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IFAC-PapersOnLine 49-3 (2016) 171–177

GNSS-, Communication- and Map-Based Control System for Initiation of a Heterogeneous Rendezvous Maneuver

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Abstract: This paper demonstrates a GNSS- (Global Navigation Satellite System), communication- and map-based control system initiating a heterogeneous rendezvous maneuver between a car-like ground vehicle and a fixed-wing aircraft. The rendezvous maneuver is intended to serve as a preparation step for an autonomous landing of the aircraft on the moving ground vehicle. The long term motivation is amongst others found in energy saving potentials seen in the use of ground-based takeoff and landing (TOL) support systems. For experimental validation, model-scale vehicles are used. While the ground vehicle itself could be seen a scaled version of a larger ground vehicle with similar 2-dimensional actuation capabilities, it is also intended to be used as a mock-up for a track-based MAGLEV system, a system often proposed in literature for ground-based TOL support systems. In order to mimic the behavior of a MAGLEV track, a *Virtual Track* application is implemented on the ground vehicle. Within the presented setup, the set-speed of the aircraft following predefined waypoints is fixed. At the same time, the longitudinal dynamics of the ground vehicle are used to synchronize it to the aircraft. The setup proposed in this paper incorporates the use of a digital map through which synchronization is assisted and automation capabilities are extended. Experimental results are shown to evaluate the possibilities of the proposed system.

Keywords: Aircraft control, Automated guided vehicles, Synchronization, Communication control applications, Autonomous landing.

1. INTRODUCTION AND MOTIVATION

Significant potential is seen in the use of ground power sources assisting **t**ake**o**ff and **l**anding (TOL) of passenger airplanes. Within the pathfinder projects "Out-of-The-Box" and "CREATE" funded by the European Commission (Truman (2007), Muller (2010)), the idea of using a ground-powered carrier platform to assist an airplane during takeoff and landing has emerged as interesting technological concept. Advantages are seen in several areas. Energy can be saved by efficiently assisting the airplanes propulsion system during the takeoff phase as well as by harvesting kinetic energy in the landing phase. Also, the structural weight of an airplane could be reduced by redesigning or even eliminating undercarriage, such as the landing gear, which contributes to a significant portion of the takeoff weight in a passenger airplane. It is also suggested that a system adapting the angle and pitch of the landing platform could eliminate the need for a so-called "decrab" maneuver that is necessary for crosswind landings with conventional airplanes, see Rohacs et al. (2014). In crosswind conditions, the runway needs to be approached with a non-zero yaw angle in order not to be carried away from the lateral centerline. Immediately before touchdown, the pilot turns the airplane back to a zero yaw angle with the decrab maneuver.

Apart from military applications, several concepts for the use of ground-based power sources for TOL applications have been proposed and documented (Hull et al. (2007), Rohacs and Rohacs (2014), Binnebesel (2013), Binnebesel (2015), Yaghoubi (2013)). At least two scaled demonstrators have been developed and partly documented. Both these demonstrators incorporate the use of a fixed track using magnetic levitation (MAGLEV) technology. At a length of $13.2\,m$ $(44\,ft)$, an experimental test track at Marshall Space Flight Center used by NASA allows to reach carrier speeds of up to $22.8\,m/s$ $(57\,mph)$ at a substantial acceleration (Nunley (2000)). However, the system addresses solely take-off support. Within the "GABRIEL" project (*Integrated Ground and on-Board system for Support of the Aircraft Safe Take-off and Landing*), which the authors are partly affiliated to, a subscale test bench containing a short MAGLEV track with a length of $5\,m$ and a speed limited to $2\,m/s$ was developed. Here, it was also possible to demonstrate an automatic landing with a tilt-wing model plane, see Rohacs et al. (2014). Rohacs separates the automatic landing into an acceleration and a synchronization phase, which is adopted for the works presented here. In the acceleration phase, the carrier is accelerated to approach the ground speed and position

