Acceleration-Based Optimal Shift Point Algorithm for GT3 Racing

ACCRPMMonitor - Assetto Corsa Competizione

1 Objective

Find the RPM at which shifting to the next gear provides better acceleration than staying in the current gear, optimizing lap times by maximizing acceleration throughout the power band. This algorithm is specifically optimized for GT3 race cars, which typically feature high-revving engines with strong power delivery near redline.

2 Mathematical Formulation

2.1 Step 1: Acceleration Calculation

For each pair of consecutive telemetry data points $(i-1, i)$, calculate the instantaneous acceleration:

$$a_i = \frac{v_i - v_{i-1}}{t_i - t_{i-1}} \tag{1}$$

where:

- a_i = acceleration at point i (m/s^2)
- v_i = speed at point i (m/s)
- t_i = timestamp at point i (seconds)

Group acceleration values by RPM buckets (100 RPM intervals):

$$\text{RPM}_{\text{bucket}} = \left\lfloor \frac{\text{RPM}_{\text{avg}}}{100} \right\rfloor \times 100 \tag{2}$$

Average all acceleration values in each bucket to create the acceleration function:

$$A_{\text{gear}}(\text{RPM}) = \frac{1}{n} \sum_{i \in \text{bucket}} a_i \tag{3}$$

where n is the number of samples in the RPM bucket $[\text{RPM}, \text{RPM} + 100)$.
This gives us the acceleration function $A_{\text{gear}}(\text{RPM})$ for each gear.

2.2 Step 2: Gear Ratio Estimation

Find the overlapping speed range between gear N and gear $N+1$:

$$V_{\text{overlap}} = \left[\max\left(V_{\min}^{N}, V_{\min}^{N+1}\right), \min\left(V_{\max}^{N}, V_{\max}^{N+1}\right)\right] \tag{4}$$

Calculate the RPM-to-speed ratio for each gear in the overlap region:

$$R_N = \frac{1}{n_N} \sum_{i:v_i \in V_{\text{overlap}}, \text{gear}=N} \frac{\text{RPM}_i}{v_i} \tag{5}$$

$$R_{N+1} = \frac{1}{n_{N+1}} \sum_{i:v_i \in V_{\text{overlap}}, \text{gear}=N+1} \frac{\text{RPM}_i}{v_i} \tag{6}$$

The gear ratio between gear N and gear $N+1$ is:

$$\text{GR}_{N \to N+1} = \frac{R_N}{R_{N+1}} \tag{7}$$

2.3 Step 3: Adaptive Crossover Point Detection

For each RPM level in gear N, predict the RPM after shifting to gear $N+1$:

$$\text{RPM}_{N+1} = \frac{\text{RPM}_N}{\text{GR}_{N \to N+1}} \tag{8}$$

Calculate the acceleration advantage ratio (relative improvement):

$$R_A(\text{RPM}_N) = \frac{A_{N+1}(\text{RPM}_{N+1}) - A_N(\text{RPM}_N)}{A_N(\text{RPM}_N)} \tag{9}$$

2.3.1 Adaptive Threshold Based on Power Curve Characteristics

Analyze the current gear's power delivery to determine optimal threshold:

$$\text{RPM}_{\text{top}} = \text{RPM}_{\max} - 0.2 \times (\text{RPM}_{\max} - \text{RPM}_{\min}) \tag{10}$$

$$\text{RPM}_{\text{mid}} = \text{RPM}_{\min} + 0.5 \times (\text{RPM}_{\max} - \text{RPM}_{\min}) \tag{11}$$

$$A_{\text{top}} = \text{avg}\left\{A_N(\text{RPM}) \mid \text{RPM} \geq \text{RPM}_{\text{top}}\right\} \tag{12}$$

$$A_{\text{mid}} = \text{avg}\left\{A_N(\text{RPM}) \mid \text{RPM} \leq \text{RPM}_{\text{mid}}\right\} \tag{13}$$

