

# ON THE TEACHING SUPPORT SYSTEM USING REAL-TIME CONNECTION OF STK, MATLAB AND AIR-BEARING TESTBED FOR SATELLITE ATTITUDE CONTROL EDUCATION

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## Abstract

This paper introduces a teaching support system to raise the effectiveness of the satellite attitude control experimental education by using the real-time connection of STK, MATLAB and air-bearing testbed. Satellite attitude determination and control are studied by using several kinds of sensors, actuators and attitude control programs in the weightless environment similar to the space in the application of air-bearing testbed for attitude control research, however the teaching support system was not studied enough to simulate, analyze and educate in real-time in relation with the orbital elements by connecting the testbed with STK. The paper proposes a method to show and analyze the attitude control process of the testbed in real-time in relation with the orbital elements provided by STK by connecting MATLAB, STK and air-bearing, and develops a teaching support system, finally verifies the effectiveness of the proposed method and teaching support system. The proposed method and teaching support system could be applied for the education and scientific research in the field of satellite control engineering.

## Keywords:

*Satellite attitude control; Satellite control education; Air-bearing testbed; STK; Real-time connection; Teaching support system*

## Introduction

In the experimental education on satellite attitude control system, simulation experiment based on MATLAB was conducted, and the results were verified by using air-bearing testbed in laboratory.

[1-6] proposed an air-bearing based satellite attitude dynamics simulator to construct a real-time hardware-in-the-loop simulation environment. The advantage is that the satellite attitude dynamics could be simulated by the actuators and sensors mounted on the air-bearing testbed. However, the detailed consideration on satellite motion in space is not sufficient in relation with the orbital elements of satellite.

The application method regarding communication and speed control was proposed using the floating satellite platform to help students understand the basic systems and subsystems of satellite in [7-10]. However, the analysis in relation with the orbital elements of satellite in space is not provided.

[11] proposed a three-axis attitude control of nanosatellite platform composed of the set of modular characteristic satellite subsystems (power, data handling, attitude control, communications, and payload) to be used for student educations at different levels. In [12-14] studied a prototype of the ADCS to study the attitude determination and control using the momentum wheels and magnetorquers, and presented an air-bearing-based satellite attitude simulator to test the satellite techniques in the realistic environment.

[15] studied a benchmark of industrial relevance to propose a modeling philosophy necessary for education of the future GNC engineers and the GNC space community. So, it could combine the theoretical studies with the industrial practice closely.

In [16-17] studied a small satellite attitude control simulator table where sensors, actuators and control computer are mounted to help students conduct the preliminary experiments on the attitude dynamics of small satellites.

From the analyses on the preceding data we noticed that the investigation and education on the satellite attitude control system are not sufficient in relation with the orbital elements using the special simulation tools.

Recently STK and MATLAB are widely used for several purposes in the design, modeling, simulation and analysis of satellite attitude control system.

STK is short for Systems Tool Kit, and it allows to simulate and analyze the flight process of several kinds of flying bodies and equipment in all fields of space, sky, land and sea. It also allows not only to simulate exactly with kinds of calculating algorithms, but also to show and analyze the dynamic data by the real-time data connection.

Thus, the paper studies the real-time connecting method of STK, MATLAB and air-bearing testbed and proposes a teaching support system based on the method where students could conduct the satellite attitude control simulation experiments using MATLAB and STK in any places, and conduct real-time attitude control experiments using the satellite attitude control air-bearing testbed in the laboratories successfully.

## 2. Connection of STK with MATLAB

There are two methods to connect STK with MATLAB.

The first one is to use 'Object Model', and the other one is to use 'Connect'.

STK provides powerful APIs to control it from the outsides.

Using the above connecting methods users can simulate and analyze from the creation of STK objects to the engine driving and the creation of simulating environment and individual objects in MATLAB.

Therefore, users can show, simulate and analyze the attitude motion process by connecting the static or real-time attitude information of satellites to STK from MATLAB.

STK and MATLAB could be started by the following instructions in MATLAB.

```
uiapp = actxserver('STK11.application');
root = uiapp.Personality2;
uiapp.visible = 1;
root.NewScenario('Attitude_Control_Via_232_From_Real_Device');
scenario = root.CurrentScenario;
```

Satellite objects could be created by the following instructions.

