# Fundamental Study on Design and Control of an All-Directional Mobile Robot for Advanced Mobility on Agricultural Field

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## Introduction

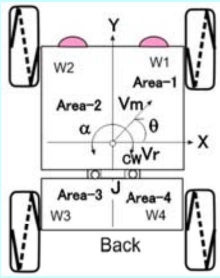



Figure 1: Structural design

This research proposes a new robot design and control for making the robot move to all-directions by the signals from a joystick of 3-DOFs. The robot is free to move on unstructured terrain by the operation of the joystick, even on such unstructured terrain including sandy or muddy area encountering on the agricultural field, in general. Main contents are in robot design, generation of synchronized signals to four driving motors, manufacturing and assembly of the prototype robot, and laboratory experiments to verify the motion to all-directions. In the robot design, wheel threads and arrangement of four wheels are discussed as shown in Fig. 1.

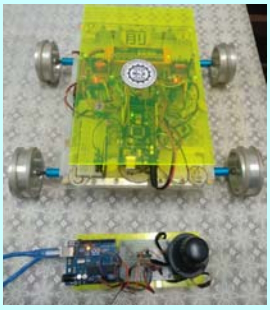


Figure 2: Proposed system

In the signal processing, three raw signals from the joystick are integrated to generate four signals to drive motors synchronously as shown in Fig. 2.

Figure 3: Simple swing joint

As shown in Fig. 3, a simple rotation joint for flexible swing between front and rear body parts is attached at the beneath of the robot frame. It behaves as a vehicular suspension to adapt the robot stand with four points on any shape of the ground.

## Design

Threads on each wheel are designed so that each behaves without influence of wheel angles. Fig.4 shows that the wheel is designed assigning such parameters that r; radius of the outer diameter of wheel, W; wheel width, β; inclination angle of the thread, n; number of threads on the wheel periphery, i.e., natural number, and L; initial thread pitch, and L'; final thread pitch.

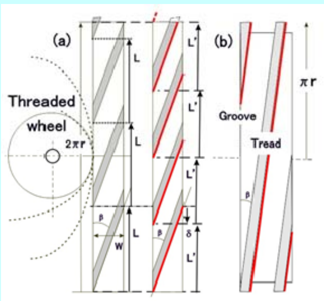



Figure 4: Design of the screw thread on the wheel periphery

$$L = W / \tan\beta$$
$$\delta = \left(nL - 2\pi r\right)/n$$

| Description | Value |
|---|---|
| Radius of the wheel, r | 40 mm |
| No. of threads on the wheel periphery, n | 1 |
| Width of the wheel, W | 40 mm |
| Thread inclination angle, β | 6.8˚ |
| Pitch length, δ | 0.0 |
| Initial thread Pitch, L | 251.32 mm |
| Final thread pitch, L' | 251.32 mm |

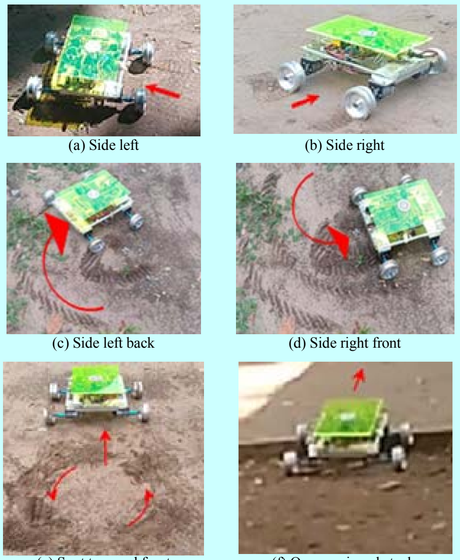
Table 1: Decision rules of driving four motors using joystick

