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Case study

Daran robot, a reconfigurable, powerful, and affordable robotic platform for STEM education

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Abstract: Robot and programming education, as a key part of STEM education, is attracting more and more attention in the education industry. In this paper, a novel open-sourced educational robotic platform, *Daran* robot, is proposed with key features in terms of reconfigurable, powerful, and affordable. As an entry-level robotic platform, the *Daran* robot consists of three individual robots, which are a Mecanum-wheeled robot, a three-wheeled robot, and a 4-DoF robot arm. Both graphical and Python programming environments are developed for students with different entry levels. Thanks to the reconfigurability, four classic constructions of the *Daran* robot are presented with corresponding case studies, based on which the students can practically learn basic knowledge of sensing and control technologies.

Keywords: STEM education, robotic platforms, programming education, mobile robots, robot arms

1. Introduction

STEM education, known for science, technology, engineering, and mathematics, is a prevailing concept of education in this ever-changing world [1]. In recent years, along with the popularization of STEM education in China, robot and programming education is attracting more and more attention in China's education industry [2].

Along with the aims of STEM education to cultivate the students' creativity, imagination, and comprehensive application talents, the robot education and programming education are focused on enhancing the students' creative, practical, and problem-solving abilities. Guided by the STEM education concept, various robotic educational platforms have been developed with different aiming to the market. In Table 1, several typical robotic platforms are listed by considering factors in terms of aiming age, country, program pattern, assembly-needed, open-sourced and price. It can be noted that (i) these robotic platforms are mostly from developed countries and can cover different ranges of students before colleges; (ii) most of them are based on only one programming mode, graphical or code, which is imperfect for students to learn different programming skills consistently with only one platform; (iii) most of them are assembly needed to enhance the practical hands-on skills; (iv) structure parts of them are with plastic materials and save costs; (iv) none of them is open-sourced which limited the students self-motivated learning.

Table 1. List of robotic platforms for STEM education

Robotic Platform	Aiming Age	Country	Program Pattern	Assembly needed	Material	Open-sourced	Price (£)
KIBO [3]	4-24	USA	graphical/code	Y	plastic	N	160-433
Mio [4]	8-12	USA	graphical/code	N	plastic	N	156
Cue [5]	5-12	USA	graphical	Y	plastic	N	110-147
Fischertechnik [6,7]	13+	Germany	graphical	Y	plastic	N	-
Lego [8]	3-16	Denmark	graphical	Y	plastic/metal	N	385
ROBOROBO [9,10]	8-13	Korea	code	N	metal	N	-
Honda [11]	18+	Japan	graphical	N	plastic	N	-
Matatalab [12,13]	4-9	China	graphical	Y	metal	N	110-258
WeeeMake [14]	5-12	China	graphical	N	plastic	N	114-148
DFRobot [15,16]	7-16	China	graphical	Y	plastic	N	29-74

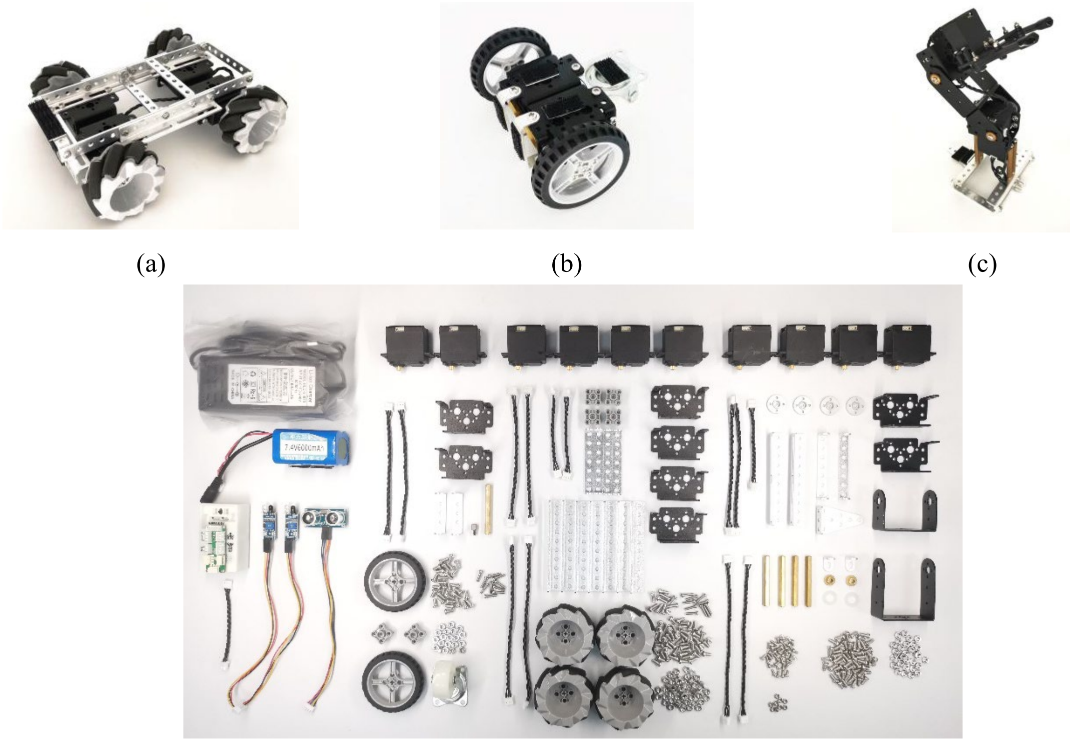
By carefully considering the above factors, a novel open-sourced educational robotic platform, *Daran*, is proposed to fill the gap in the market for STEM education in this paper. The *Daran* aims to develop an entry-level robotic platform for freshmen and sophomores without age limitations. To achieve this, in this paper, the overall design and development of the robotic platform (hardware and software) are presented in Section 2. In Section 3, four typical constructions of the platform are introduced with corresponding applications. In the end, the conclusion and future work are discussed in Section 4.

