Computer Organization & Assembly Language

Traffic Light Control System

An Assembly Language Approach to Intelligent Intersection Management

ABSTRACT

This project implements an intelligent Traffic Light Control System using x86 Assembly Language to manage four-way intersections. The system features multiple operational modes, pedestrian safety integration, and real-time monitoring capabilities. Utilizing port-based I/O and BIOS interrupts, it provides adaptive timing control with emergency response and rush hour optimization. The modular architecture ensures safe traffic flow while supporting future enhancements.

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Objective

The objective of this project is to design and implement a comprehensive traffic light control system using x86 Assembly Language (8086) that simulates real-world traffic management scenarios.

The system aims to:

1. **Automate Traffic Flow:** Regulate vehicular movement at a four-way intersection with synchronized North-South (NS) and East-West (EW) traffic lights
2. **Enhance Pedestrian Safety:** Provide dedicated pedestrian crossing phases with visual indicators and on-demand crossing requests
3. **Enable Emergency Response:** Implement emergency mode that overrides normal operation to facilitate emergency vehicle passage
4. **Adapt to Traffic Conditions:** Support rush hour mode with extended green time for main roads and reduced timing for side roads
5. **Provide Night Operation:** Include night mode with blinking yellow lights for reduced traffic hours
6. **Track Performance Metrics:** Monitor and display real-time statistics including cycle counts and estimated vehicle throughput
7. **Ensure User Control:** Allow operators to manually control system modes through keyboard inputs

This project demonstrates practical application of assembly language programming concepts including hardware I/O port communication, interrupt handling, timing mechanisms, and real-time system control.

Innovation/Modification

This traffic light control system incorporates several innovative features that distinguish it from conventional traffic management systems:

1. Multi-Mode Operation Framework

- **Normal Mode:** Standard traffic light cycling with configurable timing
- **Emergency Mode:** All-directional yellow flashing with audio alerts to clear intersection
- **Night Mode:** Blinking yellow caution lights for low-traffic hours (22:00-06:00)
- **Rush Hour Mode:** Adaptive timing that extends main road green time (8 seconds) while reducing side road duration (3 seconds)

2. Pedestrian-Centric Design

- **Dynamic Pedestrian Crossing:** Dedicated crossing phases synchronized with traffic lights
- **On-Demand Request System:** Pedestrian button functionality (P key) that extends green time by 3 additional seconds
- **Phase-Aware Processing:** Intelligent request handling that grants extensions only during appropriate green phases
- **Visual Feedback:** Color-coded pedestrian status messages (green for "CROSS", red for "STOP", yellow for "GET READY")

3. Real-Time Performance Monitoring

- **Cycle Counter:** Tracks total number of complete traffic light cycles
- **Vehicle Throughput Estimation:** Calculates approximate vehicles passed based on green light duration (2 cars per second model)
- **Separate NS/EW Statistics:** Independent tracking for North-South and East-West traffic flow
- **Live Timer Display:** Countdown timers showing remaining seconds for each direction

4. Safety-First Architecture

- **All-Red Safety Phase:** 5-second all-red interval before each cycle to clear intersection
- **Mandatory Yellow Transitions:** Yellow lights between green and red to prevent sudden stops
- **Emergency Override Priority:** Emergency mode can be activated instantly from any state
- **Mode Persistence:** System remembers previous mode when returning from emergency

5. User-Friendly Interface

- **Comprehensive Key Commands:** E (Emergency), N (Normal), P (Pedestrian), R (Rush Hour), M (Night), D (Day), ESC (Exit)
- **Color-Coded Status Messages:** Visual feedback using different colors for different alert types
- **Help Display:** Persistent control key reference at top of screen
- **Screen Management:** Auto-scrolling message display with overflow prevention

6. Hardware Integration

- **Port-Based Control:** Output to port 4 for physical LED control in simulation environments
- **Bit-Pattern Encoding:** Efficient 16-bit patterns to control 12 traffic lights (4 directions × 3 colors)
- **Audio Feedback:** System beeps during countdowns and emergency alerts
- **Real-Time Timing:** Precision timing using BIOS interrupt 15h for 1-second intervals

7. Technical Optimizations

- **Fixed Timing Bugs:** Corrected INT 15h microsecond delay calls with proper AL=0 initialization for DOSBox compatibility
- **16-bit Arithmetic:** Proper handling of multiplication operations to prevent overflow
- **Memory-Efficient Design:** Direct video memory access (0xB800) for fast screen updates
- **Modular Code Structure**: Well-organized subroutines for maintainability and debugging

Expected Input

Key	Function	Description
E	Emergency Mode	Activates emergency mode with flashing yellow lights
N	Normal Mode	Returns to normal traffic light operation
P	Pedestrian Request	Extends green light by 3 seconds (phase-dependent)
R	Rush Hour Toggle	Switches between normal (5s/5s) and rush hour (8s/3s) timing
M	Night Mode	Activates night mode with blinking yellow caution lights
D	Day Mode	Returns to daytime operation from night mode
Esc	Exit	Terminates the program gracefully

System Configuration (Internal Parameters)