Using 'Connect':

```
New / */Satellite MySatellite_Con
```

Using 'Object Model':

```
satellite = root.CurrentScenario.Children.New(18, "MySatellite_OM");
```

As well many APIs are provided to set and show the orbital parameters, attitude control information, simulating duration and the analytic data of satellite, so users can write, simulate and analyze programs based on the APIs.

### 2.1 Simulation based on the Connection of STK with MATLAB

Simulation results of satellite attitude control system using MATLAB Simulink could be connected to STK, and the attitude control process of satellite could be shown and analyzed in MATLAB and STK.

#### 2.1.1 Main Steps of Simulation

- ① Opening of the Simulink block diagram
- ② Determination and simulation of the parameters of control system
- ③ Creating a new instance of STK, new scenario and new satellite object and setting the initial values such as the six elements of orbit and attitude information using STK's API functions in MATLAB
- ④ Connecting the simulation parameters (satellite attitude information such as quaternion, Euler angles, angular velocities, etc) to the previously created objects using API functions (Object Model, Connect) of STK

- ⑤ Analyzing the attitude control process of satellite in MATLAB Simulink.
- ⑥ Showing and analyzing the attitude control process of satellite in STK

### 2.1.2 User Interface of Simulation Experimental Program

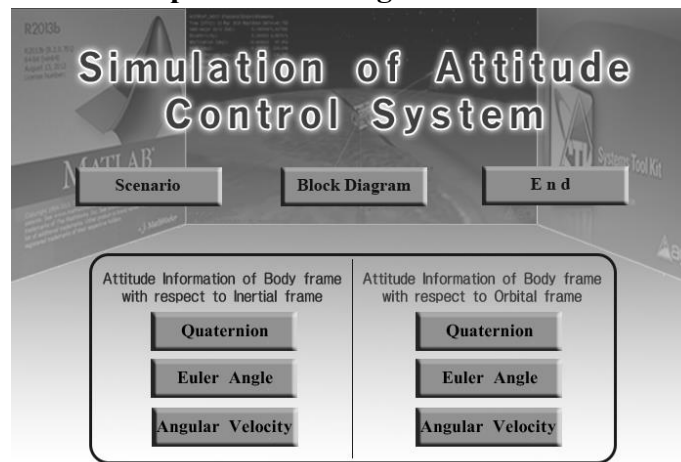


Figure 1: User interface of simulation experimental program

### 2.1.3 Some Part of the Simulation Experimental Program

```
function [sys,x0,str,ts,simStateCompliance] = stk(t,x,u,flag,root)

switch flag,

case 0,

[sys,x0,str,ts,simStateCompliance]=mdlInitializeSizes;

case 1,
sys=mdlDerivatives(t,x,u);
case 2,
sys=mdlUpdate(t,x,u);
case 3,
sys=mdlOutputs(t,x,u,root);
case 4,
sys=mdlGetTimeOfNextVarHit(t,x,u);
case 9,
sys=mdlTerminate(t,x,u);
otherwise
DASudio.error('Simulink:blocks:unhandledFlag', num2str(flag));
end

function [sys,x0,str,ts,simStateCompliance]=mdlInitializeSizes
sizes = simsizes;
sizes.NumContStates = 0;
sizes.NumDiscStates = 1;
sizes.NumOutputs = 1;
sizes.NumInputs = 3;
```

```

sizes.DirFeedthrough = 1;
sizes.NumSampleTimes = 1; % at least one sample time is needed
sys = simsizes(sizes);
x0 = 0;

str = [];

ts = 1;
simStateCompliance = 'UnknownSimState';

function sys = mdlDerivatives(t,x,u)
sys = x;

function sys = mdlUpdate(t,x,u)
sys = [];

function sys = mdlOutputs(t,x,u,root)
if (t == 0)
root.ExecuteCommand('SetAttitude */Satellite/GMSSat ClearData');
end

set = ['AddAttitude */Satellite/GMSSat Euler "25 Mar 2025 11:00:', num2str(0+t)," 213 0.0 0.0 ',
num2str(u(1)*10+0.0)];

root.ExecuteCommand(set);
sys = 1;

function sys = mdlGetTimeOfNextVarHit(t,x,u)
sampleTime = 1;
sys = t + sampleTime;

function sys = mdlTerminate(t,x,u)
sys = [];

