

# Improving the Closed-Loop Tracking Performance Using the First-Order Hold Sensing Technique with Experiments

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## Abstract

This paper proposes a new perspective in the enhancement of the closed-loop tracking performance by using the first-order hold (FOH) sensing technique. Firstly, the literature review and fundamentals of the FOH are outlined. Secondly, the performance of the most commonly used zero-order hold (ZOH) and that of the FOH are compared. Lastly, the detailed implementation of the FOH on a pendulum tracking setup is presented to verify the superiority of the FOH over the ZOH in terms of the steady state tracking error. The results of the simulation and the experiment are in agreement.

**Keywords:** First-order hold, Zero-order hold, Tracking performance, Sensing technique, Pendulum experiment

## 1. Introduction

The first-order-hold (FOH) method is a mathematical model to reconstruct the sampled signals that could be done by a conventional digital-to-analog converter (DAC) and an analog circuit which is called an integrator. The FOH signal is reconfigured as a piecewise linear approximation of the original sampled signal. In [1], the FOH signal is used for real-time substructure testing, which is a novel method of testing structures under dynamic loading. An extrapolation of a first-order-hold discretization is used which increases the accuracy of the numerical model over more direct explicit methods. The improvements are demonstrated using a series of substructure tests on a simple portal frame. Some deep mathematical relationship between ZOH and FOH is revealed in [2-5]. It is shown that the zeros of sampled-data systems resulting from rapid sampling of continuous-time systems preceded by a ZOH are the roots of the Euler-Frobenius polynomials. The simplicity, negative realness, and interlacing properties of the sampling zeros of ZOH and FOH sampled systems are proven for the first time in literature. The paper [6] deals with the quality requirements of the synthesized sine waves reconstructed through a ZOH and FOH for testing purposes, especially when a switching demodulator is used. Results show that a FOH implies a decrease of total harmonic amplitude distortion, but the measured spurious harmonics are kept lower or equal when using a ZOH in the 15 closest components. It is concluded in the paper that in testing applications a ZOH yields better results, thus the benefits of using a FOH need further investigation. The effects of various sensing techniques on the performance of the motion canceling bilateral control (MCBC) are studied [7-9]. MCBC is a method to synchronize motion of a teleoperation robot and a target, while an operator can obtain tactile sensation of the remote target [10, 11]. Results show that a FOH yields better performance compared with a ZOH, but it has a peak gain near the Nyquist frequency. Therefore, in order to make full

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## **Table of Contents Experiments In Telecommunications**

1. Understanding the eBook Experiments In Telecommunications
  - The Rise of Digital Reading Experiments In Telecommunications
  - Advantages of eBooks Over Traditional Books
2. Identifying Experiments In Telecommunications
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Experiments In Telecommunications
  - User-Friendly Interface
4. Exploring eBook Recommendations from Experiments In Telecommunications
  - Personalized Recommendations
  - Experiments In Telecommunications User Reviews and Ratings
  - Experiments In Telecommunications and Bestseller Lists
5. Accessing Experiments In Telecommunications Free and Paid eBooks
  - Experiments In Telecommunications Public Domain eBooks
  - Experiments In Telecommunications eBook Subscription Services
  - Experiments In Telecommunications Budget-Friendly Options
6. Navigating Experiments In Telecommunications eBook Formats

- ePub, PDF, MOBI, and More
  - Experiments In Telecommunications Compatibility with Devices
  - Experiments In Telecommunications Enhanced eBook Features
7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Experiments In Telecommunications
    - Highlighting and Note-Taking Experiments In Telecommunications
    - Interactive Elements Experiments In Telecommunications
  8. Staying Engaged with Experiments In Telecommunications
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Experiments In Telecommunications
  9. Balancing eBooks and Physical Books Experiments In Telecommunications
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Experiments In Telecommunications
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Experiments In Telecommunications
    - Setting Reading Goals Experiments In Telecommunications
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Experiments In Telecommunications
    - Fact-Checking eBook Content of Experiments In Telecommunications
    - Distinguishing Credible Sources
  13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks
  14. Embracing eBook Trends
    - Integration of Multimedia Elements
    - Interactive and Gamified eBooks

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