

UDP Server Manager Architecture

Document Version: 2.0

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Target: UDP Server Manager v2.0+

Overview

This project is a modular Supervisor for managing UDP-connected devices. Each device type has its own worker, handler, and command dictionary, allowing for scalable and maintainable code. The application features a modern Qt-based GUI with advanced command management, real-time status monitoring, and multimedia capabilities.

System Architecture

High-Level Structure

```
UDP Server Manager
├── Application Layer (main.py)
├── UI Layer (app/ui/)
│   ├── Main Window (gui.py)
│   ├── Device Panel (device_panel.py)
│   ├── Message Creator Panel (message_creator_panel.py)
│   └── Status Panel (status_panel.py)
├── Core Layer (core/)
│   ├── UDP Networking (udp.py)
│   └── Workers (workers/)
│       └── Device-specific implementations
├── Shared Dictionaries (shared_dictionaries/)
│   └── Command Dictionaries (JSON)
├── Data (data/)
│   └── Server Configurations (servers.json)
```

Key Components

Application Core

- **main.py:** Application entry point
 - Loads server configurations from `data/servers.json`
 - Initializes GUI with server list and status icons
 - Manages application lifecycle
- **config.py:** Centralized configuration
 - Window dimensions and layout parameters
 - UI component sizes (interactive frame: 350px, status frame: 350px, logging frame: 200px)

- Styling constants for consistent UI appearance

Networking Layer

- **core/udp.py**: UDP networking engine
 - **UDPClientThread**: Worker thread for UDP communication
 - Single UDP socket per device for bidirectional communication
 - Automatic port binding and management
 - Thread-safe message queue and mailbox system
 - Signal-based communication with GUI

User Interface

The application features a three-tier vertical layout:

1. Interactive Frame (Top - 350px)

Layout: Three-column horizontal split

Left Column - Device Panel (**app/ui/device_panel.py**)

- Device selection dropdown by location
- Server list with status indicators
- Connection status visualization
- Width: 200px

Center Column - Message Creator Panel (**core/workers/capstanDrive/message_creator_panel.py**)

- **Hierarchical Command Menu System:**
 - Grouped flyout menus by command category:
 - Device Control (LED, HPL, STEPPER, ENCODER)
 - Device Status (GET_LED, GET_HPL, GET_STEPPER, GET_ENCODER, GET_ALL)
 - Error Handling (CLR_WARN, GET_ERROR_LOG, CLEAR_ERROR_LOG, etc.)
 - System Administration (SET_TIME, GET_TIME_STATUS)
 - Context-sensitive parameter display (up to 10 parameters)
 - Real-time message assembly
 - Dropdown-based enum selection
 - Type-validated input fields
 - Conditional parameter visibility based on command context

Right Column - Send/Reply Panel

- Send button for command transmission
- Request box showing sent commands
- Reply box displaying device responses
- Width: 200px

2. Status Frame (Middle - 350px) [NEW]

Component: **app/ui/status_panel.py**

The Status Panel provides two switchable display modes:

Table Mode:

- Two-column table (Item Name | Item Data)
- Sortable and searchable
- Alternating row colors for readability
- Dynamic content updates

Split Mode:

- Left: Text box for status messages and device information
- Right: Media display area supporting:
 - **Static Images:** PNG, JPG, BMP, GIF
 - **Video Playback:** MP4, AVI, MOV with full controls
 - Play/Pause/Stop buttons
 - Seekable timeline slider
 - Time display (current / total duration)
 - Aspect ratio preservation
 - **Network Streams:** HTTP/HTTPS/RTSP URLs (basic support)
 - **Future:** Live streaming from Raspberry Pi 4B devices

3. Logging Frame (Bottom - 200px)

- Read-only text area for application logs
- Auto-scroll to latest messages
- Timestamped entries
- UDP communication tracking

Worker/Handler Pattern

Each device type follows a modular pattern:

Structure:

```
core/workers/deviceType/  
├─ deviceType_worker.py      # Worker thread implementation  
├─ deviceType_handler.py    # Command execution logic  
├─ deviceType_config.py     # Device-specific constants  
├─ deviceType_commandDictionary.json # Command definitions  
└─ message_creator_panel.py  # Device-specific UI (optional)
```

Components:

- **Worker Thread:** Manages UDP communication and command routing
- **Handler:** Implements device-specific command logic
- **Config:** Device constants (timeouts, defaults, instance mappings)
- **Command Dictionary:** JSON-based command definitions with:
 - Command categories for menu organization

