Dynamic Planning in Spacecraft Approaching and Docking Control

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In this paper problems of spacecraft control automatization on the stages of approaching and docking are considered. For solving these problems, we are offer using onboard scheduler, based on rules. Onboard scheduler, based on dynamic planning methods, developing in artificial intelligence researches, is integrated with global knowledge-base, including empirical, experimental and other rules. Also scheduler consider discrete and continuous components interaction.

1. Introduction

The problem of driven objects safe approaching, docking or divergence is actual for many branches (motor transport, air and space vehicles (SV)) and concerns to the most difficult problems of motion control, since is connected to increased risk. Now one from the most important problem becomes a spacecraft safe docking with an orbital space station. The process of docking represents a complex from three goals of control, realizing a full set of possible safe outcomes: tethering, station keeping and safe divergence (fig. 1.).

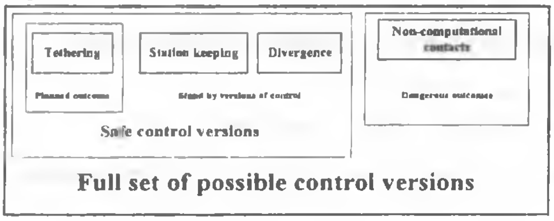

Fig. 1. Possible versions of approach control procedure outcome.

The SV control process can pass in two modes: nominal and abnormal. The nominal mode represents SV control on rigid, beforehand-calculated program. The abnormal mode arises in case of emergencies, such as engine failures, motion control systems failures, failures of radio engineering approaching system or because of time limitations, and assumes transferring the space vehicle control in manual mode. During a spacecraft docking process it is necessary to an astronaut to have a maximum of information about current situation, and also about possible versions of its development. In cause of singularity of docking process, and also in cause of spacecraft design features there are situations, requiring astronaut's immediate operations, that increases probability of incorrect solution acceptance. For the solution of circumscribed above problems is conducted the development of an intellectual onboard space vehicle control system, and within the framework of it the research prototype of the scheduler is offered.

2. Control system model description

The model of a control system actuates the following components:

1) Analytical description of control zones.
2) Database of spacecraft state.
3) Spacecraft model.
4) System of rules.
5) Scheduled trajectory.

Spacecraft model contains:

1) Coordinates of spacecraft mass center.
2) Coordinates and directions of spacecraft engines, relatively to the mass center.

3) Parameters of engines activity.
4) Velocities on axes of coordinates for mass center.
5) Angular velocity vector on axes.

The full set of possible system states is broken on some groups, called as control zones. In each zone there are own control laws, developed on the analysis of long-term statistics of approaching and tethering operations fulfilment, during "SOYUZ" spacecraft manned space flights to orbital space stations "SALUT" and "MIR", and on the research works in the field of hodographs theory [1]. There are chosen the following control zones:

1) Indicator mode zone.
2) Zone of active approaching.
3) Zone of possible tethering.
4) Non-computational contacts zone.

The relative motion of space vehicle is mapped not on a conditional phase portrait, but on a plane of gross error, defined by the vectors of relative distance and relative velocity (Fig. 2.).

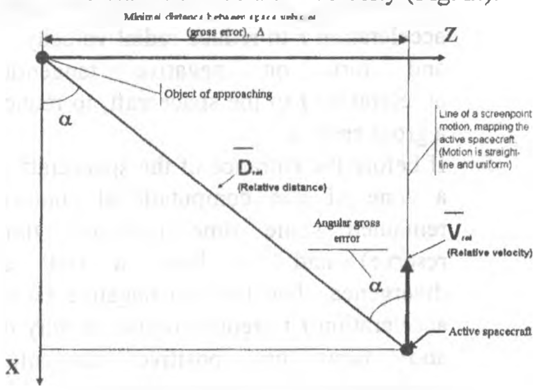

Fig. 2. Mapping of relative motion on a plane of gross error in state coordinates (distance and angle).

Limitations of relation motion control process (Fig. 3.) are represented on a plane of a gross error as a lines, separated the areas:

- Indicator mode, where the control command errors exceed the initial measurement errors, and consequently the approaching control is inexpedient;
- Possible tethering control, where the spacecraft manoeuvrable capabilities provide it docking with given final parameters of relative movement;
- Possible spacecraft station keeping on secure distance from object of approaching;
- The secure divergence of two space vehicles, where the minimum spacing interval between them during manoeuvre fulfilment does not become less than given.

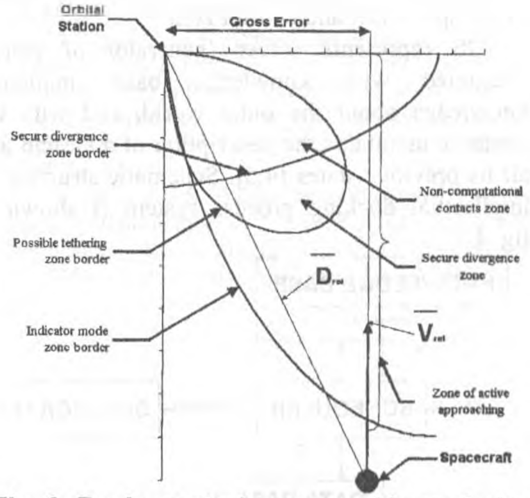

Fig. 3. Basic control areas and boundaries between them.

