Hardware-Based Random Number Generation

Using STM32 and Analog Noise

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Motivation & Goal

- Randomness is essential for:
  - Cryptography
  - Simulations
  - Secure communication

Why This Project?

- **Pseudo-RNGs (PRNGs)** → deterministic, algorithmic
- **True RNGs (TRNGs)** → rely on physical noise

Goal:

> Can analog noise from an ADC be used as a true random number source?

Theory: Randomness & Entropy

- **Entropy measures unpredictability:**

$$H(X) = -\sum p(x) \log_2 p(x)$$

- For binary variables:
  $H(p) = -p \log_2 p - (1-p) \log_2 (1-p)$
- Max entropy when $p(0) = p(1) = 0.5$

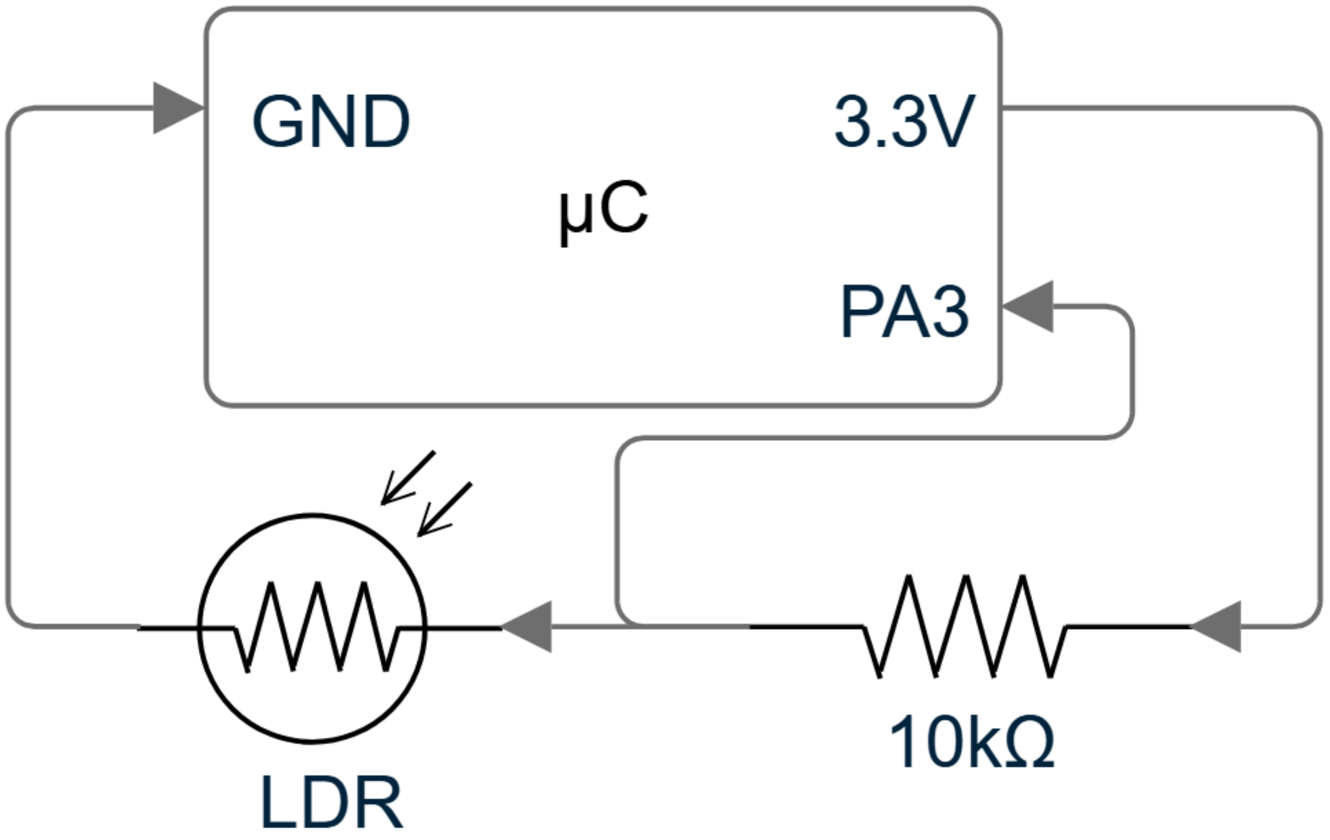
Why Can We Expect High Entropy?

