Nonlinear problems are of interest to engineers, biologists, physicists, mathematicians, and many other scientists because most systems are inherently nonlinear in nature. Among them, underactuated systems attract special attention, but a complete understanding of these systems is still an open scientific problem. By definition, underactuated systems have fewer control inputs than degrees of freedom, which in general, complicates the design of the system and makes its control non-trivial.

To date, many methods have been proposed to control underactuated nonlinear systems, most of which are only applicable to a single application or a subclass of systems. Due to its elegant construction and ability for generalization, differential flatness has gained a lot of attraction in the design of tracking controllers and trajectory planning for nonlinear control systems. As differential flatness one can understand such system property, which requires determining a so-called flat output: a function of the system's state and possibly inputs such that the state variables and the input trajectories can be parameterized in terms of the flat output trajectory and its derivatives. Challenging design problems like planning of optimal trajectories, stabilization of equilibria, or trajectories by state feedback are significantly easier to solve for flat systems than for non-flat ones. Some control problems formulated in flat coordinates can be solved by better-studied linear methods.

The research aims to analyze the applicability of control algorithms based on the differential flatness approach for a group of nonlinear underactuated systems. Despite the large popularity of flatness-based methods for nonlinear open and closed-loop control, fundamental questions have not been answered yet and remain open. One of the most elementary of these questions is a systematic computation of flat outputs. The construction of flat outputs can be practically seen as a problem of sensor placement to achieve the flatness of the resulting input-state-output system. As a dual to this approach one can consider the problem of actuator placement such that a system with given output becomes flat. This relatively new concept can be an interesting way of extending the use of algorithms based on differential flatness to systems that have so far been considered as non-flat. However, the literature often argues that this approach is physically difficult to implement, so the solution remains an open problem. The significant part of this research is to develop control strategies based on differential flatness either with the use of flat outputs or inputs and to clarify procedures to select the appropriate approach. It is also intended to analyze the effectiveness of this approach in the design of tracking controllers and trajectory planning for nonlinear control systems in the context of its robustness. The assessment is to be supported by both a mathematical analysis of stability and robustness to uncertainties and disturbances of the proposed solutions as well as their verification by numerical simulations and advanced laboratory experiments in the field of robotics, which is the most important planned result of the project.

It is planned that the obtained results will constitute the next step in the development and dissemination of differential flatness-based control methods for underactuated systems, as well as in the development of solutions leading to their application in practice. Therefore, as far as possible, great attention will be focused on the experimental verification of the results, which will form the basis for further applications of the studied methods, and at this stage will allow for their publication in top-class journals and scientific conferences in this field.