```

## 2.2 Real-time Connection of STK, MATLAB and Air-bearing Testbed

### 2.2.1 Configuration of Real-time Linkage Experimental System of STK, MATLAB and Air-bearing Attitude Control Testbed

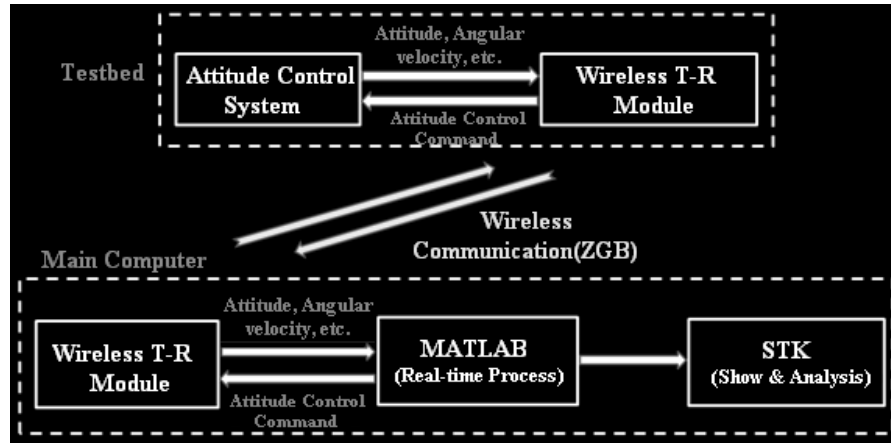


**Figure 2:** Configuration of real-time linkage experimental system. Data transmission and reception between testbed and main computer were accomplished through wireless communication module.

### 2.2.2 User Interface of the Real-time Linkage Experimental Program

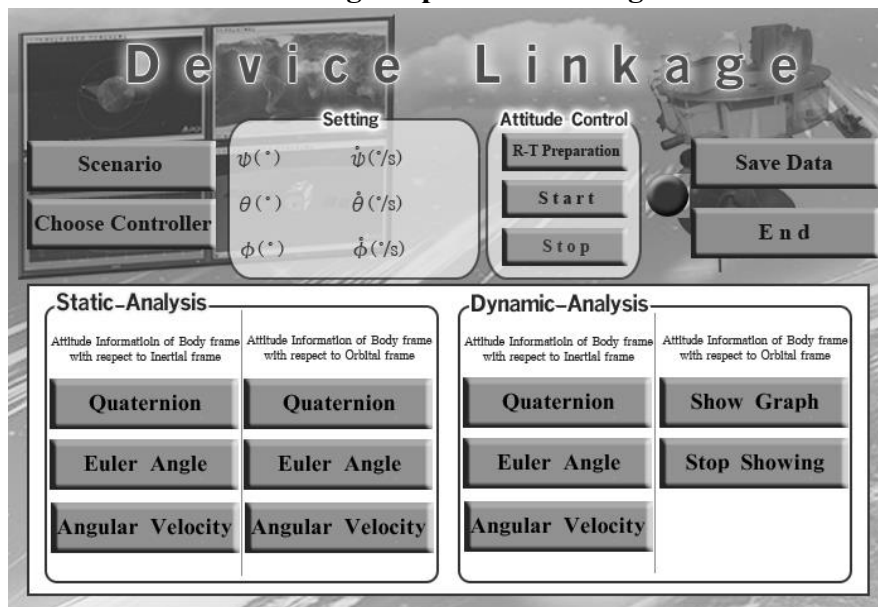


**Figure 3:** User interface of the real-time linkage experimental program. The air-bearing testbed attitude and control information received through the wireless communication module is connected in real-time from MATLAB to STK, thus the control process of testbed can be shown and analyzed in STK.

