Daniele Mortari

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General Data

- Civil Status: Married
- Date of Birth: June 30, 1955
- Languages: Italian (native), English, and French.
- Married: T. Andreea, born in Bucharest - Romania, 1973.
- Children: Anna 2001.

Education

- 1975-1981: Attends the courses of Nuclear Engineering at the University "La Sapienza" of Rome. Attains the degree of "Dottore" by discussing a thesis on the safety of the Canadian CANDU nuclear reactors with the Nuclear Reactor Physics course, May the 28th, 1981, with marks 110/110.
- 1981-1983: Attends the two-year courses of the Aerospace Engineering School at the University "La Sapienza" of Rome, during which he starts to work, as external consultant, with the Centro di Ricerca Progetto San Marco, an International Co-operative Program for Space Research with NASA.
- 1983-1987: Attends various training and educational courses at the Goddard Space Flight Center (NASA), on the Attitude and Orbit Control Systems for the San Marco V satellite. In 1987 he attended a training program at Goddard on specific tasks related to data processing software algorithms for star pattern identification and attitude estimation using the Star Mapper data of the San Marco V satellite.
- 1991: Studies the problems and the operational tasks associated with the position of Range Safety Officer for the San Marco Project within the framework of a new Italian launch vehicle. Manages specifically the safety and the computation of climb trajectories of solid rocket vehicles.

Professional Experience

- 1983-1990: Consultant at the San Marco Project working on the following topics: Attitude determination, Attitude control by means of magnetic maneuvers, Spin axis drift, Orbital dynamics, and data reduction of the *Drag Balance Instrument*, the Italian experiment. For each of these items he conducts analysis and then develops the operational software for the San Marco V satellite, which carried five scientific experiments for the upper atmosphere physics analysis.

- 1985-1989: Consultant with several companies under ESA and Aeritalia contracts with relation to the following: Structural dynamics, Dynamics of docking, Eigenanalysis of numerically defective matrices (Jordan forms). Implements algorithms in the associated software.

- 1988-1989: Member of the San Marco Project staff that operationally manages the San Marco V satellite from the launch (March 25, 1988) throughout the S/C lifetime up to December 2, 1988 (re-enter), determining and controlling satellite attitude. Participates in the data reduction of the Drag Balance Instrument.

- 1989-2002: Member of the San Marco Project professional staff working on basic and applied research in astrodynamics, attitude determination, and control.

- 1990-1995: Consultant for the Computer Control System Company. He analyzes the dynamic problems of an endoscope working inside the segments of the Ariane V vehicle and implements the relevant operating software.

- 1992-2002: Assistant Professor, Aerospace School of Engineering, University "La Sapienza" of Rome, Italy. Researches and publishes in the following fields: attitude determination, attitude data processing, attitude dynamics, matrix and numerical analysis. Teaches in the two courses of *Space Systems* and *On-board Instrumentation* at the Aerospace School of Engineering, and in the course *Aerospace Systems* at the Faculty of Aerospace Engineering, both of the University "La Sapienza" of Rome, Italy.

- 1998-2001: Visiting Professor offering of the "Aerospace Systems" course, Electronic Engineering, University of Perugia, Italy.

- 1998-2001: Visiting Associate Professor, Department of Aerospace Engineering, Texas A&M University, College Station, TX, USA.

- 2002-present: Associate Professor, Department of Aerospace Engineering, Texas A&M University, College Station, TX, USA

Research Interests

- Spacecraft Attitude Estimation and Attitude Determination Systems
- Sensor Data Processing (Especially Star Identification)
- Aerospace Navigation, Dynamics, and Control
- Orbital Mechanics, Satellite Constellation Design
- Linear Algebra, Numerical Analysis.

Research Summary

- **Spacecraft Attitude Estimation**

  1. **Energy Approach Algorithm** (EAA). EAA is derived from a mathematical equivalence between the optimal attitude determination problem and the problem of finding the static equilibrium of a rigid body constrained by a set of spherical springs. Three different solutions have been found, all fully complying with the Wahba optimality criterion. The EAA3 solution form is, approximately, as fast as QUEST.
  2. **EULER-2, TRIAD-2, and EULER-n.**
     (a) **EULER-2** computes the optimal Euler axis and angle in a deterministic way, and its application is restricted to cases when $n = 2$ observed directions are available. This method is based on the attitude matrix rotation property and on a demonstrated co-planarity condition.
     (b) **TRIAD-2**. Thanks to the results obtained in EULER-2, the extension of the existing TRIAD algorithm to the optimal solution, getting TRIAD-2, has been also obtained.
     (c) **EULER-n** algorithm computes the optimal Euler axis and angle by an iterative technique. The iterative procedure, which starts from the Euler axis evaluated by EULER-2, converges to the optimal solution with a precision better than 1/1000 degree and with only one or two iterations.
  3. **EULER-q** is derived from a new cost function for optimal attitude definition. The optimality criterion is derived from the Euler axis rotational property and allows a fast and reliable computation of the optimal eigenaxis. The mathematical procedure leads to the eigenanalysis of a 3×3 symmetric matrix whose eigenvector, associated with the smallest eigenvalue, is the optimal Euler axis. A simple cross vector evaluates this eigenvector and the singularity is avoided using the method of sequential rotations. Wahba optimality criterion is shown to be a little bit better than that introduced by EULER-q, which, in turn, demonstrates a clear gain in computational speed.

4. **EStimator of the Optimal Quaternion** (ESOQ) provides a closed-form solution to the problem of optimal spacecraft attitude estimation based on vectors observation, known as the Wahba problem. The algorithm first provides the closed-form expressions of a 4×4 matrix eigenvalues and then computes the eigenvector associated with the greatest of them, representing the optimal quaternion, using two different methods. The first method uses a vector cross product in a 4-Dimensional space, while the second uses an equivalent technique requiring a 3×3 nonsingular matrix inversion. The resulting ESOQ algorithm does not present any singularities and allows an easy identification of the approaching of the irresolvable condition of quasi-parallel observed vectors. Accuracy and speed numerical tests demonstrate ESOQ as the fastest optimal attitude estimation algorithm to-date. This fact validates ESOQ as the most suitable algorithm when a fast-and-optimal attitude determination is required.

5. **Second EStimator of the Optimal Quaternion** (ESOQ-2). This optimal algorithm out stands for its speed. Presently it is the fastest available optimal attitude estimation algorithm. The ESOQ-2 algorithm starts from the q-method solution equation; the procedure leads to the computation of the optimal principal axis as a cross product between two row vectors of a symmetric 3×3 matrix. The optimal quaternion is then immediately computed. The introduced singularity is optimally avoided by employing only one sequential rotation. The resulting proposed algorithm is reliable, nonsingular, easy to code, and able to identify the quasi-parallel condition when the attitude computation is impossible. It has been adopted and tested by a flight experiment on-board the Space Shuttle mission STS-107. Adopted in the GSAT spacecraft mission (by ISRO Satellite Center, Bangalore, India), launched by the first Geo-Stationary Launch Vehicle (GSLV) in April 2001.

6. **Optimal Cones Intersection Technique** (OCIT). This algorithm allows to optimally estimating the direction (e.g. the spin axis) of a pointing instrument without computing the overall attitude of spacecraft. In particular OCIT-2 and OCIT-n algorithms use $n = 2$ and $n > 2$ observed vectors respectively. OCIT-2, which fully complies with the Wahba optimality criterion, optimally estimates the intersection of two cones in closed-form. OCIT-n provides the solution as a weighted sum of OCIT-2 solutions.

7. **Optimal Linear Attitude Estimation** (OLAE). This algorithm, using a Cayley Transform, establishes the relationship between the observed and reference directions with the Gibbs vector. The singularity of the Gibbs vector attitude representation is avoided by adopting one sequential rotation.