- Noise inherent to all electrical circuits.
- $V(t) = V_{\text{Signal}}(t) + V_{\text{Noise}}(t)$
- $V(t)_{\text{Noise}} \sim \mathcal{N}(0, \sigma^2_{\text{Noise}})$
- $\Delta V = \frac{3.3v}{12^2}$
- $\sigma_{\text{Noise}} \gg \Delta V \Rightarrow$ LSBs should be high entropy

Hardware Setup

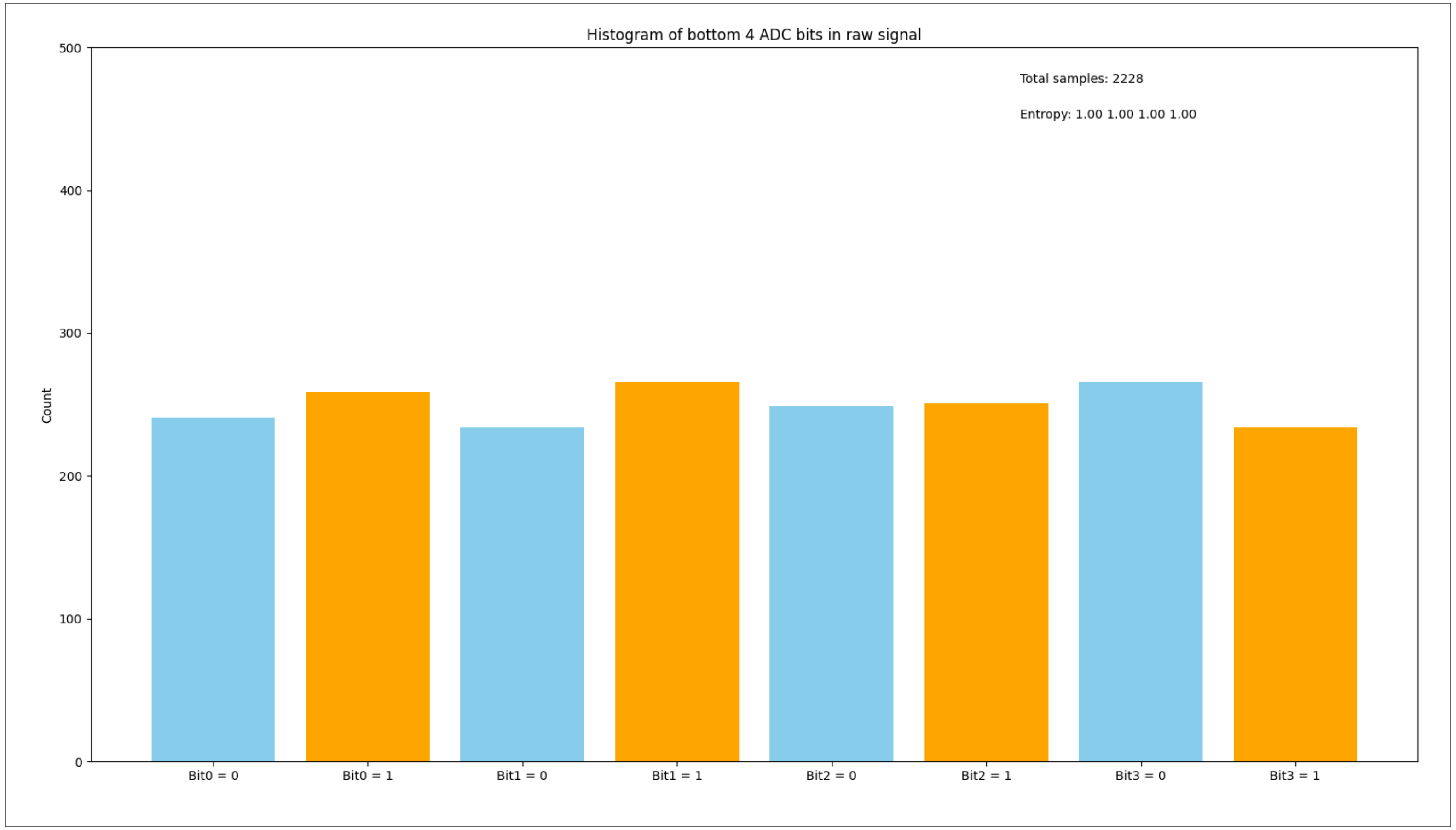
- **STM32F767ZI** with **photoresistor sensor**
- ADC samples 12-bit analog voltage
- Transmit data to PC over serial (USB)
- Keep **4 least significant bits (LSBs)** — hopefully dominated by analog noise