Define adaptive minimum advantage threshold (GT3-optimized):

$$\theta_{\min} = \begin{cases} 0.05 & \text{if } A_{\text{top}} < 0.70 \times A_{\text{mid}} \quad \text{(power drops significantly)} \\ 0.10 & \text{otherwise} \quad \text{(GT3 default - high-revving)} \end{cases} \tag{14}$$

Find the optimal shift point where the advantage is both significant and maximized:

$$\text{RPM}_{\text{optimal}} = \arg\max_{\text{RPM}} \{R_A(\text{RPM}) \mid R_A(\text{RPM}) > \theta_{\text{min}}\} \tag{15}$$

This GT3-optimized adaptive approach:

- **Default: 10% advantage** for typical GT3 power curves (prevents early shifting near redline)
- **Fallback: 5% advantage** only when power clearly drops off (¿30% loss at high RPM)
- Designed for high-revving race engines that maintain strong acceleration to redline
- Automatically adapts to each GT3 car's unique power characteristics

3 Algorithm Pseudocode

function FindOptimalShiftPoint(gear$_N$)
  // Step 1: Calculate acceleration curves
  $A_N \leftarrow$ CalculateAccelerationCurve(gear$_N$)
  $A_{N+1} \leftarrow$ CalculateAccelerationCurve(gear$_{N+1}$)

  if InsufficientData(A_N) **or** InsufficientData(A_{N+1}) **then**
    return FallbackMaxSpeedMethod(gear$_N$)
  end if

  // Step 2: Estimate gear ratio
  GR $\leftarrow$ EstimateGearRatio(gear$_N$, gear$_{N+1}$)

  if GR ≤ 0 **then**
    return FallbackMaxSpeedMethod(gear$_N$)
  end if

  // Step 3: Find crossover point with adaptive threshold
  best_rpm $\leftarrow$ null
  best_advantage_ratio $\leftarrow 0$

  // Determine adaptive threshold based on power curve
  $\text{RPM}_{\text{max}} \leftarrow \max(A_N.\text{keys}())$
  $\text{RPM}_{\text{min}} \leftarrow \min(A_N.\text{keys}())$
  $\text{RPM}_{\text{top}} \leftarrow \text{RPM}_{\text{max}} - 0.2 \times (\text{RPM}_{\text{max}} - \text{RPM}_{\text{min}})$
  $\text{RPM}_{\text{mid}} \leftarrow \text{RPM}_{\text{min}} + 0.5 \times (\text{RPM}_{\text{max}} - \text{RPM}_{\text{min}})$

  $A_{\text{top}} \leftarrow \text{avg}\{A_N[\text{rpm}] \mid \text{rpm} \geq \text{RPM}_{\text{top}}\}$
  $A_{\text{mid}} \leftarrow \text{avg}\{A_N[\text{rpm}] \mid \text{rpm} \leq \text{RPM}_{\text{mid}}\}$

// GT3-optimized: Default to 10%, lower only if power drops significantly
if $A_{\text{top}} < 0.70 \times A_{\text{mid}}$ **then**
  $\theta_{\text{min}} \leftarrow 0.05$ // Power drops significantly: 5% sufficient
else
  $\theta_{\text{min}} \leftarrow 0.10$ // GT3 default: 10% required
end if

for each rpm $\in A_N$.keys() **do**
  $a_{\text{current}} \leftarrow A_N[\text{rpm}]$
  $\text{rpm}_{\text{next}} \leftarrow \text{rpm}/\text{GR}$
  $a_{\text{next}} \leftarrow A_{N+1}[\text{ClosestRPM}(\text{rpm}_{\text{next}})]$

  // Calculate relative advantage (percentage improvement)
  $R_a \leftarrow (a_{\text{next}} - a_{\text{current}})/a_{\text{current}}$