- Parameter specifications (type, range, conditions, units)
- Instance configurations
- Validation rules

Command Dictionary System

Command dictionaries are JSON files that define device capabilities:

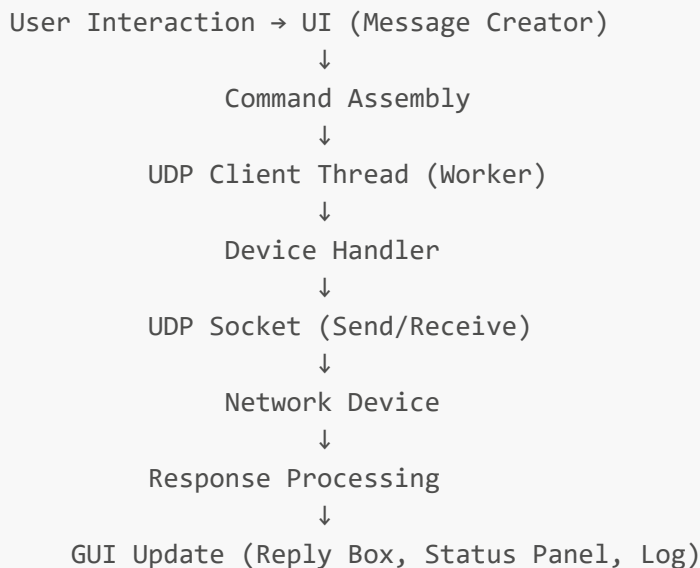
Structure:

```
{
  "categories": [
    "Device Control",
    "Device Status",
    "Error Handling",
    "System Administration"
  ],
  "commands": {
    "COMMAND_NAME": {
      "category": "Device Control",
      "description": "Command description",
      "param_count": 3,
      "parameters": [
        {
          "name": "param_name",
          "type": "enum|integer|float|boolean|string",
          "param_number": 1,
          "options": ["option1", "option2"],
          "condition": ["parent_param == value"],
          "range": {"min": 0, "max": 100},
          "units": "ms",
          "notes": "Additional information"
        }
      ],
      "function": "handler_function_name"
    }
  }
}
```

Features:

- Category-based command organization for hierarchical menus
- Conditional parameter display based on parent parameter values
- Type validation and range checking
- Unit specifications for clarity
- Enum-based options for controlled input

Communication Flow



Detailed Flow

1. Device Selection:

- User selects device from Device Panel
- GUI creates UDP worker thread for selected device
- Local ephemeral port assigned for bidirectional communication

2. Command Creation:

- User selects command from hierarchical menu
- Message Creator displays relevant parameters
- Real-time message assembly with validation

3. Message Transmission:

- User clicks SEND button
- Command queued in worker thread
- UDP packet sent to device
- Local port logged for response tracking

4. Response Handling:

- Worker thread receives UDP response on same socket
- Handler processes response
- GUI updated via Qt signals:
 - Reply box shows device response
 - Status panel updated with device state
 - Log panel records transaction

5. Status Display:

- Status Panel shows device information in table or split mode
- Video/images displayed for visual feedback

- Real-time updates as device state changes

Error Handling

Network Errors

- **Port Mismatch Detection:** Log analysis tools for debugging UDP port issues
- **Timeout Handling:** Configurable timeouts per command type
- **Retry Logic:** Automatic retry for transient network failures
- **Connection State Tracking:** Visual indicators for connection health

Command Errors

- **Validation:** Pre-send validation of parameters
- **Malformed Commands:** Handler-level error detection
- **Device Errors:** Error message parsing and display
- **Log Context:** Detailed error logging with stack traces

UI Error Handling

- **Graceful Degradation:** UI remains responsive during errors
- **User Feedback:** Clear error messages in appropriate UI panels
- **Recovery Options:** Retry mechanisms and connection reset

Extending the System

Adding a New Device Type

1. Create Worker Structure:

```
core/workers/newDevice/  
├── __init__.py  
├── newDevice_worker.py  
├── newDevice_handler.py  
├── newDevice_config.py  
├── newDevice_commandDictionary.json  
└── message_creator_panel.py (if custom UI needed)
```

2. Define Command Dictionary:

- Create JSON file with command definitions
- Organize commands into logical categories
- Specify parameters with types and validation rules

