Mixed Reality Simulation Framework for Multimodal Remote Sensing

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ABSTRACT

Aerial photographs play a major role in current remote sensing applications. Traditionally such photographs were acquired using airplanes or satellites, and later processed in order to generate a virtual environment (VE). The industrial research project AVIGLE explores novel approaches to multimodal remote sensing by using a swarm of Miniature Unmanned Aerial Vehicles (MUAVs), which are equipped with different sensing and network technologies. The acquired data will be sent in quasi-real time to a ground control station, where a VE will be generated automatically. Although this approach introduces a new low-cost alternative to the traditional remote sensing processes, it opens up numerous research and engineering challenges. In this position paper we introduce a mixed reality (MR)-based simulation framework, which has been developed in the scope of the AVIGLE project. The main idea for this framework is to create a controlled environment in which parts of the system are real, whereas other parts are virtual and can be simulated for testing purposes. This MR simulation framework is intended to use virtual and real sensing technology in combination to provide a flexible solution to simulate and evaluate different hardware setups and algorithms.

Author Keywords

Mixed Reality, Sensor Simulation, Miniature Unmanned Aerial Vehicles

INTRODUCTION

Aerial images play an essential role in surveying, the creation of maps and many other applications. Since the emergence of tools like Google Maps and Google Earth, photographs taken from airplanes and satellites are no longer restricted to specific uses, but are widely accessible. These images are often combined with geo-referenced basis data that represent the geometric properties of the corresponding region [4]. While capturing a region airplanes usually follow exact trajectories and time protocols. For instance, a common pattern is to acquire images with an overlap of approximately 60%. In addition, in most cases metric cameras and exact on-board measurement devices are used in such setups in order to simplify the registration and generation process. All these constraints enable the extraction of 3D points from the aerial images based. However, most of these systems require a significant amount of manual processing, and usually it takes a long time (up to several weeks) until the recorded data is fully processed and a corresponding 3D representation can be visualized. Therefore, the automatic generation of virtual 3D models is of major interest in many application domains, e. g., large scale geography or the creation of topological maps.

MUAVs are a low-cost, low-latency alternative to existing approaches. Because of the emergence of MUAVs, the nowadays widespread use of non-metric digital cameras and the progress of photogrammetric technologies, image acquisition by low altitude images attracts significant attention in photogrammetry. Currently, the mostly used low altitude platforms for image data acquisition are helicopters, remotely controlled model aircraft or tethered balloons. Until now, in the context of MUAVs none of the existing solutions provides sufficient concepts which allow to reconstruct a 3D model of the captured area in quasi real-time. The *AVIGLE (Avionic Digital Service Platform)* project is an industrial research project which provides a promising approach to this challenge. The academic partners in this project work on flight dynamics, communication networks and computer graphics, virtual reality and visualization together with industry experts for building MUAVs, wireless communication technology, multimodal and traditional aerial photogrammetry to create a swarm of partly autonomous flying robots. Besides the quasi-realtime creation of a 3D model of the captured region multiple MUAVs will be used as "aerial" communication hotspots in places where no sufficient cellular network coverage is available, e. g., in catastrophe management. Swarming strategies have to be developed in order to provide an optimal coverage. In order to integrate the different hardware systems and software interfaces, it is essential to have an advanced control and simulation framework, which allows to monitor and control the processing of already existing components, whereas other components not yet available are simulated by virtual counterparts.

In this position paper we introduce our MR framework that is developed in the scope of the AVIGLE project. Since the development of the MUAVs to be used for our aerial platform is still in the early stages and the MUAVs are not yet available, a tool is needed for simulating the different processes