  // Require adaptive threshold to avoid early shifting
  if $R_a > \theta_{\text{min}}$ **and** $R_a >$ best_advantage_ratio **then**
    best_advantage_ratio $\leftarrow R_a$
    best_rpm $\leftarrow$ rpm
  end if
end for

if best_rpm $\neq$ null **then**
  return best_rpm
else
  return FallbackMaxSpeedMethod(gear_N)
end if
end function

4 Example Calculation

Consider shifting from 2nd gear to 3rd gear:

4.1 Given Data

- At 6800 RPM in 2nd gear: $A_2(6800) = 2.5$ m/s^2
- At 6500 RPM in 2nd gear: $A_2(6500) = 2.8$ m/s^2
- At 6200 RPM in 2nd gear: $A_2(6200) = 3.0$ m/s^2
- Gear ratio: $\text{GR}_{2\to 3} = 1.31$
- Minimum advantage threshold: $\theta_{\text{min}} = 0.05$ (5%)

4.2 Analysis at 6800 RPM

After shifting to 3rd gear:

$$\text{RPM}_3 = \frac{6800}{1.31} \approx 5191 \text{ RPM} \tag{16}$$

If $A_3(5191) = 3.1$ m/s^2, then:

$$R_A(6800) = \frac{3.1 - 2.5}{2.5} = \frac{0.6}{2.5} = 0.24 = 24\% \tag{17}$$

Since $24\% > 5\%$, this is a valid shift point with significant advantage. **(SHIFT NOW!)**

4.3 Analysis at 6500 RPM

After shifting to 3rd gear:

$$\text{RPM}_3 = \frac{6500}{1.31} \approx 4962 \text{ RPM} \tag{18}$$

If $A_3(4962) = 2.4$ m/s^2, then:

$$R_A(6500) = \frac{2.4 - 2.8}{2.8} = \frac{-0.4}{2.8} = -0.14 = -14\% \tag{19}$$

Since $-14\% < 5\%$, staying in 2nd gear is better. **(TOO EARLY, STAY IN GEAR)**

4.4 Analysis at 6200 RPM

After shifting to 3rd gear:

$$\text{RPM}_3 = \frac{6200}{1.31} \approx 4733 \text{ RPM} \tag{20}$$

If $A_3(4733) = 3.05$ m/s^2, then:

$$R_A(6200) = \frac{3.05 - 3.0}{3.0} = \frac{0.05}{3.0} = 0.017 = 1.7\% \tag{21}$$

Since $1.7\% < 5\%$, the advantage is marginal and not significant. **(TOO EARLY, WAIT)**

This example shows how the 5% threshold prevents premature shifting when acceleration advantage is minimal.

5 Adaptive Threshold Example

Consider two different vehicle types to demonstrate adaptive threshold selection:

5.1 Typical GT3 Car (Mercedes AMG GT3)

Data Analysis:

- RPM range in 3rd gear: 4000-8000 RPM
- Average acceleration at mid-range (4000-6000 RPM): $A_{\text{mid}} = 3.2$ m/s^2
- Average acceleration at top range (6400-8000 RPM): $A_{\text{top}} = 2.9$ m/s^2

Threshold Selection (GT3-optimized):

$$A_{\text{top}} = 2.9 \geq 0.70 \times 3.2 = 2.24 \quad \Rightarrow \quad \theta_{\text{min}} = 0.10 \tag{22}$$

Power remains strong at high RPM (default GT3 behavior), so require 10% advantage. At 7500 RPM with $A_3(7500) = 2.7$ m/s^2:

$$R_A = \frac{A_4(\text{calculated}) - 2.7}{2.7} \text{ must exceed 0.10 to shift} \tag{23}$$

Result: Shifts near 7800 RPM (close to redline).

