Swarm navigation and reconfiguration using electrostatic forces

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Abstract

The concept of controlling a large group of spacecraft has been extensively studied for different applications. Recently some of the authors proposed a real time navigation technique able to make a swarm of identical spacecraft acquire a given configuration. The method achieves a good level of coordination between the spacecraft and requires a small amount of communications. In missions involving a large number of satellites the swarm navigation algorithm design is not the sole problem to be considered. In such missions also the propulsion system design represents a crucial issue. In 2002 King and Parker have shown how the interaction between the spacecraft and the surrounding plasma combined with active emission of electric charges can be exploited to generate, at a price of spending small amount of propellant, inter spacecraft forces suitable for control purposes. The study in this paper aims at assessing the possibility of integrating the electrostatic actuators into the swarm navigation technique in order to increase the efficiency of the system. Therefore different strategies for integrating the electrostatic actuation into the swarm navigation scheme will be proposed in this work. In particular the electrostatic actuation will be integrated into the system in such a way that the performance of the navigation scheme will be enhanced for both formation keeping and acquisition maneuvers.

Introduction

Many researchers have faced the question whether it is possible or not to design systems in which clusters of vehicles autonomously behave in a coordinated manner performing high level tasks. This question has been recently also considered for space applications and several techniques [1, 2] have been developed to design navigation schemes suitable for groups of satellites. In all such works the navigation technique is always the result of a trade off between autonomy and optimality. The more the swarm of satellites is required to perform optimal maneuvers (i.e. from the point of view of fuel consumption), the higher is the computational load for the on board computer. In a recent paper [3] a behavior based navigation technique has been introduced able to make a group of identical spacecraft acquire a given configuration solving the target selection problem on line. This navigation technique, dubbed Equilibrium Shaping (from now on ES), allows to deal with large swarms of spacecraft and has shown to be simple and robust even though not optimal from the fuel consumption perspective. Moreover even though this technique has shown good performances when applied to acquisition maneuvers of large swarms of spacecraft, it may still result too demanding for station keeping maneuvers. The technological challenges presented by the design and development of systems made of swarms of satellites working in a coordinated manner are not only related to the path planning area. In such missions in fact usually also the propulsion system design represents a crucial issue. In 2002 King and Parker [4] have shown how the interaction between the spacecraft and the surrounding space plasma combined with an active emission of electric charge can be exploited to generate, with high efficiency, inter spacecraft forces suitable for control purposes. Even though this novel actuation concept (from now on Coulomb Satellite, CS) is basically propellantless, it has also several drawbacks and its application is by far not straightforward. From the first study on, many researchers have been trying to provide a better understanding of the properties of such a complex system. Even if many promising results have been already obtained, many aspects of the CS concept have still to be studied and clarified. The scenario outlined above allows to understand which advantages could be triggered by integrating the concept of electrostatic actuation in the afore mentioned ES navigation technique. The resulting capabilities of such an hybrid actuated swarm of satellites could in fact be significantly increased from the fuel consumption perspective and the total system performance enhanced with respect to the classical actuated swarm of satellites.

ES and CS background

In this section a brief introduction to both the ES and the CS concepts will be presented in order to highlight the main problems connected to the integration of these two concepts and to better introduce the solution approaches proposed in the forthcoming sections.

ES navigation technique

The ES technique aims at steering a swarm of N homogeneous satellites to acquire a target formation in orbit in a way such that each spacecraft belonging to the swarm can autonomously decide which position it will take in the final configuration. The method draws the inspiration from behavior based techniques and designs a desired velocity field as a sum of different behavioral contributions acting at different length scales. For each spacecraft three velocity vectors are considered each of them taking over one of the tasks that each spacecraft at any time has, to gather with the rest of the group, to avoid any collision and to reach the final target configuration. The resulting expression for the desired velocity of the $i-$th spacecraft is

$$\mathbf{v}_{d_i} = \mathbf{v}_i^{Avoid} + \mathbf{v}_i^{Dock} + \mathbf{v}_i^{Gather} \quad (1)$$

where each velocity vector in “(1)” is relative to the target formation center of mass velocity. The $\mathbf{v}_i^{Avoid}$,$\mathbf{v}_i^{Dock}$ and $\mathbf{v}_i^{Gather}$ vectors are themselves sums of different contributions and their main characteristics are listed below:

- **Gather behavior:** This behavior introduces N different global attractors towards the N targets belonging to the formation to be acquired. The $\mathbf{v}_i^{Gather}$ vector is the weighted sum of all these N attractive contributions with weighting parameters $c_1.....c_N$.
- **Dock behavior:** This behavior introduces N different local attractors towards the N targets belonging to the formation to be acquired. Also in this case the $\mathbf{v}_i^{Dock}$ vector is a weighted sum of all these N contributions with weighting parameters $d_1.....d_N$.
- **Avoid behavior:** This local behavior drives the spacecraft away from each other when they are in a dangerous condition of close proximity.

At any time the desired velocity vector is the sum of all these contributions and therefore it depends linearly on the weighting parameters c_j,d_j. If we want the target configuration to be achieved and kept, whenever the swarm of satellites acquires the final formation, the desired velocity vector associated to each spacecraft has to be zero

$$\begin{aligned} &\mathbf{v}_{d_i} = \mathbf{v}_i^{Avoid} + \mathbf{v}_i^{Dock}(d_j) + \mathbf{v}_i^{Gather}(c_j) = 0 \\ &i = 1.....N, j = 1.....N. \end{aligned} \tag{2}$$

This condition results in a set of $3N$ linear scalar equations in the $2N$ unknowns c_j,d_j that in general does not have a solution. Therefore not all possible formations can be acquired using this technique. Conditions of compatibility of a target formation with the ES technique have been derived in [3] and a list of all the formations that may be acquired with this technique is there presented. Once the desired kinematical field is designed, a control feedback law is introduced that allows each spacecraft to track the desired motion. This method has been seen to allow the swarm of satellites to acquire and maintain a given formation in space in a fully decentralized and autonomous way, not requiring any communication link to be established between the members of the swarm.

Coulomb Satellite

The CS system consists of a group of satellites each of them able to actively control its own charging level. The total specific force acting on each charged spacecraft belonging to the formation can be therefore split into two different contributions. The first one comes from the inertial and gravity force and the second one comes from the electrostatic interaction between different spacecraft influenced by the plasma media. In particular the latest effect can be modelled [4] using the Coulomb expression scaled with an exponential term depending on the Debye length λ_d

$$\mathbf{u}_{el} = \frac{\kappa_c}{m_i} q_i \sum_{j=1}^{N} q_j \frac{\mathbf{r}_{ij}}{|\mathbf{r}_{ij}|^3} e^{-\frac{|\mathbf{r}_{ij}|}{\lambda_d}} \tag{3}$$

where $\mathbf{r}_{ij} = \mathbf{r}_i - \mathbf{r}_j$ is the relative position vector between the $i-$th and the $j-$th spacecraft, κ_c represents the Coulomb constant, q_i and q_j are the charging levels of the $i-$th and $j-$th satellite and m_i is the $i-$th spacecraft mass. Using this expression and under the assumption that the center of the CS formation is on a circular orbit the inertial and gravity gradient induced accelerations can be expressed using the Clohessy-Wiltshire equations

$$\begin{cases} \ddot{x}_i - 2n\dot{y}_i - 3n^2 x_i = u_{el_x} \\ \ddot{y}_i + 2n\dot{x}_i = u_{el_y} \\ \ddot{z}_i + n^2 z_i = u_{el_z} \end{cases} \tag{4}$$

where n is the orbital mean motion of the Hill's frame, $[x_i, y_i, z_i]^T$ represent the position of the $i-$th spacecraft and $[u_{el_x}, u_{el_y}, u_{el_z}]^T$ is the electrostatic induced specific force, both projected in the Hill's reference frame. Writing "(4)" for each satellite yields a set of $3N$ scalar coupled equations describing the dynamics of the whole CS system.

