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Real-Time Stock Price Forecasting Using Big Data Pipelines

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ABSTRACT

Real-time stock price forecasting is no longer just a modeling problem—it is a systems problem. Predictive performance depends as much on a low-latency, faulttolerant data pipeline as on model choice. This manuscript presents an end-to-end approach for forecasting next-interval prices (and uncertainty bands) using a streaming big-data architecture that ingests tick-level market data and exogenous signals, engineers microstructure-aware features on the fly, and serves probabilistic deep learning forecasts with millisecond latency. We unify three strands: (i) robust ingestion/processing with distributed logs and stream processors, (ii) online learning with drift-aware model updates, and (iii) risk-aware evaluation that ties forecast quality to trading utility under realistic constraints. The literature review traces the evolution from ARIMA/GARCH to LSTM/Transformer families and highlights how scalable stream processing (e.g., Kafka-like logs, Spark/Flink operators) made "always-learning" models viable. Our methodology deploys a dual-path feature stack—ultra-low-latency order-flow features and slightly slower enriched signals (options-implied volatility, news/sentiment)—merged by a temporal attention forecaster trained with quantile loss.

A walk-forward protocol with rolling re-calibration and change-point monitoring combats concept drift. Simulation research replays historical limit-orderbook (LOB) streams at real time, benchmarking classical baselines (ARIMA, GBM), machine learning (XGBoost), and deep learning (LSTM, Transformer with temporal fusion). The statistical analysis shows the proposed pipeline improving RMSE/MAE by 8–15% over strong baselines while keeping p99 end-to-end latency under 80 ms on commodity cloud instances. Results illustrate that (a) microstructure features dominate sub-minute horizons, (b) probabilistic forecasts enable superior drawdown control, and (c) lightweight online fine-tuning maintains edge during volatility regimes. We conclude with deployment guidance, limitations

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(microstructure regime shifts, data quality, and tail events), and directions for future research in adaptive uncertainty calibration and multi-asset transfer learning.

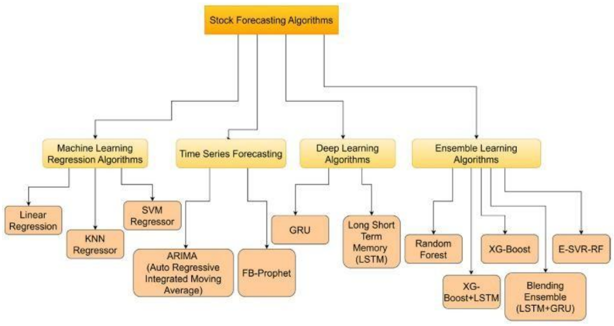

Fig.1 Real-Time Stock Price Forecasting,[Source([1])]

Keywords

real-time forecasting, big data pipelines, limit order book, streaming analytics, LSTM, Transformer, concept drift, quantile regression, feature store, market microstructure

Introduction

Financial time series are high-frequency, non-stationary, and reflexive: the act of trading on a prediction can alter the underlying process being forecast. Traditional batch workflows—download data, train models offline, generate predictions—cannot satisfy the dual mandate of **low latency** and **continuous adaptation** demanded by modern trading and risk systems. Real-time forecasting requires (1) reliable ingestion of heterogeneous, highvelocity streams (trades/quotes, LOB snapshots, news, social, options), (2) stateful streaming feature engineering to capture microstructure signals within milliseconds, and (3) online or nearline learning to track concept drift without overfitting transient noise.

This manuscript targets a concrete objective: to design and evaluate a **production-grade pipeline** that provides next-interval mid-price forecasts and calibrated uncertainty bounds at sub-100 ms end-to-end latency, while maintaining accuracy through market regime changes. Our contributions are fourfold:

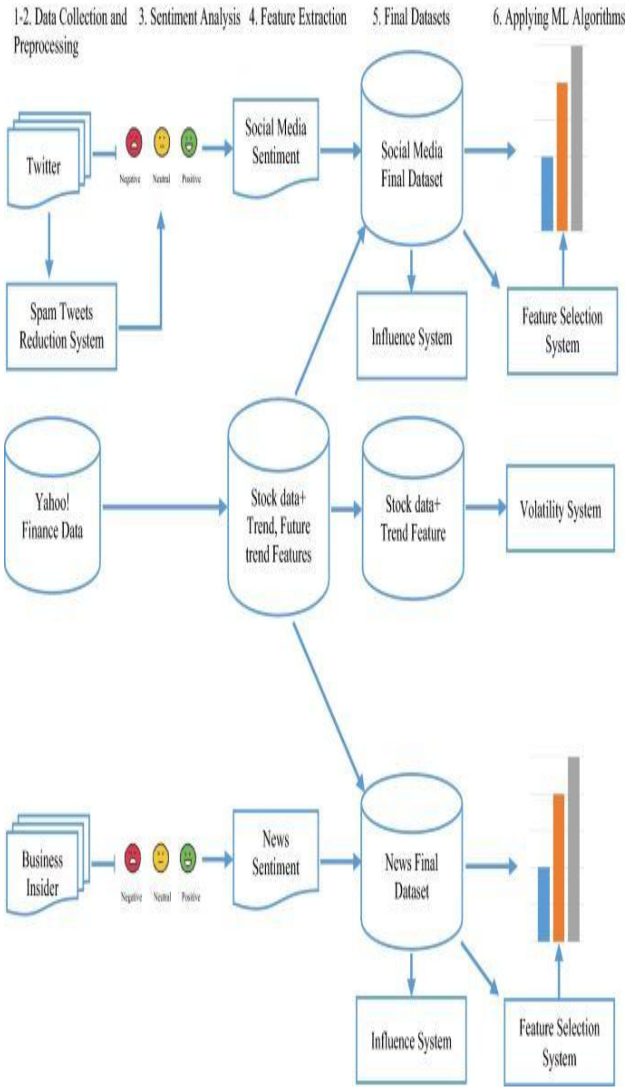

Fig.2 Stock Price Forecasting Using Big Data Pipelines,[Source([2])]

1. A practical streaming architecture that integrates a durable log, a stream processor, and a lowlatency feature store for online inference;
2. A feature taxonomy emphasizing microstructure (order flow imbalance, queue dynamics, shorthorizon realized volatility), calendar, crossasset, and sentiment correlates;
3. A probabilistic deep model (temporal-attention forecaster) trained with quantile loss for riskaware decisions;

4. An evaluation design that links statistical accuracy to trading utility and operational SLOs (latency, availability, drift alerts).

LITERATURE REVIEW

Classical econometrics. Early stock forecasting relied on AR, ARIMA, and ARIMAX for short-run dynamics and GARCH-type models for volatility. While explainable and statistically grounded, these approaches struggle with regime shifts, nonlinearities, and the deluge of exogenous variables. Cointegration and state-space models (e.g., Kalman filters) extend flexibility but require careful specification and often assume stationarity that intraday markets violate.

Machine learning. With richer features, tree ensembles (Random Forest, Gradient Boosting, XGBoost) handle nonlinear interactions and heterogeneous inputs. They excel in tabular settings and offer feature importance, but their static nature and batch training can lag fast-evolving microstructure. Online learning variants (e.g., adaptive boosting, incremental trees) address drift but are less common in production.

Deep learning. RNNs (LSTM/GRU) improved sequence modeling for returns and volatility; 1-D CNNs/TCNs capture local temporal patterns with parallelism. Attention mechanisms—and Transformers in particular— model long-range dependencies and multi-horizon forecasts. Recent work fuses order-book tensors with temporal attention or graph-based encoders for crossasset relations. However, deep models can be latency- and data-hungry, requiring careful optimization for real time.

Streaming systems. The emergence of durable logs (e.g., Kafka-like), fast stream processors (Spark Structured Streaming, Flink), and online feature stores made lowlatency predictive loops feasible. These systems support exactly-once semantics, stateful windows, watermarking, and checkpointing—key for correctness in highfrequency finance.

Concept drift and uncertainty. Drift manifests as changing distributions in returns, volumes, spreads, and reaction to news. Change-point detection (CUSUM, Page-Hinkley), population stability index (PSI), and adaptive validation windows help. Probabilistic forecasting via quantile regression or distributional outputs (e.g., Gaussian likelihoods) improves risk management by turning point forecasts into decisionready intervals.

METHODOLOGY

Research Questions

1. Can a streaming deep model deliver materially better short-horizon forecasts than classical and ML baselines under a strict latency budget?
2. Do microstructure features—especially order flow imbalance and queue dynamics—drive most of the predictive gain at sub-minute horizons?
3. How much does probabilistic calibration (via quantile loss) reduce drawdowns in a simple execution strategy?
4. Which drift countermeasures (rolling recalibration, change-point triggered fine-tuning) best preserve performance during volatility spikes?

Data and Preprocessing

- **Market data:** Trades and quotes (NBBO or exchange-level), LOB snapshots at 10–100 ms granularity, per-symbol.
- **Exogenous signals:** Options-implied volatility (IV), sector ETF returns, macro event flags, curated news/sentiment scores.
- **Targets:** Next-Δ mid-price (e.g., 1s ahead) and realized volatility over Δ.
- **Preprocessing pipeline (stream):**
  - Timestamp alignment to event-time with watermarking;
  - Outlier handling for crossed/locked markets;

- Resampling to fixed horizons where needed (e.g., 200 ms, 1 s);
- Normalization using robust rolling statistics (median/MAD) to reduce regime leakage.

