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The Design of a Mother Robot for Marsupial Robotic System

Peng Zhao, Zhiqiang Cao, Lingyi Xu, Chao Zhou
State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, 100190, China
{peng.zhao, zhiqiang.cao, lingyi.xu, chao.zhou}@ia.ac.cn

De Xu
The Research Center of Precision Sensing and Control, Institute of Automation, Chinese Academy of Sciences, Beijing, 100190, China
de.xu@ia.ac.cn

***Abstract* - A mother or transporting robot is designed in this paper, which is dedicated to retrieve, transport and deploy the children or smaller robots to configure a robotic team called the marsupial robotic system. In order to manage children robots flexibly, a multi-floor docking station is mounted on the mother robot with a lifting platform which is dragged via lead-screw driving. Touch switches are utilized to initialize the lifting height and identify whether a child robot arrives at the parking position. Also, a dock camera is set on the top of the station to recognize different children robots for the purpose of deploying or retrieving. The locomotion ability is enhanced by combining the advantages of the wheeled-mobile platform and tracked-mobile platform with the concept of wheel-track combo, which barely increases the complexity of mechanism. Finally, a prototype of mother robot is developed and implemented.**

Index Terms - mother robot, marsupial robotic system, docking station, wheel-track combo.

I. Introduction

Comparing with the single robot, multi-robot system is endowed with many advantages such as flexibility, parallelism and robustness, which has been attracting more and more attentions [1]. During the recent three decades, considerable contributions [2]-[4] have been achieved concerning the hierarchy of control, tasks or resource distribution, team formation, resolution of conflicts, and swarm intelligence, etc. With the expansion of the multi-robot application, inspired by marsupial animals such as the kangaroos, a novel type of agent team named marsupial robotic system has been exploited. It is a heterogeneous robotic composition that benefits from the combination of mother robot's navigation strength to satisfy the travel distance and the children robots' adaptability for specific environment and tasks, which offers an important perspective to improve the robots' performance to replace human for harmful environments and boring tasks [5]-[7]. Many research efforts have been dedicated to this kind of multi-agent collaboration, including UGV-UGV cooperation [8], UGV-UAV alliance [9], USV-UAV system and USV-USV combination [10]. Most of the study focuses on UGV-UGV Marsupial Systems. The MACS-RACS [11] system has been developed for the characterization of indoor radiation levels for American Department of Energy. The MACS has a larger size with more radiation detectors. When it arrives at a room whose entrance is too narrow for it to get in, it releases the small-sized "child" the RACS to complete surveillance. Dellaert unites one ATRV-Mini and four Sony Aibo legged robots into a marsupial robotic team for urban rescue [12]. The mother robot ATRV-Mini provides computational resources to mapping the scene after disaster based on laser radars, and the children robots operated by the supervisor are deployed from it to explore suspicious locations of survivors with on-board cameras. The Silver Bullet-Bujold alliance is a prototype system comprised with the marsupial Silver Bullet and the shape-shifting Bujold [13]. The docking behavior for Bujold has been conducted [14]. A similar system is researched with its application for coal mine rescue [15]. Unfortunately, the above-mentioned mother robot is usually opened a hole in or tied a flat to the rear for containing or carrying children robots with less flexibility. University of Minnesota Minneapolis exploits a spring-based delivery mechanism that can deploy children robots like a revolving pistol delivering its bullets [16], and later, a modular docking station is designed to retrieve the children robots [17][18].

This paper contributes to design a mother robot with docking station that can store children robots of different functions and freely deploy the one as needed. And it also presents a wheel-track combo to improve mother robot's locomotion to expand the application area.

The remainder of the paper is organized as follows. Section II proposes the basic hardware architecture to build the mother robot. The mechanism of its docking station is described in Section III. The concept of wheel-track combo is depicted in Section IV. The prototype is demonstrated in Section V and section VI concludes the paper.

