

Summary of Major Research Activities 1961 – 2011

Dr. Schmidt's 50-years' continuous scientific research, engineering and publication activities can be roughly decomposed into 3 major (partly overlapping) periods.

The **FIRST** period starts with the time of his Dr.-Ing. studies and research at the TU Darmstadt, Germany (1961-1965). It continues with his engagement as a Research Associate at the Division of Engineering Mechanics of Stanford University, USA (1966-1967) and next, as the Head of the Flight and Vehicle Control Group and Vice-Head of the Defense Electronics Department of the Dornier Aerospace Co., Friedrichshafen, Germany (1968-1972). Main contributions of research and development during this phase are in the area of *Systems and Control*. Outstanding examples of this early work are an adaptive control system based on a reference model [1], a new design method for robust discrete-time controls [2], a novel concept for stabilization and attitude control of an unmanned tethered helicopter (UAV), forming the base of a radar border surveillance system [3]. Other innovative scientific and engineering work (partly confidential) is related to the development and test of hover and transition control strategies for the VTOL transport aircraft DO 31 [4], optimal motion control of high speed trains [5], or an approach to the analysis and evaluation of the coupling structure of large-scale nonlinear socioeconomic processes, such as Forrester's World Dynamics model [6].

References cited in this summary are selected from a complete list of publications with more than 470 entries, available on Dr. Schmidt's HomePage: <http://www.lsr.ei.tum.de/gs.html>

Selected references related to work in Phase I:

[1] Schmidt, G.: Selbsteinstellender Regelkreis mit Bezugsmodell – An Adaptive Control System based on a Reference Model. *Regelungstechnik* rt, Oldenbourg Verlag, 10 (1962) 4, pp. 145-151.

[2] Schmidt, G.: Sensitivity Considerations of Sampled-data Feedback Systems with Minimal Prototype Response. - In book: ED. Radanovic, L., "Sensitivity Methods in Control Theory", Oxford: Pergamon Press, 1966, pp 307-324.

[3] Schmidt, G. and Swik, R.: Automatic Hover Control of an Unmanned Tethered Rotorplatform, *Automatica*, pp.393-403, vol. 10, 1974.

[4] Schmidt, G. and Weimann, A.: Fuel Optimal Landing Transitions of Jet Engine Supported VTOL-Aircraft (in German), *Ingenieur-Archiv*, pp.96-106, vol. 40, 1971

[5] Schmidt, G. and Torres-Perraza, M.: Energy Optimal Drive Strategies for Trains - An Optimal Control Approach" (in German), *Zeitschrift für Eisenbahnwesen and Verkehrstechnik (ZEV)*, pp. 265-270, vol. 93, Sept. 1969

[6] Schmidt, G.: Ein Beitrag zur regelungstheoretischen Analyse sozioökonomischer Prozessmodelle, erläutert an Forresters Modell der Weltdynamik - A Control Theoretic Approach for the Analysis of Socio-economic Processes, Applied to Forrester's World Dynamics Model. - In: *Tagung der Ges. for Wirtschafts- and Sozialkybernetik 1975*. J. Baetge, Ed. Berlin, Duncker & Humblot, 1975, pp. 99-125.

The **SECOND** phase commences around 1972 when Dr. Schmidt joined the Electrical Engineering Department of the TU München, Munich, Germany as a Full Professor of Control and Automation. During this period he established the well-known *Control and Automation Laboratory* (1972-1990). Remarkable contributions of this phase are the early (1973) development of HW and SW of a novel type of user-friendly single and multi-loop microprocessor controllers, and failure-tolerant networked control systems, both forming the base of industrial products later developed by the Siemens Co. and Hartmann & Braun Co. [7,8]. Research on digital nonlinear filtering, control and signal processing had a massive impact on the disturbance rejection capability and reduction of settling time of ultra-high precision weighing systems of the Sartorius Co., Göttingen, Germany [9]. Research on advanced methodologies and systems for model-based automation of large scale processes, such as gas pipeline transportation and distribution networks, resulted in a line of highly competitive software systems for dynamic simulation, predictive control, dynamic state reconstruction, leak detection etc. [10], still used under license by major gas suppliers in Europe, e.g. Ruhrgas, Salzgitter Gas, Gas de France, British Gas, as well as in Australia and USA. This work had a major impact on the development of advanced schemes for monitoring, control and optimization of network operation, with a major focus on safety, service security and economy.

