

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, Lutsky 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 Lutsky 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

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

with $\alpha = \alpha_0$ for the identity, *i.e.*,

$$f^j(x^i; \alpha_0) = x^j. \quad (2)$$

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

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

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

$$t = \int_{\alpha_0}^{\alpha} \psi(\alpha) d\alpha, \quad (4)$$

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

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

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