2025-11-01

# E010: Documentation System & Navigation

## 706 Files, 5 Learning Paths, Automated API Reference

**Part 2 · Duration: 15-20 minutes**

***Beginner-Friendly Visual Study Guide***

**Repository:** https://github.com/theSadeQ/dip-smc-pso
**Documentation:** academic/paper/presentations/podcasts/episodes/

**Learning Objective:** Understand the Sphinx documentation system (706 files), automated API reference generation, 5 learning paths, cross-reference validation, and freshness mechanisms

## The Documentation Challenge

**Key Concept**

**Question:** How do you document 105,000 lines of code across 358 files?
**Answer:** 706 documentation files in Sphinx + automated API generation + 5 learning paths
**Key Insight:** Assume future you will forget everything current you knows!

### Three Core Principles

**Documentation Philosophy**

**Principle 1: Colocate Documentation with Code**
Every controller in `src/controllers/` has corresponding page in `sphinx_docs/controllers/`
**Principle 2: Automate What You Can**
API reference generated from docstrings - NEVER write manually
Code changes → Docs update automatically (no synchronization problems!)
**Principle 3: Multiple Navigation Strategies**
5 learning paths for 5 audience types with different mental models

## Sphinx: The Librarian for Scattered Notes

**Key Concept**

**What is Sphinx?**
Gathers code comments, theory explanations, tutorial examples → Organizes into chapters → Creates TOC → Builds index → Adds cross-references → Outputs searchable website
**Why Sphinx?** Standard in Python ecosystem (NumPy, SciPy, Django, Flask all use it)
**Alternative:** Chaos - dozens of disconnected markdown files nobody can navigate

**Location:**

- `academic/paper/sphinx_docs/`
- `conf.py` - 19 KB of configuration

**Source Subdirectories:**

- `api/` - Auto-generated reference
- `controllers/` - Theory & implementation
- `benchmarks/` - Performance results
- `architecture/` - Design decisions
- `development/` - Contributor guides
- `deployment/` - Installation & production
- `examples/` - Runnable tutorials
- `for_reviewers/` - Academic paper materials

**Build Process:**

```
lstnumbersphinx-build -M html docs
    docs/_build
```

**What It Does:**

- **1.** Reads `conf.py`
- **2.** Parses markdown & reST files
- **3.** Generates API from docstrings (autodoc)
- **4.** Builds cross-reference links
- **5.** Outputs searchable HTML

**Strict Mode:**
`-W` flag: Warnings become errors
Catches broken links, missing docstrings, invalid markup EARLY

## Directory Structure: 706 Files Organized

**Eight Main Categories**

1. **api/** - Auto-generated API reference for 358 source files
Every public class, function, module documented from docstrings
2. **controllers/** - Theory & implementation (7 subdirectories, one per controller)
Classical SMC, STA, Adaptive, Hybrid Adaptive STA, Swing-up, Terminal, Integral
3. **benchmarks/** - Performance results from 11 research tasks (MT-5, MT-6, MT-7, MT-8, LT-4, LT-6, LT-7, etc.)
4. **architecture/** - Design decisions and patterns
Module design, controller factory, simulation engine, testing strategy
5. **development/** - Contributor guides and coding standards
6. **deployment/** - Installation, production setup, HIL integration
7. **examples/** - Runnable tutorials (5 numbered scripts + markdown explanations)
8. **for_reviewers/** - Materials for academic paper reviewers

## API Reference: Automated Documentation

**Key Concept**

**Key Insight:** Documentation should live NEXT TO the code it documents!
Write docstring inside Python function → Sphinx auto-generates formatted reference pages
Change function signature → Docs update automatically → NO manual copy-pasting!