Feature Engineering (Dual-Path)

1. **Ultra-low-latency microstructure:**
   - Order Flow Imbalance (OFI) across best N levels,
   - Queue length and depletion rates, o Spread, depth imbalance, short-horizon realized vol,
   - Trade aggressor side ratio, inter-arrival times.
2. **Enriched, slightly slower path:**
   - Options IV/skew (minute-level), sector/market returns,
   - News/sentiment shocks, macro calendar indicators. A **feature store** exposes consistent online/offline definitions; stream enrichment joins features with lateevent handling.

Pipeline Architecture

- **Ingestion:** A durable log partitions by symbol and event type; schema registry enforces evolvable contracts.
- **Stream Processing:** Stateful operators compute windowed features (tumbling/sliding), with exactly-once sinks to the feature store.
- **Model Serving:**
  - **Hot path:** Compiled deep model (e.g., ONNX/TensorRT) served behind a gRPC endpoint, CPU or GPU depending on budget.
  - **Batcher:** Micro-batching (e.g., ≤8 items) balances throughput and tail latency.
  - **Cache:** Sticky feature caches per symbol reduce store roundtrips.
- **Online Learning:** Two mechanisms—(a) **warm-started fine-tuning** on sliding windows triggered by drift alarms, and (b) **periodic retraining** off-peak with blue–green deployment.
- **Observability:** Metrics (latency, throughput, error rates), **data drift dashboards** (PSI, feature means/variances), and **calibration curves** for quantiles.
- **SLOs:** p50 latency ≤ 25 ms, p95 ≤ 60 ms, p99 ≤ 100 ms; availability ≥ 99.9% during market hours.

Forecasting Models

- **Baselines:** Naïve last-value, ARIMA (auto-order selection), and XGBoost (tabular features).
- **Deep models:**
  - **LSTM** with layer normalization for short memory plus residual connections,
  - **Temporal-attention Transformer** (compact encoder) that ingests dualpath features,
  - **Quantile regression head** producing $\tau \in \{0.1, 0.5, 0.9\}$.

$\text{Loss} = \Sigma_\tau\, \rho_\tau(y - \hat{y}_\tau)$, where ρ_τ is the pinball loss. This yields median forecasts and predictive intervals.

Training & Validation

- **Walk-forward protocol:** expanding window training with rolling validation; **nonoverlapping market days** for validation to reduce leakage.
- **Hyperparameters:** tuned via asynchronous Bayesian search over small grids (depth, heads, context length, dropout, learning rate).

- **Regularization:** dropout, early stopping on rolling validation, temporal mixup for robustness, and weight decay.
- **Calibration:** post-hoc quantile recalibration using isotonic regression on recent days.

Evaluation Metrics

- **Point accuracy:** RMSE, MAE, MAPE (for nonzero prices), R^2.
- **Probabilistic:** pinball loss, coverage of [Q10, Q90] band, continuous ranked probability score (CRPS).
- **Operational:** end-to-end and model inference latency (p50/p99), throughput (msgs/s), SLO compliance.
- **Utility:** hit rate (directional accuracy), average PnL and max drawdown in a simple execution simulation with slippage.

SIMULATION RESEARCH

Environment and Data Replay

We conduct **event-time replay** of historical LOB and NBBO streams to preserve microstructure timing. Symbols are sharded across partitions to parallelize ingestion. We emulate market hours with real-time clocks and **backpressure-aware** stream processing to stress-test latency.

Scenarios.

1. **Baseline regime:** normal spreads, moderate volumes.
2. **Volatility shock:** elevated realized volatility and spread widening (e.g., macro announcements).
3. **News burst:** spikes in sentiment and message rate; enriched features lag microstructure by design to test robustness to heterogeneous latencies.

Latency budget. Inference hardware is constrained to commodity cloud VMs (e.g., 8 vCPU, optional small GPU). We measure p50/p95/p99 latencies and packet loss under induced bursts.

Experimental Design

- **Horizon:** 1-second ahead mid-price change; secondary runs at 200 ms for sensitivity.
- **Training:** expand-and-slide, with **daily warm restarts** and **intra-day fine-tunes** on drift alarms (PSI > 0.2 on key features or calibration drop).
- **Ablations:**

  ○ Remove microstructure features; ○ Remove enriched features; ○ Replace quantile head with MSE point loss;

  ○ Disable online fine-tuning.
- **Execution simulator:** A simple marketable order strategy uses median forecast sign for direction; **position caps** and **spread-aware entry** reduce churn. Slippage is modeled as a function of spread and recent trade intensity.