8. **Singularity Avoidance**. An algorithm to avoid singularity associated with famous minimum element attitude parameterization, Euler

angle set, has been devised. The proposed algorithm makes use of method of sequential rotation to avoid singularity associated with Euler angle set. Further, a switching algorithm is also proposed to switch between different Euler angle sets to avoid the singularity while integrating the kinematics equations corresponding to Euler angles for spacecraft motion.

9. **Estimator of MRP**. Two new single-point optimal attitude determination algorithms in terms of the Modified Rodrigues Parameters (MRP) have been devised. These new algorithms present the advantage of further reducing the computational burden by keeping a singularity-free algorithm with a minimum parameter attitude representation. One has been derived from the solution of the ESOQ-2 algorithm (by replacing quaternion with MRP) while the second algorithm has been derived from the OLAE algorithm. Simulation results show that the latter optimal attitude determination algorithm can be an efficient alternative over the quaternion-based algorithms (q-Method, ESOQ-1, QUEST, SVD, etc) in terms of computational efficiency for singularity-free attitude representation.

- **Misalignment Estimation**

1. **Spin axis Misalignement**. For a spin-stabilized satellite a technique to estimate the spin axis misalignment, has been developed. The method uses the data provided by a 3-slit star mapper. This study defined the constraints (misalignment amplitude, time truncation, spin velocity) under which deriving the spin axis misalignment is possible. The method proposed was tested with the star mapper data of the San Marco 5 satellite.

2. **Multi-FOV Star Tracker Interlock Assembly Misalignement**. He developed two different methods to compute the interlock misalignment for the Multiple FOVs star tracker NavStar II and III. The first method, which evaluates the misalignment by a least-square approach, can be used if the misalignment can be considered small enough, that is, such that the star-identification process can still be performed. The second method, which can be used for any value of the interlock misalignment, implies that the star identification process can be performed for each sub-FOV. Results and tests of both the methods are shown.

- **Attitude Data Processing**

1. **Drag Balance Instrument** (DBI). In this field he studied, by developing the relevant data reduction, the information provided by the Italian DBI experiment, which was carried on the San Marco 5 spacecraft. The DBI aim was to detect the neutral air density variations in the higher atmosphere. He has also develops the theory and the

software to use the DBI as an attitude sensor. From this instrument it is possible to estimate the velocity vector direction, which can be used as an observed direction in the attitude determination problem.

2. **Acquisition and centroiding**. Two methods to speed up the acquisition and centroiding have been developed: 1) the Peak Finder (PF) which uses two integer vectors, and 2) the Run Length Encode (RLE) which uses an iterative approach applied to an adjacent star segment table and performs acquisition and centroiding simultaneously. Also for centroiding, the use of recursive functions, have been proposed. Recursive and ellipsoidal masks present centroiding accuracy gains with respect to the standard squared mask, which is more affected by the mask edge errors. Also two Gaussian Best-Fitting methods to increase centroiding accuracy have been introduced and compared versus standard Center-Of-Mass approach.
3. **Time Estimation using Star Trackers**. An automatic methodology to identify visible planets observed by digital star trackers has been developed. The planet identification allows to estimate the time. A single-point technique, giving an average accuracy of 3-4 minutes for Venus and Mars, has been published. A recursive estimation technique using Kalman filtering is presently under development. This approach will give us order of magnitude gain.

- **Star-Identification**

1. **Search Less Algorithm** (SLA). He presented two new star identification techniques, which does not use the magnitude information, for the star pattern recognition of wide field-of-view star trackers. The first is based on a best-fitting criterion and the second on a suitably devised k-vector. The proposed two star-pair-ID techniques can be regarded as general procedures, which can be included in almost all existing star-matching algorithms. The methods are able to identify and discard spikes (due to electronic noise, planets, light reflections, etc.), which demonstrate the algorithm robustness. A variation of SLA, was adopted in the "Fast Recovery Star Sensor" of the GSAT spacecraft mission (ISRO Satellite Center, Bangalore 560-017, India), launched in April 2001.
2. **Spherical-Polygon Search Algorithm** (SP-Search). He presented the SP-Search to accomplish the star pattern recognition and its extension to the recently proposed multiple field-of-view star trackers NavStar II and III which observe star fields in orthogonal directions, thus providing substantial gain in both the attitude estimation accuracy and in the operating time. The main idea of the proposed algorithm, which extensively uses the k-vector technique (a new range searching), is based on the fact that any star direction can always be expressed as a linear combination of two star directions (star pair

basis) together with their vector cross product. Using this property, which does not depend on the used system of coordinates, the problem of accessing candidate stars is then transformed into one of accessing the stars falling within a cone about a given direction. The cone observed surface is approximated herein as a spherical polygon, and its aperture is set to be h times of the star image centroiding accuracy standard deviation . Linear Error Theory is then applied for to establish an analytical approximation of h while, for fast applications, an empirical formula, is also presented. The resulting algorithm is fast and has a high probability of quickly identifying the imaged stars. This approach has the additional capability to identify and discard spurious images and it is a suitable and reliable concept to perform star pattern recognition in the most general lost-in-space case, that is, when no attitude information is available.

3. **Pyramid**. The Lost-In-Space *Pyramid* Algorithm is a new star pattern recognition algorithm, which is based on a *Pyramid* structure of stars. This solution highly increases the capability to identify spikes (due to electronic noise, planets, light reflections, etc.). Usually, a high percentage of spikes presence puts in crisis almost all of the existing algorithms. It has been proven that the Lost-In-Space *Pyramid* Algorithm is capable to accomplish the star identification process with 4 stars and 24 spikes! This results, demonstrates that the *Pyramid* algorithm, which has been derived from an analytical approach of the star pattern recognition probability, is presently the most robust algorithm for star pattern recognition.

4. **Non-Dimensional Star Pattern Recognition**. This algorithm allows solving the *Lost-In-Space* case without the knowledge of the sensor focal length. This will be useful for star pattern recognition systems to avoid the focal length computation after lens change and as rescue program. The theory uses the k-vector approach and a special preparation of the star catalog.

5. **Recursive Approach**. Two novel algorithms for recursive mode star identification are presented. The first approach is derived by the Spherical Polygon Search algorithm, that accesses all the cataloged stars observed by the sensor field of view and recursively add/remove candidate cataloged stars according the predicted image motion induced by camera attitude dynamics. Star identification can be then accomplished by a star pattern matching technique which identify the observed stars in the reference catalog. The second method uses star neighborhood information and a cataloged neighborhood pointer matrix to access the star catalog. In the recursive star identification process, and under the assumption of a *slow attitude dynamics*, only the stars in the neighborhood of previously identified stars are considered for star identification in the succeeding frames.

