Patient Agent - Personalized Baseline System

Overview

The Patient Agent learns what's "normal" for each individual patient and detects meaningful deviations from their personal baseline. This enables personalized cardiac risk assessment.

Key Philosophy

- **Stable, Not Reactive**: Uses slow adaptation (EMA with α=0.05) to prevent single bad days from shifting the baseline
- **No Deep Learning**: Uses interpretable statistical methods only
- **Conservative**: Requires sustained changes (3+ days) before escalating behavioral state
- **Explainable**: Every assessment can be traced to specific deviations from baseline

What It Tracks

Cardiac Baseline

- **Heart Rate**: Mean and std deviation
- **HRV (RMSSD)**: Short-term variability baseline
- **HRV (SDNN)**: Overall variability baseline
- **Arrhythmia Rate**: Normal percentage of time with arrhythmia detected
- **Physio Risk**: Average daily risk score

Activity Baseline

- Time spent in each activity (WALKING, SITTING, STANDING, LAYING, etc.)
- Activity pattern disruptions indicate behavioral changes

Behavioral State

- **STABLE**: Normal patterns, sensitivity = 1.0x
- **DEGRADED**: Minor deviations detected, sensitivity = 1.15x
- **AT_RISK**: Sustained abnormalities (3+ days), sensitivity = 1.3x

How It Works

1. Daily Aggregation

At end of each day (automatically detected at midnight):

- Collects all sensor outputs from the day
- Computes daily statistics (mean HR, mean HRV, arrhythmia frequency, etc.)

2. Baseline Update (Online Learning)

Uses **Exponential Moving Average** for stable adaptation:

```
new_baseline = (1 - α) × old_baseline + α × today's_value
```

- **First 7 days**: α = 0.20 (faster learning)
- **Day 8+**: α = 0.05 (very stable, 95% weight on history)

This prevents:

- Overreacting to single bad days
- Baseline drift from outliers
- Unstable alert thresholds

3. Risk Factor Detection

Checks 5 key indicators daily:

1. **HR Elevation**: >1.5 std above personal baseline
2. **HRV Reduction**: >1.5 std below baseline (lower HRV = worse)
3. **Arrhythmia Increase**: >10% absolute increase from baseline rate
4. **Physio Risk Elevation**: >2.0 std above baseline (double weighted)
5. **Activity Disruption**: >30% change in daily activity patterns

4. Behavioral State Logic

```
risk_factors = count of triggered indicators

if risk_factors >= 3:
    degrading_days += 1
elif risk_factors == 0:
    improving_days += 1

if degrading_days >= 3:
    state = AT_RISK
elif degrading_days >= 1:
    state = DEGRADED
else:
    state = STABLE
```

Conservative by design: Requires 3 consecutive degrading days for AT_RISK.

5. Sensitivity Adjustment

Sensitivity factor modulates alert thresholds in Decision Agent:

- **STABLE**: 1.0x (normal thresholds)
- **DEGRADED**: 1.15x (15% more sensitive)
- **AT_RISK**: 1.3x (30% more sensitive)

Early in tracking (low confidence), adjustments are dampened.

API Endpoints

GET /api/patient/baseline

Returns learned baseline values:

json


```
{
 "baseline": {
  "hr_mean": 72.5,
  "hr_std": 12.3,
  "hrv_rmssd_mean": 38.2,
  "arrhythmia_rate": 0.04,
  "physio_risk_mean": 0.18
 },
 "activity_profile": {
  "SITTING": 0.42,
  "WALKING": 0.18,
  "STANDING": 0.22,
  "LAYING": 0.18
 },
 "days_seen": 15,
 "confidence": 0.5
}
```


GET /api/patient/state

Returns current behavioral assessment:

json


```
{
 "behavioral_state": "STABLE",
 "sensitivity_factor": 1.0,
 "confidence": 0.5,
 "days_seen": 15,
 "recent_trend": {
  "degrading_days": 0,
  "stable_days": 12,
  "improving_days": 3
 }
}
```


GET /api/patient/risk_context

Compares current metrics to baseline:

```json
{
  "deviations": {
    "hr_zscore": 1.2,
    "hr_status": "normal",
    "hrv_zscore": -0.5,
    "hrv_status": "normal",
    "arrhythmia_above_baseline": false
  },
  "behavioral_state": "STABLE",
  "baseline_hr": 72.5,
  "baseline_hrv": 38.2
}
```

POST /api/patient/trigger_update

Manually trigger end-of-day update (normally automatic at midnight):

```json
{
  "message": "Processed 432 sensor outputs",
  "patient_output": {
    "day": "2025-12-27",
    "sensitivity_factor": 1.0,
    "behavioral_state": "STABLE",
    "confidence": 0.5
  }
}
```

Confidence Building

The Patient Agent builds confidence over time:

- **Days 1-7**: Confidence = 0-0.23 (Learning mode, no sensitivity adjustments)
- **Days 8-30**: Confidence = 0.23-1.0 (Calibration, gradual adjustments)
- **Day 30+**: Confidence = 1.0 (Full personalization active)

Formula: `confidence = min(1.0, days_seen / 30.0)`

Persistent State

Stored in `data/patient_state.json`:

json


```
{
 "patient_id": "patient_001",
 "created_date": "2025-12-01T00:00:00",
 "days_seen": 15,
 "last_update": "2025-12-15T23:59:59",
 "baseline": { ... },
 "activity_profile": { ... },
 "behavioral_state": "STABLE",
 "sensitivity_factor": 1.0,
 "confidence": 0.5,
 "recent_trend": { ... }
}
```


Integration with System

1. **Sensor Agent** → Outputs every 2 seconds
2. **Flask App** → Collects outputs throughout the day
3. **Midnight** → Automatic daily_update() triggered
4. **Patient Agent** → Updates baseline, assesses state
5. **Decision Agent** → Uses sensitivity_factor for alert thresholds

Example Scenario

Day 1-7: Patient walks 5000 steps/day, HR avg 70, HRV 40

- Agent learns this is "normal" for them

Day 15: Patient walks 5200 steps, HR 72, HRV 38

- Within baseline → STABLE state

Day 20: Patient walks 2000 steps, HR 85, HRV 25

- Multiple risk factors triggered (activity disruption, HR elevation, HRV reduction)
- degrading_days = 1 → DEGRADED state → sensitivity 1.15x

Day 21-22: Pattern continues

- degrading_days = 3 → AT_RISK state → sensitivity 1.3x
- Alerts now trigger at lower thresholds

Day 23: Patient resumes normal activity

- improving_days begins
- After 3 days of improvement → back to STABLE

Design Principles

✅ **Stable**: EMA prevents baseline jumps
✅ **Conservative**: Requires sustained changes (3 days)
✅ **Transparent**: Every decision traceable to metrics
✅ **Adaptive**: Learns individual norms over time
✅ **Interpretable**: No black-box models

This is the **intelligence** that makes the system personalized without being unpredictable.