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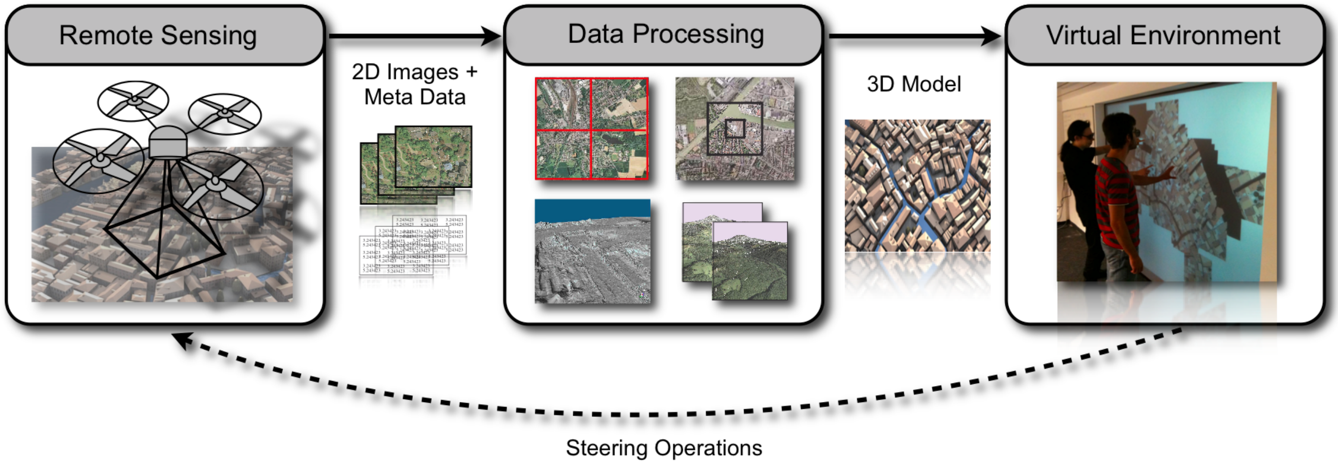

Figure 1. The workflow of the AVIGLE project divided into three basic steps: (1) Remote Sensing, (2) Data Processing and (3) Virtual Environment.

involving the MUAVs without relying on the availability of the hardware. Additionally, fully testing the entire process chain involves a number of risks and requires flight permissions in urban regions which are not granted at this stage of development. Obviously, it would be dangerous to test different routing and obstacle avoidance algorithms within urban regions. Since it is critical to replace the entire simulation framework with real hardware and a real environment at once and then perform a real-world test MR provides essential benefits for this project. It allows to successively replace components of the simulation with their real counterparts. In addition, certain hardware components can be tested before actually deploying real hardware.

A similar MR simulation framework has been used in the context of robot simulation [1]. We want to discover to what extend MR can be used to assist the development of critical systems like AVIGLE.

AVIGLE FRAMEWORK

The aim of the AVIGLE project is the development of a swarm of partly autonomous, interconnected flying robots that can support different high-tech services. In particular, AVIGLE's MUAVs will be equipped with different multimodal sensing technologies such as image, thermal or gas cameras. Location and orientation awareness of the MUAVs is achieved through a GPS receiver and an inertia measurement unit. One of the main objectives of the AVIGLE project is to create a VE derived from the sensor data captured by the MUAVs. Sensors mounted on MUAVs will acquire image data of a scene or area. These image data will be transferred to a ground station where they are further processed in order to build a 3D model. An incrementally constructed model is then used as a basis for a VE showing the 3D world in the area covered by the MUAVs. Since the system is intended to be used in catastrophe management scenarios, it is crucial that the results are displayed as soon as possible, and that this incrementally growing VE can be explored interactively. Therefore, an initial 3D model of the area covered by the MUAVs needs to be created in *quasi* real-time, i. e., within a couple of minutes.