5.2 GT3 Car with Early Power Drop (Honda NSX GT3)

Data Analysis:

- RPM range in 3rd gear: 3500-7200 RPM
- Average acceleration at mid-range (3500-5350 RPM): $A_{\text{mid}} = 3.5$ m/s^2
- Average acceleration at top range (5760-7200 RPM): $A_{\text{top}} = 2.3$ m/s^2

Threshold Selection:

$$A_{\text{top}} = 2.3 < 0.70 \times 3.5 = 2.45 \quad \Rightarrow \quad \theta_{\text{min}} = 0.05 \tag{24}$$

Power drops significantly at high RPM (¿30% loss), so allow earlier shifting with 5% threshold. Shifts around 6400 RPM where next gear provides 5%+ advantage.

Result: Shifts earlier to avoid power drop-off zone (still optimized for this specific GT3 car).

6 Key Parameters

- **RPM Bucket Size**: 100 RPM (groups similar RPM levels)
- **Minimum Time Delta**: 0.01 seconds (10 ms, filters noise)
- **Maximum Time Delta**: 1.0 seconds (filters different laps)
- **RPM Match Tolerance**: ±175 RPM (acceptable range for gear ratio lookup)

- **Minimum Data Points per Gear**: 30 full-throttle samples
- **Minimum Samples per Bucket**: 3 samples for statistical reliability
- **Full Throttle Threshold**: $\geq 85\%$ throttle position
- **Minimum Speed Threshold**: > 5 km/h (excludes low-speed/stationary data)
- **Adaptive Advantage Threshold** (θ_{min}) - GT3 Optimized:
  - 0.10 (10%) default for GT3 cars (typical high-revving behavior)
  - 0.05 (5%) only when power drops significantly (when $A_{\text{top}} < 0.70 \times A_{\text{mid}}$)
- **High-RPM Detection Threshold**: Top 20% of RPM range
- **Mid-RPM Reference Range**: Bottom 50% of RPM range
- **Redline Pull Detection**: Speed at 90%+ RPM vs max speed (95% threshold)
- **Fallback Redline Shift Point**: 98% of max observed RPM

7 Fallback Strategy

If acceleration-based method fails (insufficient data, invalid gear ratio, etc.), use an intelligent maximum speed fallback that adapts to redline behavior.

7.1 Redline Detection

Check if the vehicle continues to accelerate strongly near redline:

$$\text{RPM}_{\text{top10\%}} = 0.90 \times \text{RPM}_{\text{max}} \tag{25}$$

$$v_{\text{top}} = \text{avg}\left\{v_i \mid \text{RPM}_i \geq \text{RPM}_{\text{top10\%}}\right\} \tag{26}$$

$$\text{PullsToRedline} = \begin{cases} \text{true} & \text{if } v_{\text{top}} \geq 0.95 \times v_{\text{max}} \\ \text{false} & \text{otherwise} \end{cases} \tag{27}$$

7.2 Adaptive Fallback Shift Point

$$\text{RPM}_{\text{optimal}} = \begin{cases} 0.98 \times \text{RPM}_{\text{max}} & \text{if PullsToRedline} \\ \max\left\{\text{RPM}_i \mid v_i \geq 0.99 \times v_{\text{max}}, \text{gear} = N\right\} & \text{otherwise} \end{cases} \tag{28}$$

This approach:

- Shifts at 98% of max RPM for cars that accelerate well to redline (e.g., high-revving GT3 cars)

- Uses the highest RPM (not lowest) that achieves 99% max speed for cars with traditional power curves
- Prevents premature shifting by always preferring higher RPM ranges

8 Benefits

1. **Physics-based**: Directly uses Newton's second law ($F = ma$)
2. **Vehicle-specific**: Adapts to each car's unique power curve
3. **Track-independent**: Works on any track configuration
4. **Self-optimizing**: More data yields better shift points
5. **Robust**: Graceful degradation with fallback strategy
6. **Optimal for lap times**: Maximizes acceleration = minimizes time
7. **GT3-optimized adaptive thresholds**:
    - 10% default for GT3 cars (prevents early shifting, maximizes redline usage)
    - 5% fallback for GT3 cars with significant power drop-off (¿30% loss)
8. **High-quality data**: Filters out invalid telemetry (speed = 0, throttle ¡ 95%)
9. **Intelligent fallback**: Detects redline behavior and shifts accordingly
10. **Power curve analysis**: Automatically characterizes engine characteristics

