Collision-Avoidance Assured Path-Planning for Starlight Interferometer

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Abstract

Coordinated flying of multiple spacecraft platforms is needed in several future space science missions. Starlight is one such mission where two spacecraft form a variable-baseline space interferometer where spacecraft-spacecraft separations can range from a few meters to several hundred meters. Close proximity operations mandate an appropriate collision avoidance strategy not only for this mission but all such precision, multiple spacecraft applications. The problem addressed here is that of autonomous formation translation planning subject to some optimality criteria and collision avoidance constraints. In addressing the collision avoidance requirements it is not sufficient to guarantee preclusion of collisions during nominal operations. It is necessary that the translation motions be planned such that the collisions are avoided even when single or multiple spacecraft failures occur mid-stream.

The problem of collision-avoidance during *nominal* operations has been recently addressed [1-2]. This work is an extension of this research. It addresses the collision-avoidance problem when simultaneous failures aboard the formation member spacecraft render them uncontrollable, i.e. unable to apply control forces. The requirement to handle this important requirement imposes additional constraints on the relative translation motions. The constraints require that the unforced, linear relative motion trajectories in the aftermath of the presumed loss of control, preclude collisions. They require satisfaction of certain relationships between relative positions and velocities at all times. The problem is illustrated in a series of figures shown below. Consider first the nominal case where the motions of the two spacecraft starting at t_0 and ending at t_f are shown below. The collision avoidance constraint in the nominal case requires that spheres of radius R_1 and R_2 respectively around the two spacecraft come in tangential contact with each other.

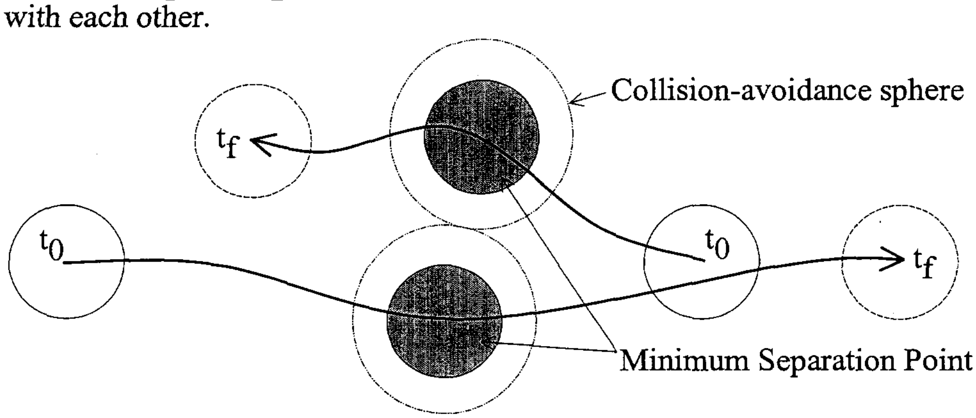

Figure 1. *Nominal* Collsion-Avoidance Path

Consider next a situation where simultaneous loss-of-control occurs on the two spacecraft at some time t_1 during the nominal case. Subsequent coasting motions, which are linear in this case result in a collision at some future time t_2.

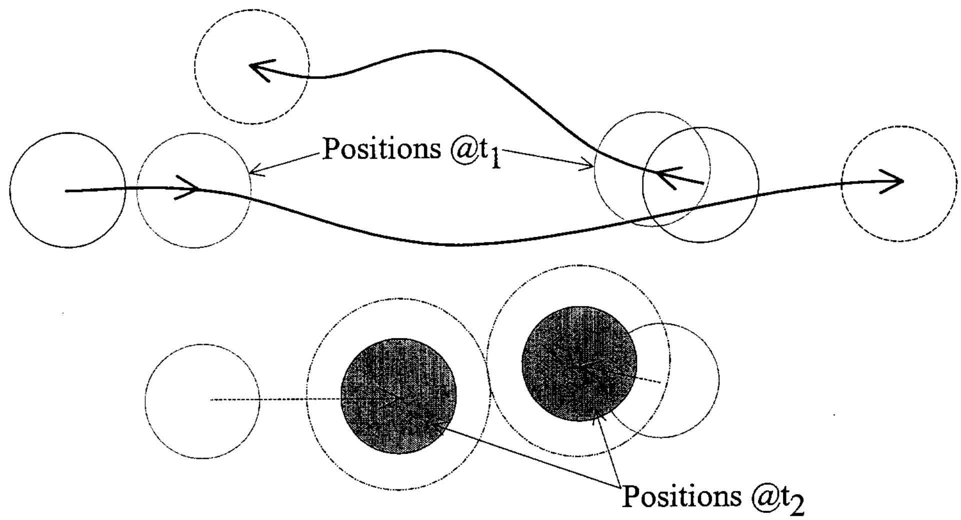

Figure 2: *Nominal* Collision-Avoidance Path: Failure @t_1, collision @t_2

It is desirable that the situation illustrated in Figure 2 does not occur for *any* t_1. This requirement, referred to here as collision-avoidance assured path planning, places an additional constraint on motions realized in Figure 3.

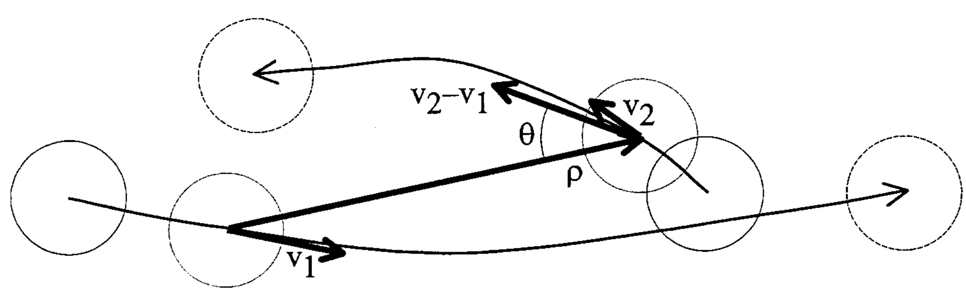

Figure 3: Collision-Avoidance *Assured* Path-Planning:
Maintain a desired angle between the relative velocity and relative position vectors:
$|\rho| \sin\theta \geq (R_1+R_2)$, when $\rho \bullet (v_2 - v_1) < 0$

In addition to satisfying the collision-avoidance assured constraints on motions, the translation paths are also required to be optimal in some way. The chosen optimality metric is a weighted combination of maneuver duration, and kinetic energy imparted to the two spacecraft. The latter is closely related to the fuel consumption. We also show that the relative weights between the expended kinetic energy can be chosen in straightforward way such that resulting motion is fuel-balancing, i.e. fuel is consumed in prescribed proportion on the two spacecraft. The fuel-balancing aspect of motion is an important consideration in formation-flying applications. In the proposed mathematical framework it is also straightforward to impose addition practical constraints on motion, specifically, upper bounds on the total maneuver duration and relative radial and transverse velocities. The constrained optimization problem requires a numerical solution which is well within the real-time capabilities of modern-day processors.

Although the application used as a benchmark is a two-spacecraft interferometer, none of the assumptions made in the problem formulation stage prevent this methodology from being extended to larger formations. The only added cost is of course numerical complexity.

1. G. Singh, F.Y. Hadaegh, " Collision Avoidance Guidance for Formation Flying Applications", AIAA Guidance, Navigation, and Control Conference, Montreal, Quebec, Canada, August 6-9, 2001.

2. G. Singh, F.Y. Hadaegh, " Autonomous Path-Planning for Formation Flying Applications", 16th International Symposium on Space Flight Dynamics, Pasadena, California, U.S.A., December 3-7, 2001