REVIEW
of a foreign research advisor on the dissertation
of Maral Bakytkanovna Tolykbayeva
titled “Adaptive Control of a Robotic Manipulator,”
submitted for the degree of Doctor of Philosophy (Ph.D.)
in the educational program 8D07101 – "Automation and Control"

Currently, although electrically driven manipulators utilizing position and velocity control remain the most common type of serial manipulator, there is a surge of interest in force control (torque control). This trend is driven by several objective factors, most notably advancements in motor technology and electric drive systems. These developments have led to the availability of high-torque motors, which in turn have enabled the creation of "direct-drive" systems that eliminate the need for high-ratio reduction gearboxes. Unlike geared electric drives, direct-drive systems allow for indirect force control without the need for dedicated torque sensors.

A powerful impetus for the development of this research area has been the explosive growth of interest in fields such as the creation of humanoid robots, robotic dogs, robotic arms, and similar devices. The use of gearless (direct-drive) motors in such applications offers clear advantages—primarily a significant reduction in the system's inertia—which are equally beneficial when these drives are employed in manipulators. Furthermore, force control provides substantial advantages in the development of co-bots and manipulators designed for tasks involving physical interaction with the environment (e.g., in surgical robotics or mechanical processing tasks like drilling), as well as in the implementation of impedance/resistance control. At the same time, force control for a manipulator is a considerably more complex challenge than position control, both theoretically and practically (in terms of the technical difficulty of implementing such systems). On the other hand, methods developed for force control—specifically trajectory control—in serial manipulators are frequently applied across the broader field of robotics. For instance, "computed torque control" (CTC)-like methods are used for the trajectory control of various types of mobile robots, even though the computed torque method was originally developed—and continues to be used—specifically for the trajectory control of serial manipulators.

Thus, it can be asserted that the subject matter of this dissertation is highly relevant, both from a theoretical perspective and for a wide range of practical applications in robotics. The dissertation was completed within the framework of two projects with state budget funding from the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan.: AP19679327 "Methods of machine learning for tasks of automatic control and inertial navigation of mobile robots" and AP13068317 "Development of new robot-manipulator control algorithms for 3D scanning technologies and additive microplasma spraying of coatings".

Maral Tolykbaeva developed and tested new manipulator models and control methods, in particular, a new adaptive control method based on the exact linearization of a control system describing a sequential manipulator using a coordinate transformation. The new approaches presented in the dissertation have theoretical significance and can be applied to problems of automatic control of other mechatronic systems. Furthermore, the computer simulation results provided suggest the potential for the practical, hardware-based implementation of this new adaptive control method for manipulators. In addition, the dissertation well covers a number of aspects of Lie group theory as applied to robotics

problems and demonstrates the connection of these theoretical aspects with practical robotics problems. The correctness of the developed models and the adaptive control law for a robotic manipulator has been verified in practice through computer simulations.

The main new scientific results of this dissertation are the following, proven in the dissertation and in publications by M. B. Tolykbaeva:

1) The configuration space of a sequential manipulator is represented as a Riemannian manifold with a metric defined by the kinetic energy of the manipulator. A dynamic model of a serial manipulator on this Riemannian manifold has been developed.

2)Exact linearization of a serial manipulator has been performed. A trajectory control system for the manipulator, based on this exact linearization, has been developed.

3)An adaptive trajectory control system for a serial manipulator—based on the linearization of the controlled object (the manipulator)—has been developed and tested using computer simulations.

The research results presented in this dissertation were obtained by the author independently. It should be noted that a portion of the research—specifically concerning the modeling and control of a robotic manipulator—was conducted and discussed within the laboratories of the Research and Innovation Center (EKIK) at Óbuda University (Budapest, Hungary) during two research internships undertaken by the doctoral candidate: from November 15 to 29, 2023, and from May 14 to 28, 2024. Furthermore, Maral presented and discussed her dissertation research findings at the 18th International Symposium on Applied Informatics and Related Areas (AIS 2023), held on November 16, 2023, at Óbuda University in Székesfehérvár, Hungary. Consequently, the author's personal contribution to the results presented in this dissertation was comprehensive, encompassing every stage from the planning and execution of experiments to the formulation and discussion of the research findings. The main results of the dissertation, supporting its scientific findings and conclusions, have been published in peer-reviewed scientific journals and conference proceedings.

Thus, in terms of scientific novelty, completeness, and the significance of the results obtained, the dissertation by M. B. Tolykbayeva meets the requirements set forth in Chapter 2 of the "Rules for the Conferment of Academic Degrees" (established by the Committee for Control in the Sphere of Education and Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan) for works submitted for the degree of Doctor of Philosophy (Ph.D.); it is therefore recommended for public defense.

Maral Bakytkanovna Tolykbayeva merits the conferment of the Ph.D. degree in "Automation and Control."

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Budapest, 09 November 2026.