Workflow

The workflow of the AVIGLE project shown in Figure 1 consists of three blocks: (1) Remote Sensing, (2) Data Processing and (3) Virtual Environment. At this stage of development the first block in the workflow is provided by the AVIGLE simulation framework. The real world is replaced by a complete virtual model, which has to be reconstructed. The main data source for the construction of the VE are aerial photographs currently generated in the AVIGLE simulation framework by rendering images of such a city model. In the next processing step a 3D model is reconstructed from the aerial photographs. The image data received from the MUAVs are processed in a pipeline that involves the following stages: (1) *Rectification and Georeferencing*: Since the images captured by the MUAVs may have different perspectives with respect to the orientation of the MUAVs, at first, the rectangular perspective images have to be rectified in order to provide a texture, which can be further processed. Therefore, we use the data captured by GPS and an inertia measurement unit for each image to initially reference the image with respect to the world coordinate system. (2) *Image Registration*: The precision of the sensors may lead to inaccuracies in the 3D reconstruction process. Hence, it is necessary to register the images with each other. Unique features in the current image have to be detected which then have to be located in the overlapping image. (3) *2D Tile Generation*: The entire set of the registered images forms a mosaic of aerial images. In order to be able to visualize the enormous amount of data, smaller textures have to be generated from the set of aerial images. (4) *3D Mesh Generation*: The images captured by a swarm of MUAVs will partly overlap. During the registration process the images will be registered based on features. Certain features will have completely different positions in corresponding images. Such situations usually occur when the image covers three-dimensional objects from different perspectives. These features allow the extraction of three-dimensional information about the object. This reconstruction of several feature points results in a 3D point cloud from which a 3D mesh can be derived. In the last step of the virtual model generation, the data is sent to the visualization and interaction module.

Apart from the reconstruction of the 3D model from 2D images it is planned to consider also other sensing technologies such as a thermal or gas that either give additional information in catastrophic scenarios or can be used to support the 3D image creation or obstacle avoidance.

MIXED REALITY SIMULATION

In the scope of the AVIGLE project, we developed the AVIGLE simulator [6] that helps to simulate sensors and MUAV movement. By simulating the MUAV movement and sensing in a VE, a data processing workflow can be developed using simulated data, which is independent of hardware manufacturing and flight permissions.

By using the simulation framework, the project started entirely as a virtual simulation. During the development more and more parts will be replaced with physical counterparts until the entire AVIGLE prototype can be used in real world scenarios. Furthermore, the AVIGLE project is highly interdisciplinary, and often several decision makers are involved, for example, in determining what sensing technology should be used or in finding the best design for the flight platform. MR setups as described below allow several collaborators to revise the setup simultaneously without risks and problems involved in a real world test, but with more valuable insights in contrast to a purely virtual simulation.

We intend to use MR during the development process in a general way by “moving along” the virtuality continuum first introduced in [2] (see Figure 2). Similar approaches are already used in robotics [5]. In the AVIGLE project, at first all components (i. e. the MUAVs and the sensor devices) are simulated in a virtual world. Hence we reside at the virtuality end of the continuum. As the development continues more and more components are successively replaced by their real counterparts until the reality end is reached which means that the hardware sensors and algorithms can be used in a real world scenario. The possibility to replace parts successively and not at one stroke makes allowance for the fact that not all components are available during the development process or that it is too risky to test several components in the real world at an early stage of the project. Amongst other things the MR setup should serve to refine the simulation of these components so that the risks are minimized when using them in a real environment. Throughout the development we do not intend to move in a one way direction from virtuality to reality. There are particular situations where it makes sense to move back towards virtuality when some new information becomes available which has been obtained by replacing a virtual by a real component. Therefore, real and virtual components can be exchanged seamlessly. One of these use cases will be discussed later.

Since one of the main objectives of the AVIGLE project is to create a VE based on the sensor data of the MUAVs, knowledge of the position and orientation where and how the data has been obtained is crucial. The position and orientation of the MUAV provides the basis for every dataset created by the sensors. Therefore, when setting up our MR simulation the first step is to replace the simulation of the MUAV and the determination of its position and orientation by real world data.

Currently, we use a cheap, commercially available MUAV (AR.Drone by Parrot), which can be operated indoors. This device differs from the MUAVs which will finally be used in the project. However, its usage gives first insights into the behavior of sensors when being attached to an aerial vehicle. The position and orientation data of the MUAV is obtained within the laboratory with an active optical tracking system (PPT X4 of WorldViz), which provides sub-millimeter precision and sub-centimeter accuracy at a maximum refresh rate of 60 Hz. In order to track not only the position but also the orientation of the MUAV we use a rigid body tracking approach. If a tracked MUAV hovers in our laboratory, its position and orientation is mapped to the coordinate system of the VE. In order to enable the operator to observe the MUAV in the MR setup see-through head-mounted displays or any other see-through device may be used. The operator can interact with the MUAV by steering it directly with a joystick or by specifying a path.