- **Attitude Determination Systems**

  1. **DBI Attitude Sensor**. Develops the theory and the software to use the DBI as an attitude sensor. From this instrument it is possible to estimate the velocity vector direction, which can be used as an observed direction in the attitude determination problem.
  2. **Moon-Sun Attitude Sensor** (MSAS). The derivation that led to the MSAS is based on two facts: 1) the Moon is a gravity stabilized satellite and therefore it shows, approximately, always the same side to an Earth orbiting S/C. This implies that a Moon Reference Image (MRI) is available in the inertial reference system as a function of time and of the S/C, Sun and Moon orbital positions. 2) By comparing the MRI with the Moon Observed Image (MOI) and by a proper image processing of the MOI, it is possible to derive redundant data for attitude determination.
  3. **Earth-Sun Attitude Sensor** (ESAS). The basic idea behind the MSAS, (that the Sun terminator on the Moon can provide enough information for a complete three-axis attitude computation), is extended to an Earth-observing sensor working in similar manner. This sensor is the Earth-Sun Attitude Sensor. Data processing for this type of sensor is many ways completely alike the one (more general) of the MSAS. Hence, many algorithms developed for the latter, (particularly those exploiting the knowledge of the illuminated edge of the observed body) can be adapted to the ESAS with few modifications. However, the general problems regarding the ESAS are different.
  4. **Multiple FOVs Star Tracker** *KhalStar*. This is a project on a dual field-of-view star tracker, patented together with John L. Junkins and Thomas Pollock to the Texas A&M Technology Licence Office. For this project we developed the state of the art of the star tracker data processing. This includes image acquisition, new centroiding techniques, the extension of the *Pyramid* Star Pattern Recognition algorithm to two-FOVs star tracker (getting Pyramid II), the FOVs interlock misalignment, and the latest optimal attitude estimation algorithm.
  5. **Compass Star Tracker**. Star trackers are the most accurate attitude sensors to perform the complete 3-axis attitude estimation of spacecraft. However, even though they are specifically designed to estimate attitude, we have demonstrated that they can also be used to estimate the local coordinates of the camera on the Earth as well as the direction of East. This requires us to align the camera with the local direction of the gravity and to have knowledge of the time that can be provided by an accurate clock. The resulting system is the Compass Star Tracker, that is, a star tracker used as a global surface navigation system. This system would certainly not substitute the Global Positioning System which, in turn, does not suffer of the

limitation night-only operation and in clear weather conditions. On the contrary, the Compass Star Tracker does not require any satellite information or other support from ground stations to be used in lieu of the traditional Global Positioning System. Use of Kalman filtering, presently under development, will greatly increase the accuracy in positioning estimation.

- **Attitude Dynamics and Control**.

  1. **Dynamics Induced by Thermal Transitions**. He developed a theoretical dynamic study for the attitude dynamics induced by thermal orbital transitions (Sun-shadow and vice versa) on a spin stabilized spacecraft carrying four cable booms with tip mass. A direct theory confirmation was obtained by applying it to the star mapper data of the San Marco 5 satellite. Within this study he presented a new mathematical best fitting technique (Optimal Best Fitting). This method compresses the abscissa axis by a proper variable change, which reduces the condition number of the matrix to be inverted; thus allowing the numerical problems characteristic of the least-square traditional method to be avoided.
  2. **Control of a Gradient Gravity Stabilized S/C**. He developed a research concerning the auxiliary magnetic control strategies for a gradient stabilized satellite. The purpose was to find an optimization technique (with respect to the noise) for uncertainty parameters systems. A non-linear control approach, based on an exact linearization via feedback, has been adopted. He developed the dynamics of a gravity gradient stabilized spacecraft, placed on a circular orbit, which used an adaptive technique to control the in-plane librations caused by the solar panels rotations.

- **Linear Algebra and Matrix Analysis**

  1. **Jordan Optimized Eigensolver** (JOE). Research and studies have been carried out for the eigenanalysis of numerically defective matrices, which led to the development of the JOE software package.
  2. **n-Dimensional vector cross-product**. The extension to n-Dimensional space of the vector cross product and its application to the eigenvectors computation for real, complex, and defective matrices was done.
  3. **Rotation in n-Dimensional Spaces**. Generalization of the $n \times n$ proper orthogonal matrix performing the rigid rotation in the n-Dimensional space.
  4. **Generalized Euler Theorem**. Found the relationship between the Orientation (General Rotation) and a minimum set of rigid rotation matrices, which constitutes the extension to n-Dimensional space of the Principal Axis Theorem (Euler Theorem).

5. **Orthogonal Matrix Decomposition**. Introduces a new decomposition for $n \times n$ proper orthogonal matrices into a product - or a sum - of planar rotation matrix set.
6. **Skew-Symmetric Matrix Decomposition**. A new decomposition for $n \times n$ skew-symmetric matrices into the sum skew-symmetric planar rotation matrix set, has been introduced.
7. **Ortho-Skew and Ortho-Sym matrices**. The Ortho-Skew and the Ortho-Sym set of matrices have been introduced. These matrices represent the extension to the n-Dimensional space of the imaginary unit. They satisfy the properties of the complex relationships, such as the Euler and the Moivre formulae.
8. **Matrix Trigonometry**. Developed the matrix trigonometry for the Ortho-Skew and the Ortho-Sym matrices.
9. **Matrix Mapping**. Introduces and completes the matrix mapping between Orthogonal, Skew-Symmetric, and Symmetric matrices which describe the Orientation in n-Dimensional spaces.

- **Numerical Analysis**

1. **k-vector Range Searching**. Alternative approach to solve the *Range Searching* problem for large databases. The method, which is search-less, and instantaneous, has been widely applied to the star pattern recognition algorithms. For databases with less than 65,000 elements the speed gain with respect to the standard binary search technique is more than 50 times. The method has been modified to deal with dynamic databases.
2. **n-Dimensional Multilevel k-vector Range Searching**: This research concerns with the development of a set of new and extremely fast techniques to access very large databases and multidimensional databases. The proposed techniques are general and can be specialized for any context. In particular, applications in aerospace engineering (star identification), in space science (sub-catalog extraction), and in other exploratory investigations, are under deep analysis. The proposed techniques constitute the extension of the k-vector range searching technique, presently developed with 1-Level only and for 1-Dimensional databases. This technique will have dramatic impact on several of the existing searching techniques.
3. **Optimal Best Fitting** (OBF). OBF is a new method to perform polynomial best fitting which minimizes the condition number of the matrix to be inverted. This allows avoiding numerical problems associated with data ranging over a wide range and high degree interpolation or exponential polynomials. The optimum is achieved by replacing the independent variable with a new one, linearly correlated. The method has been extended to several best fittings, namely, those

using the trigonometric functions, the Legendre orthogonal polynomials, and the Tchebychev polynomials.

- **Orbital Mechanics**

  1. **Flower Constellations** (FC). This project has an international team: 1) from Texas A&M two graduate students (C. Bruccoleri, and V. Shah), a pos-doc (Dr O. Abdelkhalik), and two previous graduate students (Dr M. Wilkins, Dr K.J. Park), 2) from Tor Vergata University (Prof. Ruggieri, Prof. Salvini, and 3-4 students), and 3) from European Space Agency (Dr D. Izzo). This project, for which the ad-hoc *Flower Constellation Visualization and Analysis Tool* (FCVAT) software has been developed, requires an incredible amount of efforts. A *Disclosure of Software* by D. Mortari, M. Wilkins, and C. Bruccoleri for the FCVAT software has been signed with the Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369. October 15, 2003. The phasing rules, that is, how to find *all the admissible positions for satellites following an identical relative trajectory with respect to any rotating reference frame*, and the *Secondary Paths* constitute the heart and the hidden secret of the FC. The FC have generated a remarkable impact on the scientific community. I already gave several invited seminars and risen great interest from NASA-JPL and from Analytical Graphics Inc., who has interest in having the FCVAT software fully compatible with STK, the world leader on orbital mechanics software. Another great interest on FC comes from the Advanced Concepts Division of European Space Agency and from two Italian universities (Tor Vergata in Rome and Politecnico di Milano).

     (a) **Global Navigation Flower Constellation**. The Flower Constellations have the satellites following the same relative trajectory with respect to an Earth rotating reference frame. This allows you to design an approximate uniform relative trajectory over the region of interest (which can be global) and uniformly distribute in time the satellites along the relative trajectory. Based on this idea, a new constellation of 30 satellites is here proposed, designed, and compared with the existing GPS and GLONASS constellation and the proposed European Galileo constellation. The proposed solution presents much better characteristics in terms of position (GDOP) and attitude (ADOP) errors or, the same error levels using four or five fewer satellites.