Similar innovative contributions resulted from research on modeling, monitoring and control of high-speed mixed car traffic on the German Autobahn system [11], and from the development of control

strategies for automatic merging of queues of cars [12, 13]. Simulation and animation results of automatic merging control are presented in [14]. These items of original research led to novel approaches for real-time traffic management and control.

Prominent examples of other large scale system research and development are the design of a MIMO plasma position control system for ASDEX Upgrade, a fusion reactor of the Tokamak type [15], and proof-mass based vibration control of high-rise buildings [16].

Selected references related to work in Phase II:

[7] Schmidt, G. and Birk, H., "Microprocessors for Process Controllers" (in German), Regelungstechnische Praxis, Oldenbourg Verlag, pp. 308-315, vol. 12, 1974

[8] Schmidt, G. and Sandler, W. "A Failure Tolerant Multi-Microprocessor Controller Station for Process Control Applications", pp. 77-84, Process Automation, vol.2, 1980

[9] Maier, R. and Schmidt, G., "Integrated Digital Control and Filtering for an Electrodynamically Compensated Weighing Cell", IEEE Trans. On Instrumentation and Measurement, pp.998-1003, vol.38, Sept. 1989

[10] Schmidt, G. and Lappus, G., "Novel Approaches to Real-time Simulation, Network State Reconstruction and Predictive Control of Gas Distribution Networks" (in German), Zeitschrift für Messen, Steuern, Regeln (MSR), pp.60-65, Vol. 27, Febr. 1984

[11] Papageorgiou, M. and Schmidt, G., "Modelling, Surveillance and Multilayer Control of Freeway Traffic", pp.1736-1741, in Singh, M. G. "Systems and Control Encyclopedia", Oxford, New York: Pergamon Press, 1984

[12] Schmidt, G. and Posch, G., "A Two-layer Control Scheme for Merging of Automated Vehicles", Proc. 22nd IEEE CDC Conf., pp. 495-500, vol. 1, 1983

[13] Schmidt, G. and Posch, B.: Automatische Zusammenführung zweier Fahrzeugströme - Eine Rückblende (Vehicle Merging Control - Revisited). -In: at-Automatisierungstechnik 58 (2010) 6, Oldenbourg Verlag, pp. 317 - 321.

[14] http://www.lsr.ei.tum.de/gs_files/merge.html

[15] Schmidt, G., Woyke, W.: Probleme der Automatisierung eines Experiments zur kontrollierten Kernfusion. –In: at-Automatisierungstechnik 35 (1987) 6, pp. 235-241.

[16] Raps, F.; Schmidt, G.: Modelling, Simulation and Experiments in Active Vibration Control for Flexible Structures. - In: Proc. of IMACS/IFAC Int. Symposium on Modelling and Simulation of Distributed Parameter Systems. Sunahara Y., et al., Ed. Hiroshima, October 6-9, 1987, pp. 633-639.

The **THIRD** and most recent period started around 1985 and is continuing to date. Respective research and development is directed to *Advanced Mobile Robotics, Telepresence and Neuroprosthetic Systems*, as well as the modeling and control design of *Discrete Event Processes*. This broad spectrum of scientific activities led among others to the establishment of the *Intelligent Control, Robotics and Telepresence Laboratory* at the TU München around 1992 and the foundation of four prominent *Centers of Excellence (SFB)* in the greater Munich research area, directed to topics such as *Systems Engineering, 1990-1998; Mobile Manipulation, 1985-1995; Sensorimotor Systems, 1986-2003; and Multimodal Telepresence, 1998-2011*.

Details of unique research contributions achieved during this phase are outlined next.

A. Vision-guided Biped Walking, 1996-2011

When started around 1996 this topic was hardly covered in the robotics literature, although some impressive biped robot designs with advanced walking capabilities were already available. A major objective of this research is increasing the intelligence and autonomy of robot walking by use of environment perception and by closing higher-level (guidance, navigation) loops around the lower-level biped joint motion and body stabilization loops. Unique and world-class contributions resulting from related conceptual, theoretical and experimental work are

- (i) Development of a biologically inspired guidance and control architecture for biped robot walking.
- (ii) Development and experimental evaluation of a situation-

- dependent (non-trivial arrangement of obstacles typical for indoor environments) and task-dependent (obstacle avoidance, self-localization) gaze control strategy based on a decision theoretic approach [17, 18].
- (iii) Visual scene reconstruction by a combination of line and texture-based image processing methods and free space representation for biped robot path planning in 3D-space [19, 20]
 - (iv) Automatic synthesis of a walking primitive database for online application to perception-based walking sequence planning [21, 22]
 - (v) Implementation, test and evaluation of the proposed intelligent guidance strategy resting upon items (ii), (iii) and (iv) on two full-scale bipeds [23].
 - (vi) An example of more than 60 spectacular life demonstrations of intelligent and autonomous biped operation during the Hannover Messe, Germany in April 2003 is documented by a movie [24a]. A second movie presents experimental work with another vision-guided biped [24b].