The algorithm of attitude control is realized in two ways.

The first one is to realize in one-chip processor mounted on testbed, and the other one is to realize in MATLAB program of main computer.

### 2.2.3 Main Steps of the Real-time Linkage

- ① Creating a new instance of STK, new scenario and new satellite object and setting the initial values such as the six elements of orbit and attitude information using STK's API functions in MATLAB

- ② Transmitting the attitude control commands from MATLAB to testbed, and receiving the valid information related to the control process of testbed such as attitude parameters, angular velocities, etc.
- ③ Real-time connecting the received information from testbed to the previously created objects using STK's API functions (Object Model, Connect)
- ④ Showing and analyzing the attitude control process of testbed in STK

#### ***2.2.4 Some Part of the Real-time Linkage Experimental Program***

function startReceiving\_Callback(hObject, eventdata, handles)

global root;

global is232Open;

if is232Open == true

fclose(s); delete(s); clear s;

end

is232Open = true;

instrhwinfo('serial')

s = serial('COM3')

set(s, 'BaudRate', 115200, 'StopBits', 1);

set(s, 'Terminator', '', 'Parity', 'none');

set(s, 'FlowControl', 'none');

set(s, 'InputBufferSize', 61);

set(s, 'ReadAsyncMode', 'manual');

fopen(s)

while(is232Open == true)

readasync(s);

data = fread(s, 61, 'uint8');

if length(data) >= 5

psi = data(3)

theta = data(4)

fai = data(5)

else

psi = 0.0

theta = 0.0

fai = 0.0

end

setAttForSat(root, psi, theta, fai);

pause(0.5);

end

```
fclose(s);delete(s);
```

```
clear s;
```

```
function stopReceiving_Callback(hObject, eventdata, handles)
```

```
global is232Open;
```

```
is232Open = false;
```

### 3. Teaching Support System for Satellite Attitude Control Experiment

A website for satellite attitude control experiment was developed to help students experiment the satellite attitude control at any places, and the satellite attitude control experiment can be conducted in two steps of simulation and device linkage based on the website. And the results from the simulation can be verified and analyzed with the testbed.

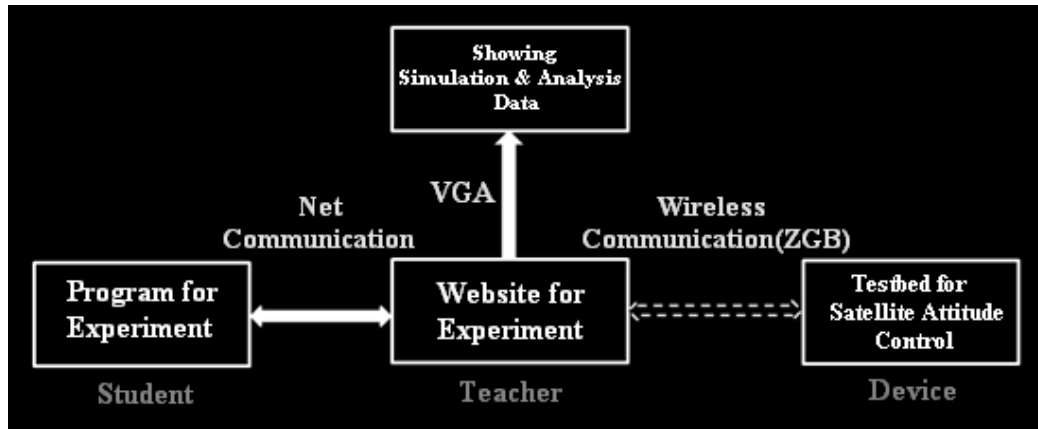
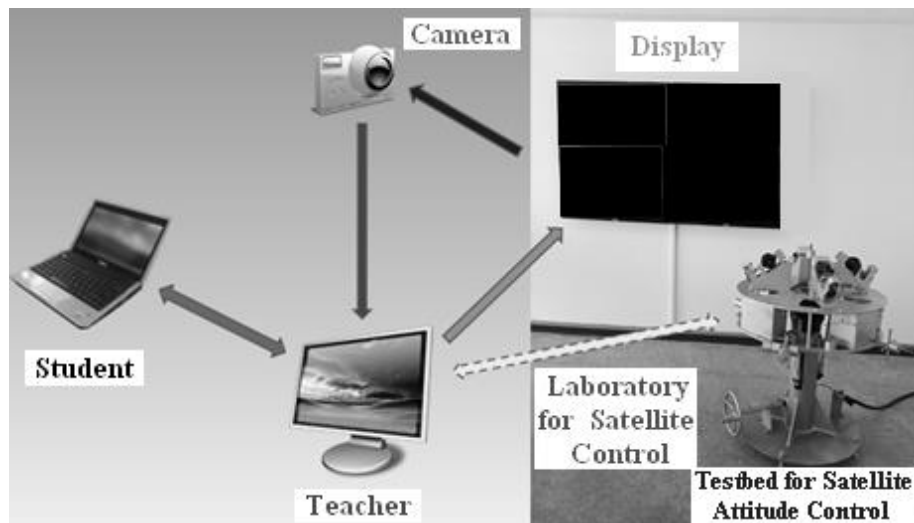


