IK System Architecture

Technical Documentation

Version 1.0

Inverse Kinematics Framework

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Contents

1 Introduction

The Inverse Kinematics (IK) system has been redesigned with the IK Context as the central API hub. This architecture provides a clean, ROS-like separation of concerns where IK Context manages all solver operations and TCP Context manages all end effector data including position, orientation, and link references.

1.1 Key Features

- TCP Context as single source of truth for end effector data
- Central IK Context for solver orchestration
- Automatic TCP tool integration
- Dynamic solver loading from `/public/IKSolvers/`
- Standardized solver interface with end effector link
- Real-time end effector tracking
- Extensible architecture for custom solvers

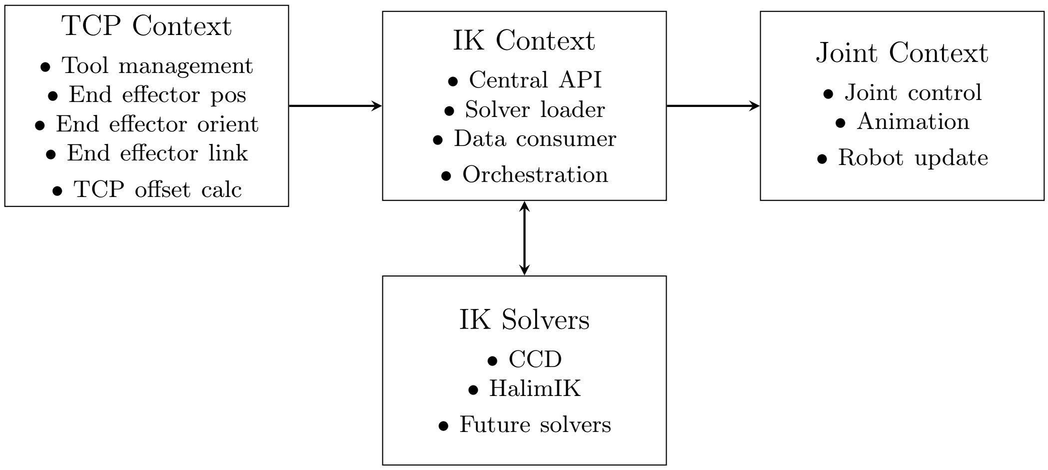
1.2 Design Principles

1. **Single Responsibility**: TCP Context manages all end effector data
2. **Centralized Control**: IK Context orchestrates solver operations
3. **TCP Transparency**: Tools work automatically without solver modifications
4. **Dynamic Loading**: Add solvers without recompiling
5. **Clean Interface**: Standardized solver API
6. **Performance Optimized**: Efficient data flow with caching

2 Architecture Overview

2.1 System Architecture

The IK system follows a hierarchical architecture with clear data flow:



2.2 Data Flow

The system implements a unidirectional data flow pattern:

1. **TCP Tool Attached**
   - TCP Context calculates offset
   - Stores end effector link reference
   - Emits `'tcp:endeffector-updated'`
   - IK Context receives update
   - Stores TCP-aware position and link
2. **IK Execution Request**
   - IK Context gets end effector data from TCP Context
   - Calls `solver.solve()` with complete data
   - Solver receives position, orientation, and link
   - Solver returns joint angles
   - IK Context emits to Joint Context
   - Joint Context animates robot

3 Core Components

3.1 TCP Context

The TCP Context serves as the single source of truth for all end effector data:

3.1.1 Responsibilities

- Tool attachment management
- End effector position calculation (with TCP offset)
- End effector orientation tracking
- End effector link identification and caching
- TCP offset calculations

3.1.2 Key Methods

Method	Description
`getCurrentEndEffectorPoint()`	Returns current end effector position with TCP offset
`getCurrentEndEffectorOrientation()`	Returns current end effector orientation
`getEndEffectorLink()`	Returns the robot's end effector link for kinematic chain
`attachTool()`	Attaches a TCP tool to robot
`removeTool()`	Removes TCP tool from robot

Table 1: TCP Context Core Methods

3.2 IK Context

The IK Context serves as the central orchestrator for all IK operations:

3.2.1 Responsibilities

- Dynamic solver loading
- Solver state management
- Data orchestration (consuming from TCP Context)
- Event coordination
- Animation control

3.2.2 Key Methods

Method	Description
`loadSolver()`	Dynamically loads IK solver from file
`executeIK()`	Executes IK calculation with current solver
`configureSolver()`	Updates solver configuration
`setCurrentSolver()`	Switches active solver
`stopAnimation()`	Halts ongoing IK animation

Table 2: IK Context Core Methods

3.3 Standardized Solver Interface

All IK solvers implement a standardized interface for consistency:

```
class IKSolver {
  static metadata = {
    name: "Solver Name",
    description: "Description",
    author: "Author Name",
    version: "1.0.0"
  };
```

```

  static defaultConfig = {
    // Solver-specific configuration
    maxIterations: 100,
    tolerance: 0.001
  };

  constructor(config = {}) {
    Object.assign(this, IKSolver.defaultConfig, config);
  }

  async solve(params) {
    const {
      robot,                // Robot model
      endEffectorLink,      // End effector link (from TCP Context)
      currentPosition,      // Current position (includes TCP)
      currentOrientation,   // Current orientation quaternion
      targetPosition,       // Target position
      targetOrientation     // Target orientation (euler angles)
    } = params;

    // Calculate joint angles
    const solution = this.calculateJointAngles();

    return solution; // { jointName: angle, ... }
  }
}

export default IKSolver;
```

