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Review Article

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Reducing MTTR Using Spectral Resilience Index: Experimental Validation via Observability and FEA-Inspired Modeling

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Abstract

This paper presents an experimental evaluation of the Spectral Resilience Index (SRI) as a control metric for reducing Mean Time To Recovery (MTTR) in distributed systems. Using observable runtime signals (latency, throughput, error rate, saturation), we derive interaction strengths and compute SRI from spectral properties. We validate the approach using classical statistical methods, ablation studies, and controlled failure scenarios. Results show that SRI enables earlier detection of non-recoverable states, reduces ineffective remediation cycles, and improves operational decision-making under failure.

Methodology and Experimental Setup

System Model

We model the system as a graph G = (V,E) with interaction weights:

$$w_{ij} = rij.\frac{T_{ij}}{L_{ij}}(1-S_i)(1-E_{ij}) \tag{1}$$

Spectral Resilience Index

$$SRI = \frac{\lambda_2}{\lambda_{\max}} \tag{2}$$

Stability Potential

$$\Phi = \sum_{(i,j)} w_{ij}(x_i - x_j)^2 \tag{3}$$

Experimental Design

We conducted controlled experiments with:

- Injected failures at API layer
- Increasing traffic load
- Fixed infrastructure capacity
- Repeated auto-healing actions

Validation Methods

We used classical validation techniques:

- Time-series analysis (trend, velocity, acceleration)
- Correlation analysis (ρ between signals and SRI)
- Ablation studies (removing signals)
- Statistical significance (paired comparisons of MTTR)

Results

Observed System Behavior

Table 1: Golden signal Observations During Failure

Metric	Observed Value	Trend	Interpretation	Impact
SRI	0.09–0.12	Slight increase	Plateaued recovery	Degraded stability
Errors	11%–33%	Persistent	Functional failure	Dominant signal
Latency	Low	Stable	No infra issue	Non-limiting

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Saturation	Low	Stable	No resource bottleneck	Non-limiting

RCA and Failure Localization

Table 2: Root Cause Analysis and Stress Distribution

Component	RCA Score	Stress	Yield Status
API	0.59–0.60	High	Exceeded
Queue	0.28–0.34	Moderate	Stable
Backend	0.37	Low	Stable
Cache	0.17–0.19	Low	Stable
DB	0.15–0.17	Low	Stable

FEA Interpretation

Table 3: FEA-Based System Interpretation

Property	Observation	Interpretation	Outcome
Strain Energy	Concentrated at API	Localized stress	Bottleneck
Displacement	Compensatory	Elastic behavior	No resolution
Edge Strain	API → Queue	Propagation path	Cascade risk

Table 4: Auto-Healing Action Effectiveness

Action	Avg ΔSRI	Effectiveness	Status
Rate limit	0.0	Ineffective	Exhausted
Circuit breaker	0.0	Ineffective	Exhausted
Cache flush	0.0	Ineffective	Exhausted
DB reset	0.0	Ineffective	Exhausted
Queue drain	0.00028	Negligible	Exhausted
Error suppression	< 0	Negative	Exhausted

Table 5: Comparison of MTTR Strategies

Phase	Traditional MTTR Behavior	SRI-Based Behavior
Detection	Delayed	Immediate (SRI drop)
Recovery Attempts	Repeated blindly	Evaluated via ΔSRI
Plateau	Undetected	Identified via trend
Escalation	Late	Early trigger

Adaptation Effectiveness

MTTR Analysis

Key Experimental Finding

We observe that:

$$\frac{d(SRI)}{dt} \approx 0 \wedge SRI < SRI_{threshold} \tag{4}$$

indicates a non-recoverable state.

Discussion

The experiments show that system recovery is not guaranteed even under active remediation. Instead, systems enter a regime of:

- Elastic stabilization
- Stress redistribution
- Persistent imbalance ($\Phi > 0$)
- SRI captures this state, unlike traditional metrics.

Conclusion

We demonstrate that SRI enables a new paradigm for MTTR reduction:

- Early detection of failure through spectral degradation
- Identification of ineffective recovery actions via ΔSRI
- Recognition of non-recoverable states through trend analysis
- Prevention of wasted recovery cycles

Practical Application to Reduce MTTR Using SRI:

- Monitor SRI continuously
- Track SRI velocity and acceleration
- Evaluate each action using ΔSRI
- Trigger escalation when stagnation is detected

Final Insight

SRI transforms MTTR from a passive measurement into an active control variable, enabling systems to not only recover faster but also recognize when recovery is not achievable within current constraints.