II. Hardware Architecture of The Mother Robot

As shown in Fig. 1, the on-board PC and Li-battery are installed inside of mother robot, with two motors and motor-drivers surrounding them. The two motors support driving force for the locomotion mechanism which consists of right wheel-track combo and left wheel-track combo. A laser-radar and an exploring camera are mounted on the front and work as the major sensors for environment understanding such as SLAM (simultaneous localization and mapping). A dual-floor docking station is added on the rear with a lifting platform driven by two step-motors. A dock camera for detecting children robots is fixed on the roof of the docking station. A step motor driver and a MCU controller are fixed inside of the station with touch switches.

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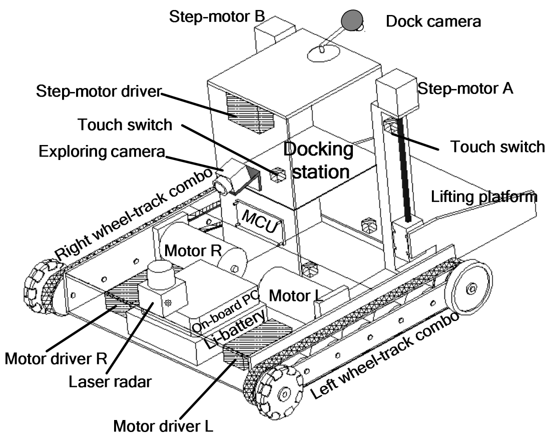


Fig. 1 Configurations of the mother robot

The hardware architecture of the mother robot is described in Fig. 2. The on-board PC is embedded with a wireless network card to contact the user interface via Ethernet. Environment scenes captured by the exploring camera as well as the surrounding obstacles collected with the laser radar are integrated in the on-board PC for map construction and path planning. The on-board PC also processes the images of the children robots captured by the dock camera. The MCU, a secondary control unit, receives commands from PC and generates pulse signals to stimulate the motor drivers and step-motor driver. Also, it samples the signals of touch switches, counts the height of lifting platform, and feeds data back to the PC. It should be emphasized that the two wheel-track combo's motors are driven by different motor drivers to form a differential locomotion mechanism; however, the pair of step-motors dragging the lifting platform are actuated by a single step-motor driver to guarantee the dragging smoothly.

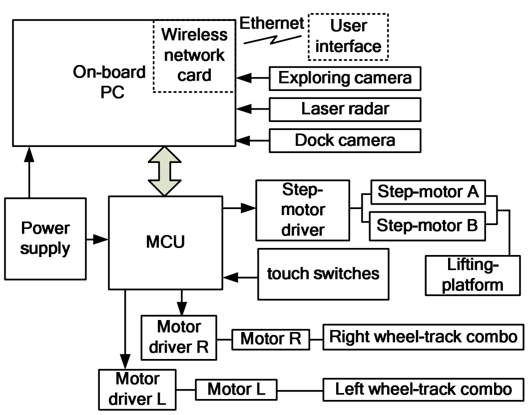


Fig. 2 Hardware architecture of the mother robot

III. THE DOCKING STATION

The docking station is segmented into two separate parking capsules (the number of parking capsules varies according to the children robots' quantity and size). And the lifting platform carries various children robots. Several touch switches are arranged in and out the docking station to initialize the height of the lifting platform or report the arriving of a child robot. A dock camera captures the images around the lifting platform to recognize the roles and poses of children robots based on certain colored badges.