Listing 1: IK Solver Interface

4 TCP Integration

4.1 Automatic TCP Handling

The TCP integration is completely transparent to users and solver developers:

4.1.1 Tool Attachment Flow

```
// User attaches a gripper tool
tcpContext.attachTool(robotId, 'gripper');

// TCP Context now provides:
// - Gripper tip position (with offset)
// - End effector orientation
// - End effector link reference

// IK automatically uses all TCP data
const { currentPosition, getEndEffectorLink } = useTCP();
// currentPosition includes gripper offset
// getEndEffectorLink returns cached link

```

```
// Execute IK - solver receives complete data
moveToTarget(targetPosition); // Solver gets TCP-aware data
```

Listing 2: TCP Tool Attachment Example

4.1.2 TCP State Management

State	Behavior
TCP Tool Attached	TCP Context provides tool tip position, orientation, and link
TCP Tool Hidden	TCP Context still provides tool data
TCP Tool Removed	TCP Context falls back to robot end effector
No TCP Tool	TCP Context provides robot's default end effector data

Table 3: TCP State Management

4.2 Event Flow

The system uses events for loose coupling between contexts:

```
// TCP Context emits when tool state changes
EventBus.emit('tcp:endeffector-updated', {
  robotId: 'ur5_robot',
  endEffectorPoint: { x: 0.5, y: 0.3, z: 0.8 },
  endEffectorOrientation: { x: 0, y: 0, z: 0, w: 1 },
  hasTCP: true
});

// IK Context listens and updates automatically
EventBus.on('tcp:endeffector-updated', (data) => {
  if (data.robotId === activeRobotId) {
    updateEndEffectorPosition(data.endEffectorPoint);
    updateEndEffectorOrientation(data.endEffectorOrientation);
  }
});
```

Listing 3: TCP Event Flow

5 Creating IK Solvers

5.1 Solver Development Guide

Creating a new IK solver involves implementing the standardized interface:

5.1.1 Step 1: Create Solver File

Create a new file in `/public/IKSolvers/YourSolver.jsx`:

```
import * as THREE from 'three';

class YourSolver {
  static metadata = {
```

```
    name: "Your Solver Name",
    description: "What your solver does",
    author: "Your Name",
    version: "1.0.0"
  };

  static defaultConfig = {
    maxIterations: 100,
    tolerance: 0.001,
    // Add your custom parameters
    customParam1: 1.0,
    customParam2: true
  };

  constructor(config = {}) {
    Object.assign(this, YourSolver.defaultConfig, config);

    // Initialize reusable objects
    this.tempVector = new THREE.Vector3();
    this.tempQuaternion = new THREE.Quaternion();
  }

  // Optional: Configuration methods
  getConfig() {
    return {
      maxIterations: this.maxIterations,
      tolerance: this.tolerance,
      customParam1: this.customParam1,
      customParam2: this.customParam2
    };
  }

  configure(config) {
    Object.assign(this, config);
  }

  async solve(params) {
    const {
      robot,
      endEffectorLink,    // Provided by IK Context (from TCP)
      currentPosition,    // Already includes TCP offset!
      currentOrientation,
      targetPosition,
      targetOrientation
    } = params;

    // Validate inputs
    if (!robot || !robot.joints) {
      console.error('[YourSolver] Invalid robot model');
      return null;
    }

    if (!endEffectorLink) {
      console.error('[YourSolver] End effector link not provided');
      return null;
    }
```

```

    // Your IK algorithm implementation
    const solution = this.calculateSolution(params);

    return solution; // { joint1: angle1, joint2: angle2, ... }
  }

  // Private helper methods
  calculateSolution(params) {
    // Implementation details
    const jointAngles = {};

    // Calculate joint angles...

    return jointAngles;
  }
}

export default YourSolver;
```

Listing 4: Custom IK Solver Template

5.1.2 Step 2: Solver Best Practices

1. **Use Provided Data**: Use `currentPosition`, `currentOrientation`, and `endEffectorLink`
2. **Don't Find Links**: The end effector link is provided - don't search for it
3. **Return Joint Map**: Return an object mapping joint names to angles
4. **Handle Errors**: Return `null` if no solution found
5. **Optimize Performance**: Use reusable objects to reduce garbage collection
6. **Document Configuration**: Clearly document all configuration parameters

5.1.3 Step 3: Testing Your Solver

```
// Configure and test your solver
const { configureSolver, setCurrentSolver } = useIK();

// Select your solver
setCurrentSolver('YourSolver');

// Configure parameters
configureSolver('YourSolver', {
  maxIterations: 200,
  customParam1: 0.5
});

// Test execution
moveToTarget(targetPosition);
```