     (b) **Sun-Synchronous Flower Constellations**. Within the general theory of the Flower Constellations, it has been proposed a set of constellations whose relative trajectory follows the Sun. The resulting constellations are called Sun-Synchronous Flower Constellations.

2. **Synodic and Dual/Relative Flower Constellations** (S&R-FC). The S&R-FC constitute two novel and alternative methodologies to design FC synchronized with the motion of two celestial objects (e.g., two planets) orbiting about the same gravitational mass. These two "objects" can also be natural or artificial satellites (e.g., moons, spacecraft) orbiting about a planet and one of these two objects can also be the central body itself. In particular, a *Synodic* FC is made with orbits that are compatible with a reference frame rotating with a period suitably derived from the synodic period of the two objects, while a *Relative* FC is made of orbits that are, simultaneously, compatible with both the objects rotating reference frames. The latter, however, can be achieved under a very particular condition that is here approximated. The resulting dynamics of these constellations are synchronized with the dynamics of the geometrical positions of the two objects. Potential applications can be to design a Space Network Architecture for planetary communications, to design Solar Global Navigation System, to design small constellations for Surveillance and Reconnaissance and well as for space and Earth science.
3. **Multi Sun-Synchronous orbits**. These orbits represents the generalization of the Sun-Synchronous orbits. The Multi Sun-Synchronous Orbits (MSSO) are built such that the relative trajectory, with respect to a rotating reference frame having one axis constantly aligned with the Earth-Sun direction, constitutes a closed loop repeating trajectory. Among all the possible choice of this rotating reference frame, the reference frame having the has one axis aligned along with the ecliptic pole plays an important role.
4. **Shifting Sun-Synchronous Constellations**: In this constellation, after every orbit period, the constellation is shifted by a constant angle, such that the constellation appears identical with respect to the Sun direction.
5. **Two-Way Orbits**. Some compatible orbits, having odd number of petals, having the relative trajectory with the property of being retrograde and prograde over a long parte of the ground track. It is possible to build special *Two-Way Constellations* that have, simultaneously, one spacecraft being prograde (at apogee) and one spacecraft being retrograde (at perigee).
6. **Space Surveillance**: Earth and Space surveillance problem (observation of discrete targets of interest, on Earth and on space) is an important problem in remote sensing which has several important military applications. For Earth targets this problem is solved by finding a repeated Earth relative trajectory (compatible orbit) so that all the assigned sites will be visited within a given time period. The objective is to find the best satellite orbit that achieves this mission. In a general case, a single satellite may not found to achieve the mission and hence a constellation of satellites will be used and

optimization process will then look for the minimum number of satellites that achieves the mission and the best orbit for each. We are studying this problem using the compatible orbits and using a new optimality criterion. For space targets this problem is solved using the *Relative* FC theory which allows to design orbits having close periodic encounters with assigned space targets.

- **Aerospace Navigation**

  1. **Differential Image Navigation** (DIN). The DIN is a new technique to perform proximity navigation and/or docking/landing with an object whose shape and dynamics are known within a non negligible uncertainty. Our challenge is that the spacecraft carries a fixed single digital camera only, and that the control system, during the critical phase of landing/docking, takes all the decisions based on the information contained in subtracting subsequent pictures. This results into a novel and passive vision-based technology to perform proximity navigation. In particular, we have shown how to estimate the rotational dynamic and how to design the control maneuvers sequence to land onto an asteroid.

Teaching Experience in Engineering

1. *Sistemi Aerospaziali* 1992-1998. (Prof. C. Arduini). Part: Attitude dynamics, Estimation, Stability and Control, Dynamics of flexible structures, space environment, and space systems architecture. Aerospace School of Engineering of University "La Sapienza" of Rome, Italy.

2. *Strumenti di Bordo* 1995-1997. (Prof. L. Iess). Part: Attitude parameterization, sensors, actuators, estimation, and data processing. Aerospace School of Engineering of University "La Sapienza" of Rome, Italy.

3. *Sistemi Aerospaziali* 1996-1998. (Prof. C. Ulivieri). Part: Astrodynamics, Rigid Body Dynamics and stability, Attitude Parameterization, Error, Determination, Sensors, Space environment, and Space Systems architecture. Dipartimento di Ingegneria Elettronica ed Informatica, Facoltà di Ingegneria, Università di Perugia, Italy.

4. *Attitude Estimation* (2000). Prepared for the industry Officine Galileo of Alenia Spazio, Firenze, Italy.

5. *Le Matrici di Rotazione nella Determinazione e Descrizione dell'Orientamento dei Veicoli Spaziali* (2001). Prepared as a doctorate course of *Metodi e Modelli Matematici per le Scienze Applicate*, Facoltà di Ingegneria, University "La Sapienza" of Rome, Italy.

6. *Sistemi Aerospaziali* (1998-2002). Dipartimento di Ingegneria Elettronica ed Informatica, Facoltà di Ingegneria, Università di Perugia, Italy.

7. AERO-423 *Space Technology I*, from Fall 2002, through Spring 2006. Department of Aerospace Engineering. Texas A&M University, College Station, TX.

8. AERO-689 *Spacecraft Attitude Determination*, Spring 2004 and Spring 2005. Department of Aerospace Engineering. Texas A&M University, College Station, TX.

9. AERO-681 *Seminar Series*, Fall 2004. Department of Aerospace Engineering. Texas A&M University, College Station, TX.

10. AERO-489 *Attitude Determination*, Spring 2003. Department of Aerospace Engineering, Texas A&M University, College Station, TX.

Mentoring of Ph.D. Dissertations and M.S. Thesis

1. Dr Emilio Francesco Morandini, Ph.D. Principal Advisor, *Sensori ed Algoritmi per la Determinazione Puntuale dell'Assetto in Campo Spaziale*, Università degli Studi "La Sapienza" di Roma, Scuola di Ingegneria Aerospaziale. Graduated 1994.

2. Alessandro Sigalot, M.S. Principal Advisor, *Problemi di Determinazione d'Assetto di Satelliti Artificiali e Identificazione di Stelle con Sensori Stellari*, Università degli Studi "La Sapienza" di Roma, Facoltà di Fisica. Graduated 1996.

3. Davide Paciulli, M.S. Principal Advisor, *Analisi ed Algoritmi per l'Elaborazione Dati di un Sensore Luni-Solare*, Università degli Studi di Perugia, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Elettronica. Graduated 1997.

4. Michela Angelucci, M.S. Principal Advisor, *Sensori Stellari a Campi di Vista Multipli: Identificazione Stellare e Disallineamento*, Università degli Studi "La Sapienza" di Roma, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Aerospaziale. Graduated 1999.

5. Dr Ju Gwanghyeok, Ph.D. External Advisor (prior to arrival at TAMU), *Autonomous Star Sensing, Pattern Recognition, and Attitude Determination for Spacecraft: An Analytical and Experimental Study.* Department of Aerospace Engineering. Texas A&M University, Graduated May 2001.

6. Sònia Maria Martinho Marques, M.S. Invited External Examiner, *Small Satellites Attitude Determination Methods*, Electric Engineering and Computers, Instituto Superior Tècnico, Technical University of Lisboa, Portugal, Graduated May 2001.

7. Amit Sanyal, M.S. External Advisor (prior to arrival at TAMU), *Research, which includes a Theoretical Study on Rotation in Higher Dimensions and Attitude Estimation for Star Sensors.* Texas A&M University, Department of Aerospace Engineering. Graduated June 2001.

8. Mauro Bellezza, M.S. Principal Advisor, *Problematiche di Elaborazione Dati e di Sistema per le Prove a Terra di un Sensore Luni-Solare*, Università degli Studi di Perugia, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Elettronica. Graduated June 2001.