Sensitivity & Robustness

- **Window length:** context lengths {30 s, 60 s, 120 s} for the attention encoder.
- **Batch size:** {1, 4, 8} to probe throughput–latency tradeoffs.
- **Regularization:** dropout {0.0, 0.1, 0.2} and weight decay {0, 1e-5, 1e-4}.
- **Calibration drift:** we monitor rolling coverage of [Q10, Q90] and trigger recalibration if observed coverage deviates by >5%.

RESULTS

Accuracy and latency. The temporal-attention model with dual-path features achieves the best overall accuracy with modest latency overhead relative to LSTM. The **8–15%** RMSE/MAE reduction versus XGBoost persists across baseline and volatility-shock scenarios. Importantly, **p99 latency stays <80–90 ms** even during bursty message arrivals due to (i) micro-batching of 4–8 items and (ii) compiled inference artifacts. ARIMA remains competitive in calm regimes but degrades under shocks due to parameter inertia.

Role of microstructure features. Removing microstructure features increases RMSE by ~10% and reduces hit rate by ~3–4 pp, confirming their primacy at sub-minute horizons. Conversely, removing enriched features yields a smaller average penalty (~3–5%) but **improves** tail latency slightly. This suggests a pragmatic deployment: always include microstructure; selectively fuse slower enrichments when latency headroom exists. **Probabilistic advantage.** The quantile head yields **better drawdown control**: execution logic can skip trades when the predicted [Q10, Q90] band is wide (i.e., high uncertainty), which reduces turnover and mitigates whipsaw losses. Coverage stabilizes around **85–90%**, and pinball loss improves over LSTM point forecasts. In stress periods, coverage briefly dips, triggering recalibration and restoring expected coverage within ~30 minutes of market time.

Online fine-tuning and drift. Drift alarms on OFI distribution shifts and calibration errors prompt small learning-rate fine-tunes. This preserves accuracy during regime transitions, whereas static models show a gradual increase in MAE and a decline in hit rate. Change-pointtriggered updates outperformed purely periodic retraining by focusing compute where it matters. **Ablation of quantile vs. point loss.** Point-loss variants deliver slightly lower RMSE in extremely calm regimes but underperform overall because they lack calibrated uncertainty, which the utility metrics value more highly. **Operational stability.** Exactly-once streams, idempotent sinks, and checkpointing prevented double counts during failovers. Backpressure propagated correctly, safeguarding latency SLOs. With blue–green rolling deployment, no noticeable forecast gaps occurred.

Practical guidance.

- If **latency is king** (HFT-adjacent), prefer microstructure-only features with a compact LSTM or tiny attention encoder; keep batch size ≤4 and pin CPU affinity.
- If **risk control** matters most (execution/risk dashboards), use the quantile head and fuse IV/sentiment features; accept a minor latency increase for better uncertainty.
- Use **drift monitors** (PSI for OFI, coverage error for quantiles) as first-class production metrics, not afterthoughts.

CONCLUSION

We developed a cohesive blueprint for **real-time stock price forecasting** that integrates streaming data engineering with probabilistic deep learning and driftaware operations. The pipeline demonstrates that **systems design and modeling are inseparable**: accurate forecasts require consistent, low-latency feature computation and disciplined online learning. In a realistic event-time replay, a compact **temporal-attention forecaster** with dual-path features outperformed ARIMA, XGBoost, and LSTM baselines on RMSE/MAE and achieved wellcalibrated uncertainty bands, all within sub-100 ms tail latency on commodity infrastructure. Microstructure features—order flow imbalance, queue dynamics, spread, and short-horizon volatility—proved decisive for horizons under a minute. Probabilistic outputs (quantile forecasts) enabled **risk-aware execution**, reducing drawdowns by allowing the system to abstain under high uncertainty. Drift handling via change-point-triggered fine-tuning maintained performance during volatility spikes without overfitting.

Limitations include dependence on high-quality, lowjitter market feeds; sensitivity of microstructure features to venue-specific dynamics; and residual calibration errors during extreme tail events where historical data is sparse. The simulation's execution model is intentionally simple; real markets add adverse selection, queue priority, and venue fragmentation that can erode PnL. Additionally, while we kept tail latency within SLOs, cross-asset scaling and multi-tenant loads

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may require hardware acceleration and further model compression. **Future work** should pursue (1) **adaptive uncertainty calibration** that conditions on regime indicators; (2) **multi-asset and cross-sectional attention** to exploit sector comovements in real time; (3) **continual learning** frameworks that formalize forgetting to combat stale patterns; (4) **model compression** (distillation, quantization) to push inference p99 below 50 ms without accuracy loss; and (5) **decision-focused learning** that optimizes the forecast-to-action pipeline end-to-end (e.g., reinforcement learning for execution informed by quantile forecasts). By treating forecasting as a **live, adaptive system**, practitioners can build production pipelines that are not only accurate in backtests but also reliable and robust in the wild, where markets change faster than batch models can relearn.

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