Preliminary integration between the ES and CS concept

A preliminary integration between the ES and the CS concepts is ensured if there exist some formation that can be acquired using the ES path planning technique and then maintained, at list at first order, using electrostatic actuation. This last condition is ensured if the target formation is a static equilibrium position for the system "(4)" i.e. if condition in "(5)" left hand side

$$\begin{cases} -3n^2 x_i = u_{el_{xi}} \\ 0 = u_{el_{y_i}} \\ n^2 z_i = u_{el_{z_i}} \end{cases} \implies \begin{cases} \tilde{u}_{th_x} = \tilde{u}_{el_{xi}} + 3x_i \\ \tilde{u}_{th_y} = \tilde{u}_{el_{y_i}} \\ \tilde{u}_{th_z} = \tilde{u}_{el_{z_i}} - z_i \end{cases} \tag{5}$$

holds for each spacecraft belonging to the swarm. Such a set of equations is coupled and nonlinear and in general it requires the use of numeric tools to be solved. In [5] such a problem has been recast into an optimization problem and solved by means of a Genetic Algorithm technique. Following this line in this work we propose a numerical approach based on a Differential Evolution optimization algorithm (see [6] for further details). For this reason the set of equations is modified including the residual accelerations of the i-th spacecraft that in our setting corresponds to that part of the total specific force that must be provided by means of the thrusting system $[u_{th_x}, u_{th_y}, u_{th_z}]$. Moreover, according to [5] in order to avoid numerical problems, the equations in "(5)" are made non dimensional by setting $\tilde{q}_i = q_i\sqrt{\kappa_c}/n$ and $\tilde{\mathbf{u}} = \mathbf{u}/n^2$. The set of equations used for optimization becomes the one in "(5)" right hand side. Formations that may be achieved using the ES are defined in terms of relative geometry and may therefore be oriented anyhow in the Hill's frame. Therefore each formation solution to "(2)" defines an entire set of formations in the Hill's reference frame, each identified by means of three Euler angles ($[\phi, \theta, \psi]$) and a characteristic length (r). Defining $\mathbf{p} = [\phi, \theta, \psi, r, \tilde{q}_i]$ as the search space, the optimization problem is aimed at minimizing the residuals in "(5)" i.e.:

$$\min_{\mathbf{p}}(C_1(\mathbf{p})) = \min_{\mathbf{p}}(\sum_{i=1}^{N} ||\tilde{\mathbf{u}}_{th_i}||). \tag{6}$$

We may also consider to minimize the portion of total specific force that has to be provided by the thrusters in which case the resulting optimization problem turns out to be

$$\min_{\mathbf{p}}(C_2(\mathbf{p})) = \min_{\mathbf{p}}(\sum_{i=1}^{N} \frac{||\tilde{\mathbf{u}}_{th_i}||}{||\tilde{\mathbf{a}}_{g_i}||}) \tag{7}$$

where $\mathbf{a}_{g_i} = [3n^2 x_i, 0, -n^2 z_i]$ is the specific gravitational force acting on the $i-$th satellite. In order to reduce the search to only the feasible solutions the variables are set to vary in specific ranges. In particular a saturation charging level is introduced such that $q_i \in [-0.3, 0.3]\mu C$. Moreover the characteristic length is limited within the range $r \in [3, 100]m$ and the center of the formation is set to be on a GEO orbit. This allows to neglect the exponential term in the expression of the electrostatic force since the typical Debye length in a GEO environment ranges between $140m$ and $1400m$. In line with the work in [5], in order to simplify the analysis, all the spacecraft have been set to have unitary mass. In Table 1 the best values of C_1 and C_2 over 20 runs of the differential evolution algorithm are presented. These values have been divided by the number of spacecraft in the formation so that both of them can give an indication of the average non dimensional residual acceleration of each spacecraft. Moreover in Table 1 also the average cost function ($\overline{C}_i$) and the standard deviation (σ_{C_i}) computed over the runs of the optimizer are included. These values give reason of the optimizer different behavior with respect to the optimization problems in "(6)" and "(7)". The square formation, the tetrahedron formation and the octahedron formation reach very low values of the cost functions and therefore represent the most suitable configurations to be acquired using the ES technique and maintained at first order using only electrostatic actuation. These configurations are shown in Figure 1 from a) to c) where the spacecraft are represented as spheres whose radius has been set to be proportional to the charging level. On the other hand the octagonal formation displayed in Figure 1 d) yields an average consume in terms of specific force that is 82% smaller with respect to the case in which no electrostatic actuation is used for formation maintenance. A possible application for the results obtained so far is described in the following. Typically a formation flying mission requires a group of satellites to achieve a precise configuration with a predetermined shape and orientation in the Hill's reference frame. Moreover in general such missions may require the swarm of satellites to keep the desired configuration only during a fraction of the orbit. In this case the configuration exploiting the electrostatic actuation could represent an attractive possibility for the design of stand-by formations. In Figure 2 this possibility is explored for a swarm of 6 satellites. The target configuration (i.e. the one chosen from the design of the mission) is an hexagonal formation in the Hill's $y-z$ plane whereas the stand-by one is octahedron shaped. The acquired stand-by configuration can be maintained with virtually no fuel consumption. The bold lines in Figure 2 rep-