| | 3 DOF Joystick | | | | | | Action | | | Motor 1 | | Motor 2 | | Motor 3 | | Motor 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X-angle | | Y-angle | | Center-axis | | | | | | | | | | | | |
| Area | X(+) | X(–) | Y(+) | Y(–) | S(+) | S(–) | Motion | Direction | Speed | W1 | Speed | W2 | Speed | W3 | Speed | W4 | Speed |
| Y | 0 | 0 | 1 | 0 | 0 | 0 | Front | 90˚ | Vm | Df | Y(+) | Df | Y(+) | Df | Y(+) | Df | Y(+) |
| –Y | 0 | 0 | 0 | 1 | 0 | 0 | Back | 270˚ | Vm | Db | Y(–) | Db | Y(–) | Db | Y(–) | Db | Y(–) |
| X | 1 | 0 | 0 | 0 | 0 | 0 | Right | 0˚ | Vm | Db | X(–) | Df | X(+) | Db | X(–) | Df | X(+) |
| –X | 0 | 1 | 0 | 0 | 0 | 0 | Left | 180˚ | Vm | Df | X(+) | Db | X(–) | Df | X(+) | Db | X(–) |
| +S | 0 | 0 | 0 | 0 | 1 | 0 | Spin (CW) | CW | Vs | Db | S(–) | Df | S(+) | Df | S(+) | Db | S(–) |
| –S | 0 | 0 | 0 | 0 | 0 | 1 | Spin (CCW) | CCW | Vs | Df | S(+) | Db | S(–) | Db | S(–) | Df | S(+) |
| (1) | 1 | 0 | 1 | 0 | 0 | 0 | Omni-Area1 | θ | Vm | Df | V | Df | V* | Df | V | Df | V* |
| | ▮ | ▮ | ▮ | ▮ | 1 | 0 | | θ+S(CW) | Vm, Vs | Df | V–S(–) | Df | V*+S(+) | Df | V+S(+) | Df | V*–S(–) |
| | ▮ | ▮ | ▮ | ▮ | 0 | 1 | | θ+S(CCW) | Vm, Vs | Df | V+S(+) | Df | V*–S(–) | Df | V–S(–) | Df | V*+S(+) |
| (2) | 0 | 1 | 1 | 0 | 0 | 0 | Omni Area2 | θ | Vm | Df | V* | Df | V | Df | V* | Df | V |
| | ▮ | ▮ | ▮ | ▮ | 1 | 0 | | θ+S(CW) | Vm, Vs | Df | V*–S(–) | Df | V+S(+) | Df | V*+S(+) | Df | V–S(–) |
| | ▮ | ▮ | ▮ | ▮ | 0 | 1 | | θ+S(CCW) | Vm, Vs | Df | V*+S(+) | Df | V–S(–) | Df | V*–S(–) | Df | V+S(+) |
| (3) | 0 | 1 | 0 | 1 | 0 | 0 | Omni-Area3 | θ | Vm | Db | V | Db | V* | Db | V | Db | V* |
| | ▮ | ▮ | ▮ | ▮ | 1 | 0 | | θ+S(CW) | Vm, Vs | Db | V–S(–) | Db | V*+S(+) | Db | V+S(+) | Db | V*–S(–) |
| | ▮ | ▮ | ▮ | ▮ | 0 | 1 | | θ+S(CCW) | Vm, Vs | Db | V+S(+) | Db | V*–S(–) | Db | V–S(–) | Db | V*+S(+) |
| (4) | 1 | 0 | 0 | 1 | 0 | 0 | Omni Area4 | θ | Vm | Db | V* | Db | V | Db | V* | Db | V |
| | ▮ | ▮ | ▮ | ▮ | 1 | 0 | | θ+S(CW) | Vm, Vs | Db | V*–S(–) | Db | V+S(+) | Db | V*+S(+) | Db | V–S(–) |
| | ▮ | ▮ | ▮ | ▮ | 0 | 1 | | θ+S(CCW) | Vm, Vs | Db | V+S(+) | Db | V*–S(–) | Db | V–S(–) | Db | V*+S(+) |

## Experiments

The mobile vehicle is controlled by the joystick remote controller as illustrated in Table 1, and tested on sandy ground. The robot motion error can be quickly cancelled when control results are monitored visually by the driver. In the experiment, we show that the skid-steering vehicle using screw-threaded wheels are beneficial to make a quick change of both positional and directional displacements for pursuing mobility on unstructured ground like an agricultural field.

- ► Df ; Forward driving = (+),
- ► Db ; Backward driving = (–),
- ► V < V* (V*–V means additional voltage depending on the screw pitch),
- ► ±S means additional signals for the linear motion with spinning



(a) Side left
(b) Side right
(c) Side left back
(d) Side right front
(e) Spot turn and front
(f) Overcoming obstacle

Figure 5: Experimental demonstrations

As shown in Figs.5(a) and 5(b), the vehicle can move forward/backward and laterally with skipping the screw-threaded wheels. Also, just a small joystick change in the horizontal and spin angles made the vehicle move side backing as shown in Figs.5(c) and 5(d). Furthermore, the vehicle can make a pivot turn and then move forward or any direction as shown in Fig.5(e), and overcome obstacles along its path by a self-gripping enabled by the side edge of the thread on the suspended wheel as shown in Fig.5(f). Then, the experimental results verify the usefulness of the skid-steering vehicle driven by screw-thread wheels. A swing joint beneath the robot body worked well to make the robot adapt to any rough or bumpy terrains after various experiments on different grounds.

## Conclusions

According to the experimental demonstrations, the robot can move linearly with a small directional change that are difficult by traditional mobile robots, and easily escape from being buried in the case when the wheels dig the sandy or muddy soil. Our future work is to clarify the influences of the thread pitch and the weight distribution on four wheels for formulation in the signal generator.

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