A. *The Mechanism of Rising and Descending*

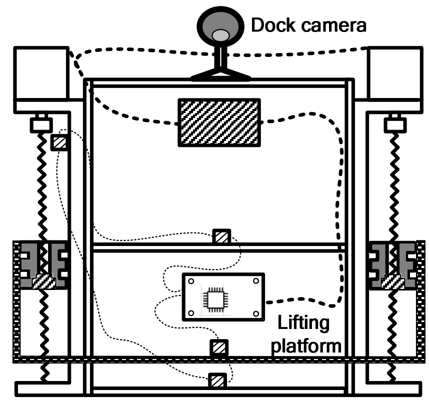


Fig. 3 Mechanism of rising and descending

As shown in Fig. 3, the lifting platform is dragged via lead-screw driving. The two step-motors receive identical step pluses from their common driver to work in parallel. Both of their shafts are fixed with a lead-screw which penetrates a cupreous nut embedded in the through-holes of the sliders that are tied to both sides of the platform. At the starting up, the sliders rise up with the platform along the guide rail until they contact the touch switch under the step motor. The MCU then records the height of the lifting platform as the top value h_{top}. After that, the height h will be changed according to the total count of the control pluses sent to the step-motor driver from the MCU, as formula (1).

$$\begin{aligned} \delta &= \frac{\alpha S}{360^o} \\ h &= h_{top} - \sum \delta p_{down} + \sum \delta p_{up} \end{aligned} \qquad (1)$$

where the equivalent height shift δ per pulse is calculated by the step motor's step angular α and the screw helical pitch S. The p_{up} and p_{down} mean the quantities of the driving pulses for dragging up or down.

B. *The sampling circuit of touch switches*

The touch switches fixed on every parking capsule are used to sense whether a child robot is arrived or leaving this capsule, and the touch switch mounted near the inside of the lifting platform is adopted to identify whether the child robot get a proper position on the platform for rising or descending. For example, after the lifting platform touches the ground, if a child robot arrives at its anticipated position from outside for lifting, the touch switch will generate a "rising edge" signal.

To economize the I/O ports of the MCU and simplify the wires, all the switches are in series connection and sampled by a single ADC pad of the MCU, and all touch switches are checked via the voltage measurement. As shown in Fig. 4, every touch switch S_i is in parallel with a resistance of different value R_i. When the S_i is triggered, the resistance R_i is shorted out from the circuit.

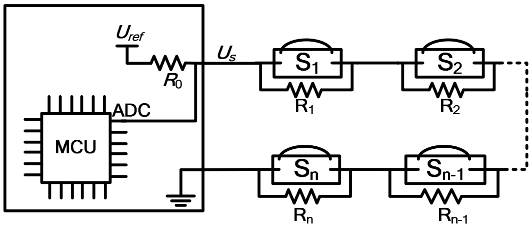


Fig. 4 The series circuit of the touch switches

Then the total resistance R_S of the circuit can be calculated in formula (2).

$$R_S = \frac{U_S}{U_{ref} - U_S} R_0 = \sum (1 - T_i) R_i \tag{2}$$

$$R_i > \sum_{j=i+1}^{n} R_j \tag{3}$$

where the Boolean variable T_i is 1 when the S_i is triggered; the value of R_i (i=1,2,…,N_S) is chosen with the constraint of an inequality in formula (3). Then the triggered touch switches could be identified with Algorithm 1.

Algorithm 1. The trigger identification of touch switches

Input: total resistance value R_S, the number N_S of touch switches, and R_i (i=1,2,…,N_S).

Output: the trigger status vector $\boldsymbol{T}$.

$R_{temp} \leftarrow R_S$;
for i=1: N_S
  if ($R_{temp} \geq R_i$)
    T_i=0;
    $R_{temp} \leftarrow R_{temp} - R_i$;
  else
    T_i =1;
  end
  $\boldsymbol{T} \leftarrow T_i$;
end

It should be mentioned that we should not connected too much touching switches in a single circuit line because the value of the last resistance is considerably small contrasted to that of the first one and may not be distinguished because of the finite resolution of the ADC conversion.