3. Principles of the intellectual scheduler construction

During a spacecraft docking with orbital station, one of major is the problem of a spacecraft rational trajectory selection. Its solution allows to eliminate (or to minimise) a capability of abnormal situations originating, and also to reduce fuel consumption, that is one of the major factors during a docking process. The offered scheme of the spacecraft mission control organisation allows to select a trajectory of a spacecraft docking at every moment of time, on the basis of the available information about a current position, motion direction and velocity of spacecraft, in view of engines design features, and, depending on control mode, to give: a) the applicable guidelines to an astronaut (manual docking mode), b) the applicable commands on the spacecraft controls.

The kernel of a developed system is the intellectual scheduler (IS), where is realised one of the most effective methods of dynamic processes control, based on the individual plan generation (correction of previous plan) for a current system state in each moment of time (dynamic scheduling) [2,6]. Thus, there is arising a problem of building plans for behaviour control of active object, depending on stages and current goals. Plan – is a sequence of commands (operators) with computed values of parameters. These commands can be described by setting preconditions (conditions of precedent), list of attachments and list of omissions. Conditions of precedent - formula, which realisability one depends on a current state of the spacecraft and control zone.

IS represents solver (generator of plans), integrated with knowledge base, maintains knowledge about the outer world, and with the database maintains the description of a system and all its previous states [4,5]. Schematic structure of intellectual docking process system is shown at fig. 4.

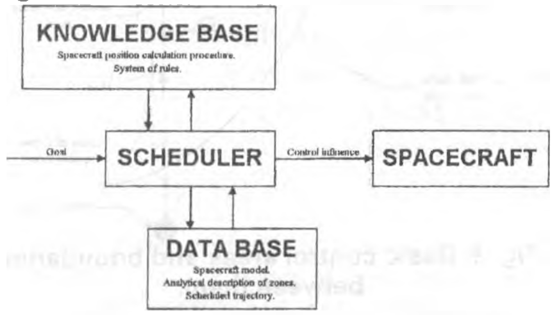

Fig. 4. Intellectual docking process system schematic structure.

The common algorithm of the scheduler includes following actions:

1. Check the target state reaching.
2. Get the necessary information about current system state from the database.
3. Get rules, applicable on existing facts, from the knowledge base.
4. Applying of the rules extracted from a knowledge base, thus updating information about current system state.
5. Check knowledge base for availability of applicable rules, if there are no applicable rules, then go to 6, else go to 3.
6. Build new set of sub-goals on the base of current system state analysis.
7. Rebuild the plan, corresponding to the new set of sub-goals, by adding new and deleting of unrealisable rules.
8. Send the plan on fulfilment.
9. Go to 1.

In given algorithm the methods of deliberative scheduling (dynamic scheduling with time limits)[2,3,6] are used.

System of rules depends on control zones (see fig. 3) and control tasks (tethering, station keeping, divergence). Zones arrangement varies dynamically, i.e. supposed, that each moment of time the spacecraft position is calculated on the base of its relational velocity, using special algorithms [2]. Procedure of spacecraft position calculation works in knowledge base and the outcomes stored in database. Let see the fragment of system of rules of control system (scheduler):

1. If the spacecraft is in a zone of indicator mode, then control is not present.
2. If before the entrance of the spacecraft in a zone of active approaching remained some time (minimal time reserve), then turn on negative tangential acceleration ***t*** to the spacecraft, to reduce a gross error Δ.
3. If before the entrance of the spacecraft in a zone of a safe divergence remained some time (minimal time reserve), then turn on positive tangential acceleration ***t*** to the spacecraft, to increase a gross error Δ.
4. If before the entrance of the spacecraft in a zone of non computational contacts remained some time (minimal time reserve) and we have a task of approaching, then turn on negative radial acceleration ***r*** to reduce radial velocity ω_r and turn on negative tangential acceleration ***t*** to the spacecraft, to reduce a gross error Δ.
5. If before the entrance of the spacecraft in a zone of non computational contacts remained some time (minimal time reserve) and we have a task of divergence, then turn on negative radial acceleration ***r*** to reduce radial velocity ω_r and turn on positive tangential acceleration ***t*** to the spacecraft, to increase a gross error Δ.
6. If before reaching the boundary of station keeping some time (minimal time reserve) is remained, then turn on negative radial acceleration ***r***.
7. If relative velocity $\mathbf{V}_{rel}$ is negative, then turn on positive radial acceleration ***r***.

4. Conclusion

Realisation of the intellectual scheduler for approaching and docking processes of space vehicles management will allow to decide many problems of safety, arising during space flights and will reduce number of emergency situations. The demonstration prototype of a system, using concept of motion objects intellectual control, which can be used in various areas of practical application, is now developed.

5. References

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