9. Aurora Ntumba, M.S. Principal Advisor, *Identificazione Stellare per il Sensore d'Assetto a Tre Campi di Vista StarNav III*, Università degli Studi di Perugia, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Elettronica. Graduated September 2001.

10. Silvia Sangiorgi, M.S. Principal Advisor, *ASTRIUM Internship: Unusual behaviour study of the TWTAs, Travelling Wave Tube Amplifiers, Embarked in ASTRIUM Telecommunications Satellites*, Università degli Studi di Perugia, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Elettronica. Graduated January 2002.

11. Serena La Rosa, M.S. Principal Advisor, *Sviluppo di un Sistema Autonomo di Identificazione Stellare*, Università degli Studi di Perugia, Facoltà di Ingegneria, Corso di Laurea in Ingegneria Elettronica. Graduated March 2002.

12. Christian Bruccoleri, M.S. Principal Advisor, *Elaborazione di Immagini Stellari per la Navigazione Aerospaziale*, Università degli Studi "La Sapienza" di Roma, Corso di Laurea in Ingegneria Informatica, Facoltà di Ingegneria. Graduated March 2002.

13. Dr Malak Anees Samaan, Ph.D. External Co-Advisor, *Research on Multiple FOVs Star Sensor Data Processing*. Department of Aerospace Engineering, Texas A&M University. Graduated June 2003.

14. Dr Keun Joo Park, Ph.D. Principal Advisor, *GPS Receiver Self Survey and Attitude Determination Using Pseudolite Signals*. Department of Aerospace Engineering, Texas A&M University. Graduated August 13, 2004.

15. Dr Matthew Paul Wilkins, Ph.D. Principal Advisor, *The Flower Constellations - Theory, Design Process, and Applications*, Department of Aerospace Engineering, Texas A&M University. Graduated December 17, 2004.

16. Dr Mauro Massari, Ph.D. Invited External Examiner (*Controrelatore*) of the Ph.D. dissertation of Dr Mauro Massari, "Trajectory Optimization for Spacecraft flying in Formation", Department of Aerospace Engineering of the Politecnico di Milano (Italy). Graduated March 2005.

17. Dr Ossama Omar Abdelkhalik, Ph.D. Principal Advisor, *Orbit Design and Estimation for Surveillance Missions using Genetic Algorithms*. Department of Aerospace Engineering, Texas A&M University. Ph.D. dissertation defended on September 19, 2005.

18. Michael John Swanzy, MS Committee Member and Advisor, "Analysis and Demonstration of a Compass Star Tracker," Department of Aerospace Engineering, Texas A&M University. December 2005.

19. Marilee Ruth Myres, MS Committee Member, nonthesis, Department of Aerospace Engineering, Texas A&M University. December 2005.

20. Michael Muzheve, MS Committee Member and Advisor, nonthesis, Department of Mathematics, Texas A&M University. December 2005.

21. Iohan Ettouati, MS Principal Advisor. Department of Aerospace Engineering, Texas A&M University. Expected graduation August 2006.

22. Bruccoleri, Christian, Graduate Ph.D. student, Principal Advisor. Department of Aerospace Engineering, Texas A&M University. Expected graduation December 2006.

Invited Seminars

1. *San Marco Project and Space Research at the University of Rome*, Keynote lecture on plenary session at the Fourth International Symposium on Automatic Control and Computer Science (SACCS' 93), Iasi, Romania, October 29-30, 1993.

2. *The Moon-Sun and the Earth-Sun Attitude Sensors*, Flight Dynamics Division of the Goddard Space Flight Center (NASA), Greenbelt, MD, January 22, 1997, Invited by Dr F. Landis Markley and Dr Julie Deutschmann.

3. *The Moon-Sun and the Earth-Sun Attitude Sensors*, System Sciences Division of the Computer Science Corporation of Lanham-Seabrook, MD. June 13, 1997, Invited by Dr Dipak Oza and Dr Murty Challa.

4. *Recently Proposed Sensors and Algorithms for Spacecraft Attitude Determination*, Department of Aerospace and Mechanics Engineering, University of Minnesota, Minneapolis, MN, July 10, 1997, Invited by Prof. Yiyuan J. Zhao.

5. *New Algorithms and Sensors for Attitude Determination*, Mathematics Department of the Naval Postgraduate School, Monterey, CA, November 30, 1998, Invited by Prof. Guillermo Owen and Prof. Beny Neta.

6. *New Algorithms and Sensors for Attitude Determination*, Department of Aerospace Engineering, Texas A&M University, College Station, TX, December 7, 1998, Invited by Prof. John L. Junkins.

7. *From Planar to General Rotation in the n-Dimensional Spaces*, Department of Aerospace Engineering, Texas A&M University, College Station, TX, September 14, 2000, Invited by Prof. John L. Junkins.

8. *Ortho-Skew and Ortho-Sym Matrices: the Extension of the Imaginary Unit to n-Dimensional Spaces*, Department of Aerospace Engineering, Texas A&M University, College Station, TX, September 14, 2000. (invited by Prof. John L. Junkins).

9. *From Planar to General Rotation in the n-Dimensional Spaces*, Department of Aerospace Engineering, University of Texas, Austin, TX, September 15, 2000, Invited by Prof. Maruthi Akella.

10. *From Planar to General Rotation in the n-Dimensional Spaces*, Instituto de Sistemas e Robotica, Instituto Superior Tecnico of Lisbon Technical University, Portugal, May 3, 2001, Invited by Prof. Pedro U. Lima.

11. *General One-to-One Mapping Among Orientation Matrices*, Department of Aerospace Engineering, Texas A&M University, College Station, TX, March 7, 2002, Invited by Prof. Ramesh Talreja and Prof. John L. Junkins.

12. ESOQ: *From Theory to Application*, Department of Aerospace Engineering, Texas A&M University, College Station, TX, March 7, 2002, Invited by Prof. Ramesh Talreja and Prof. John L. Junkins.

13. *Conformal Mapping among Orthogonal, Symmetric, and Skew-Symmetric Matrices*, AERO 681 Seminar Series, Department of Aerospace Engineering, Texas A&M University, College Station, TX, February 4, 2003 at 4:00pm.

14. *ANNA: a Slide Presentation*, Circolo Italiano, Texas A&M University, College Station, TX, March 19, 2003 at 19:30pm.

15. *The Flower Constellations*, AIAA Learn and Lunch Speech, NASA's Johnson Space Center, Houston, TX, June 11, 2003 at 11:00pm.

16. *The Flower Constellations*, Aerospace and Ocean Engineering Department of the Virginia Polytechnic Institute and State University, Blacksburg, VA, September 21, 2003 at 04:00pm.

17. Seminar *Space Magic*, AERO-101 Annual Seminar at *Texas A&M University*, College Station, TX. Seminar given on October 10, 2003, February 27, 2004, October 8, 2004, March 4, 2005, October 7, 2005, and February 17, 2006.

18. *The Flower Constellations*, College of Architecture, Texas A&M University, College Station, TX, November 25, 2003 at 11:00pm.

19. *The Flower Constellation Set*, NASA's Jet Propulsion Laboratory, Pasadena, CA, January 15, 2004 at 11:00am.

20. *Secondary Paths in Flower Constellations*, Algebra and Combinatorics Seminar, Department of Mathematics, Texas A&M University, College Station, TX, January 30, 2004 at 03:00pm.

21. *The Flower Constellations*, IEEE Seminar, Department of Aerospace Engineering, Tor Vergata University, Rome, Italy, July 12, 2004 at 03:00pm.

22. *Flower Constellation: a New Space Object*, Department of Aerospace Engineering and Engineering Mechanics, University of Texas, Austin TX, April 14, 2005 at 03:30pm. Invited by Prof. Maruthi Akella.

