ARM EXOSKELETON REQUIREMENTS DOCUMENT

Project: "Iron Arm" - Single DOF Elbow Assist Exoskeleton
Version: 1.0
Purpose: For fun, learning, and demonstration

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1. FUNCTIONAL REQUIREMENTS

Primary Function

- **FR-01**: System SHALL provide assistive force to elbow flexion/extension motion
- **FR-02**: System SHALL amplify user input force by a configurable factor (1.5x to 3x)
- **FR-03**: System SHALL operate transparently when user is not applying force
- **FR-04**: System SHALL provide smooth, responsive assistance with <100ms delay

Control Requirements

- **FR-05**: System SHALL detect user intent through force sensing
- **FR-06**: System SHALL provide variable assist levels (low/medium/high)
- **FR-07**: System SHALL include emergency stop functionality
- **FR-08**: System SHALL have power on/off control

Range of Motion

- **FR-09**: System SHALL allow natural elbow motion from 0° to 120° flexion
- **FR-10**: System SHALL NOT restrict normal arm movement when unpowered
- **FR-11**: System SHALL accommodate shoulder motion without interference

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2. PERFORMANCE REQUIREMENTS

Mechanical Performance

- **PR-01**: Maximum assist force: 150N at forearm cuff
- **PR-02**: System backlash: <5° of joint angle
- **PR-03**: Mechanical efficiency: >70%
- **PR-04**: Operating noise level: <60dB at 1m distance

Electrical Performance

- **PR-05**: Battery life: Minimum 2 hours continuous operation
- **PR-06**: Control loop frequency: 100Hz minimum
- **PR-07**: System response time: <100ms from force input to assist output
- **PR-08**: Power consumption: <50W average, <100W peak

Dynamic Performance

- **PR-09**: System SHALL track user motion up to 180°/sec angular velocity
- **PR-10**: Force tracking accuracy: ±10N
- **PR-11**: Stable operation across full temperature range: 0°C to 40°C

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3. SAFETY REQUIREMENTS

Mechanical Safety

- **SF-01**: System SHALL include mechanical stops to prevent overextension
- **SF-02**: All user contact surfaces SHALL be padded and smooth
- **SF-03**: System SHALL fail to safe (unpowered) state on any fault
- **SF-04**: Maximum force output SHALL be software and hardware limited

Electrical Safety

- **SF-05**: System SHALL include emergency stop accessible during operation
- **SF-06**: Battery SHALL include overcharge/overdischarge protection
- **SF-07**: All electrical components SHALL be protected from user contact
- **SF-08**: System SHALL shut down if overheating detected

Control Safety

- **SF-09**: Force amplification SHALL have maximum limit (3x)
- **SF-10**: System SHALL timeout and stop if no user input for 30 seconds
- **SF-11**: System SHALL include watchdog timer for control system
- **SF-12**: All sensor failures SHALL result in safe shutdown

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4. PHYSICAL REQUIREMENTS

Size and Weight

- **PH-01**: Total system weight: <2.5kg
- **PH-02**: System SHALL fit users with arm length 55-75cm
- **PH-03**: Cuffs SHALL accommodate arm circumference 20-40cm
- **PH-04**: Maximum system width: <15cm from arm centerline

Ergonomics

- **PH-05**: System SHALL be donnable/doffable by user in <2 minutes
- **PH-06**: No pressure points or discomfort during 30-minute wear test
- **PH-07**: System weight distribution SHALL not cause user fatigue
- **PH-08**: All controls SHALL be accessible while wearing system

Durability

- **PH-09**: System SHALL withstand 1000 flex cycles without degradation
- **PH-10**: System SHALL survive 1m drop test when not worn
- **PH-11**: Water resistance: IP32 (protected against spraying water)

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5. INTERFACE REQUIREMENTS

User Interface

- **UI-01**: Power indicator (LED)
- **UI-02**: Battery level indicator (3-state LED or display)
- **UI-03**: Assist level indicator
- **UI-04**: Emergency stop button (red, prominent)
- **UI-05**: Mode selection (assist level adjustment)

Connectivity

- **UI-06**: USB-C charging port
- **UI-07**: Optional: Bluetooth connectivity for smartphone app
- **UI-08**: Optional: Data logging capability

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6. MANUFACTURING REQUIREMENTS

Materials

- **MF-01**: Frame components: 3D printable (PLA+/PETG)
- **MF-02**: Structural elements: Standard aluminum extrusion (20x20mm)
- **MF-03**: All fasteners: Stainless steel or aluminum
- **MF-04**: User contact materials: Soft, washable, hypoallergenic

Assembly

- **MF-05**: System SHALL be assemblable with common tools
- **MF-06**: No specialized manufacturing equipment required
- **MF-07**: All custom parts SHALL be 3D printable on 200x200mm bed
- **MF-08**: Assembly time: <8 hours for experienced maker

Cost

- **MF-09**: Target bill of materials cost: <$300
- **MF-10**: All components SHALL be available from standard suppliers

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7. TESTING REQUIREMENTS

Functional Testing

- **TS-01**: Force amplification accuracy test
- **TS-02**: Response time measurement
- **TS-03**: Battery life test
- **TS-04**: Range of motion verification

Safety Testing

- **TS-05**: Emergency stop function test
- **TS-06**: Maximum force limit test
- **TS-07**: Fault condition response test
- **TS-08**: Overload protection test

User Testing

- **TS-09**: Comfort test (30-minute wear)
- **TS-10**: Ease of use test (don/doff time)
- **TS-11**: User satisfaction survey

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8. SUCCESS CRITERIA

Minimum Viable Product (MVP)

- ✓ Provides noticeable force assistance
- ✓ Safe for operator use
- ✓ Operates for minimum battery life
- ✓ Meets basic ergonomic requirements

Stretch Goals

- ✓ Smartphone connectivity and control
- ✓ Data logging and analysis
- ✓ Multiple user profiles
- ✓ Advanced control algorithms (impedance control)

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9. CONSTRAINTS AND ASSUMPTIONS

Constraints

- **Budget**: Maximum $300 for materials
- **Timeline**: 3-6 months for complete build
- **Tools**: Standard maker tools (3D printer, basic electronics)
- **Experience**: Single builder with robotics background

Assumptions

- User has normal arm mobility and strength
- Indoor use environment
- Occasional use (not daily medical device)
- User can follow safety procedures

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10. ACCEPTANCE CRITERIA

The system will be considered complete when:

1. All functional requirements are met
2. All safety requirements are verified
3. User can safely don/doff and operate the system
4. System provides measurable force assistance
5. Documentation and user manual are complete

Sign-off: Ready for detailed design phase upon requirements approval.