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IN-FLIGHT DEMONSTRATION OF GUIDANCE, NAVIGATION, AND CONTROL SYSTEM FOR PINPOINT-LANDING OF REUSABLE LAUNCH VEHICLES

Abstract

On June 23, 2024, China successfully conducted its inaugural 10-km vertical takeoff and vertical landing (VTVL) flight test, achieving a pioneering 1-meter-level precision touchdown with a reusable rocket prototype. This milestone demonstrates critical technologies for next-generation reusable space transportation systems. The slender-body configuration of conventional rockets presents unique Guidance, Navigation, and Control (GNC) challenges during atmospheric re-entry and powered descent and landing, characterized by unfavorable lift-to-drag ratios, high thrust-to-weight ratio requirements, and heightened sensitivity to vertical state estimation errors. These challenges are further compounded by aerodynamic uncertainties, disturbance rejection demands, and stringent terminal position and velocity constraints. This paper details the integrated GNC architecture developed for the complete flight envelope encompassing atmospheric entry, powered descent, and landing phases. A hierarchical control framework combining adaptive trajectory planning with online disturbance compensation control is presented, supported by multi-sensor fusion navigation employing IMU/DGNSS/vision integration. Flight telemetry analysis reveals the attitude tracking accuracy during critical landing phases and vertical velocity maintenance at touchdown surpassed design specifications. The experimental validation provides crucial insights into three fundamental challenges for orbital-class reusable vehicles: 1) real-time dynamic parameter identification throughout re-entry and landing phases, 2) integrated fault-tolerant GNC architecture for propulsion anomalies, and 3) terrain-relative navigation enhancement requirements. This study proposes an engineering-oriented system implementation framework for achieving sub-meter-level landing precision in vertical recovery of fully reusable launch vehicles, based on the above discussion.