Super-twisting Adaptive Sliding Mode Disturbance Observer based Attitude Control for Mars Entry under Uncertainty

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Abstract: *Most Mars landers to date continue to rely on the entry, descent and landing (EDL) technologies developed for the Viking missions in the mid-seventies of the last century, which usually lead to a larger landing error ellipse. With the continuous progress of science and technology, the estimated Mars landing accuracy has gradually improved from ~150 km of Mars Pathfinder to ~35 km for the Mars Exploration Rovers and to ~10 km for 2012 Mars Science Laboratory (MSL). It is believed that MSL is challenging the capabilities of the Viking-heritage EDL technologies, and defining an upper performance bound of the first-generation EDL systems and GNC mode. Future Mars missions, such as Mars sample return, manned Mars landing and Mars base, need to achieve the pin-point Mars landing (safe landing within tens of meters to 100 m of a preselected target site). Since the current EDL system and GNC methods cannot satisfy the requirements for future pinpoint Mars landing missions, the next generation of EDL system and GNC methodologies are required in order to deliver the larger and most capable lander/rover to date to the surface of Mars.*

The model parameter uncertainty and external disturbance are the main impediment for further improving Mars landing accuracy. For Mars entry phase, the lack of a reliable model of Martian atmosphere and the external disturbance moments on Mars entry vehicle usually result in large uncertainty between the designed model and the real flight state, which inevitably degrades the performance of Mars entry guidance and control algorithms. In order to ensure Mars landing missions are executed safely and accurately, a robust flight control system of Mars entry vehicle should be carefully designed to compensate and suppress those uncertainties and disturbances.

Disturbance observer is one of the effective means to address the flight control problem with uncertainty and disturbance, which utilizes some known data to estimate unknown data. For Mars entry with large uncertainty and disturbance, the disturbance observer can online approximate the composite uncertain items, which is conducive for designing a compensation controller in order to achieve high precision and robustness. However, the boundary of disturbance is needed for traditional sliding mode control. High order sliding mode not only can commendable overcome the chattering problem of one order sliding mode, but also retain the merits of the latter. As one of useful second order sliding mode control methods, super-twisting algorithm is the unique because it doesn't need any differential information of sliding mode variable respect to time in advance, and has less adaptive learning parameters to be propitious for real-time control. Since the super-twisting algorithm contains a discontinuous function under the integral, chattering is not eliminated but attenuated.

The aim of this paper is to develop new robust tracking control in order to further improve the robustness and accuracy of Mars atmospheric entry in the presence of larger uncertainty/ disturbance. Motivated by the preceding works, we design a novel super-twisting adaptive sliding mode disturbance observer based attitude control low, which is able to continuously *drive the sliding variable and its derivative to zero in the presence of the bounded disturbance with the unknown boundary. The proof is based on recently proposed Lyapunov function that is used for the derivation of the novel adaptive super-twisting algorithm. Based on the real-time approximate value of the uncertainty/disturbance during Mars entry, the attitude of the entry vehicle can be tracked quickly and smoothly by the sliding mode controller.*

This paper is organized as follows. Firstly, six degree-of-freedom dynamic model for Mars atmospheric entry with uncertainty/disturbance is established. Secondly, super-twisting adaptive sliding mode disturbance observer is designed to estimate the uncertainty and disturbance in the attitude loop. Thirdly, sliding compensation control is designed by the application of Lyapunov method. The information of uncertainty and disturbance approximated by super-twisting adaptive sliding mode disturbance observer is feed back to the control system, and the harmful effect is offset by compensation control. Finally, the effectiveness of this method is demonstrated through the simulation test.

Keywords: *Mars entry, Uncertainty and disturbance, Super-twisting algorithm, Disturbance observer, Sliding mode control.*