C. *Badges for perceiving children robots*

Affected by the badges of military rank, a kind of colored badge is designed for the mother robot perceiving its children robots. As shown in Fig. 5, the color badge consists of three basic rectangles and several encoding cycles. The rectangles are coated with the three original RGB colors and their boundary lines form a shape of capital letter T. Also, the quantity and colors of the encoding cycles are encoded to represent the roles of different children robots. Captured by the dock camera, the T-shaped colors boundary lines in a badge could be easily extracted with image processing. And according to their coordinates in the image plane, the badge's relative pose to the dock camera may be calculated in the Cartesian Space with the camera needed to be calibrated. Then the relative pose between the children robots and the docking station is obtained

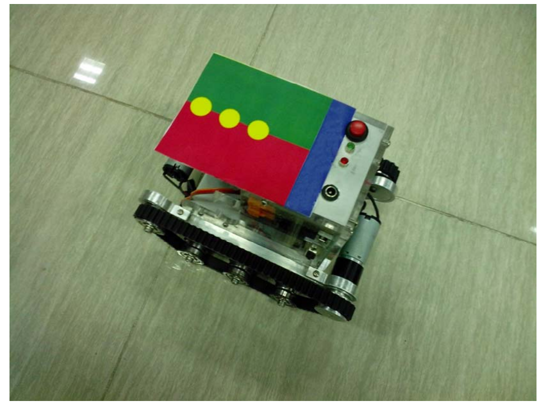


Fig. 5 A colored badge on a child robot

On the basis of the mechanism of rising and descending, multiple children robots are deployed or retrieved orderly with the help of visual servoing and the information sampled from the touch switches.

IV. MOBILE PLATFORM OF THE WHEEL-TRACK COMBO

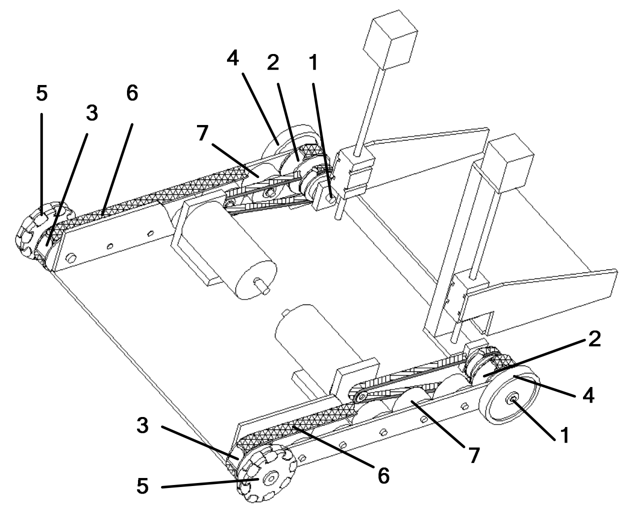


Fig. 6 Mechanism of the wheel-track combos.
1: Actuating shaft; 2: Rear crawler wheel; 3: Front crawler wheel;
4: Common wheel; 5: Omni-wheel; 6: Track band; 7: auxiliary wheel

The differential wheeled-mobile platform is variously applied to indoor robots because of its simple structure, low noise and being easy for reckoning or control, but it is not suitable for the rugged pathways. On the contrary, the tracked-mobile platform is commonly used in outdoor robots. Fig. 6 demonstrates a convenient approach to take the advantages of both kinds of mobile platforms, as combining them into the wheel-track combos. Via the transmission of synchronous belts, each motor drives an actuating shaft that is tied to a rear crawler wheel and a common wheel at the same time. As rotating with the actuating shaft, the rear crawler wheel puts a set of track unit in motion, including several auxiliary wheels, the front crawler wheel and a track band. The spindle of the front crawler wheel is extended to drive an omni-wheel. The point is that the common wheels and the omni-wheels have a radius which is slightly larger than that of the crawler wheels. Hence, when moving on a smooth indoor floor, the track units will be suspended and the robot achieves locomotion based on differential wheeled driving; the track driving comes into service if the track units touch the rugged ground with their track bands.

Besides, the track units help the pairs of omni-wheel & common wheel rotating in synchronization and improve the kinematic quality of the wheeled driving with transforming sole-rear driving into front-rear driving.