Regular Polygon Formation

N	C_1/N(m)	$(\overline{C}_1 \pm \sigma_{C_1})/N$(m)	C_2/N	$(\overline{C}_2 \pm \sigma_{C_2})/N$
4	$5.3 \cdot 10^{-7}$	$(8.0 \cdot \pm 1.3) \cdot 10^{-7}$	$5.9 \cdot 10^{-7}$	$(8.6 \pm 1.0) \cdot 10^{-}7$
5	1.1	(1.13 ± 0.05)	$5.3 \cdot 10^{-2}$	$(8.9 \pm 2.5) \cdot 10^{-2}$
6	1.3	(1.41 ± 0.03)	$9.1 \cdot 10^{-2}$	$(1.8 \pm 1.1) \cdot 10^{-2}$
7	1.9	(1.97 ± 0.02)	$2.7 \cdot 10^{-1}$	$(3.1 \pm 0.8) \cdot 10^{-1}$
8	2.0	(2.01 ± 0.03)	$1.8 \cdot 10^{-1}$	$(4.6 \pm 0.7) \cdot 10^{-1}$
9	2.3	(2.28 ± 0.01)	$2.7 \cdot 10^{-1}$	$(3.8 \pm 1.1) \cdot 10^{-1}$
10	2.2	(2.19 ± 0.01)	$4.9 \cdot 10^{-1}$	$(5.6 \pm 0.3) \cdot 10^{-1}$
11	2.3	(2.27 ± 0.01)	$3.2 \cdot 10^{-1}$	$(4.7 \pm 1.2) \cdot 10^{-1}$
12	2.2	(2.23 ± 0.02)	$4.6 \cdot 10^{-1}$	$(6.3 \pm 0.5) \cdot 10^{-1}$

Regular Solid Formation

N	C_1/N(m)	$(\overline{C}_1 \pm \sigma_{C_1})/N$(m)	C_2/N	$(\overline{C}_2 \pm \sigma_{C_2})/N$
4	$6.3 \cdot 10^{-7}$	$(9.21 \pm 1.31) \cdot 10^{-7}$	0.14	$(1.41 \pm 0.02) \cdot 10^{-1}$
6	$1.1 \cdot 10^{-3}$	(0.53 ± 0.33)	$9.9 \cdot 10^{-7}$	$(2.82 \pm 0.08) \cdot 10^{-}4$
12	14.2	(15.02 ± 1.72)	$5.7 \cdot 10^{-1}$	$(5.7 \pm 0.2) \cdot 10^{-1}$

Bravais Lattice Formations

N	C_1/N(m)	$(\overline{C}_1 \pm \sigma_{C_1})/N$(m)	C_2/N	$(\overline{C}_2 \pm \sigma_{C_2})/N$
9 (BCC*)	4.1	(4.07 ± 0.01)	$2.2 \cdot 10^{-1}$	$(2.5 \pm 0.1) \cdot 10^{-1}$
14 (FCC*)	1.5	(2.97 ± 1.05)	$2.6 \cdot 10^{-1}$	$(2.6 \pm 0.1) \cdot 10^{-1}$

*BCC Body Centered Cubic Lattice, FCC Face Centered Cubic Lattice.

Table 1: List of the cost function values for some formations that can be acquired by means of the ES technique. In this table N represents the number of spacecraft in the formation.

resent the spacecraft trajectories towards the final stand-by configuration. Moreover note that, since the acquisition of the stand-by formation is performed by means of the ES technique each agent autonomously decides which position it will have in the final formation. Different navigation techniques could be used for the reconfiguration maneuver to privilege optimality with respect to autonomy.

