Motion specification algorithms for both platform and arms of a mobile robot for planetary research

I Nanyageev1,2, I Shardyko1, I Dalyaev1

1The Russian State Scientific Center for Robotics and Technical Cybernetics (RTC), Saint-Petersburg, Russia

iliasnan@yandex.ru

Abstract. This article describes some aspects of the control system design for a four-wheel mobile platform with individual wheel-steering equipped with two redundant robotic arms. The considered control issues include different ways of platform maneuvering as well as a solution of inverse kinematics problem for a redundant arm with an original approach to redundancy resolution depending on operator’s intention.

1. Introduction

Nowadays there is a clear tendency that the interest for Moon research has revived. There is an active discussion on this topic in Russia as well and some preliminary studies are being conducted. One potential concept of a moon rover was presented as a result of the study [1]. 3d model of this rover for moon exploration showed in figure 1a.

(a) (b)

Figure 1. Design concept of a moon rover.
The chassis of a moon rover consist of four motor-wheels that are connected with the platform through a 2-DoF walking mechanism. Each wheel has the ability to rotate about vertical axis independently of three other wheels. This feature is important for control of curvilinear motion and for maneuverability of the moon rover.

The moon rover has two 7-DoF manipulator arms for execution of different tasks on the Moon surface, which are placed on the front side of the rover. Each pair of adjacent joints have axes that are perpendicular to each other. The root joints axes are located in a plane that is perpendicular to the forward direction of the rover (figure 1b).

2. Moon rover maneuvering algorithm

Independent rotation of each motor-wheel makes it possible to implement a number of different motion strategies (see figure 2). However, this feature has one important restriction: the direction of the force produced by each motor-wheel must be kinematically compatible with direction of the force produced by other wheels to avoid the chassis destruction.

![Figure 2. Different strategies of moon rover motion.](image)
In this paper five strategies of kinematically compatible movements are considered:

- **Car-turn**: only the wheels on the front axis turn (figure 2a). This mode is the basic mode associated with the forward motion of the rover.
- **Rear-wheels turn**: this time only the wheels of the rear axis turn (figure 2b). This mode is convenient for the case of backward motion of the rover.
- **Counter-directed turn**: of the wheels of front and rear axes (figure 2c). This mode decreases the turning radius of the rover and increases maneuverability.
- **Co-directed turn**: of the wheels of front and rear axes (figure 2d). This mode makes it possible to combine forward or backward motion of the rover with its lateral displacement.
- **Skid-steering**: This mode is based on the speed difference of the left and right sides of the moon rover.

### 3. IK solution for manipulator

Effective employment of the moon rover needs some convenient approach to control the 7DoF robotic arms. The paramount importance presents the TCP motion of each arm, that happens in Cartesian space and represents the major task for control system, however, the primary source of movement is the set of electric motors located within the joints, and the joints positions constitute a vector of generalized coordinates for both arms. Thus, it becomes necessary to solve inverse kinematic (IK) task for each robotic arm. IK solution proposed in this paper is based on the numeric Levenberg–Marquardt algorithm [2] with minimum norm of joints speed as a criterion. This part of the solution is implemented with functions of Orocos kinematic and dynamic library [3].

The manipulator has one redundant degree of freedom and, consequently, the equation for IK solution can be written as:

\[
q_{\text{result}} = IK_{\text{LMA}}(\text{cartPose}) + S_T \cdot q_{\text{zero}} = IK_{\text{LMA}}(\text{cartPose}) + S_T \cdot s \cdot Z
\]

where \(q_{\text{result}}\) is the combination of a minimum-norm solution for target pose and some solution that optimizes intermediate joints configuration,

\(IK_{\text{LMA}}(\text{cartPose})\) is the Levenberg–Marquardt algorithm function for pose \(\text{cartPose}\) in Cartesian space,

\(Z\) is the null-space basis obtained from singular value decomposition of Jacobian matrix corresponding to the given configuration of an appropriate arm [4],

\(s > 0\) is a factor, characterizing motion rate in the null-space,

\(S_T\) is a factor (a sign), that determines the direction of null-space motion generated by a control marker. The control marker is an object in the 3D-scene, which is a part of the user interface. The motion of this object determines the direction of joints rotation while maintaining constant TCP position. A algorithm to determine this sign is described further in the paper.

The moon rover can be represented with an abstraction called simplified tree structure (STS), that is described in [5]. Thus, considering a situation when both robotic arms are operating with the same payload, IK solution can be found with appropriate algorithms from [5].