Hardware Setup



Data Collection & Pre-processing

- Python program receives ADC values
- Extracts **4 LSBs per reading**
- Combines into **256-bit blocks** for analysis



Roughly equal bit frequency ⇔ high entropy (~1 bit/bit)

Statistical Testing

Based on **NIST Statistical Test Suite**
(Rukhin *et al.*, 2010)

Tests Used

1. **Monobit Frequency Test**

$$Z = \frac{|S_n - n/2|}{\sqrt{n/4}}$$

   Checks 0/1 balance.

2. **Runs Test**
   - Tests alternation of bits.

3. **Serial Overlapping Test**

$$\chi^2 = \sum (C_i - E)^2 / E$$

Checks 4-bit subsequence distribution.

Interpreting p-values

- Use **significance level** α = 0.01
- Pass if **p ≥ 0.01**
- That means ≤1% chance of wrongly rejecting a truly random sequence
  ✅ High p → consistent with randomness
  ❌ Low p → statistically unlikely to be random

Post-Processing Methods

Goal: reduce bias and correlation while keeping entropy.

XOR Whitening

$$y_i = x_i \oplus x_{i-1}$$

- Removes local correlation
- Fast, minimal computation

Von Neumann Corrector

- Pairs of bits:
    - (0,1) → 0
    - (1,0) → 1
    - (0,0) / (1,1) discarded
- Removes bias but reduces throughput

LFSR Whitening

- Linear Feedback Shift Register using primitive polynomial

$$x^{256} + x^{10} + x^5 + 1 \in \mathbb{F}_2[x]$$

- Acts as linear filter
- Strong whitening with no data loss

Results

Method	Monobit	Runs	Serial
Raw	79%	9%	45%
XOR	92%	12%	57%
LFSR	99%	23%	94%
LFSR → XOR	98%	24%	93%
LFSR → VN → XOR	**99%**	**22%**	**95%**