Integration of the electrostatic actuation for the acquisition maneuvers

Electrostatic actuation can be successfully integrated into the navigation scheme also during the acquisition maneuver. In this section the approach used in order to perform such integration for a simple formation of two satellites is presented. During the

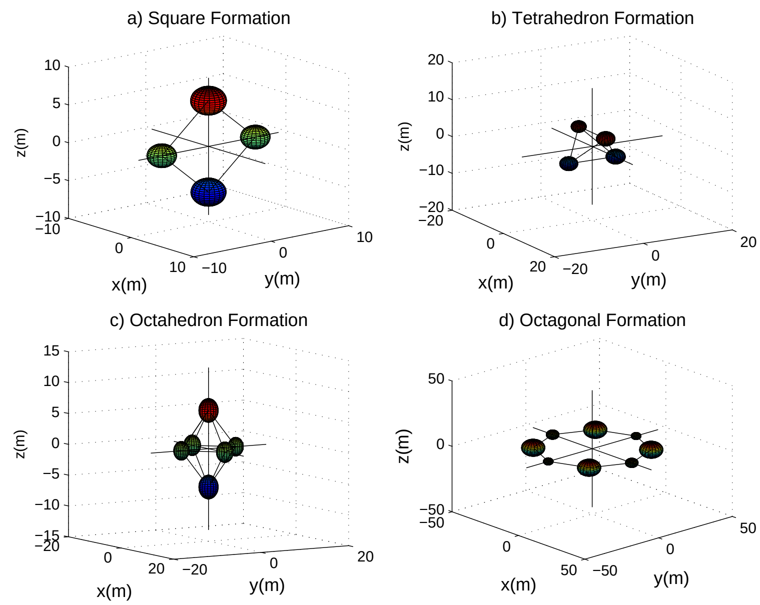

Figure 1: Formations that can be acquired by means of the ES technique and maintained with high efficiency exploiting the CS concept.

acquisition each satellite belonging to the formation can evaluate at each instant its desired velocity according to "(1)" and a control specific force $\mathbf{u}_i$ that will allow to track it. If an electrostatic actuator is mounted on board each satellite, the two spacecraft can interact one with the other by means of the Coulomb force along the direction $\mathbf{r}_{12} = \mathbf{r}_2 - \mathbf{r}_1$. Therefore part of the required specific force for each satellite can be provided by means of the electrostatic actuation system, i.e. $\mathbf{u} = \mathbf{u}_{el} + \mathbf{u}_{th}$. The equation of the specific force balance for the two spacecraft projected along the direction connecting them is

$$\begin{cases} u_{\|_1} = u_{\|_{th1}} - \frac{\kappa_c Q_{12}}{m_1 r_{12}^2} \\ u_{\|_2} = u_{\|_{th2}} + \frac{\kappa_c Q_{12}}{m_2 r_{12}^2} \end{cases} \tag{8}$$

where $Q_{12} = q_1 q_2$ and $u_{\|_{\cdot i}} = \mathbf{u}_i \cdot \frac{\mathbf{r}_{12}}{r_{12}}$. Note that the Debye exponential term is dropped in "(8)" since the assumption is done that $r_{12} < \lambda_d$. Moreover in the direction orthogonal to $\mathbf{r}_{12}$ the electrostatic actuation can not reduce the specific force to be provided with the thrusting system, i.e. $u_{\perp_i} = u_{\perp_{thi}}$. Since the charging level of each spacecraft will effect the motion of the other member of the formation the two spacecraft must find in a coordinated manner the Q_{12} value that will allow for the best exploitation of the electrostatic actuation. If the main objective is to reduce the total fuel required to perform the maneuver at that instant, the required charging value can be found

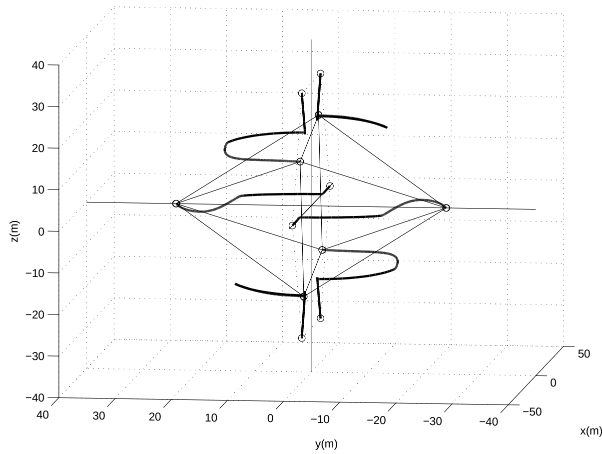

Figure 2: Switch maneuver between the design 6 spacecraft formation (dotted line) and the stand-by one (continuous line).

