shown, also the result of 3D map building and transfer to simulated environment is presented. The model of virtual teleoperated robot is shown. The general idea of AR system is introduced, also interaction between reality and virtual simulation is emphasized. The final experiment of AR system composed by real mobile robot, real base station, virtual teleoperated robot and simulation of robot perception based on 3D real data acquisition is presented. It is important to emphasize that such system can be used not only for robotic system development but also for advanced low cost training. Future work is related to improve camera calibration, multi robot localization, 3D map building and reconstruction, robot navigation. We believe that introduced AR system can be used for several existing robotic systems development, testing and operator training.

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