2. Systematic design of *Daran* robotic platform

In this section, the *Daran* robotic platform is proposed with the motivation to develop an entry-level robotic platform for STEM education. The systematic platform design is presented consisting of mechanical, electrical as well as software.

2.1. Mechanical design

The *Daran* robotic platform, as shown in Figure 1, consists of three individual robots, which are a Mecanum-wheeled robot (Figure 1a), a three-wheeled robot (Figure 1b), and a 4-DoF robot arm (Figure 1c). All of the three robots are designed with low-cost and user-friendly features and all of the hardware components are listed as shown in Figure 1d and specifications in Table 2.



(a) (b) (c)

(d)

Figure 1. Overview of *Daran* educational robotic platform: (a) Mecanum-wheeled robot, (b) two-wheeled robot, (c) 4-DoF robot arm, and (d) illustration of hardware components

Table 2. Specification of the Daran robotic platform

Robot Name	Dimension (L*W*H, mm)	Weight (g)	Motors No. & torque (Nm)	Power supply (V)	Price (£)
Mecanum-wheeled robot	212*164*88	942	4 / 1.5	7.4	57
Three-wheeled robot	110*123*90	545	2 / 1.5	7.4	25
4-DoF robot arm	158*100*115	777	4 / 1.5	7.4	47
Control package	/	-	0	7.4	92
Total	/	2264	10	7.4	220

The Mecanum-wheeled robot, as shown in Figure 1a, is a four-wheeled mobile robot based on Mecanum wheels, which is well-known for its omnidirectional wheel design. By integrating four Mecanum wheels on a chassis, the Mecanum-wheeled robot can achieve efficient all-direction mobility under the combined actuation of four servomotors.

The three-wheel robot, as shown in Figure 1b, consists of two ordinary rubber wheels and an additional balancing wheel at the rear. It can be noted that only two front wheels are actuated by servomotors while the rear one is passive only for keeping the stability of the robot.

The 4-DoF robot arm, as shown in Figure 1c, combines three servomotors for 3-DoF positioning and a four-bar linkage for 1-DoF gripping. It can be noted that a pair of soft fingers are attached at the tip of the gripper to increase the friction between the gripper and objective. Moreover, with this combination, the robot arm can perform a pick-and-place task that mimics a lot of real industrial applications.

