

Article

Detection Optimization of an Optically Trapped Microparticle in Vacuum with Kalman Filter

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Abstract: The optical trapping of micro-nano particles in a high vacuum has become a popular research platform in various frontier fields of physics because of its excellent isolation from the environment. The precise measurement of particle motion information is required to analyze and control particle motion modes in traps. However, the detection accuracy is limited by measurement noise and coupling signals from other axes in microparticle optical traps. In this study, we use the Kalman filter to extract the real motion information of each axis under simulation conditions, and the results show that the Kalman filter performs well in noise suppression, improving the RMSE from 12.64 to 5.18 nm and enhancing the feedback cooling performance by approximately 27% through reducing the axes' signal coupling ratio. We believe that as a solution to these challenges, the Kalman filter will bring a significant achievement to micrometer particle optical traps in vacuums.

Keywords: optical trap; Kalman filter; feedback cooling; axial signal decoupling

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1. Introduction

Since Ashkin et al., used a single-beam optical trap to levitate a 20 μm silica sphere in 1971 [1], optical trapping has inspired various researches and applications in quantum physics, life science, and engineering. Trapping is developing rapidly towards smaller scales, including nanostructured trapping [2–4], on-chip-optical levitation with a metasensor in a vacuum [5], multiplexed near-field optical trapping [6], light polarization measurements [7], single-cell manipulation [8], on-chip protein sensing [9], and many other areas. Tongcang Li et al. used an optical trap in a vacuum to measure the instantaneous velocity of a Brownian particle [10] and to cool an optically trapped microsphere from room temperature to millikelvins [11], demonstrating the great potential of optical traps in frontier physics. Optical trapping in vacuums has also been applied to precise force and acceleration measurements and reached sub-100 $\text{ng}/\sqrt{\text{Hz}}$ and sub-aN/ $\sqrt{\text{Hz}}$ spectral sensitivity while providing a much larger dynamic range than clamped resonators because of its outstanding decoupling from environment noise vibrations and gas molecule collisions [12–17]. Optical trapping, which is enabled by the ability to detect ultra-weak forces and acceleration, is expected to make a significant contribution to fields, such as searching for non-Newtonian interactions at the micrometer scale [18,19], high-frequency gravitational waves [20], and dark matter [21].

To achieve high acceleration sensitivity, the micrometer particle is more suitable than the nanometer particle because of the inverse relationship between the minimum measurable acceleration and the square of the particle radius [13]. Before the measurement process, the particle must maintain stable suspension in an ultra-high vacuum with the help of a feedback control system to suppress the Brownian motions of the trapped particle. The rapid and accurate displacement detection via photodiodes is the key part of the feedback control system. However, due to the close resonance peaks and detection coupling in microparticle optical traps [11,22], extracting the real signal requires not only considering

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Electrochemical Society. Meeting, 1999 **Surgical Endocrinology** John Lynn, Stephen Robert Bloom, 1993 Surgical Endocrinology presents the fundamentals and practical application of the subject matter. It discusses the molecular background and physiology of the endocrine systems. It addresses the legal aspects of endocrine surgery such as duty of care and breach of such duty. Some of the topics covered in the book are the principles of endocrine surgery, molecular structures of organisms, physiology of endocrine system, multiple endocrine neoplasia and molecular genetics, non-surgical management of pituitary tumors, assay formulations and automation technology, syndrome of ectopic hormone production, *American Journal of Veterinary Research*, 2013. Volumes for 1956 include selected papers from the proceedings of the American Veterinary Medical Association **Genetic Engineering News**, 2005 **Clinical Laboratory Reference**, 1997 Laboratory products and services currently available in the United States. Product information section arranged alphabetically by companies. Entries include description and ordering information, Indexes by manufacturer, brand names and test equipment and services, Product photograph section **The FASEB Journal**, 1990 **Clinical Immunology** Catherine Sheehan, 1997 Introducing clinical immunology this text offers detailed instruction in immunobiology, lab methods and clinical serology and is divided into three sections covering the whole scope of clinical immunology. Coverage includes immune reactions by the human host in response to a challenge, fundamental mechanisms of the immune system, antigens and antibodies and their interaction in serologic testing, the principles of in vitro serologic reactions and the sources of error and quality control in testing and immunologic diseases in which measurement of an immune product or reaction is a significant tool for diagnosing or monitoring the disease. Features new to this edition include chapter outlines, learning objectives, colour plates, review questions and case studies. New chapters highlight nucleic acid probes and blotting techniques, spirochetal infection and serology, *Burrelia Burgdorfei* infections and serology and transplantations **International Pulp & Paper Directory**, 2001 **American Laboratory**, 2007 **Government Reports Announcements & Index**, 1993-06

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