solving the following nonlinear optimization problem

$$\forall t, \quad \min_{Q_{12}}(J(Q_{12})) = \min_{Q_{12}}(\| \mathbf{u}_{th_1} \|_2 + \| \mathbf{u}_{th_2} \|_2). \tag{9}$$

Note that if the problem would have been to find the minimum of $\| \mathbf{u}_{th_1} \|_2^2 + \| \mathbf{u}_{th_2} \|_2^2$ then the solution could have been computed using a pseudo inverse calculation of the matrix in “(8)”. For a swarm of two satellites it is possible to solve “(9)” in an analytical way and therefore to compute the Q_{12} value simply performing algebraic calculations. In order to test the performances of such a strategy a complete simulation campaign has been performed for a formation of two spacecraft starting from different initial conditions and performing acquisition maneuvers driven by the ES navigation technique. The results have shown that the exploitation of the CS can lead to a saving in terms of the total fuel consumption of the formation up to 80% with respect to the case in which no electrostatic actuators are mounted on board. In formation flying control a crucial issue is also to perform maneuvers such that the required fuel consumption is balanced for all the satellites belonging to the formation. The CS concept can be also used for this purpose since it establishes a force connection between the spacecraft that can be used to redistribute at each instant the specific force required to perform the maneuver. In this case the new optimization problem to be solved at every instant is

$$\begin{aligned} &\forall t \quad \min_{\mathbf{Q}_{12}}(\| \mathbf{u}_{th_i} \|_2) \\ &with \quad \min_{i\in[1,2]}(\Delta v_1(t), \Delta v_2(t)). \end{aligned} \tag{10}$$

The solution of this optimization problem can be easily computed with a pseudo-inverse calculation involving only one of the equations in “(8)”. In a recent work [7] the CS concept has been considered to control the relative position of satellites in a formation. In this work a switching strategy is introduced such that at each time the electrostatic actuation is exploited to control the spacecraft with the highest tracking error. Therefore, according to this scheme the control system attempts at any time to reduce the residual specific force acting only on the spacecraft with the highest tracking errors disregarding the disturbances induced to the other members of the swarm. All the charging strategies described so far can be compared in order to assess the

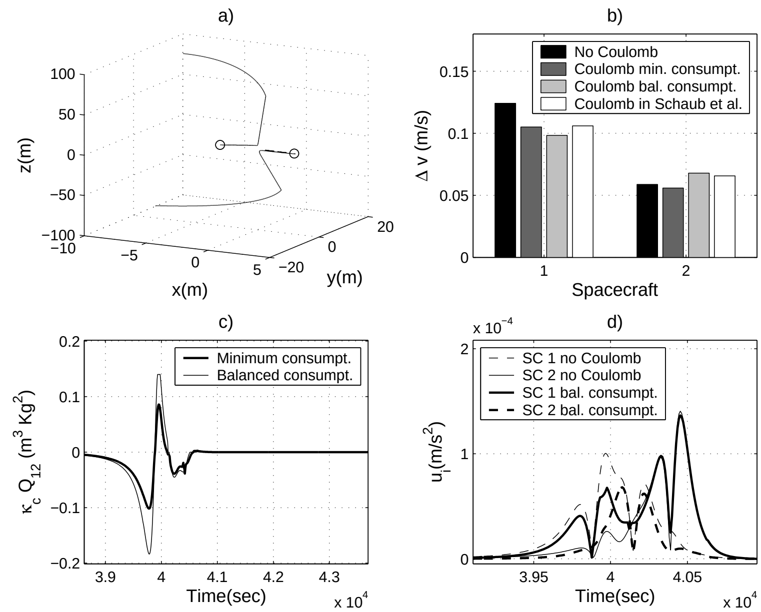

Figure 3: Results of the integration of the CS concept with the ES navigation scheme. Note: Minimum consumptions stands for the algorithm in "(9)" whereas Balanced consumptions stands for the algorithm in "(10)".

