

Continuous groups of transformations and time-dependent invariants

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In this paper we present a very simple derivation of the constants of motion for dynamical systems, which requires only an elementary knowledge of the theory of continuous groups. In addition, through the infinitesimal Lorentz transformations group, we obtain a clear interpretation of the invariant for the harmonic oscillator.

Keywords: Lie groups; Lorentz group; dynamical systems; Noether's theorem; infinitesimal transformations.

Se presenta un método sencillo para la derivación de las constantes de movimiento de sistemas dinámicos, la cual requiere solamente conocimientos elementales de la teoría de grupos continuos. Además, mediante las transformaciones infinitesimales de Lorentz, se obtiene una interpretación clara del invariante para un oscilador armónico.

Descriptores: Grupos de Lie; grupo de Lorentz; sistemas dinámicos; teorema de Noether; transformaciones infinitesimales.

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1. Introduction

In recent years, many authors have investigated Ermakov's invariants for linear dynamical systems, such as the harmonic oscillator [3, 4, 6, 7], and some of them have generalized the applications to non-linear systems described by a more general Lagrangian [5, 8, 9]. However, a clear physical interpretation of the invariants of motion has not been given, although a general interpretation has been mentioned [9, 11]. On the other hand, Lutzky derived constants of motion from the eight-parameter symmetry group for the one-dimensional harmonic oscillator using Noether's theorem [3, 4] and suggested a physical interpretation. Besides the mathematical interest in finding invariants, from the physical point of view their relevance lies in the fact that in some cases the differential equations that describe the evolution of the systems are not easy to solve but they admit invariants, and the knowledge of certain functions of the coordinates and momenta which remain constant during motion can be of great help in simplifying the equations of motion, and can lead to their solution. In contrast to Lutzky derivation, in this paper we present, as an alternative method, a very simple way to obtain invariants using only elementary notions of the theory of continuous groups and Noether's theorem. We also give an interpretation of the invariants using the generator of the transformation, which is possible thanks to the fact that Noether's symmetry is a Lie point transformation that leaves the action invariant, up to an additive time constant that is a function of the group parameter [12, 13]. In this paper, Eq. (13) is used to find the physical interpretation of the invariants, and this equation is precisely the generator of the one-parameter infinitesimal transformation. It is important to note that, with the method

presented here, in contrast to Ermakov's method for finding invariants, we do not need an auxiliary equation in order to obtain the invariants [5, 6].

The outline of the paper is as follows: in Sec. 2 we obtain the constant of motion and in Sec. 3, via the Lorentz transformation, we interpret the invariant for the case of a harmonic oscillator. Finally, in Sec. 4 some concluding remarks are given.

2. Continuous groups of transformations and Noether's invariant

Let us suppose that we have a one-parameter group of transformations written in the form

$$x^j = f^j(x^i; a), \quad i, j = 1, 2, \dots, n, \quad (1)$$

with $a = a_0$ for the identity, i.e.,

$$f^j(x^i; a_0) = x^j. \quad (2)$$

Let f^j be the solution of the system of ordinary differential equations

$$\frac{df^j}{da} = \xi^j(x^i) \psi(a), \quad (3)$$

satisfying the initial conditions (2) [1, 2]. If we define parameter t by

$$t = \int_{a_0}^a \psi(a) da, \quad (4)$$

then $t = 0$ yields the identity, and Eq. (3) becomes

$$\frac{dx^j}{dt} = \xi^j(x^i). \quad (5)$$

Continuous Groups Of Transformations

Scott C. Dulebohn



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Table of Contents Continuous Groups Of Transformations

1. Understanding the eBook Continuous Groups Of Transformations
 - The Rise of Digital Reading Continuous Groups Of Transformations
 - Advantages of eBooks Over Traditional Books
2. Identifying Continuous Groups Of Transformations
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Continuous Groups Of Transformations
 - User-Friendly Interface
4. Exploring eBook Recommendations from Continuous Groups Of Transformations

- Personalized Recommendations
- Continuous Groups Of Transformations User Reviews and Ratings
- Continuous Groups Of Transformations and Bestseller Lists
- 5. Accessing Continuous Groups Of Transformations Free and Paid eBooks
 - Continuous Groups Of Transformations Public Domain eBooks
 - Continuous Groups Of Transformations eBook Subscription Services
 - Continuous Groups Of Transformations Budget-Friendly Options
- 6. Navigating Continuous Groups Of Transformations eBook Formats
 - ePub, PDF, MOBI, and More
 - Continuous Groups Of Transformations Compatibility with Devices
 - Continuous Groups Of Transformations Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Continuous Groups Of Transformations
 - Highlighting and Note-Taking Continuous Groups Of Transformations
 - Interactive Elements Continuous Groups Of Transformations
- 8. Staying Engaged with Continuous Groups Of Transformations
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Continuous Groups Of Transformations
- 9. Balancing eBooks and Physical Books Continuous Groups Of Transformations
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Continuous Groups Of Transformations
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Continuous Groups Of Transformations
 - Setting Reading Goals Continuous Groups Of Transformations
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Continuous Groups Of Transformations

- Fact-Checking eBook Content of Continuous Groups Of Transformations
- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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