Listing 5: Testing Custom Solver

6 API Reference

6.1 useIK Hook

The `useIK()` hook provides a clean interface for IK operations:

Property/Method	Description
State Properties	
`currentPosition`	Current end effector position (TCP-aware)
`currentOrientation`	Current orientation quaternion
`targetPosition`	Target position for IK
`targetOrientation`	Target orientation for IK
`isAnimating`	Animation in progress flag
`solverStatus`	Current solver status message
`currentSolver`	Active solver name
`availableSolvers`	List of available solver names
Methods	
`setTargetPosition()`	Set target position
`setTargetOrientation()`	Set target orientation
`setCurrentSolver()`	Change active solver
`moveToTarget()`	Execute IK to target
`moveRelative()`	Move relative to current
`rotateRelative()`	Rotate relative to current
`syncTargetToCurrent()`	Sync target with current position
`stopAnimation()`	Stop current animation
`configureSolver()`	Configure solver parameters
`getSolverSettings()`	Get current solver settings

Table 4: useIK Hook API Reference

6.2 useTCP Hook

The `useTCP()` hook provides access to all end effector data:

Property/Method	Description
State Properties	
`currentEndEffectorPoint`	Current position with TCP offset
`currentEndEffectorOrientation`	Current orientation quaternion
`hasTool`	Whether a TCP tool is attached
`currentTool`	Current tool information
Methods	
`getEndEffectorLink()`	Get robot's end effector link
`attachTool()`	Attach TCP tool to robot
`removeTool()`	Remove TCP tool from robot
`setToolTransform()`	Update tool transform

Table 5: useTCP Hook API Reference

6.3 Event Reference

6.3.1 IK Context Listens For

Event	Description
`'tcp:endeffector-updated'`	Updates end effector position with TCP data
`'ik:animation-complete'`	Animation finished notification
`'joint:stop-animation'`	Stop animation request

Table 6: IK Context Input Events

6.3.2 IK Context Emits

Event	Description
`'ik:joint-values-calculated'`	Sends calculated joint values to Joint Context
`'joint:stop-animation'`	Requests animation stop from Joint Context

Table 7: IK Context Output Events

7 Benefits and Features

7.1 Architectural Benefits

1. **Single Responsibility**: TCP Context manages all end effector data
2. **Clean Separation**: IK Context focuses on solver orchestration
3. **TCP Transparency**: Tools work automatically without solver awareness
4. **Dynamic Loading**: Add new solvers without recompiling
5. **Consistent Interface**: Standardized solver API with end effector link
6. **Better Testing**: Isolated components are easier to test
7. **Easy Extension**: Drop in new solver files to extend functionality

7.2 Performance Optimizations

- End effector link cached in `robot.userData` for fast access
- Reusable object pools in solvers reduce garbage collection
- Efficient event-based communication between contexts
- Single calculation of end effector data per IK execution
- Optimized matrix operations using Three.js utilities

8 Example Usage

8.1 Basic IK Controller

```
function IKController() {
  const {
    currentPosition,
    targetPosition,
    moveToTarget,
    isAnimating,
    currentSolver,
    setCurrentSolver,
    availableSolvers
  } = useIK();

  const handleMove = () => {
    // IK automatically uses TCP position if tool attached
    moveToTarget(true); // Animate to target
  };

  return (
    <div className="ik-controller">
      <div className="status">
        <p>Current Position:
          X: {currentPosition.x.toFixed(3)},
          Y: {currentPosition.y.toFixed(3)},
          Z: {currentPosition.z.toFixed(3)}
        </p>
        <p>Active Solver: {currentSolver}</p>
      </div>

      <select
        value={currentSolver}
        onChange={(e) => setCurrentSolver(e.target.value)}
      >
        {availableSolvers.map(solver => (
          <option key={solver} value={solver}>{solver}</option>
        ))}
      </select>

      <button onClick={handleMove} disabled={isAnimating}>
        Move to Target
      </button>
    </div>
  );
}
```

Listing 6: IK Controller Implementation

8.2 Advanced Configuration

```
function AdvancedIKControl() {
  const {
    configureSolver,
```

```
    getSolverSettings,
    currentSolver,
    moveToTarget,
    setTargetOrientation
  } = useIK();

  const settings = getSolverSettings(currentSolver);

  const updateSolverConfig = (key, value) => {
    configureSolver(currentSolver, {
      ...settings,
      [key]: value
    });
  };

  const executeWithOrientation = () => {
    // Set target orientation
    setTargetOrientation({
      roll: 0,
      pitch: Math.PI / 4,  // 45 degrees
      yaw: 0
    });

    // Execute IK with orientation
    moveToTarget(true);
  };

  return (
    <div>
      {Object.entries(settings).map(([key, value]) => (
        <div key={key}>
          <label>{key}:</label>
          <input
            type="number"
            value={value}
            onChange={(e) => updateSolverConfig(key, parseFloat(e.
                target.value))}
          />
        </div>
      ))}

      <button onClick={executeWithOrientation}>
        Move with Orientation
      </button>
    </div>
  );
}
```

Listing 7: Advanced IK Configuration