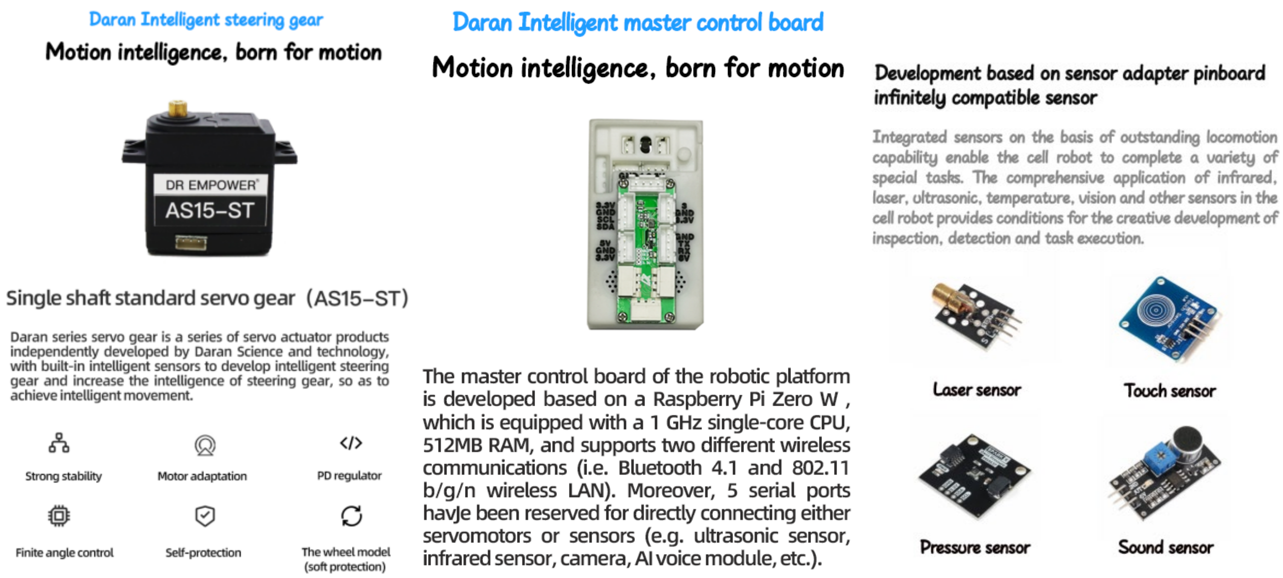
In addition, it can be noted that all these three robots are only has a small number of components and are very easy to assemble, which allows students at entry-level to put their hands on. Moreover, there is a series of fixing holes on the structural components that are made in steel plates. This not only enhances the reliability of the entire robot but also provides convenience for further development (e.g., adding more sensors). Furthermore, apart from working independently, these three robots can be also combined to perform even more complex tasks, for instance, instead of obstacle avoidance, this robotic platform can clear the obstacles by mounting the 4-DoF robot arm on the wheeled robots. These reconstruction capabilities of the proposed robotic platform will be discussed in Section 3.

2.2. Electrical design

To provide a powerful and affordable platform that covers the main features of STEM education, key electrical elements, i.e., servomotors and control boards have been designed for Daran robotic platform.

Daran servomotors (AS15-ST), as shown in Figure 2a, are especially self-developed with intelligence by integrating sensing and controlling modules for the Daran robotic platform. Based on these, the servomotors not only can perform precise motion but also provide key information for advanced control (e.g., current status, PID parameters), allow hybrid communications (series and parallel connections) and update parameters in real-time. All these features allow to development of robots more smartly and conveniently.

The master control board of the robotic platform is developed based on a *Raspberry Pi Zero W* [17], which is equipped with a 1 GHz single-core CPU, 512MB RAM, and supports two different wireless communications (i.e., Bluetooth 4.1 and 802.11 b/g/n wireless LAN). Moreover, 5 serial ports have been reserved for directly connecting either servomotors or sensors (e.g., ultrasonic sensor, infrared sensor, camera, AI voice module, etc.).