23. *Satellite Ballet with Flower Constellation*, TexGraph 2005 Conference, May 7, 2005 at 09:30am, Computer Sciences and Visualization Laboratory, Texas A&M University, College Station, TX. Invited by Prof. Ergun Akleman.

24. *Advances in Constellation Design: The Flower Constellation Set*, Advanced Concepts Division, ESTEC, European Space Agency, Noordwijk (The Netherlands), July 6, 2005 at 10:00am., Invited by Dr. Franco Ongaro and Dr. Dario Izzo. Travel and accomodation provided.

25. *Advances in Constellation Design: The Flower Constellation Set*, IEEE Distinguished Lecture, Invited seminar for "Advanced Systems for Communication and Satellite Navigation," Department of Electronic Engineering, Tor Vergata University, Rome, Italy, July 18, 2005 at 04:30pm. Invited by Prof. Marina Ruggieri.

26. Elected Distinguished Speaker in the IEEE Distinguished Lectures Program, on February 2005.

27. *On a Family of Real Curves Arising from Satellite Placement*, September 9, 2005 at 04:00pm, Geometry Seminar Series, Department of Mathematics, Texas A&M University, College Station, TX.

28. *Flower Constellations as Rigid Objects in Space*, Invited lecture of the 2006 Innovative System Design Concepts Workshop of ESA's Space Research and Technology Center (ESTEC) in Noordwijk, The Netherlands, February 21, 2006. Invited by Dr Roger Walker and Dr Dario Izzo. Travel and accommodation provided.

Funded Projects

In addition to the projects described below, in which Dr. Mortari has been the sole Principal Investigator, he has served as a Co-I or visiting researcher for several projects over the past ten years at the San Marco Project and for three years at Texas A&M University; the total budgets for these projects are several million dollars. In collaboration with Prof. J.L. Junkins and Prof. T. Pollock at Texas A&M on the StarNav project, the methods developed for star pattern recognition have been adopted for the EO-3 mission (a $130M spacecraft), and a pending patent has been commercialized.

Projects performed at University of Rome, Italy

1. PI. *Feasibility Study of the Moon-Sun and the Earth-Sun Attitude Sensors: Algorithm Development*
   Sponsor: Italian Space Agency
   Amount: Lire 173M (≈ $86.5K)
   Dates: One year contract, completed by May 31, 2000.

2. PI. *Feasibility Study of the Moon-Sun and the Earth-Sun Attitude Sensors: Ground Tests*
   Sponsor: Italian Space Agency
   Amount: Lire 150M (≈ $75K)
   Dates: One year contract completed by May 31, 2001.

3. PI. *Feasibility Study of the Multiple FOVs Star Tracker NavStar III*
   Sponsor: Italian Space Agency
   Amount: Lire 100M (≈ $50K)
   Dates: Six month contract completed by September 30, 2001.

4. PI. *Design of an Elegant Breadboard for the Multiple FOVs Star Tracker NavStar III*
   Sponsor: Italian Space Agency
   Amount: Lire 90M (≈ $45K)
   Dates: One year contract completed by August 13, 2002.

Projects performed and pending at Texas A&M University, USA

5. Co-I. *Solar Sail Diagnostic Package*
   PI: Richard Pappa (LaRC)
   Sponsor: NASA Langley
   Amount: Overall $2.3M (TAMU $500K)
   Dates: 06/03-06/04.[1]

6. Co-I. *Mission Planning Studies for Near-Earth Asteroids*
   PI: John L. Junkins (TAMU)
   Sponsor: Science Applications International Corporation
   Amount: $25K
   Dates: 02/04-08/04.

7. Co-I. *Satellite Situational Awareness Camera System*
   PI: Nick Combs (STC)
   Sponsor: Schafer Corporation. Contract No. SC-03A-22-08
   Amount: Overall: $240,234, Mortari: $102,293
   Dates: 02/22/05-08/31/05.

8. PI. *Optimal Reconfiguration of Space Assets and Orbit Design for Responsive Space*
   Sponsor: AFRL (BAA VS-05-01)

[1]Following solution of our proposal for funding, an ITAR restriction resulted in D. Mortari not being eligible to perform the research, so T. Pollock assumed the PI role for TAMU.

Co-Is: K.T. Alfriend, S.R. Vadali (TAMU)
Amount: $150,001
Dates: December 1, 2005 - November 31, 2006.

9. PI. *SEARCH: Space-Eye Awareness and Reconnaissance Camera Hardware*
   Sponsor: AFRL (CASS)
   Co-I: E. Akleman (TAMU Visualization Sciences Program)
   Amount: $270,000
   Date: 05/01/06 - 04/30/09
   Status: **Approved for funding**.

10. Co-I. *Constellations for Space Situational Awareness*
    Sponsor: AFRL (CASS)
    PI: D. Hyland (TAMU)
    Amount: $270,000
    Date: 05/01/06 - 04/30/09
    Status: **Approved for funding**.

11. Co-PI. *Space Situational Awareness Camera System (SSACS) for Military and Commercial Space Assets*
    PI: C. Hill (STC)
    Sponsor: AFSC, BAA-SYK-05-0001. TEES Proposal 06-0056.
    Amount: Overall: $980,475
    Date: 12/1/05-11/30/07.
    Status: **Pending**.

12. Co-PI. *Proximity Operations (PROPS) Test Bed*
    Sponsor: AFSC, BAA-SYK-05-0001. TEES Proposal 06-0067.
    PI: J.L. Junkins (TAMU)
    Amount: $2,525,638
    Date: 12/1/05-11/30/07.
    Status: **Pending**.

13. Co-PI. *Proposal to AeroAstro for Space Situational Awareness Using Start Trackers (SmartLight)*
    Sponsor: AeroAstro. TEES Proposal 06-0341
    PI: C. Hill (STC)
    Amount: Overall: $348,455
    Commitment: 3.00 mo/yr
    Date: 2/1/06-10/3/06
    Status: **Pending**.

14. PI. Title: *Flower Constellations: from Theory to Applications*
    Sponsor: TSGC
    Amount: $10,000
    Commitment: 0.00 mo/yr

Date: 09/01/06-07/31/08
Status: **Pending**.

Professional Societies

- American Astronautical Society: Member, 1992 - present.
- American Institute of Aeronautics and Astronautics: Member, 1994 - present.
- Phi Beta Delta, Honorary Association, Member, October 2002 - present.
- Sigma Xi, The Scientific Research Society. Full Member, January 2003 - present.
- IEEE Aerospace and Electronic Systems Society, January 2005 - present.

Professional Activities

- Keynote Lecture "San Marco Project and Space Research at the University of Rome," at the Fourth International Symposium on Automatic Control and Computer Science (SACCS' 93), October 29-30, 1993, Iasi, Romania.
- Session Chair of *Attitude Determination II* at the AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, July 29-31, 1996.
- Invited paper at the Third International Conference on Non Linear Problems in Aeronautics and Astronautics, ICNPAA-2000, Daytona Beach, FL, May 10-12, 2000.
- Session Chair at the Third International Conference on Non Linear Problems in Aeronautics and Astronautics, ICNPAA-2000, Daytona Beach, FL, May 10-12, 2000.
- Associate Editor of the AAS *Journal of the Astronautical Sciences*, January 2003 - Present.
- Co-Organizer of the 2003 AAS John L. Junkins Astrodynamics Symposium, Texas A&M University, College Station, TX, May 23-24, 2003.
- Session Chair of the 2003 AAS John L. Junkins Astrodynamics Symposium, Texas A&M University, College Station, TX, May 23-24, 2003.
- Guest-Editor of the Special Issue: The John L. Junkins Astrodynamics Symposium of the *Journal of the Astronautical Sciences.*
- Program Committee member for the 6th International Conference on Dynamics and Control of Systems and Structures in Space 2004, Riomaggiore, Italy, 18-22 July, 2004.

