

SubRiemannian Geometry on the Sphere S^3

Ovidiu Calin, Der-Chen Chang, and Irina Markina

Abstract. We discuss the subRiemannian geometry induced by two noncommutative vector fields which are left invariant on the Lie group S^3 .

1 Introduction

The study of step 2 subRiemannian manifolds has the Heisenberg group as a prototype. This is a noncommutative Lie group with the base manifold $\mathbb{R}^3$ and endowed with a nonintegrable distribution spanned by two of the noncommutative left invariant vector fields. This structure also enjoys the property of being a contact structure or a CR-manifold. The study of the subRiemannian geodesics on the Heisenberg group started with the work of Gaveau [9]. One trend in the literature has been to use the geometry of the Heisenberg group to describe the Heisenberg Laplacian and its heat kernel, see Beals, Gaveau, and Gröner [1–4]. Later, this structure led to generalizations of the Heisenberg group as can be seen in Calin, Chang, and Gröner [5, 6] and Chang and Markina [7]. For more fundamental issues on subRiemannian geometry, see Strichartz [10].

Is there another 3-dimensional noncommutative Lie group besides the Heisenberg group? The answer is positive and this paper deals with it. The sphere S^3 and the group $SU(2)$ have these properties. More important, this is the first compact subRiemannian manifold has been under consideration.

The present paper starts with an introduction to quaternions and then defines the 3-dimensional sphere as the set of quaternions of length one. The quaternion group induces on S^3 a structure of a noncommutative Lie group. This group is compact and the results obtained in this case are very different from those obtained in the case of the Heisenberg group, which is a noncompact Lie group. As in the Heisenberg group case, we introduce a nonintegrable distribution on the sphere and a metric on it using two of the noncommutative left invariant vector fields. This way S^3 becomes a subRiemannian manifold. It is known that the group $SU(2)$ is isomorphic with the sphere S^3 and represents an example of subRiemannian manifold where the elements are matrices. The main issue here is to study the connectivity by horizontal curves and geodesics on this manifold. In this paper, we are using Lagrangian methods to

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