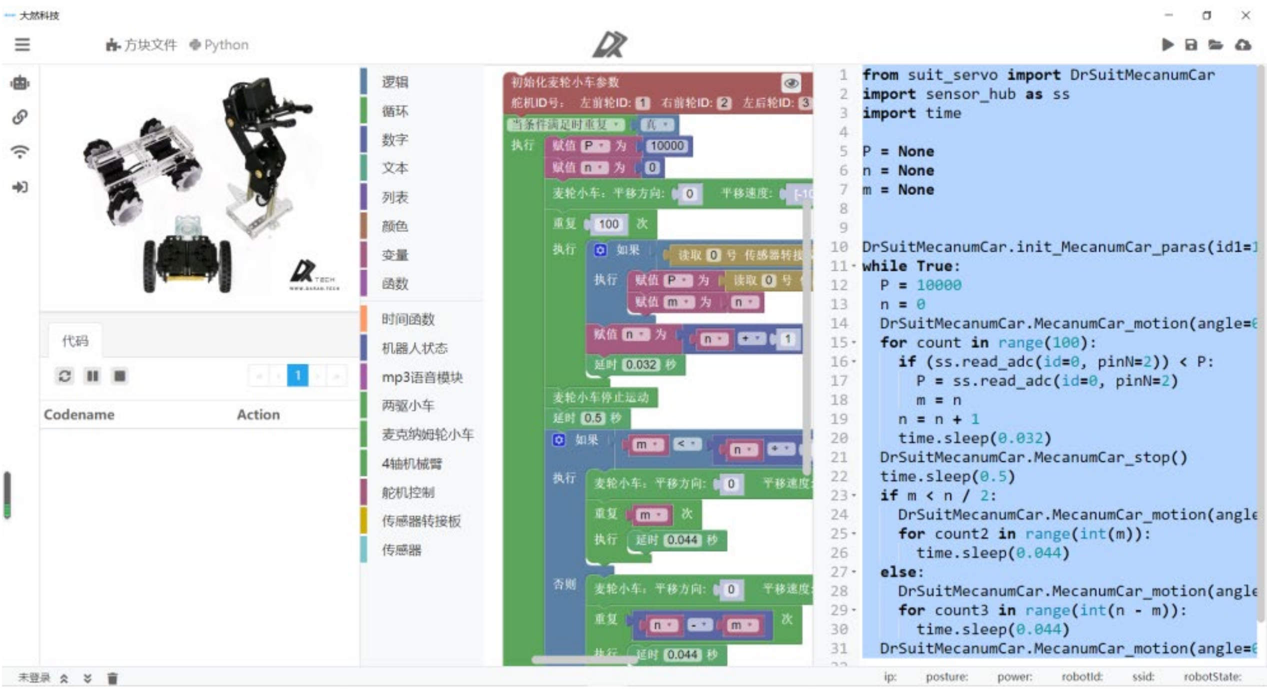
(a) (b) (c)

Figure 2. Detailed illustration of electrical components in *Daran* educational robotic platform: (a) servomotor, (b) master control board, and (c) sensors

2.3. Software design

To enhance the students' creative, practical, and problem-solving abilities, the software of the Daran robotic platform has been designed to support both graphical programming and Python programming. In Figure 3, a snapshot of the software interface is presented including three key parts: robotic platform window (Figure 3a), graphical programming environment (Figure 3b), and Python programming environment (Figure 3c).

It's well known that graphical programming, in contrast to text-based counterpart, is pictures or symbols of physical things based. This is ideal to inspire or attract students without any programming foundation, as it removes the boundaries for these students to implement basic control of robots at the very beginning. Moreover, as shown in Figure 3c, our software will automatically generate the Python code corresponding to the graphical program, which significantly helps the student's transit from graphical programming to Python programming. Furthermore, the merit of Python programming, such as concise, user-friendly, general-purpose, and so on, will allow the students to avoid complex setting requirements like "configuration of compilation environment", and upload the program and run it on the robot with only one click.



(a) (b) (c)

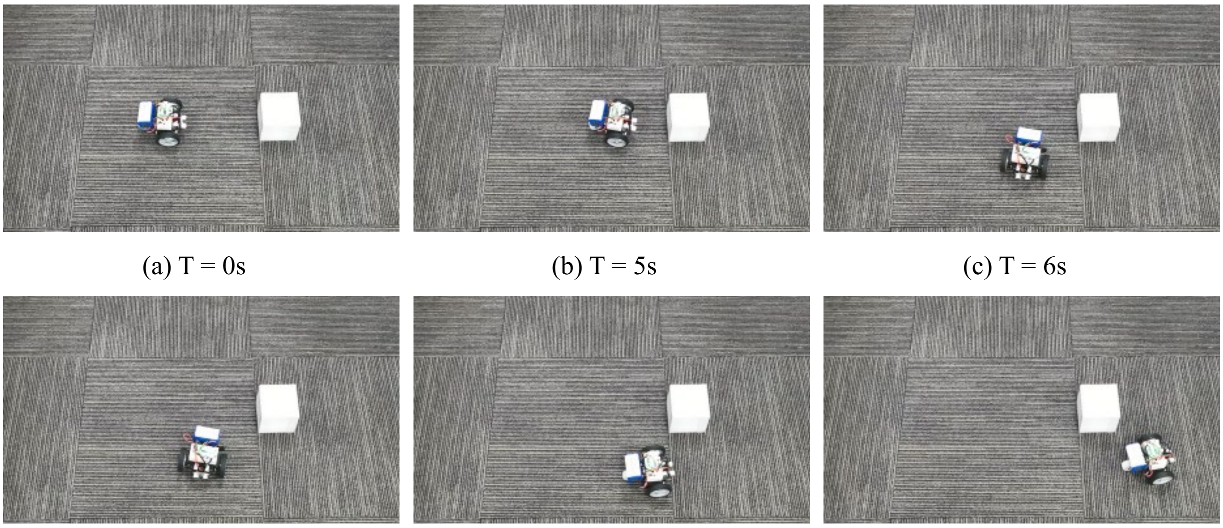
Figure 3. Illustration of the software interface of Daran robotic platform: (a) robotic platform window, (b) graphical programming environment, and (c) Python programming environment