- Organizing Committee Member for the International Conference on Dynamics and Control of Systems and Structures in Space 2004, Riomaggiore, Italy, 18-22 July, 2004.

- Session Chair of the "Planetary Exploration" session of the International Conference on Dynamics and Control of Systems and Structures in Space 2004, Riomaggiore, Italy, 18-22 July, 2004.

- Completed a "Memorandum of Agreement" with the School of Engineering at Tor Vergata University (Rome, Italy). This agreement has been signed at College of Engineering level for Texas A&M University. The proposed areas of cooperation of this agreement are:

  1. *Faculty Exchange*. Lectures and On-Campus Visits. Goal is a minimum of two exchanges per year.
  2. *Development of Externally Funded Research*. Goal is a minimum of two proposals per year.
  3. *Student Exchanges*. Goal is the development a workable plan and offer some type of courses within the next two years. This goal will be resolved as soon as funding for American students will be found. This would cover the gap between the student tuition fees that prevent US students to apply.
  4. *Joint Degree Offerings*. Goal is to explore the feasibility of such an arrangement and ascertain whether it should be pursued further. The initial report could be completed within one year and appropriate actions taken there after.

- Initiated a "Memorandum of Agreement" with the School of Engineering at Politecnico di Milano (Italy). This agreement would be signed at College of Engineering level for Texas A&M University. The proposed areas of cooperation of this Agreements are similar to that signed for Tor Vergata University.

- A research collaboration proposal on "Enhanced Environmental Policies and Resources Management through Orbital Surveillance and Interaction", written with Prof. R. Rugescu (Bucharest, Romania) has been successfully selected for a "Fulbright Senior Scholar Award" of $13,750.00 for the 2006-07 academic year. Prof. Rugescu will join me and the Department of Aerospace Engineering starting on September 2006. The research collaboration is scheduled five month long.

- Elected Distinguished Speaker in the IEEE Distinguished Lectures Program (February 2005).

- Reviewer of the AIAA *Journal of Guidance, Control, and Dynamics*, since 1997, of the AAS *Journal of the Astronautical Sciences*, since 1998, of the *Acta Astronautica*, since 2004, and of the ASME *Journal of Dynamic*

Systems, Measurement, and Control, since 2004, and of the IEEE *Transactions on Aerospace and Electronic Systems* since 2004.

- Invited by Dr. David Schmidt, Editor-in-chief of the AIAA *Journal of Guidance, Control, and Dynamics* (JGCD) to be Associate Editor for JGCD; I declined serving as editor for JGDC because other time commitments. Invitation was re-iterated on October 8, 2004, declined again.

- Elected in AcademicKeys Who's Who in Engineering Education on June 3, 2005.

- Session Chair of the AAS *Malcolm D. Shuster* Astronautics Symposium, June 13-15, 2005. University at Buffalo, State University of New York.

- Member of the Program Committee of the *International Conference on Dynamics and Control of Systems and Structures in Space 2006*, Greenwich, London, England, July 16-20, 2006.

- *Flower Constellations as Rigid Objects in Space*, Invited lecture of the 2006 Innovative System Design Concepts Workshop of ESA's Space Research and Technology Center (ESTEC) in Noordwijk, The Netherlands, February 21, 2006. Invited by Dr Roger Walker and Dr Dario Izzo. Travel and accommodation provided.

Consulting

- The Charles Stark Draper Laboratory, Inc., Cambridge, MA. The Pyramid and the ESOQ-2 algorithms have been adapted to the Stellar Inertial Compass for the JPL New Millennium Program ST6. Pyramid solves the the Star Identification problem in the *Lost-in-Space* case and ESOQ-2 optimally estimates the spacecraft attitude from vector observations, respectively.

- Massachusetts Institute of Technology, Cambridge, MA. The successfully application of Pyramid by Draper Labs. has convinced the MIT Center for Space Research, to adopt Pyramid for the High Energy Transient Explorer (HETE) spacecraft. Pyramid has been successfully operating on orbit aboard HETE since July 2002. Pyramid is also planned for use aboard the HETE2 and has been licensed for commercialization by Star Vision Technologies.

- *European Space Agency* (ESA-ESTEC), Noordwijk, The Netherlands. The successful application of the *Flower Constellations* theory to Global Navigation Systems (we proved that GalileoSat can be built with 25-26 satellites while keeping the same level of accuracy) has motivated the Advanced Concepts Division of ESA-ESTEC to allocated a 35.000 Euro research grant for studies on theory and applications of Flower Constellations. Only European universities were eligible to respond to this announcement. University of Tor Vergata has been awarded by this grant.

- Prof. M. Ruggieri of Tor Vergata University in Rome (Italy), in collaboration with Prof. A. Ercoli-Finzi of Politecnico di Milano (Italy), has submitted the proposal "Advanced Satellite Applications on Communications and Navigation based on Flower Constellations" to the Italian *Ministry of Education, University and Research* (MIUR) within the Italian Programme named "An Incentive for the Process of Internationalization of the University System". The University of Tor Vergata is the leader in Italy in the Communications area. That Program is specifically aimed to provide support to scientific and teaching initiatives between Italian and foreign Universities. This proposal, which includes a modest 4.5K Euro travel funds to support traveling for myself and/or for my students, has been awarded.

Honors

- NASA Group Achievement Award (1981) for activities related to Spacecraft Attitude Determination and Control of the San Marco Spacecraft.
- Spacecraft Technology Center Award (Jan. 16, 2003) for activities related to the StarNav I payload, which flew aboard the ill-fated Space Shuttle Columbia, Mission STS-107.

Patents

- Junkins, J.L., Pollock T.C., and Mortari, D. *System and Method for Attitude Determination Based on Optical Imaging*, U.S. Patent No. US 6,556,351 B1, April 29, 2003.
- *Software Disclosure* by Daniele Mortari, Matthew P. Wilkins, and Christian Bruccoleri for "The Flower Constellation Visualization and Analysis Tool (FCVAT)," Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369. October 15, 2003.
- *Software Disclosure* by Daniele Mortari and Christian Bruccoleri for "The *Pyramid* Star Identification Software," Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369.
- *Software Disclosure* by Daniele Mortari, Malak A. Samaan, and John L. Junkins for "The *Recursive* Star Identification Software," Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369.
- *Software Disclosure* by Daniele Mortari, Malak A. Samaan, and John L. Junkins for "The *Non-Dimensional* Star Identification Software," Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369.

- *Invention Disclosure* by Daniele Mortari, Malak A. Samaan, and John L. Junkins for "The *Compass* Star Tracker," Technology Licensing Office, TAMU 3369, 707 Texas Ave, College Station, TX 77843-3369.

Publications

Textbooks

1. *The John L. Junkins Astrodynamic Symposium*, Srinivas Rao Vadali and Daniele Mortari, Eds. American Astronautical Society, San Diego, 2003 Paperback: 542 pp., illus. ISBN 0877035067. Advances in the Astronautical Sciences, Vol. 115.

2. *The Journal of the Astronautical Sciences*, Special Issue: The John L. Junkins Astrodynamics Symposium, Srinivas Rao Vadali, Daniele Mortari, and Kathleen C. Howell Editors. American Astronautical Society. Vol. 52, Nos. 1 and 2, January-June 2004.

3. Mortari, D. *Attitude Determination and Star Navigation*, In preparation (Status: 70% done, about 300 pages). To be submitted to the AIAA Educational Series.