V. Implementation

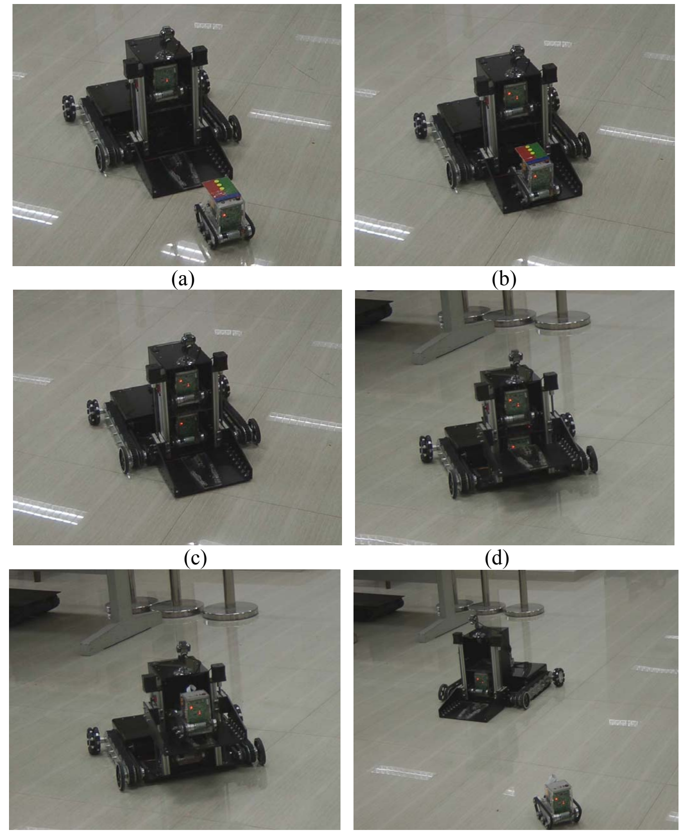
A prototype of the mother robot is developed and demonstrated in Fig. 7, where three children robots are loaded in its docking station. Table I describes its main specifications.

Fig. 7 The prototype of the mother robot with three children robots

Fig. 8 shows the video snapshots of retrieving a child robot and then deploying another child robot. Firstly, the lifting platform descends to the ground and a child robot to be retrieved approaches to it (see Fig. 8(a)). After the child robot arrives at a proper position in the lifting platform, the platform lifts to the floor corresponding to a specified empty capsule, as depicted in Fig. 8(b). Once the child robot has entered its capsule (see Fig. 8(c)) whose touch switch is triggered, the retrieving process is finished. Fig. 8(d)-Fig. 8(f) give the snapshots of deploying process of another stored child robot.

TABLE I
Main specifications of the mother robot

Item	Specification
Dimension	67cm×57cm×40cm
Weight	21.2KG
Speed	<3.5km/h
Battery	24V/10AH
On-board PC	CPU: Intel® Celeron 1037U/ 1.8GHZ RAM: 4GB SSD: 128GB
MCU	Cortex-M3/72MHZ
Carrying Capacity	Three children robots / 3×7.5kg



(a) (b) (c) (d) (e) (f)

Fig. 8 The video snapshots of retrieving/ deploying the child robot.

VI. Conclusion

This article presents the hardware architecture and mechanism of a mother robot applied to the marsupial robotic system. The mother robot is mounted with a multi-floor docking station, which deploys or retrieves the children robots via a lifting platform. A series circuit of touch switches for sensing the height of lifting platform and the parking positions of children robots is exploited, which simplifies the circuit and reduces the hardware cost. A kind of colored badge is designed for perceiving children robots. The concept of the wheel-track combo is introduced to combine the locomotion advantages of the differential wheeled-mobile platform and the tracked-mobile platform. The prototype of the mother robot demonstrates its ability to transport and retrieve children robots.

Our future work will focus on the exploiting and improvement of the wheel-track combed mobile platform, dedicating to the implementation of a low-cost marsupial robotic system that can serve daily activities of human without disturbing dwelling environment.

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