different performances and to verify pros and cons of each one of them. For this reason in Figure 3 a) the trajectories of two spacecraft performing an acquisition maneuver driven by the ES navigation algorithm are shown. The spacecraft are starting from an initial position of $\mathbf{r}_1 = [-10, 9, -100]m$ and $\mathbf{r}_2 = [-7, 5, 100]m$ with initial velocities $\mathbf{v}_1 = [0, 0, 0.1](m/s)$ and $\mathbf{v}_2 = [0, 0, 0](m/s)$ both with respect to the Hill's reference frame centered in the center of the target formation that is set to be on a GEO orbit. The target configuration is set to $\mathbf{r}_1^{des} = [3, 0, 0]m$ and $\mathbf{r}_2^{des} = [-3, 0, 0]m$ and the acquisition time is approximately $4,5 \cdot 10^4 sec$. The actuation capabilities of the spacecraft are assumed to be limited so that $\| \mathbf{u} \| = 0.005 m/s^2$ and $|Q_{12}| < 4\mu C$. Moreover the mass of both the spacecraft is assumed to be $50kg$. The details about how the simulations are performed are not described here and can be found in [3]. For the proposed simulation the exploitation of the CS concept leads to a saving of

13% of the total fuel consumption required for the acquisition maneuver with respect to the situation without electrostatic actuation. If the same simulation is performed exploiting the algorithm proposed in [7] the reduction in terms of total fuel consumption is 7%. Note that in the Δv computation also the maneuvers performed at the very beginning of the simulation are considered. Anyway at the very beginning of the simulation the two spacecraft are too far apart one from each other and no electrostatic actuation can be exploited. When this phase of the acquisition is not considered in the Δv computation the saving induced by the integration of the ES and CS concepts reaches 21% of the total Δv required. The same simulation has been used to test the charging strategy in "(10)". Since the tracking error of the spacecraft 1 at the very beginning of the simulation is higher with respect to the one of satellite 2 at each time during the maneuver $\Delta v_1 > \Delta v_2$. So according to "(10)" the swarm will decide during the maneuver to assume the value of Q_{12} such that $\| \mathbf{u}_{th_1} \|_2$ will be minimized at any time. The savings in terms of fuel consumption of satellite 1 induced by the CS concept are 21% whereas the savings for the entire formation are 9%. As expected this strategy attempts to reduce the fuel consumption of satellite 1 rather than the one of the all formation. The bars diagram in Figure 3 b) can be used to verify that the fuel consumption of satellite 1 when the strategy in "(10)" is used, is lower with respect to the one induced with the other strategies considered in this paper. In Figure 3 c) and d) the control signals for some actuation strategies are displayed in the specific time range between $3.9 \cdot 10^5 sec$ and $4.1 \cdot 10^5 sec$. In this time interval the spacecraft are close to each other and therefore the electrostatic actuation is particularly effective in increasing the system efficiency. In Figure 3 c) the variation in time of the charge product Q_{12} is displayed for both the algorithm in "(9)"and in "(10)". Moreover in Figure 3 d) the thrusting specific forces required during the acquisition without electrostatic actuation and with electrostatic actuation exploited according to "(10)" are displayed. From this plot it is possible to see how the Coulomb force acts in order to balance at any time the thrusting control required to each spacecraft. As a final remark we point out here that the approach in "(10)" is again different with respect to the one in [7]. In fact in the simulation of Figure 3 satellite 1 has highest tracking error in a phase of the maneuver in which no Coulomb force can be used to actuate the control signal.

Conclusions

The possibility of actively control the charging level of spacecraft can bring great advantages in missions where a swarm of satellites is considered. In particular the performances of behavior based navigation techniques, such as the recently developed Equilibrium Shaping, can be significantly enhanced if an electrostatic actuation system is available. There are relative satellite configurations that can be maintained at first order only relying upon the electrostatic actuation and these can therefore be used as stand-by positions for formations of satellites. In this way we showed how the swarm can keep the precise configuration determined by the mission objective only when needed, and then, switch in an autonomous way to the stand-by configuration that can be maintained with virtually no fuel consumption. Moreover in a preliminary investigation it has been shown that the electrostatic actuation concept can be also used to reduce or redistribute the fuel consumptions during the acquisitions maneuvers of a formation of two satellites. Two different charging strategies that achieve these tasks have been proposed in this work and their performances discussed.

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