**Figure 4:** Configuration of teaching support system for satellite attitude control experiment

As shown in Fig. 4 the teaching support system is composed of parts of teacher, student, device and display. Students can download the experimental program for satellite attitude control from the experiment supporting website serving from the teacher's main computer and conduct the simulation experiment. Also, through the website student can conduct the attitude control linkage experiment in real-time with the air-bearing testbed in laboratory. Student can observe the results of linkage experiment directly using the experimental program and camera to verify the validity and effectiveness.

The teaching support system is realized as follows.



a) Configuration of the linkage system



**Figure 5:**Realization of the teaching support system for satellite attitude control experiment

b) Realization of the linkage system

As shown in the above figure, students can conduct the satellite attitude control experiment successfully with the air-bearing testbed by using the teaching support system in any situation apart from the laboratory.

4. Experimental Results using the Teaching Support System

4.1 Real-time Showing of the Satellite Attitude Control using Air-bearing Testbed

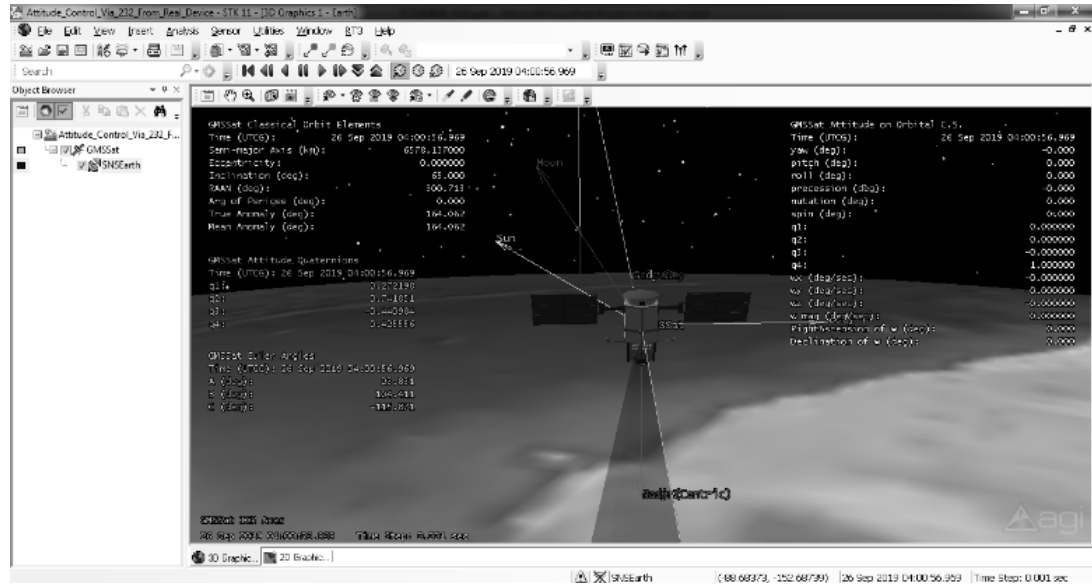


**Figure 6:** Real-time showing of the satellite attitude control  
Students can simulate and analyze the developed satellite attitude control system through the experiment. Especially student can analyze the stability and accuracy of the satellite attitude control system through the control process of the parameters such as Euler angle, quaternion, angular velocity, etc.

