## Multi-Modal Image Registration and Matching for Localization of a Balloon on Titan

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A solution was developed that matches visible/IR imagery aboard a balloon in Saturn's moon Titan's atmosphere to SAR (synthetic aperture radar) and visible/IR data acquired from orbit. A balloon in Titan's atmosphere must be able to localize itself autonomously both globally and with respect to local terrain. The orbital data is used to provide the balloon imagery with global context.

Due to the highly dissimilar appearance of imagery from the different types of sensors under consideration (radar, IR, visible), traditional image matching techniques based on pixel similarity do not work. Technology pioneered by the medical imaging community has been adapted to match across sensor modalities. These techniques are driven by information content rather than appearance. While imagery of Titan's surface taken from a visible imager may appear very different from SAR imagery, there is statistical/information theoretic similarity.

The work is novel in applying mutual information (MI) to orbital vs. aerial data. There are unique challenges in this setting. Image offsets are much higher than in medical imaging, there is local distortion due to 3D terrain relief, and the fields of regard from orbit and from the air are quite different.

Because of the large differences in image scale between an orbiter at hundreds of kilometers above the surface and a balloon at a few kilometers altitude, it is necessary to match mosaics from the balloon to single-frame orbital images. In addition to localizing the balloon, this implies the ability to generate high-resolution global maps of the surface that are correctly geo-referenced.

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## Entanglement in Quantum-Classical Hybrid

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It is noted that the phenomenon of entanglement is not a prerogative of quantum systems, but also occurs in other, non-classical systems such as quantum-classical hybrids, and covers the concept of entanglement as a special type of global constraint imposed upon a broad class of dynamical systems. Application of hybrid systems for physics of life, as well as for quantum-inspired computing, has been outlined.

In representing the Schrödinger equation in the Madelung form, there is feedback from the Liouville equation to the Hamilton-Jacobi equation in the form of the quantum potential. Preserving the same topology, the innovators replaced the quantum potential with other types of feedback, and investigated the property of these hybrid systems. A function of probability density has been introduced. Non-locality associated with a global geometrical constraint that leads to an entanglement effect was demonstrated.

Despite such a quantumlike characteristic, the hybrid can be of classical scale and all the measurements can be performed classically. This new emergence of entanglement sheds light on the concept of non-locality in physics.

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## Algorithm for Autonomous Landing

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Because of their small size, high maneuverability, and easy deployment, micro aerial vehicles (MAVs) are used for a wide variety of both civilian and military missions. One of their current drawbacks is the vast array of sensors (such as GPS, altimeter, radar, and the like) required to make a landing. Due to the MAV's small payload size, this is a major concern.

Replacing the imaging sensors with a single monocular camera is sufficient to land a MAV. By applying optical flow algorithms to images obtained from the camera, time-to-collision can be measured. This is a measurement of position and velocity (but not of absolute distance), and can avoid obstacles as well as facilitate a landing on a flat surface given a set of initial conditions.

The key to this approach is to calculate time-to-collision based on some image on the ground. By holding the angular velocity constant, horizontal speed decreases linearly with the height, resulting in a smooth landing. Mathematical proofs show that even