US008121708B1

(12) **United States Patent**
Wilson et al.

(10) **Patent No.: US 8,121,708 B1**
(45) **Date of Patent: Feb. 21, 2012**

(54) **CONTROL SYSTEM DESIGN METHOD**

(75) Inventors: **David G. Wilson**, Tijeras, NM (US); **Rush D. Robinett, III**, Tijeras, NM (US)

(73) Assignee: **Sandia Corporation**, Albuquerque, NM (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 846 days.

(21) Appl. No.: **12/052,180**

(22) Filed: **Mar. 20, 2008**

Related U.S. Application Data

(60) Provisional application No. 60/896,043, filed on Mar. 21, 2007.

(51) **Int. Cl.**
G05B 13/02 (2006.01)

(52) **U.S. Cl.** **700/45**; 700/97

(58) **Field of Classification Search** 700/45, 700/97

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,057,992	A *	10/1991	Traiger	700/52
5,329,442	A *	7/1994	Moshfegh	700/29
6,216,083	B1 *	4/2001	Ulyanov et al.	701/106
6,415,272	B1 *	7/2002	Ulyanov	706/2
6,900,456	B2 *	5/2005	Blais et al.	257/31
7,398,162	B2 *	7/2008	Downs et al.	702/27
7,440,807	B2 *	10/2008	Kanaoka et al.	700/45
2002/0016665	A1 *	2/2002	Ulyanov et al.	701/106
2003/0093392	A1 *	5/2003	Ulyanov	706/13
2003/0169041	A1 *	9/2003	Coury et al.	324/307
2004/0086117	A1 *	5/2004	Petersen et al.	380/44
2004/0173793	A1 *	9/2004	Blais et al.	257/31
2005/0250651	A1 *	11/2005	Amin et al.	505/846
2007/0087756	A1 *	4/2007	Hoffberg	455/450
2007/0206715	A1 *	9/2007	Godes	376/100

OTHER PUBLICATIONS

Anthony, K. H. et al., "HamiltonÂ?s Action Principle and Thermodynamics of Irreversible Processes—A Unifying Procedure for Reversible and Irreversible Processes", *J. Non-Newtonian Fluid Mechanics*, vol. 96,2001, pp. 291-339.

Hill, D. et al., "The Stability of Nonlinear Dissipative Systems", *IEEE Transactions on Automatic Control* Oct. 1976, pp. 708-710.

Kokotovic, P. et al., "Constructive Nonlinear Control: A Historical Perspective", *Preprint submitted to Elsevier*, Aug. 2000.

Kristic, M. et al., "Nonlinear and Adaptive Control Design", John Wiley & Sons, Inc., New York, 1985, Chapters 1 and 3.

Moylan, P. J. et al., "Implications of Passivity in a Class of Nonlinear Systems", *IEEE Transactions of Automatic Control*, vol. AC-19, No. 4, Aug. 1974, pp. 373-381.

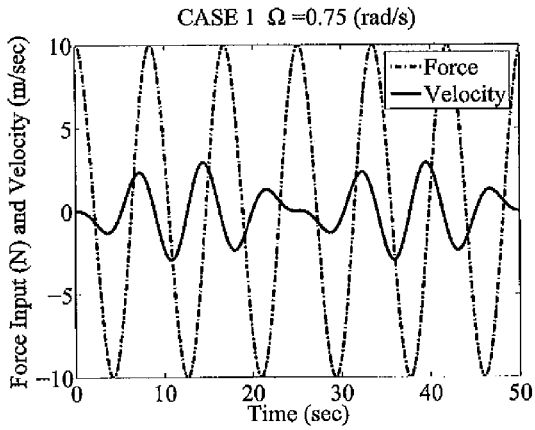
Ortega, R. et al., "Passivity-Based Control of Nonlinear systems: A Tutorial", *Proceedings of the American Control Conference*, Albuquerque, NM, Jun. 1997, pp. 2633-2637.

Robinett, Rush D. et al., "Collective Plume Tracing: A Minimal Information Approach to Collective Control", *IEEE 2007 American Control Conference*, Jul. 2007.

(Continued)

Primary Examiner — Albert Decady
Assistant Examiner — Anthony Whittington
(74) *Attorney, Agent, or Firm* — Olivia J. Tsai

(57) **ABSTRACT**

A control system design method and concomitant control system comprising representing a physical apparatus to be controlled as a Hamiltonian system, determining elements of the Hamiltonian system representation which are power generators, power dissipators, and power storage devices, analyzing stability and performance of the Hamiltonian system based on the results of the determining step and determining necessary and sufficient conditions for stability of the Hamiltonian system, creating a stable control system based on the results of the analyzing step, and employing the resulting control system to control the physical apparatus.

17 Claims, 32 Drawing Sheets