4.2 Experimental Results

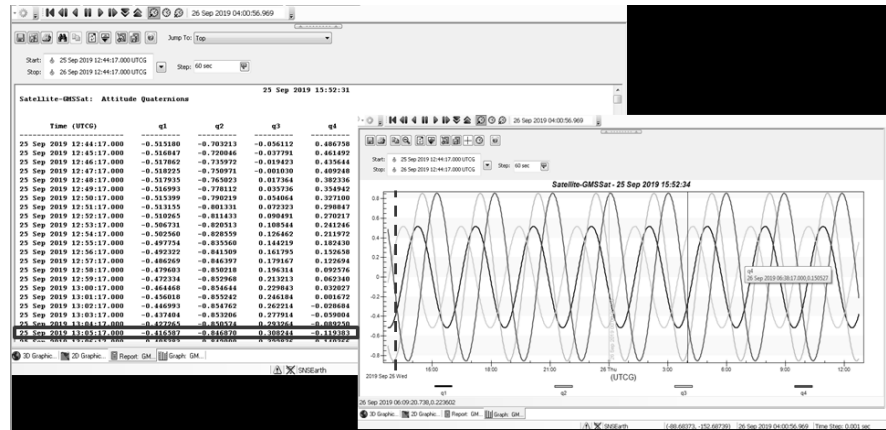


**Figure 7:** Analysis examples of quaternion  
After students finished the simulation experiments and device linkage experiments through the teaching support system for satellite attitude control experiment, teacher can evaluate based on the above results as follows.

- ① Teacher evaluates on the satisfaction of the design indexes of satellite attitude control system. Teacher analyzes and evaluates whether the accuracy of attitude control is satisfied and whether the design of the attitude control system was optimized in viewpoint of the fuel consumption using the indexes such as Euler angles of roll, pitch and yaw, quaternion, angular velocities and so on.
- ② Teacher evaluates the understanding qualification of the students on the design and experimental process of attitude control system through the analyses on the experimental report, video on the testbed control process and experimental result data that sent to the teacher by the experiment supporting website.

③ Teacher checks and evaluates the comparison results of the linkage experimental result by attitude control testbed with the simulation result from the experimental report.

## 5. Discussion

We performed the pedagogical experiment using the proposed teaching support system for satellite attitude control experiment for 3 years. We took 2 groups of students to conduct the satellite attitude control experiment. The first group performed the experiment using the traditional way with only air-bearing testbed, and the second group performed using the teaching support system with the connection of MATALB, STK and air-bearing testbed. As a result, we confirmed that the second group is 0.5 higher in the mean score and 25% higher in the spatial representation skills than the first group, and the scientific accuracy was raised 5% more than before.

**Table 1:** Pedagogical experimental results for 3 years

| Indices                      | Traditional education | Proposed teaching support system |
|------------------------------|-----------------------|----------------------------------|
| Mean Score                   | 8.7                   | 9.2                              |
| Spatial representation skill | 65%                   | 90%                              |
| Scientific accuracy          | 92%                   | 97%                              |

## 6. Conclusion

Paper proposed a method to show and analyze the attitude control process of testbed in relation with the orbital elements provided from STK in real-time by connecting MATLAB, STK and air-bearing testbed, and constructed a teaching support system to prove the effectiveness of the proposed method and the teaching support system.

Firstly, we wrote a satellite attitude control experimental program by connecting STK, MATLAB and air-bearing testbed.

Secondly, we developed a teaching support system for students to conduct the satellite attitude control experiments successfully through air-bearing testbed at any places.