9 Dynamic Audio Warning System

To provide real-time feedback, the system employs a dynamic beeping distance based on RPM rate of change:

9.1 RPM Rate Calculation

Track RPM history over a 200ms sliding window and calculate the rate of change:

$$\dot{\text{RPM}} = \frac{\text{RPM}_{\text{current}} - \text{RPM}_{\text{old}}}{t_{\text{current}} - t_{\text{old}}} \quad \text{(RPM/second)} \tag{29}$$

9.2 Dynamic Warning Distance

The beeping warning distance d_{beep} adapts to acceleration intensity:

$$d_{\text{beep}} = \begin{cases} 200 \text{ RPM} & \text{if } \dot{\text{RPM}} > 1500 \text{ RPM/s} \\ 150 \text{ RPM} & \text{if } \dot{\text{RPM}} > 1000 \text{ RPM/s} \\ 120 \text{ RPM} & \text{if } \dot{\text{RPM}} > 600 \text{ RPM/s} \\ 100 \text{ RPM} & \text{if } \dot{\text{RPM}} > 300 \text{ RPM/s} \\ 80 \text{ RPM} & \text{if } \dot{\text{RPM}} > 150 \text{ RPM/s} \\ 50 \text{ RPM} & \text{if } \dot{\text{RPM}} > 50 \text{ RPM/s} \\ 30 \text{ RPM} & \text{otherwise} \end{cases} \tag{30}$$

Beeping begins when:

$$\text{RPM}_{\text{current}} \geq \text{RPM}_{\text{optimal}} - d_{\text{beep}} \tag{31}$$

This approach provides earlier warning during rapid acceleration while avoiding premature beeping during steady-state driving.

10 Adaptive Learning Mode

The system supports continuous learning during normal driving:

1. **Real-time data collection**: Collects telemetry at 20 Hz during full-throttle acceleration
2. **Automatic filtering**: Rejects data when throttle $< 85\%$ or speed < 5 km/h
3. **RPM rising filter**: Only collects data when RPMs rising ≥ 100 RPM/sec
4. **Periodic updates**: Recalculates optimal shift points every 30 seconds
5. **Live adaptation**: Shift point thresholds update dynamically as new data is collected
6. **Persistent learning**: Optionally saves learned configuration for future sessions

This enables the system to continuously refine shift points as driving conditions and techniques evolve.

11 Performance Learning Mode (Machine Learning)

Beyond physics-based acceleration analysis, the system implements a machine learning approach that correlates shift patterns with actual lap performance:

11.1 Shift Event Detection

The system automatically detects and records every gear change during driving:

- **Upshift detection**: Requires throttle $\geq 30\%$ and RPM ≥ 3000 to filter braking
- **Downshift detection**: Requires RPM ≥ 3000 to exclude engine braking
- **Context capture**: Records RPM, speed, throttle, track position for each shift
- **Lap association**: Links all shifts to their corresponding lap performance

11.2 Lap Validation

Uses ACC's `is_valid_lap` field (offset 1408 in graphics shared memory) to determine lap validity:

$$\text{IsValid}_{\text{lap}} = \text{IsValidByACC} \wedge \text{IsValidByMetrics} \tag{32}$$

where:

$$\text{IsValidByMetrics} = (\text{LapTime}_{\text{ms}} > 0) \wedge (\text{LapTime}_{\text{ms}} < \infty) \wedge (\text{OffTrackTime} < 2.0\text{s}) \tag{33}$$

The `is_valid_lap` field is reliable in practice/qualifying sessions but may use different validation criteria in races.