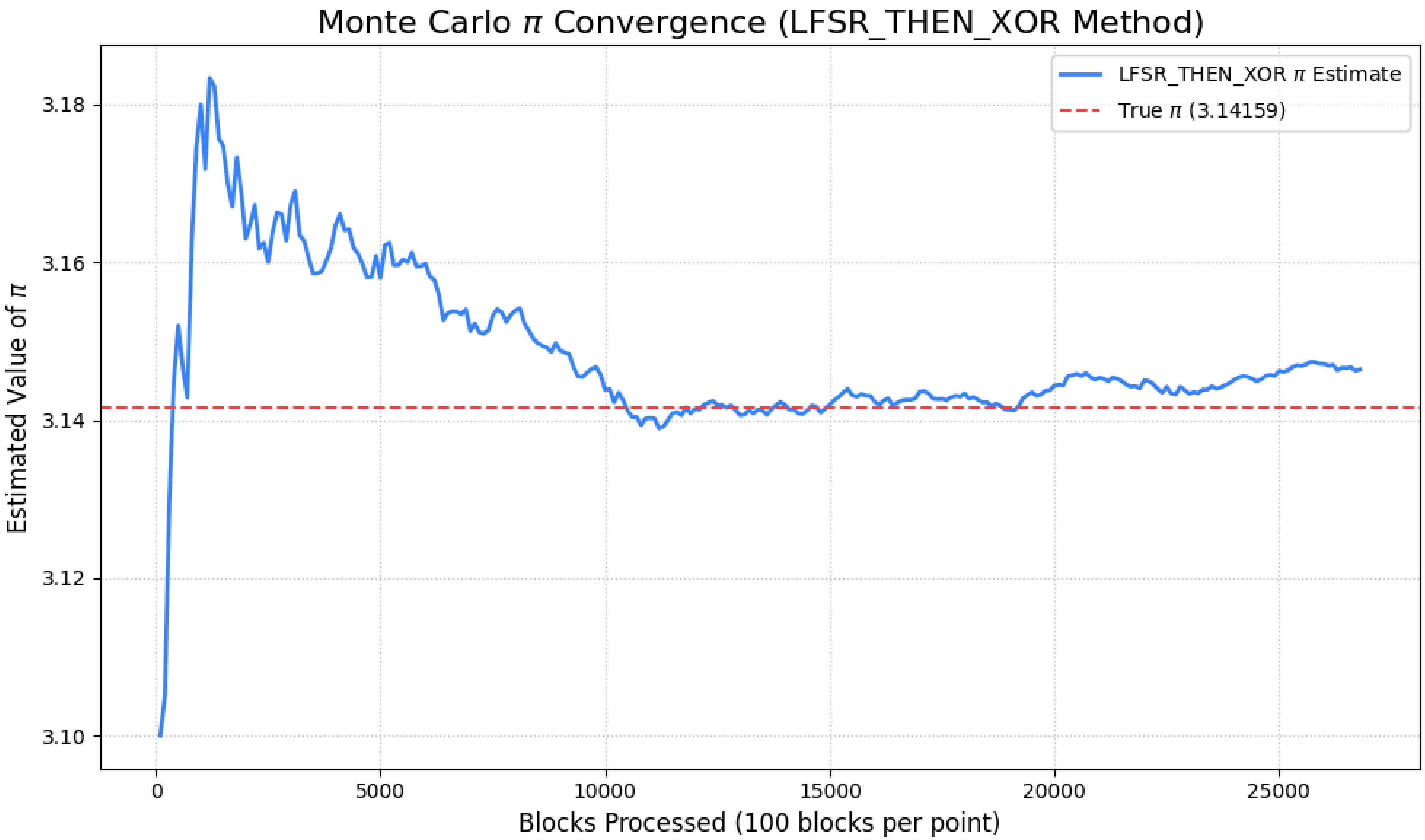
- Monobit & Serial tests greatly improved
- Runs test still low (minor correlation)

Monte Carlo π Estimation

Use RNG to simulate random (x, y) points in $[0,1]^2$

$$\pi \approx 4\frac{N_c}{N}$$

- Converged to π ≈ **3.1467** after 107,520 samples
- Error = $\left|\pi - \pi_N\right|$ ≈ **0.005**
- "Confirms" RNG uniformity and independence


Monte Carlo π Convergence (LFSR_THEN_XOR Method)
LFSR_THEN_XOR π Estimate
True π (3.14159)
Estimated Value of π
3.10
3.12
3.14
3.16
3.18
0
5000
10000
15000
20000
25000
Blocks Processed (100 blocks per point)

Conclusions

✅ Analog sensor noise can be used as entropy source
✅ Post-processing (LFSR + XOR) produces high statistical quality
✅ Monte Carlo validation reinforces randomness

Future Work

- Hardware whitening circuits
- Cross-device entropy aggregation
- Data generation speed

Thank You

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