

WAVEFORM RELAXATION METHODS FOR LIE-GROUP EQUATIONS*

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Abstract

In this paper, we derive and analyse waveform relaxation (WR) methods for solving differential equations evolving on a Lie-group. We present both continuous-time and discrete-time WR methods and study their convergence properties. In the discrete-time case, the novel methods are constructed by combining WR methods with Runge-Kutta-Munthe-Kaas (RK-MK) methods. The obtained methods have both advantages of WR methods and RK-MK methods, which simplify the computation by decoupling strategy and preserve the numerical solution of Lie-group equations on a manifold. Three numerical experiments are given to illustrate the feasibility of the new WR methods.

Mathematics subject classification: 65L05, 65L06, 65L20.

Key words: Lie-group equations, Waveform relaxation, RK-MK methods, Convergence analysis.

1. Introduction

In this paper, we consider efficient numerical methods for the following ordinary differential equation (ODE) on manifolds ([4, 15])

$$Y'(t) = A(t, Y(t))Y(t), \quad t \geq 0, \quad (1.1)$$

with the initial value $Y(0) = Y_0 \in \mathcal{G}$, where $\mathcal{G}$ is a Lie-group, the map $A(t, Y) : [0, +\infty) \times \mathcal{G} \rightarrow \mathfrak{g}$ is Lipschitz continuous and $\mathfrak{g}$ is the Lie algebra of $\mathcal{G}$. Here $A(t, Y)$ is an $n \times n$ matrix and $A(t, Y)Y$ is the usual matrix product of $A(t, Y) \in \mathfrak{g}$ and $Y \in \mathcal{G}$. It is well known that the solution of (1.1) stays in the Lie-group $\mathcal{G}$ and the equation (1.1) is also called the Lie-group equation.

In order to solve Lie-group equations efficiently, a kind of method called Lie-group method, which is a branch of Geometric Numerical Integration, has received significant attention in recent years. The main advantage of Lie-group methods is that they can preserve the numerical structure of the Lie-group equation on the manifold [2, 4–6, 10]. The pioneering work of this topic was given by Crouch and Grossman [7], who were the first to introduce numerical methods that evolve on manifolds. They applied a classical Runge-Kutta (RK) method to Lie-group equations by repeatedly freezing and thawing coefficients and keeping the flow in the correct configuration space [3, 15, 16]. RK methods on Lie-groups have been further studied in [14, 17, 25–27]. Among them, Munthe-Kaas considered applying the classical RK methods to the Lie algebra equation of Lie-group equations on manifolds and for related work see [8, 25–27, 31]. Magnus and Fer methods were derived and analysed in [17, 31]. These two kinds of algorithms require the

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