Berichte aus der Steuerungs- und Regelungstechnik

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D 29 (Diss. Universität Erlangen-Nürnberg)

Shaker Verlag
Aachen 2007

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Erlangen-Nürnberg, Univ., Diss., 2007

Printed in Germany.

ISBN 978-3-8322-6301-0
ISSN 0945-1005

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

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Many technical processes can be described by a set of differential equations, which is called a dynamics. In this context, trajectory tracking means that the dynamics are influenced such that its states evolve on a predefined reference trajectory. A special class of dynamics is the class of differentially flat dynamics, which are characterized, roughly speaking, by the fact that all states and inputs of a dynamics can be differentially parameterized with an (eventually fictitious) “flat” output. Using the differential parameterization, the design of feedforward and feedback tracking controllers with respect to the flat output is very intuitive. In this dissertation it is shown that differential parameterizations can also be a useful tool for the tracking controller design with respect to non-flat outputs and even for non-flat dynamics.

Differential flatness has originally been introduced in a differential algebraic framework, but also a differential geometric framework for flatness has been established using the concept of infinite prolongations of vector fields and Lie-Bäcklund equivalence. As the differential geometric setting allows a direct comparison with other differential geometric concepts for feedback linearization and trajectory tracking, all results on differential parameterizations of nonlinear dynamics in this thesis have been derived using the differential geometric approach.

Several aspects for the feedforward an feedback tracking controller design using differential parameterizations are investigated. At first the case of flat dynamics is considered. It is clarified for the general case of dynamics with multiple inputs under which conditions trajectories for a non-flat output can be converted into trajectories for a flat output and in which way the internal dynamics with respect to the non-flat output appear in the conversion process. Converted trajectories can be stabilized using a flatness based tracking controller. As a further step it is shown that even for flat dynamics it can be favorable to use a differential parameterization with a parameterizing output, e.g., when a trajectory for a non-flat output has to be planned. A parameterizing output includes the considered output and additional components such that a differential parameterization of all states and inputs is possible. Clearly, this approach is also applicable for non-flat dynamics. It is shown that such a differential parameterization establishes a Lie-Bäcklund equivalence to a system describing a dynamics in input-output normal form and furthermore allows to take over several of the favorable ideas for a differential parameterization with a flat output such as feedforward controller design in presence of singularities and the design of quasi-static tracking controllers which achieve a linear tracking error dynamics with respect to the considered output. An algorithm for the construction of quasi-static tracking controllers is derived based on the notion of a differential parameterization with a parameterizing output. All results have been illustrated with examples.

The above mentioned nonlinear concepts for the tracking controller design are very powerful, however, it can still happen that certain specifications for the closed loop cannot be met, especially when the internal dynamics with respect to the non-flat output are non-minimum phase or not all states are available for measurement. For this situation it is proposed to use a differential parameterization of the linearized tracking error dynamics (which can be flat even if the nonlinear dynamics are not). Based on a resulting differential operator representation a linear time varying dynamic output feedback can be constructed, which stabilizes the reference trajectory. The potential of the approach has been illustrated with examples and the application to a laboratory setup of a DC motor attached to a Boost DC-to-DC converter.