APPLICATION: TOF-SENSOR EVALUATION

In this section, we describe an example MR evaluation of a ToF-sensor. A ToF-sensor captures distance images by illuminating an object with a light pulse and measuring the time-of-flight of this pulse to the object and back to the camera. In our explicit case the ToF-sensor can either be used to support the generation of the 3D model or to provide information for collision detection. At this point of the development it is not known to what extent it can provide useful information for any of these tasks. Hence it is crucial to evaluate this sensing technology before deploying hardware. In addition to the fundamental knowledge whether a sensing technology is useful for the project, we also need information about the parameters of the sensing device, which are necessary to support the particular task in an optimal way. These parameters could be guessed from a mathematical model for simple situations, but in complex situations a MR simulation will certainly provide more valuable insights.

The MR paradigm can be used in the following way to assist the evaluation process: In the first step all components are simulated, i. e., MUAVs, ToF-sensors and the environment itself. Depth information are generated from a depth images of the VE. The parameters of the virtual ToF-sensor (depth and spatial resolution, latency, etc.) are chosen from the specifications of available hardware sensors. A first rough approximation of the parameters can be made from the simulation. In the next step of the MR continuum, the virtual MUAV is replaced by the above mentioned indoor MUAV in order to provide the simulation with real flight data. Based on the mapped position of the indoor MUAV it can interact with the VE using a virtual ToF-sensor. Now we can test whether the virtual sensor provides useful information under realistic flight conditions. Then a real ToF-sensor is chosen on the basis of the acquired data and attached to the real MUAV. Since the real ToF-sensor can only obtain data from the real world the VE has to be overlapped by some real

Figure 2. The mixed reality simulation in the context of the virtuality continuum: (left) virtual MUAV and environment, (middle) real MUAV and VE, and (right) real MUAV and environment.

components representing obstacles or objects whose shapes are to be reconstructed. Of course this cannot be done for huge objects like buildings but since the real sensor can only capture distances up to $7,5\ \mathrm{m}$ at an aperture angle of $60°$ this is not necessary and we can fully test it in a controlled environment. The real components still retain a representation in the virtual world. By using this approach data from the virtual and the real sensor can be obtained simultaneously. By comparing both datasets we are able to refine the simulation of the sensor.

Therefore, we assume to have a reliable simulation of the sensor, and we can continue from the controlled indoor environment to a more realistic use case by moving to an outdoor environment and replacing the indoor MUAV by the aerial vehicle developed in the AVIGLE project.

The outdoor environment (e. g., an airfield) should not contain real obstacles or buildings in order to avoid collisions. Since the indoor tracking system has to be replaced by a GPS receiver in an outdoor environment the accuracy of the position data is reduced. In order to simulate obstacles and buildings, a virtual city could be simulated on the airfield, and the real MUAV could be equipped with the virtual ToF-sensor as explained above. In such a setup, we could test different VEs and sensors with a real MUAV setup until the system proves to be reliable.

In addition, the swarming behavior of multiple MUAVs can be tested using the MR setup, starting with one virtual, moving to several virtual and one real MUAV such that collisions between MUAVs can only occur in the virtual world or between the real and virtual MUAVs respectively. After the swarming algorithms are adopted to the real flight data it should be possible to use several real MUAVs with a significantly reduced risk of collisions. A similar approach has been used by [3] to test the intersection management of autonomous vehicles.

CONCLUSION

In this position paper we introduced a MR simulation framework for the AVIGLE project, which supports the simulation of all hardware components of the system. In the scope of this paper we focussed on different sensing technologies attached to MUAVs. We have outlined the benefits of an MR approach for such a critical system, and have outlined an example sensor evaluation, i. e., the simulation of ToF-sensors.

In the future components of the AVIGLE system, e. g., gas, thermal or radars sensors will be simulated in our framework before they are integrated into the system. Using this procedure, we will further transfer our MR setup to the reality end of the virtuality continuum by replacing all virtual components with real counterparts until the entire system processes in a real world scenario.

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