11.3 Statistical Analysis

Group shifts into RPM buckets (200 RPM intervals) and calculate performance correlation:

$$\text{Score}_{\text{bucket}} = \text{avg}\left\{\text{LapTime}_i + (\text{OffTrack}_i \times 1000)\right\} \tag{34}$$

The optimal shift point for each gear is:

$$\text{RPM}^{\text{perf}}_{\text{optimal}} = \arg\min_{\text{bucket}} \left\{\text{Score}_{\text{bucket}} \mid n_{\text{bucket}} \geq 2\right\} \tag{35}$$

Requires minimum 5 valid laps for statistically meaningful recommendations.

11.4 Weighted Learning Algorithm

Blend physics-based and performance-based recommendations:

$$w_{\text{learn}} = \min\left(0.8, 0.2 + \frac{n_{\text{valid\_laps}}}{25}\right) \tag{36}$$

$$\text{RPM}_{\text{final}} = \frac{(1 - w_{\text{learn}}) \times \text{RPM}_{\text{physics}} + w_{\text{learn}} \times \text{RPM}_{\text{performance}}}{1.0} \tag{37}$$

- Initial learning rate: 20% (conservative, relies on physics)
- Final learning rate: 80% at 20+ valid laps (aggressive, trusts real performance data)
- Physics weight: 40%, Performance weight: 60% when both available

11.5 Confidence Building

The system increases confidence with more data:

$$\text{Confidence} = \begin{cases} \text{Building} & \text{if } n_{\text{valid\_laps}} < 3 \\ \text{Good} & \text{if } 3 \leq n_{\text{valid\_laps}} < 5 \\ \text{Excellent} & \text{if } n_{\text{valid\_laps}} \geq 5 \end{cases} \tag{38}$$

11.6 Pitch-Based Audio Guidance

In Performance Learning Mode, the audio system uses pitch modulation instead of beeping:

$$f_{\text{audio}} = \begin{cases} f_{\text{base}} + 200 \text{ Hz} & \text{if } \text{RPM}_{\text{current}} > \text{RPM}_{\text{optimal}} + 175 \\ f_{\text{base}} - 200 \text{ Hz} & \text{if } \text{RPM}_{\text{current}} < \text{RPM}_{\text{optimal}} - 175 \\ f_{\text{base}} & \text{if } |\text{RPM}_{\text{current}} - \text{RPM}_{\text{optimal}}| \leq 175 \end{cases} \tag{39}$$

where $f_{\text{base}} = 500 + (\text{gear} \times 100)$ Hz.

The ±175 RPM window provides a forgiving "optimal zone" for shift timing:

- **High pitch**: Shifting too late, shift earlier next lap
- **Normal pitch**: Within optimal window (±175 RPM)
- **Low pitch**: Shifting too early, shift later next lap

12 User Interface

12.1 Console Window Configuration

The application uses a fixed console window size of 82 columns × 40 rows:

- **Width**: 82 characters (accommodates 80-char content + borders)
- **Height**: 40 rows (compact display for critical information)
- **Window locking**: Disabled on Windows Terminal (uses legacy conhost.exe)
- **Cross-platform**: Window sizing works on all platforms, locking Windows-only

12.2 Interactive Controls

All menus use single-key input without requiring Enter:

- Main menu: Press 1-6 or ESC to exit
- Vehicle selection: Press number, A (auto-detect), N (new), D (delete), C (continue)
- Mode selection: Press 1-2 for Manual/Auto configuration
- Config editing: Press 0-9 for gear selection or save/exit

13 Implementation Notes

- **Target Platform**: .NET 8.0 on Windows (net8.0-windows)
- **ACC Integration**: Reads from shared memory (Physics + Graphics segments)
- **Audio Feedback**: NAudio with triangle wave synthesis
- **Graphing**: ScottPlot 5.x for power curve visualization
- **Window Management**: Win32 API (kernel32.dll, user32.dll) for window locking
- **Configuration Storage**: JSON files in `%LocalAppData%\ACCRPMMonitor`