### Why Docstrings Prevent Staleness

**Common Pitfall**

**Separate Files Problem:**
Change code → Forget to update docs → Docs lie → Confusion 6 months later
**Docstring Solution:**
Documentation IS the code → Sphinx just formats it nicely

### NumPy Style Docstrings

**Example**

**Standard Format Forces You to Answer 4 Questions:**

- **1.** What does this function do?
- **2.** What inputs does it need? (Parameters section)
- **3.** What does it return? (Returns section)
- **4.** What errors can it raise? (Raises section)

**Magic:** Write documentation ONCE in code → Appears in 3 places:

- IDE autocomplete
- Python `help(function)` output
- Published HTML docs

**Zero duplication!**

## Enforcement: Missing Docstrings Fail Build

⚠ Strict Checking

**What Triggers Warnings/Errors:**

- Missing docstring for public function
- Missing parameter descriptions
- Return type not documented
- Example code doesn't run

**Policy:** Function without proper docstring CANNOT be merged
**Why?** Prevents 6 months of confusion when someone asks "What is this parameter?" and original author is gone

## Learning Paths: Five Audience Types

**Five Paths for Five Audiences**

**Path 0: Complete Beginners**

- **Background:** Zero programming/control theory
- **Duration:** 125 hours over 4-6 months (about a semester)
- **Content:** Python, physics, calculus, linear algebra, control theory, SMC fundamentals
- **Location:** `.ai_workspace/edu/beginner-roadmap.md`
- **Phases:** 5 phases (Computing basics → Math foundations → Physics → Control theory → SMC)

**Path 1: Quick Start**

- **Background:** Knows Python, wants immediate results
- **Duration:** 1-2 hours
- **Content:** Install → Run `python simulate.py` → See pendulum stabilize
- **Location:** `docs/guides/getting-started.md` + Tutorial 01

**Path 2: Advanced Usage**

- **Content:** Custom controllers, PSO tuning, batch simulations

**Path 3: Research Workflows**

- **Content:** Running benchmarks, analyzing results, writing papers

**Path 4: Production Deployment**

- **Content:** Thread safety, memory management, HIL integration

### Decision Tree in README.md

**Example**

**User Self-Navigation:**

- "Have you programmed in Python before?" No → Path 0
- Yes → "Do you know control theory?" No → Path 0 theory section
- Yes → "Do you want to run a quick demo?" Yes → Path 1
- "Do you want to write custom controllers?" Yes → Path 2

**Each user finds their appropriate entry point**

## Cross-References and Linkage

**Key Concept**

**Challenge:** With 706 files, how do you prevent broken links?
**Solution:** Sphinx cross-reference syntax + automated validation

### Sphinx Reference Syntax

**Internal Links:**

```
lstnumber:ref:`section-label`
lstnumber:doc:`path/to/file`
lstnumber:class:`ClassName`
lstnumber:func:`function_name`
```

Sphinx validates ALL references during build
Emits warnings for broken links

**External Links:**

```
lstnumber[NumPy Docs](https://numpy.org/doc/)
```

Plain markdown syntax
Weekly link checker script validates external URLs
Files issue if dead links found

**Pro Tip**

**Reorganize Docs?** Update references → Sphinx catches broken links → Fix → Rebuild passes
Cannot manually verify 706 files - automated validation is CRITICAL!

## Code Examples: Runnable Tutorials

**</> Five Numbered Tutorials**

**Location:** `examples/` subdirectory
**Format:** Runnable Python scripts with extensive comments

| Tutorial | What It Teaches |
|---|---|
| 01: `tutorial_01_quick_start.py` | Run simulation with default settings |
| 02: `tutorial_02_custom_gains.py` | Modify controller gains and compare |
| 03: `tutorial_03_pso_tuning.py` | Optimize gains with PSO |
| 04: `tutorial_04_batch_simulation.py` | Run Monte Carlo validation |
| 05: `tutorial_05_hil_setup.py` | Configure hardware-in-the-loop |

**Each Tutorial Has:**

- Runnable Python script (copy-paste and run)
- Corresponding markdown in `sphinx_docs/examples/` (concepts + expected output)

