空间机器人：建模、规划与控制（P81）

D-H参数表:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 连杆i | θ/° | α/° | a/m | d/m |
| 1 | 0 | -90 | 0 | d1 |
| 2 | -90 | 0 | a2 | 0 |
| 3 | 0 | -90 | 0 | 0 |
| 4 | 0 | 90 | 0 | d4 |
| 5 | 0 | -90 | 0 | 0 |
| 6 | 0 | 0 | 0 | d6 |

a2

d6

d4

d1

z1

y1

x1

x6

y6

y5

z2

y4(z5)

x4(x5)

y3

y2(z3)

x2(x3)

1. zi-1和zi不平行不相交，取公垂线方向为x轴，方向为i-1轴指向i轴，共垂线与zi轴的交点定为坐标系{i}的原点
2. zi-1和zi平行，公垂线无数条，取与前一条公垂线共线的为x轴，方向为i-1轴指向i轴，共垂线与zi轴的交点定为坐标系{i}的原点
3. zi-1和zi相交，取zi-1和zi向量积的方向为xi轴，zi-1和zi的交点作为坐标系的{i}原点

z6

z4

x0

y0

z0

（P85）相邻连杆坐标系间的位姿关系

(i-1) T (i) =

|  |  |  |  |
| --- | --- | --- | --- |
| Cos(θi) | -Sin(θi)Cos(αi) | Sin(θi)Sin(αi) | ai\*Cos(θi) |
| Sin(θi) | Cos(θi)Cos(αi) | -Cos(θi)Sin(αi) | ai\*Sin(θi) |
| 0 | Sin(αi) | Cos(αi) | di |
| 0 | 0 | 0 | 1 |

计算：(0) T (6) = A1\*A2\*A3\*A4\*A5\*A6

(0) T (1) =

|  |  |  |  |
| --- | --- | --- | --- |
| c1 | 0 | -s1 | 0 |
| s1 | 0 | c1 | 0 |
| 0 | -1 | 0 | d1 |
| 0 | 0 | 0 | 1 |

(1) T (2) =

|  |  |  |  |
| --- | --- | --- | --- |
| c2 | -s2 | 0 | a2c2 |
| s2 | c2 | 0 | a2s2 |
| 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 |

(2) T (3) =

|  |  |  |  |
| --- | --- | --- | --- |
| c3 | 0 | -s3 | 0 |
| s3 | 0 | c3 | 0 |
| 0 | -1 | 0 | 0 |
| 0 | 0 | 0 | 1 |

(3) T (4) =

|  |  |  |  |
| --- | --- | --- | --- |
| c4 | 0 | s4 | 0 |
| s4 | 0 | -c4 | 0 |
| 0 | 1 | 0 | d4 |
| 0 | 0 | 0 | 1 |

(4) T (5) =

|  |  |  |  |
| --- | --- | --- | --- |
| c5 | 0 | -s5 | 0 |
| s5 | 0 | c5 | 0 |
| 0 | -1 | 0 | 0 |
| 0 | 0 | 0 | 1 |

(5) T (6) =

|  |  |  |  |
| --- | --- | --- | --- |
| c6 | -s6 | 0 | 0 |
| s6 | c6 | 0 | 0 |
| 0 | 0 | 1 | d6 |
| 0 | 0 | 0 | 1 |

计算中间结果：

(4)T(6) = (4)T(5) \* (5)T(6)

|  |  |  |  |
| --- | --- | --- | --- |
| c5c6 | -c5s6 | -s5 | -s5d6 |
| s5c6 | -s5s6 | c5 | c5d6 |
| -s6 | -c6 | 0 | 0 |
| 0 | 0 | 0 | 1 |

(3)T(6) = (3)T(4)\*(4)T(6)

|  |  |  |  |
| --- | --- | --- | --- |
| c4c5c6 - s4s6 | -c4c5s6 – s4c6 | -c4s5 | -c4s5d6 |
| s4c5c6 + c4s6 | -s4c5s6 + c4c6 | -s4s5 | -s4s5d6 |
| s5c6 | -s5s6 | c5 | c5d6 + d4 |
| 0 | 0 | 0 | 1 |

(1)T(3) = (1)T(2)\*(2)T(3)

|  |  |  |  |
| --- | --- | --- | --- |
| c23 | 0 | -s23 | a2c2 |
| s23 | 0 | c23 | a2s2 |
| 0 | -1 | 0 | 0 |
| 0 | 0 | 0 | 1 |

(1)T(6) = (1)T(3)\*(3)T(6)

|  |  |  |  |
| --- | --- | --- | --- |
| c23(c4c5c6 - s4s6) – s23s5c6 | c23(-c4c5s6 – s4c6) + s23s5s6 | -c23c4s5 - s23c5 | -c23c4s5d6 – s23 (c5d6 + d4) + a2c2 |
| s23(c4c5c6 - s4s6) + c23s5c6 | s23(-c4c5s6 – s4c6) – c23s5s6 | -s23c4s5 + c23c5 | -s23c4s5d6+c23(c5d6 + d4) + a2s2 |
| -s4c5c6 - c4s6 | s4c5s6 - c4c6 | s4s5 | s4s5d6 |
| 0 | 0 | 0 | 1 |

(0)T(1)

|  |  |  |  |
| --- | --- | --- | --- |
| c1 | 0 | -s1 | 0 |
| s1 | 0 | c1 | 0 |
| 0 | -1 | 0 | d1 |
| 0 | 0 | 0 | 1 |

令(1)T(6) = [a b c d; e f g h; i j k l; 0 0 0 1;]

(0)T(6) = (0)T(1)\*(1)T(6)

T(1,1) = c1\*a - s1\*i T(1,2) = c1\*b - s1\*j

T(1,3) = c1\*c - s1\*k T(1,4) = c1\*d - s1\*l

T(2,1) = s1\*a + c1\*i T(2,2) =s1\*b + c1\*j

T(2,3) = s1\*c + c1\*k T(2,4) =s1\*d + c1\*l

T(3,1) = -e T(3,2) = -f T(3,3) = -g T(3,4) = -h+d1

T(4,4) = 1