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10.1016/j.ifacol.2016.07.029

of the airplane. In the synchronization phase, remaining differences in speed and position are minimized.
In both cases mentioned, the expenses associated with a MAGLEV track seem to be a limiting factor for creating a demonstrator experiment, forcing to drastically scale down experimental speeds or scales. In order to overcome this issue, the authors intend to use an experimental vehicle, which is primarily used for research in the automotive/navigation area, as a mock-up for a MAGLEV carrier. By means of a digital controller actuating the steering, the vehicle is kept on a fixed track that is defined in a digital map. Access to the longitudinal actuation remains open for a rendezvous controller, providing the same single degree of freedom a fixed track would provide. The presented experimental setup is located at the vehicle dynamics area of the Aldenhoven Testing Center (ATC (2015)), an automotive proving grounds in close proximity of RWTH Aachen University. The vehicle dynamics area is a flat, circular area of 210 m diameter. As the runway in the experiment is defined only virtually through a digital map, it can easiliy be rotated about the centerpoint, allowing to simulate a runway heading in an arbitrary direction.

From a control engineering perspective, many interesting questions arise both for aircraft and carrier platform control. Within this paper, the focus is set on the longitudinal control of the platform. A GNSS- (Global Navigation Satellite System), communication- and map-based system for preparation of an autonomous landing is presented. The purpose of the system is to make use of the versatility that GNSS-based control systems offer to flexibly conduct the acceleration phase and then provide a rough synchronization of the ground vehicle with the airplane. Consequently, a more precise system, e.g. based on vision, could take over. The paper is structured as follows. First, the experimental setup is described. The scenario is introduced and the two vehicles used for the rendezvous experiment are briefly described. Then, the system structure and the elements of the control system are presented. Finally, experimental results are shown and a conclusion is given.

2. EXPERIMENTAL SETUP

The scenario used throughout this paper is visualized in figure 1. The ground vehicle can move along an oval track. Its initial position is defined by a *waiting point*. The upper straight part of the oval track is defined as being part of the *runway*. The aircraft approaches the runway on its path from waypoint WP_1 to waypoint WP_2. As soon as the aircraft is recognized to be above the path defining the runway, the ground vehicle synchronizes its speed and position to the aircraft. In order not to be restricted to straight line geometries, the *route distances* d_1 and d_2 to the end of the common part of the runway are used for synchronization. The aim is to achieve good synchronization for the time within which both vehicles traverse the common part of the runway.

2.1 Experimental Vehicles

Figure 2 shows depictions of the two test vehicles as well as an aerial view of the testing facility. The ground vehicle measures approximately 1.0 m by 0.8 m. In its current configuration, its weight amounts to approximately 60 kg. Its maximum speed is 12 m/s (45 kmh), a maximum acceleration of $a_{max} = 2\,m/s^2$ can be achieved. A remote control is used for manual operation. Through a CAN bus, a high-level controller can be connected, which is then able to separately take over control over the steering actuators (lateral control) and the DC motors used for propulsion (longitudinal control). As vehicle and battery weight is not a primary issue for the vehicle, enough energy can be carried to supply powerful control hardware. In this case, an embedded PC running Mathworks' XPC target operating system is used that allows to perform controller development and implementation in Matlab/Simulink. Available sensors that are relevant for the works in this paper are a low-cost GPS sensor, a 9-DOF IMU (3-axis digital compass, 3-axis gyroscope, 3-axis accelerometer inertial measurement unit) as well as wheel speed sensors. More details on the test vehicle can be found in Reiter et al. (2014).
The flight platform used for the experiments is a Multiplex TwinStarII. It has a wingspan of 1.4 m and a take-off weight of 1.5 kg. The aircraft is built from EPP foam ma-

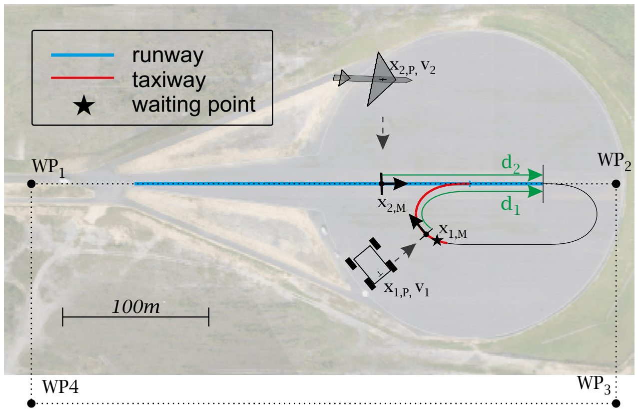

Fig. 1. Landing Scenario, Map and Distance Definitions

Fig. 2. Experimental Test Vehicles and Testing Facility