### 4. The determination of the direction of null-space motion

In most scenarios of potential application of the moon rover, TCP of both arms are located in front of the plane UV defined in figure 3a or behind this plane (figure 3b) due to rover layout, i.e. mounting of the arms. The location of UV plane is defined by the common axis of the root joints and the fact that the plane is orthogonal to the forward direction of the platform. Therefore, it is more convenient to set the direction of the null-space motion by moving the control marker, which frame is connected to the output of the fourth (elbow) joint, because the spatial motion range for this joint is the greatest in comparison with the others.
In most cases, the desired direction defined by the control marker reflects one of the following semantics: 1) motion of the elbow in the direction towards the forward axis of the rover (along vector $T$) or 2) motion of the elbow out of the axis (along vector $F$).

5. Searching for user-desired arm configuration
From equation (1) it follows that the desired direction of null-space motion depends only on the sign $S_T$. At the same time, the desired direction should be intuitive for moon rover’s operator when he moves the control marker. Special metric was developed to find the sign value, that is based on the current pose of the control marker. For this purpose, vector $A$ is defined as vector rigidly connected with the control marker but which is also collinear with the rotation axis of the elbow joint, see figure 4a.
The convenient geometrical representation of the chosen metric is angle $\alpha$, in accordance with figure 4. This angle is essentially the angle of rotation of vector $U$ to vector $B$ in clockwise direction where vector $B$ is the projection of vector $A$ on UV plane.

A number of factors influence the direction of null-space motion, which were identified empirically from simulation of the typical application scenarios:

- the sign of the first element of the null-space basis vector:
  $$S_1 = \text{sign}(Z(1))$$  \hspace{1cm} (2)

- parity (equality of signs) of the first and fifth elements of the null-space basis vector:
  $$S_2 = \begin{cases} 
1, & \text{sign}(Z(1)) = \text{sign}(Z(5)) \\
-1, & \text{sign}(Z(1)) \neq \text{sign}(Z(5)) 
\end{cases}$$  \hspace{1cm} (3)

- direction of motion commanded by the rover’s operator $S_3$: value «1» corresponds to the case when the operator moves the elbow towards the forward axis of the rover (the control marker is moved along vector $T$, see figure 3a), while value «-1» corresponds to the opposite direction (the control marker is moved along vector $F$, figure 3a).

- current pose of the control marker, specified by the angle $\alpha$:
  $$S_4 = \begin{cases} 
1, & \alpha \geq 180^\circ \\
-1, & \alpha < 180^\circ 
\end{cases}$$  \hspace{1cm} (4)

Finally, $ST$ can be defined as:
$$S_T = S_1 \cdot S_2 \cdot S_3 \cdot S_4$$  \hspace{1cm} (5)

The presented algorithm was validated by extensive tests of the robot manipulations in simulation. There were none cases when the arm moved against the operator expectations.

6. Conclusion

In this paper the control aspects were considered for a complex system that includes the mobile platform and the manipulation system comprising two robotic arms. The presence of independent wheel steering drives allows implementation of various strategies to perform the turn of the platform, each of strategies has some advantages in certain situations. An original configuration management mechanism for IK solution of the single redundant manipulator was presented. Described techniques can be used on other mobile platforms of a similar design and IK solution can also be used on any stationary manipulation systems. Based on the developed algorithms, it is planned to find and implement a mechanism for description and execution of the scripts for the autonomous functioning of mobile manipulation systems.

References

[1] Vasiliev A V, Sergeev A V 2019 Development of requirements for a ground testbed for modeling and research of remote control technologies for a small exploration lunar rover (Saint-Petersburg: THE 30th INTERNATIONAL SCIENTIFIC AND TECHNOLOGICAL CONFERENCE «EXTREME ROBOTICS-2019»)

[2] Noceald J, Wright S 1999 Numerical Optimization vol 1 (New York: Springer) pp 173-195

[3] Orocos KDL. URL: http://docs.ros.org/jade/api/orocos_kdl/html/index.html

[4] Vidyasagar M, Spong M 1989 Robot dynamics and control Wiley

[5] Shardyko I, Nanyageev I, Dalyaev I 2020 Inverse Kinematics Solution for Robots with Simplified Tree Structure and 5-DoF Robot Arms Lacking Wrist Yaw Joint Proc. of 14th Int. Conf. on Electromechanics and Robotics “Zavalishin's Readings” (Singapure:Springer) pp 113-124

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