4. Mortari, D. *Spacecraft Orbit and Attitude Dynamics*," In preparation (Status: 65% done, about 250 pages). To be submitted to College Publishers.

Archival Publications (peer reviewed journal articles)

1. A.M. Nobili, D. Bramanti, G. Catastini, E. Polacco, A. Milani, L. Anselmo, M. Andrenucci, S. Marcuccio, A. Genovese, G. Genta, E. Brusa, C. Del Prete, D. Bassani, G. Vannaroni, M. Dobrowolny, E. Melchioni, C. Arduini, U. Ponzi, F. Curti, G. Laneve, D. Mortari, M. Parisse, F. Cabiati, E. Rossi, A. Sosso, G. Zago, S. Monaco, G. Gori Giorgi, S. Battilotti, L. D'Antonio, and, G. Amicucci, "Galileo Galilei Flight Experiment on the Equivalence Principle with Field Emission Electric Propulsion," *Journal of the Astronautical Sciences*, Vol. 43, No. 3, July-September 1995, pp. 219-242.

2. Mortari, D. "EULER-2 and EULER-n Algorithms for Attitude Determination from Vector Observations," *Space Technology*, Vol. 16, Nos. 5/6, 1996, pp. 317-321.

3. Mortari, D. "Modelli Matematici per la Determinazione d'Assetto di Satelliti Artificiali," *Atti del Centro Ricerche Aerospaziali, Nuova Serie*, No. 6, March 1996.

4. Mortari, D. "Riduzione dei Dati di Sensori d'Assetto," *Atti del Centro Ricerche Aerospaziali, Nuova Serie*, No. 7, October 1996.

5. Mortari, D. "Energy Approach Algorithm for Attitude Determination from Vector Observations," *Journal of the Astronautical Sciences*, Vol. 45, No. 1, pp. 41-55, 1997.

6. Mortari, D. "Search-Less Algorithm for Star Pattern Recognition," *Journal of the Astronautical Sciences*, Vol. 45, No. 2, April-June 1997, pp. 179-194.

7. Mortari, D. "ESOQ: A Closed-Form Solution to the Wahba Problem," *Journal of the Astronautical Sciences*, Vol. 45, No. 2, April-June 1997, pp. 195-204.

8. Mortari, D. "n-Dimensional Cross Product and its Application to Matrix Eigenanalysis," *Journal of Guidance, Control, and Dynamics*, Vol. 20, No. 3, May-June 1997, pp. 509-515.

9. Mortari, D. "Moon-Sun Attitude Sensor," *Journal of Spacecraft and Rockets*, Vol. 34, No. 3, May-June 1997, pp. 360-364.

10. Mortari, D. "EULER-q Algorithm for Attitude Determination from Vector Observations," *Journal of Guidance, Control, and Dynamics*, Vol. 21, No. 2, March-April 1998, pp. 328-334.

11. Mortari, D. "Second Estimator of the Optimal Quaternion," *Journal of Guidance, Control, and Dynamics*, Vol. 23, No. 5, Sept.-Oct. 2000, pp. 885-888.

12. Markley, L.F., and Mortari, D. "Quaternion Attitude Estimation Using Vector Observations," *Journal of the Astronautical Sciences*, Special Issue: The Richard H. Battin Astrodynamics Symposium, Vol. 48, No. 2/3, April-September, 2000, pp. 359-380.

13. Mortari, D. "On the Rigid Rotation Concept in n-Dimensional Spaces," *Journal of the Astronautical Sciences*, Vol. 49, No. 3, July-September 2001.

14. Mortari, D. "Ortho-Skew and Ortho-Sym Matrix Trigonometry," *The Journal of the Astronautical Sciences*, Special Issue: The John L. Junkins Astrodynamics Symposium, Vol. 52, No. 1 and 2, January-June 2004, pp. 269-279.

15. Mortari, D., Wilkins, M.P., and Bruccoleri, C. "The Flower Constellations," *The Journal of the Astronautical Sciences*, Special Issue: The John L. Junkins Astrodynamics Symposium, Vol. 52, Nos. 1 and 2, January-June 2004, pp. 107-127.

16. Mortari, D., Samaan, M.A., Bruccoleri, C., and Junkins, J.L. "The *Pyramid* Star Pattern Recognition Algorithm," *Navigation* Vol. 51, No. 3, Fall 2004, pp. 171-183.

17. Samaan, M.A., Mortari, D., and Junkins, J.L. "Recursive Mode Star Identification Algorithms," To appear in the IEEE *Transactions on Aerospace and Electronic Systems*, Vol. 41, No. 4, October 2005, pp. 1246-1254.

18. Samaan, M.A., Mortari, D., and Junkins, J.L. "Non Dimensional Star Identification for Un-Calibrated Star Cameras," To appear in the *Journal of the Astronautical Sciences.*

19. Mortari, D. and Singla, P. "*Optimal Cones Intersection Technique*," To appear in *ACTA Astronautica.*

20. Abdelkhalik O. and Mortari, D. "Two-Way Orbits," To appear in *Celestial Mechanics and Dynamical Astronomy.*

21. Abdelkhalik O. and Mortari, D. "Orbit Design for Ground Surveillance Using Genetic Algorithms," To appear in the *Journal of Guidance, Control, and Dynamics.*

22. Mortari, D. "Flower Constellation as Rigid Object in Space," To appear in *ACTA Futura.*

Submitted and in Preparation

23. Mortari, D., Scuro, R.S., and Bruccoleri, C. "Attitude and Orbit Error in n-Dimensional Spaces," Submitted to the *Journal of the Astronautical Sciences.*

24. Bruccoleri, C. and Mortari, D. "Modified Rogrigues Attitude Determination," Submitted to the *Journal of the Astronautical Sciences.*

25. Park, K.J., Ruggieri, M., and Mortari, D. "Comparisons Between GalileoSat and Global Navigation Flower Constellations," Submitted to the IEEE *Transactions on Aerospace and Electronic Systems.*

26. Wilkins, M.P. and Mortari, D. "Secondary Paths in Flower Constellations," Submitted to the IEEE *Transactions on Aerospace and Electronic Systems.*

27. Mortari, D. and Wilkins, M.P. "Dual Compatible Flower Constellations," Submitted to the IEEE *Transactions on Aerospace and Electronic Systems.*

28. Park, K.J. and Mortari, D. "Moon-Sun Sensor Data Processing," Submitted to *Aerospace Science and Technology.*

29. Park, K.J., Wilkins, M., Bruccoleri, C., and Mortari, D. "Uniformly Distributed Flower Constellation Design Study for Global Navigation System," Submitted to ION Journal *Navigation.*

30. Samaan, M.A., Mortari, D., and Junkins, J.L. "Compass Star Tracker for GPS Applications," Submitted to ION Journal *Navigation*.

31. Mortari, D. and Abdelkhalik, O. "Planet and Time Estimation Using Star Trackers," To be submitted.

32. Abdelkhalik, O. and Mortari, D. "Formation Flying using Star Trackers," To be submitted.

33. Abdelkhalik, O., Mortari, D., and Junkins, J.L. "Space Surveillance Using Star Trackers: Estimation," To be submitted.

34. Katake, A., Mortari, D., and Pollock, T.C. "Space Surveillance Using Star Trackers: Simulations," To be submitted.

35. Katake, A., Mortari, D., and Junkins, J.L. "Dual Field-of-View Star Tracker StarNav II Data Processing," To be submitted.

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37. Clocchiatti, A. and Mortari, D. "*Responsive Space Surveillance using Periodic Close Encounters*," To be submitted.

38. Mortari, D. "*The Conical Anomaly*," To be completed and submitted.

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41. Singla, P., Mortari, D., and Junkins, J.L. "*How to Avoid Singularity for Euler Angle Set?*," To be completed and submitted.

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