Selected references related to this work:

[17] Seara, J.F.; Strobl, K.H.; Schmidt, G., "Path-Dependent Gaze Control for Obstacle Avoidance in Vision Guided Humanoid Walking", Proc. IEEE Conf. on Robotics and Automation (ICRA 2003), pp. 887-892, 2003

[18] Seara, J.F.; Schmidt, G., "Intelligent Gaze Control for Vision-guided Humanoid Walking: Methodological Aspects", Robotics and Autonomous Systems, pp. 231-248, vol.48, 2004

[19] Schmidt, G.: Perzeptionsbasiertes humanoides Gehen. –In book: F. Pfeiffer und H. Cruse Eds. "Autonomes Laufen", Springer Verlag 2005, pp. 161 -171

[20] Cupec, R.; Schmidt, G.: An Approach to Environment Modelling for Biped Walking Robots. -In: Proc. of IROS'05, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2005, pp. 3089 - 3094.

[21] Denk, J.; Schmidt, G. "Synthesis of Walking Primitive Databases for Biped Robots in 3D-Environments", Proc. IEEE Conf. on Robotics and Automation (ICRA 2003), pp. 1343-1349.

[22] Denk, J.; Schmidt, G.: Walking Primitive Databases for Perception-

based Guidance Control of Biped Robots. -In: European Journal of Control 13 (2007), pp. 171 -181

[23] Cupec R. and Schmidt, G., "Practical Experience with Vision-guided Biped Walking", pp. 592-601. In book: "Experimental Robotics VIII", Siciliano, B. and Dario, P. Eds., Berlin, Springer Verlag, 2003

[24a] <http://www.lsr.ei.tum.de/movies/IJohnnie.avi>

[24b] <http://www.lsr.ei.tum.de/movies/IBARt-UH.avi>

B. Mobile Floor Cleaning Robots and Mobile Manipulators

Key contributions to the state of knowledge in this area of research are with respect to

- (i) Automatic motion planning and navigation for floor cleaning robots [25, 26].
- (ii) Learning approach to vision-based automatic parking of a mobile robot [27].
- (iii) Multi-modal human-robot interface for a fetch-and-carry type mobile manipulator [28a]. Related experimental work with ROMAN, a mobile service robot is presented in a movie [28b].
- (iv) Novel imaging devices, such as a 3D-Laser Range Camera [29].

Results of this research were transferred into the Siemens-Hefter Co. and Hako Co. cleaning robot products, while the prototype of the Laser Range Camera forms the base of a line of laser measurement systems commercialized by the Zoller + Fröhlich GmbH, Wangen, Germany

Selected references related to this work:

[25] Schmidt, G.; Hofner C., "An Advanced Planning and Navigation Approach for Autonomous Cleaning Robot Operations", pp. 1230-1235, Proc, of the 1998 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS 1998)

[26] Neira, J.; et al.; Schmidt, G., "Fusing range and Intensity Images for Mobile Robot Localization" IEEE Trans. on Robotics and Automation, pp. 76-84, vol. 15, No. 1, 1999

[27] Daxwanger, W.A.; Schmidt, G., "Neural and Fuzzy Approaches to Vision-based Parking Control", pp. 1606-1614, Control. Eng. Practice, vol. 4, No. 11, 1996

[28a] Fischer, C.; Schmidt, G., "Multi-Modal Human-Robot-Interface for Interaction with a Remotely Operating Mobile Service Robot", pp. 397-409, Advanced Robotics, vol. 12, No. 4, 1998

[28b] http://www.lsr.ei.tum.de/movies/SFB331_Teil3.mpg

[29] Fröhlich, C.; Freyberger, F.; Schmidt, G.: A Three-dimensional laser range camera for sensing the environment of a mobile robot. In: Proc. of EuroSensors IV "Sensoren: Technologie und Anwendung", Karlsruhe, October 1-3, 1990. Ed. K. H. Härdtl. Vol. 2, Lausanne, Sequoia, S. A. Elsevier, 1991, pp. 453-458 (Reprinted from the Journal "Sensors and Actuators A", Vol. 25, 26, 27, October 1990 - May 1991).