### Keeping Examples Up-to-Date

**Key Concept**

**Problem:** Code changes → Examples break → Users confused
**Solution:** CI runs all tutorial scripts as integration tests
If tutorial fails → Build fails → Prevents merging broken examples

**</> Example**

**Additional Validation:**
Script checks if code blocks in markdown MATCH actual tutorial script files
Prevents copy-paste errors and drift between docs and code

## Search and Indexing

**Key Concept**

**Challenge:** 706 files - how do users find what they need?
**Solution:** Sphinx JavaScript search index

### Search Granularity: Section-Level

**What Gets Indexed:**

- Every heading
- Every function name
- Every class name
- Significant terms

**Example Search:** "sliding surface"
**Results:**

- Theory pages
- API reference for sliding surface module
- Tutorial examples

**What Does NOT Get Indexed:**

- Code snippets (unless manually marked)

**Manual Index Entry:**

```
lstnumber.. index:: PSO; cost function
```

Makes "PSO cost function" appear in search

**Example**

**Search: "boundary layer chattering"**
**Direct Links To:**

- Section in Classical SMC theory page (boundary layer explanation)
- API reference for boundary layer parameter
- Benchmark results showing chattering reduction (MT-6)

# Maintenance: Keeping 706 Files Fresh

**Key Concept**

**Challenge:** How do you prevent 706 files from going stale?
**Answer:** Three freshness mechanisms

Three Freshness Mechanisms

**Mechanism 1: Automated API Reference**
NEVER goes stale - generated from code
Change function signature → Docs update automatically on next build
Zero manual work, zero synchronization problems
**Mechanism 2: Link Validation**
Weekly cron job checks all internal and external links
Files GitHub issue if broken links found
**Mechanism 3: Deprecation Warnings**
Mark function as deprecated in docstring:

```
"""
.. deprecated:: 0.8.0
   Use :func:`new_function` instead.
   Removed in version 1.0.
"""
```

Sphinx generates prominent warning box in HTML

## Architecture Docs: Manual Review Required

**Common Pitfall**

**Policy:** Any PR that changes architecture MUST update corresponding `architecture/` docs
**PR Template Checklist:** "Updated architecture docs? Yes/No"
Reviewer verifies before approving
**Why?** Conceptual docs explaining design decisions require human review (can't be automated)

## Documentation Debt: Quarterly Audits

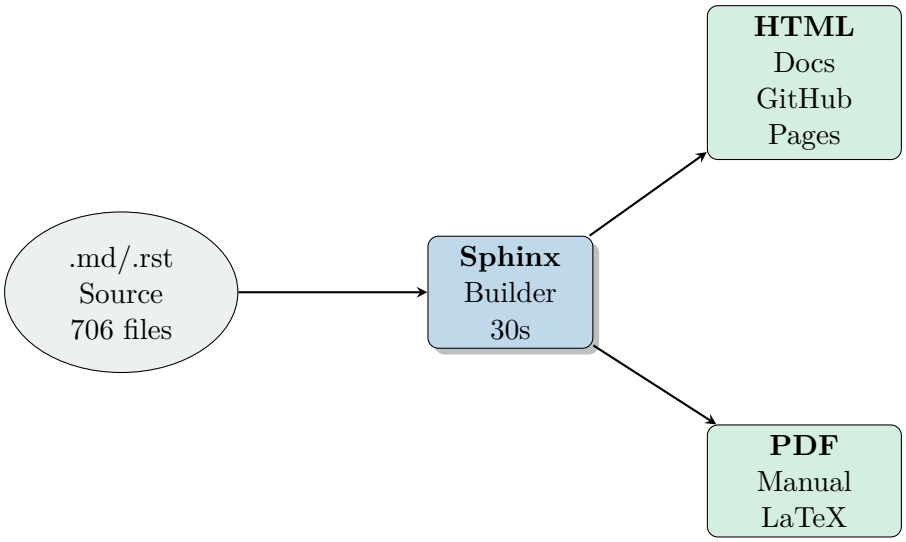
**Example**

**Audit Process:**

- **1.** Script lists files in `src/` without corresponding docs in `sphinx_docs/`
- **2.** List goes on backlog
- **3.** Prioritize based on usage:
  - Undocumented + Unused → Document or deprecate
  - Undocumented + Used → HIGH PRIORITY, document immediately

