

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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New nanomaterials are leading to a range of emerging dental treatments that utilize more biomimetic materials that more closely duplicate natural tooth structure or bone in the case of implants This book brings together an international team of experts from the fields of materials science nanotechnology and dentistry to explain these new materials and their applications for the restoration fixation replacement or regeneration of hard and soft tissues in and about the oral cavity and craniofacial region The main topics covered include applications in dental specialties Orthodontics Endodontics Pediatric dentistry Periodontics Prosthodontics and Implant dentistry salivary diagnostics using bioMEMS NEMS systems nanochips for oral cancer diagnosis biomimetic nanomaterials and nanotechnology for tooth repair and regeneration The editors previous book *Emerging Nanotechnologies in Dentistry* focused on the fabrication manufacturing processes of materials and dentistry applications This second book complements the first covers with coverage of the range of nanomaterials available today in clinical dentistry explaining the innovative techniques and applications in all of the main clinical dental specialties Nanobiomaterial engineers biomedical researchers biomedical engineers and dental oral pre clinical and clinical researchers will find the comprehensive coverage essential for working with nanotechnologies and materials in both clinical and research settings Book prepared by an interdisciplinary and international group of scientists and practitioners in the fields of nanomaterials dental implants medical devices and clinical practice Comprehensive professional reference for the subject covering materials fabrication and use of materials for all major diagnostic and therapeutic dental applications repair restoration regeneration implants and prevention Complements the editors previous book on nanotechnology applications for dentistry [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 manufacturers brand names and test equipment and services Product photograph section **Manual of Clinical Laboratory Immunology** Noel R. Rose,1997 Reflects changes being thrust upon the laboratory community [Tietz](#)

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add about 1 2 cup of the meat mixture and put into the center fold in the sides of the tortillas and then roll up the bottom and
place seam side down on a baking sheet brush the tops with olive oil

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wrapped around a filling which traditionally includes meat cheese beans and other ingredients and

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bumped into her causing her to drop a burrito into a deep fryer

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