論文の内容の要旨

Study on Advanced Descent and Trajectory Generation Scheme for Precise Lunar Landing Mission

（高精度月面着陸ミッションのための先端的降下及び軌道生成手法に関する研究）

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The Moon is recognized as an important destination for space science and exploration. To find a satisfactory answer for mystery of the universe and to make use of the lunar resources for welfare of human beings, several space agencies are planning manned and unmanned missions on the Moon. As a result, the concept of lunar vehicles has begun with advanced descent scheme to perform the function of safe and precise landing on the Moon surface. The task of lunar descent scheme is to take a horizontally oriented spacecraft from orbital speeds at a point of hundreds of kilometers from the desired landing point to the landing point at an almost vertical orientation and very low speed. Existing schemes for lunar descent and landing are date back to the Apollo epoch and cumbersome to achieve a precise landing. Precise landing technology is one of the most important technologies for future lunar exploration missions. It will help to investigate the specific and scientifically interesting places such as central peaks of a big crater. To achieve a precise landing, an improved descent solution and real-time applicable trajectory generation scheme is necessary that should fulfill the goal of these future missions being highly robust, cost effective and safely landing as possible. Reducing the complexity for developing the descent trajectories will certainly reduce pre-flight analysis cost and will increase the robustness for a precise lunar landing mission. Any scheme developed to replace the conventional schemes can have as its core the same element structure: a descent solution element and a real-time applicable reference trajectory generating element. Solution methods of lunar descent available in the previous researches are complex, iterative, numerical manner. Reference trajectory generation schemes followed the same style too. Moreover, some researches implements pre-flight reference trajectory generation techniques as well, which made

the schemes having very poor robustness. Although a few literatures investigated real-time reference trajectory generation scheme but that is only for the portion of terminal descent phase. Again, a common limitation is observed for all the previous researches is that, after earth-moon transfer, several complicated steps are included to reach till the terminal descent initiation point, these are: Hohmann transfer, de-orbit maneuver etc. None of them proposed a straightforward descent directly from parking orbit conditions in an advanced manner.

This thesis proposes a scheme of a qualitative descent solution to the equations for spacecraft speed, horizontal span, vertical range and cross range as a function of velocity vector pitch angle and develops an analytical algorithm for dual step reference trajectory generation. The new proposed scheme satisfies the vertical terminal landing condition to confirm a safe lunar landing mission. Entire descent solutions and comparisons are represented here for both two dimensional and three dimensional illuminations. Mathematical derivations of new descent solution scheme are verified in terms of conventional scheme and comparative simulation results for a fully integrated solution, conventional schemes and a proposed advanced scheme are demonstrated to test the performance. Some suitable assumptions are made during this advanced lunar descent solution to avoid complexity. As in the conventional solution methods, there exist some poor assumptions such as during descent, constant vertical gravitational acceleration is the only other force acting on the descent vehicle. This inadequate postulation limits the validity of the system solutions within a very low altitude terminal descent area; that is, close to the lunar surface. In this thesis, an advanced descent solution is proposed where the centrifugal acceleration term is retained along with the gravitational acceleration term. It allows a complete representation of the descent module motion from orbital speed conditions down to the final landing state.

A trajectory optimization study is also performed for a lunar soft landing on Moon. Legendre Pseudospectral method is used in this investigation because it is easy to use and is capable of solving a wide variety of problems. Dual step reference trajectory generation scheme is developed from equations obtained through that advanced lunar descent solution scheme to provide an accurate descent path starting from a circular or elliptical parking orbit conditions. Robustness of the proposed reference trajectory generating algorithm is studied as well. Then, the doctor thesis proposes an advanced descent scheme and trajectory generation scheme for pin-point lunar landing. Analytical studies and simulations showed the effectiveness and usefulness of the proposed schemes for future lunar mission.