C. Multimodal Telepresence

Major contributions to these fields of research are with respect to

- (i) Improvements of comprehensive haptic and visual display [31a] with experimental experience demonstrated by a movie [31b] .
- (ii) Exploration of extensive target environments by use of a mobile visual and haptic interface based on the novel principle of motion compression, i.e. transformation of a virtual or real task space into a restricted operator space [32]
- (ii) Force reflecting bimanual and bilateral haptic teloperation system for remote disposal of explosive ordnances [33] developed in cooperation with the German Armed Forces and the Telerob Co. Movies demonstrate manual [34a] and telepresent disposal of a mine [34b].

Selected references related to this work:

[30] Kammermeier, P.; Schmidt, G. et al., "Display of Holistic Haptic Sensations by Combined Tactile and Kinesthetic Feedback", Presence, MIT Press, vol. 13, no. 1, Feb. 2004, pp. 1-15

[31a] Nitzsche, N.; Schmidt, G.: Force-Reflecting Telepresence in Extensive Remote Environments. -In: Journal of Intelligent and Robotic Systems; 2007 (50), pp. 3-18

[31b] <http://www.lsr.ei.tum.de/movies/MobTel.avi>

[32] Nitzsche, N.; Hanebeck U.D.; Schmidt, G., "Motion Compression for Telepresent Walking in Large Target Environments", Presence, MIT Press, vol. 13, no. 1, Feb. 2004, pp. 44-60

[33] Kron, A.; Schmidt, G.; Petzold, B.; Zäh, M.; Hinterseer, P.; Steinbach, E.: Disposal of Explosive Ordnances by Means of a Bimanual Haptic Telepresence System. -In: Proc. of International Conference on Robotics & Automation, ICRA 2004, Eds.: Tarn, T.J.; Fukuda, T., pp. 1968-1972.

[34a] <http://www.lsr.ei.tum.de/movies/DemTel.avi>

[34b] <http://www.lsr.ei.tum.de/movies/DemMan.avi>

D. Neuroprosthetics for Walking and Simulators for Medical Training

Robotic principles applied to the design, development and evaluation of an intelligent FES (functional electric stimulation)-based feedback controller for restoration of human locomotion. A summary of many years of related inter-disciplinary research comprising conceptual and theoretical work, as well as results from clinical tests can be found in [35]. An example of experimental clinical work is presented in a movie [36].

Hands-on simulators based on kinesthetic robot principles and devices proof their usefulness for training of medical students with respect to procedures for the diagnosis of knee diseases [37].

Selected references related to this work:

[35] Fuhr, T.; Quintern, J; Riener, R.; Schmidt, G.: Walk with WALK! - A Cooperative, Patient-Driven Neuroprosthetic System. -In: IEEE Engineering in Medicine and Biology (EMB)Magazine, January/February 2008, pp. 38-48.

[36] <http://www.lsr.ei.tum.de/movies/SK5AscentDescentAVI.mpg>

[37]Hoogen, J.; Riener, R.; Schmidt, G.: Control concepts for an industrial robot used as kinesthetic knee joint simulator. – In: Proc. of the Third International Workshop on Robot Motion and Control (RoMoCo '02), pp. 21-26.

E. Control of Discrete Event Systems

Original and competitive research (according to Prof. Wonham, Canada) in this field is directed to model-based approaches for high-speed generation of correct discrete-event-control algorithms starting from specifications of the plant layout, the available resources and the tasks considered [38, 39]. Results of this work were successfully applied to FMS control in cooperation with the Bosch Co. and Call Center Traffic Control in cooperation with the Varetis Co., München, Germany.

Selected references related to this work:

[38] Seidl, M.; Schmidt, G.: Avoiding Deadlocks in Flexible Manufacturing Systems. -In: Proc. of WODES 2000, 5th Workshop on Discrete Event Systems, Analysis and Control. The Kluwer International Series in Engineering and Computer Science, Kluwer Academic Publishers, Boston/Dordrecht/London. Eds.: R. Boel, G. Stremersch, Gent University, Belgium, pp. 149-158.

[39] Seidl, M.; Schmidt, G., "Fault-tolerant and Maximally-permissive FMS Controllers Right out of the Box - An Automatic Design Approach", Robotics and Computer Integrated Manufacturing, vol. 19, 2003, pp. 431-438.

Final Remark

The complexity of research, development and systems engineering work outlined in this summary of activities needed a strong team effort, with Dr. Schmidt not only serving as a stimulating team leader, but, as a rule, also as an active contributor to the work.

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