**Prevents slow decay into undocumented codebase**

## Documentation Build Workflow




**Three Build Scenarios**

**Scenario 1: During Development**
Write code → Write docstring → Run `sphinx-build` → Verify API reference looks correct
**Scenario 2: Before Committing**
Pre-commit hook runs `sphinx-build -W`
Fails commit if documentation errors
**Scenario 3: In CI/CD**
GitHub Actions builds docs on every merge to main
Deploys to GitHub Pages: `https://thesadeq.github.io/dip-smc-pso/`
Users always see latest docs matching main branch

### Incremental Builds: Speed Optimization

**First Build:**

- All 706 files parsed
- Time: 30 seconds

**Subsequent Builds:**

- Sphinx caches parsed content
- Only rebuilds changed files
- Time: 2-3 seconds (1 file changed)

## Key Takeaways

**Quick Summary**

**706 Files Organized:** 8 categories (API, controllers, benchmarks, architecture, development, deployment, examples, reviewers)
**Sphinx System:** Gathers scattered docs → Organizes → Creates TOC → Builds index → Cross-references → Searchable HTML
**API Reference:** Auto-generated from NumPy-style docstrings (change code → docs update automatically)
**5 Learning Paths:** Path 0 (beginners, 125 hrs), Path 1 (quick start, 1-2 hrs), Paths 2-4 (advanced, research, production)
**Cross-References:** Sphinx validates ALL internal links during build (broken links → warnings → build fails)
**Runnable Tutorials:** 5 numbered Python scripts in `examples/`, CI runs as integration tests
**Freshness:** (1) Automated API, (2) Weekly link validation, (3) Deprecation warnings
**Path 0 Beginner Roadmap:** 5 phases over 4-6 months (Computing → Math → Physics → Control theory → SMC)
**Quarterly Audits:** List undocumented modules → Prioritize by usage → Document or deprecate
**Build Workflow:** Development (verify) → Pre-commit (enforce) → CI/CD (deploy to GitHub Pages)
**Search:** Section-level indexing (headings, function names, class names, manual index entries)
**Documentation as Design Tool:** Write docstring → Often realize function too complex → Simplifies design

### Quick Reference: Documentation Commands

**Build Sphinx Documentation**

```
lstnumberStrict mode (warnings are errors) sphinx-build -W docs docs/build
lstnumberIncremental build (only changed files) sphinx-build -M html docs docs/build(automaticcaching)
lstnumberServe locally python -m http.server 9000  -directory
    docs/build/htmlNavigatetohttp : //localhost : 9000
```

**Docstring Template (NumPy Style)**

```
lstnumberExtended description explaining what the function does and why.
lstnumberParameters ----- param1 :  type Description of param1 param2 :  type Description of param2
lstnumberReturns ---- returntypeDescriptionofreturnvalue
lstnumberRaises --- ErrorType When this error occurs """  Implementation
```

**Cross-Reference Syntax**

```
lstnumberLink to document :doc:‘path/to/file‘
lstnumberLink to API :class:‘ClassName‘ :func:‘module.functionname‘ : meth : ‘ClassName.methodname‘
lstnumberExternal link (markdown) [NumPy Documentation](https://numpy.org/doc/)
```

## What's Next?

**Key Concept**

**E011: Configuration & Deployment**
How `config.yaml` validates parameters, Pydantic ensures type safety, deploying in different environments
**Remember:** Documentation is not a chore - it's a design tool! If you can't explain it clearly, you shouldn't build it.