## References

- B. N. Agrawal and R. E. Rasmussen, Air Bearing Based Satellite Attitude Dynamics Simulator for Control Software Research and Development, Technologies for Synthetic Environments: Hardware-in-the-Loop Testing VI, Proceedings of SPIE Vol. **4366**, 2001.
- M. Sabatini, P. Gasbarri and G.B. Palmerini, Coordinated control of a space manipulator tested by means of an air bearing free floating platform, Acta Astronautica, 2017.
- L. O. Inumoh, J. L. Forshaw and N. M. Horri, Tilted Wheel Satellite Attitude Control with Air-Bearing Table Experimental Results, Acta Astronautica, 2015.
- Culton, Eryn and King, Design and Development of an Unrestricted Satellite Motion Simulator, 31st Annual AIAA/USU Conference on Small Satellites, 2017.

- D. C. Sternberg, C. Pong, N. Filipe, S. Mohan, S. Johnson and L. Jones-Wilson, Jet Propulsion Laboratory Small Satellite Dynamics Testbed Simulation: On-Orbit Performance Model Validation, *Journal of Spacecraft and Rockets*, pp. 1-13, 2017.
- H. Kolvenbach and M. Voellmy, Design of a low-cost, spherical air-bearing satellite simulator, In *Proceedings of ASTRA'2019, 15th Symposium on Advanced Space Technologies in Robotics and Automation*, ESTEC, Noordmijk, The Netherlands, 2019.
- K. Ahmad, A. Redah, A. Arif, A. A. Khan, M. K. Saleem and S. Montenegro, An Educational Platform for Testing and Evaluating Satellite Control Algorithms in a Real-Time and Frictionless Environment, *Electrical Engineering Department, Faculty of Engineering, University of Central Punjab, Lahore, Pakistan*, 2023.
- A. B. Probe, Low Cost Satellite Attitude Hardware Test Bed, *ASEE's 123rd Annual Conference & Exposition*, American Society for Engineering Education, 2016.
- G. Irina, S. S. Krut, M. Gouttefarde, F. Pierrot and L. Dusseau, Test Bench for Nanosatellite Attitude Determination and Control System Ground Tests, *Small Satellites Systems and Services Symposium*, 2014.
- G. Irina, S. S. Krut, M. Gouttefarde, F. Pierrot and L. Dusseau, Innovative Approach to Use Air Bearings In Cubesat Groundtests, *Small Satellites, Systems & Services(4s) Symposium*, 2016.
- U. Martínez, L. Bravo, D. Gligor, K. Olfe, A. Bello, J. M. Ezquerro, J. Rodríguez and P. Salgado, ATTITUDE CONTROL RESEARCH WITH EDUCATIONAL NANOSATELLITES, *4th Symposium on Space Educational Activities*, Barcelona, April 2022.
- B. A. M. D. Ribeiro, Development of an Air-Bearing-Based Satellite Attitude Simulator and Testing of an ADCS Solution, *Instituto Superior Tecnico, Lisboa, Portugal*, March 2021.
- J. J. Kim, Automatic Mass Balancing of Air-Bearing-Based Three-Axis Rotational Spacecraft Simulator, *JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS*, **32**(3), May–June 2009.
- C. Papakonstantinou, G. Moraitis, V. Lappas and V. Kostopoulos, Design of a low-cost air bearing testbed for nano CMG maneuvers, *Aerospace*, **9**(95), 2022.
- F. Sanfedino, P. Iannelli, D. Alazard, E. Pelletier, S. Bennani and B. Girouart, European Satellite Benchmark for Control Education and Industrial Training, *European Space Agency ESA/ESTEC*, arXiv:2406.12603v1[*eess.SY*], 2024.
- R. Fullmer, G. Peterson, W. Holmans, J. Smith, J. Nottingham, S. Anderson, T. Olsen and F. Redd, The Development of a Small Satellite Attitude Control Simulator, *Departments of Mechanical and Aerospace Engineering and Electrical Engineering Utah State University, Logan UT*, 843224130, 1996.
- J. Prado, G. Bisiacchi, L. Reyes, E. Vicente, F. Contreras, M. Mesinas and A. Juarez, THREE-AXIS AIR-BEARING BASED PLATFORM FOR SMALL SATELLITE ATTITUDE DETERMINATION AND CONTROL SIMULATION, *Journal of Applied Research and Technology*, **3**(3), pp. 222-237, 2005.

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