3. Implement Handler:

- Subclass base handler if available
- Implement command execution functions
- Add error handling and validation

4. Configure Server:

- Add entry to `data/servers.json`
- Specify device type, IP, port, and location

5. Test Integration:

- Start application and select new device
- Verify command menu population
- Test command execution and response handling

Customizing UI Components

Status Panel Customization:

```
# Add custom status display
main_window.update_status_table({
    'Device': 'NewDevice',
    'Status': 'Active',
    'Custom Field': 'Value'
})

# Display device image
main_window.update_status_image('path/to/device_image.png')

# Display instructional video
main_window.update_status_video('path/to/tutorial.mp4')
```

Message Creator Customization:

- Extend `MessageCreatorPanel` class for device-specific UI
- Override parameter rendering for custom controls
- Add device-specific validation logic

Performance Considerations

UI Responsiveness

- Worker threads prevent UI blocking during network operations
- Qt Signal/Slot mechanism for thread-safe GUI updates
- Lazy loading of command dictionaries
- Efficient message assembly algorithms

Network Optimization

- Single UDP socket per device reduces port consumption
- Configurable buffer sizes for different network conditions
- Ephemeral port binding for proper NAT traversal
- Minimal packet overhead in protocol design

Memory Management

- Bounded log buffer to prevent memory growth
- Cleanup of disconnected worker threads
- Efficient video decoding with Qt Multimedia hardware acceleration
- Resource release on application shutdown

Security Considerations

Current Implementation

- Local network operation assumed
- No authentication layer (devices trusted)
- Clear-text UDP communication

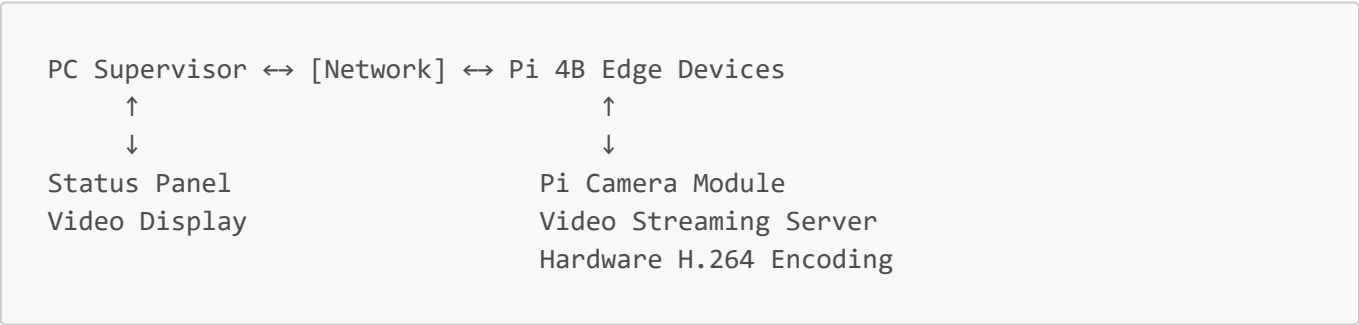
Future Enhancements (Raspberry Pi 4B Phase)

- Device authentication via shared secrets
- Encrypted UDP payloads (DTLS)
- Certificate-based device identification
- Access control lists for command authorization
- Secure video streaming (HTTPS/SRTP)

Future Architecture Evolution

Raspberry Pi 4B Integration

Planned Architecture:



Key Additions:

- Real-time video streaming from Pi Camera modules
- WebRTC support for ultra-low latency (<100ms)
- Multi-camera management and layout controls
- Stream health monitoring and auto-reconnection
- Recording capabilities for audit trails

See [docs/live_streaming_roadmap.md](#) for detailed planning.

Scalability Enhancements

- Support for multiple simultaneous devices

- Device discovery via mDNS/Bonjour
 - Command batching and macro support
 - Scriptable automation interface
 - REST API for third-party integration
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Related Documentation

- **UI Components:** See [docs/ui_components_guide.md](#) for detailed UI documentation
 - **Status Panel:** See [docs/status_panel_guide.md](#) for multimedia capabilities
 - **Command Menus:** See [docs/command_menu_system.md](#) for menu customization
 - **Usage Guide:** See [docs/usage.md](#) for end-user instructions
 - **Contributing:** See [docs/contributing.md](#) for development guidelines
 - **Live Streaming:** See [docs/live_streaming_roadmap.md](#) for future features
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