- **Normal Timing:** 5 seconds green (NS), 5 seconds green (EW), 2 sec yellow
- **Rush Hour Timing:** 8 seconds green (main road), 3 seconds green (side road), 3 sec yellow
- **Safety Interval:** 5 seconds all-red between cycles
- **Pedestrian Extension:** +3 seconds when requested
- **Traffic Model:** 2 vehicles per second during green phases

Expected Output

Visual Display Components

[E=Emerg| N=Normal P=Ped |R=Rush |M=Night |D=Day |ESC=Exit]

Cycles: 15 | NS Cars: 150 | EW Cars: 120

NS: 5s   EW: 0s

1. Status Messages (Scrolling Display Area)

- **Traffic Phase Messages:**
  - ">>> Pedestrians can CROSS now from ALL sides" (Green)
  - ">>> ONLY North-South pedestrians can CROSS now" (Green)
  - ">>> ONLY East-West pedestrians can CROSS now" (Green)
  - "[X] Pedestrians on RED side MUST STOP and wait" (Red)
  - "... Pedestrians, GET READY to walk" (Yellow)
  - "... Prepare to STOP crossing" (Yellow)
- **Mode Change Messages:**
  - "!!! EMERGENCY MODE ACTIVE - ALL TRAFFIC STOP !!!" (Bright Red on Yellow)
  - ">>> Emergency cleared - Returning to previous mode" (Green)
  - "[RUSH HOUR MODE] Heavy traffic - Extended main road timing" (Yellow)
  - ">>> Rush hour ended - Normal timing restored" (Green)
  - "[NIGHT MODE] All lights BLINKING YELLOW - Drive carefully" (Yellow)
  - ">>> Late night hours - Reduced traffic - Stay alert" (Yellow)
  - ">>> Day mode activated - Normal operation" (Green)
- **Pedestrian Request Messages:**
  - "[P] Pedestrian crossing REQUESTED - Extending green time" (Cyan)
  - "[+3s] Extra time granted for pedestrians" (Yellow)
  - "[!] Pedestrian request denied (wrong phase)" (Red)

2. Hardware Output (Port 4)

16-bit Traffic Light Patterns:

- Bits 0-2: North (Red, Yellow, Green)
- Bits 3-5: South (Red, Yellow, Green)
- Bits 6-8: East (Red, Yellow, Green)
- Bits 9-11: West (Red, Yellow, Green)

Example Patterns:

- 0000_0011_0000_1100b - NS Green, EW Red
- 0000_0100_1001_0010b - All Yellow
- 0000_1000_0110_0001b - EW Green, NS Red
- 0000_0010_0100_1001b - All Red (safety phase)

3. Audio Feedback

- Beep on Countdown: One beep per second during all-red phase
- Emergency Alert: Rapid beeps during emergency mode flashing
- System Confirmation: Single beep on mode changes

4. Statistics Tracking

- Cycle Counter: Increments after each complete 4-phase cycle
- NS Vehicle Count: Updates based on NS green time × 2 vehicles/second
- EW Vehicle Count: Updates based on EW green time × 2 vehicles/second
- Real-Time Display: Updates continuously at top of screen

System Behavior Examples

Normal Operation Sequence:

1. All Red (5s) → NS Green (5s) → All Yellow (2s) → EW Green (5s) → All Yellow (2s) → Repeat
2. Total cycle time: 24 seconds
3. Estimated throughput: 10 vehicles (NS) + 10 vehicles (EW) = 20 vehicles per cycle

Emergency Mode:

- Immediate switch to flashing yellow (all directions)
- Audio alert with each flash
- All timers reset to 0
- Continues until 'N' key pressed

Pedestrian Request:

- Press 'P' during NS green → NS gets 8 seconds total (5 + 3)
- Press 'P' during yellow/red → Request denied with red message
- Visual confirmation of granted/denied status

Rush Hour Mode:

- Main road (NS): 8 sec-green
- Side road (EW): 3 sec-green
- Yellow transitions: 3 seconds
- Prioritizes main traffic flow

Technical Specifications

Development Environment

- Language: x86 Assembly (MASM/TASM syntax)
- Target Platform: DOS/DOSBox
- Assembler: MASM 5.0 or compatible
- Emulator: DOSBox 0.74+ or PCem

Hardware Requirements

- Processor: 8086/8088 or higher
- Memory: 64KB minimum
- I/O Port: Port 4 for traffic light control
- Display: 80×25 text mode (Mode 3)

Performance Characteristics

- Response Time: Instant (<100ms) for keyboard input
- Timing Accuracy: ±50ms per second (BIOS INT 15h dependent)
- Display Update: Real-time timer-refresh every second
- Memory Footprint: <10KB code + data

Conclusion

This Intelligent Traffic Light Control System represents a comprehensive solution for intersection management that balances efficiency, safety, and adaptability. By implementing multiple operational modes, pedestrian priority features, and real-time monitoring, the system demonstrates the practical application of low-level programming concepts to solve real-world problems. The project showcases proficiency in assembly language programming, hardware interfacing, timing control, and user interface design within resource-constrained embedded system environments.