3. Constructions and case study

In this section, four constructions (three individual and one combined) are presented with corresponding case studies to demonstrate the basic functionalities of the proposed Daran robotic platform. In addition, materials such as assembly instruction, working principles and control program code have been documented in the developed software as the education database.

3.1. Construction 1 (three-wheeled robot): ultrasonic obstacle avoidance

Obstacle avoidance is a classical problem in the robotic field, which has been widely studied as based on various sensing infrastructures [18]. In this case study as an entry-level, a three-wheeled robot is utilized to demonstrate its capability of obstacle avoidance based on an ultrasonic sensor. The working principle of the ultrasonic sensors has been documented in the software as part of the knowledge database for education purposes. With this database, the students can learn the related knowledge by themselves or the educators, and then implement it on the robotic platform via either graphical or Python programming. In Figure 4, it shows a sequence of demonstration snapshots, in which (a) an obstacle was placed in the way of the robot; (b) the robot detected the obstacle and stopped; (c-e) the robot moved around the obstacle with a certain distance; (f) the robot carried on moving along the original direction.



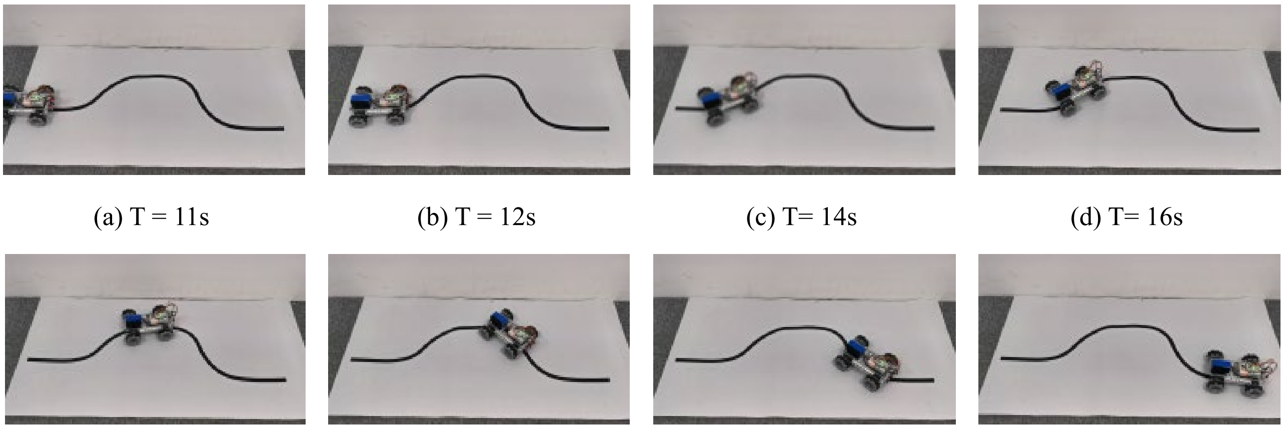
(a) T = 0s (b) T = 5s (c) T = 6s

(d) T = 7s (e) T = 8s (f) T = 11s

Figure 4. Case study I: obstacle avoidance of three-wheeled robot based on ultrasonic sensing

3.2. Construction 2 (four-wheeled robot): path following/tracking based on infrared sensing

Path following/tracking is another classical problem in robotics, such as warehouse robots, patrol robots, and so on. In this case study, the Mecanum-wheel robot was utilized to implement the line-tracking technology based on a grayscale sensor. As shown in Figure 5, the four-wheeled robot can follow a pre-drawn and random backline. It's worth noting that this robot's construction can be modified by amounting Mecanum wheels at different positions on the chassis. For example, it could be wider between two wheels or narrower, and the corresponding mobility would be slightly different from one to another. Therefore, each student's robot could not be exactly the same and the programs they write would be different, which would encourage the students to develop their constructions and programs for better mastering the skills involved in line tracking.



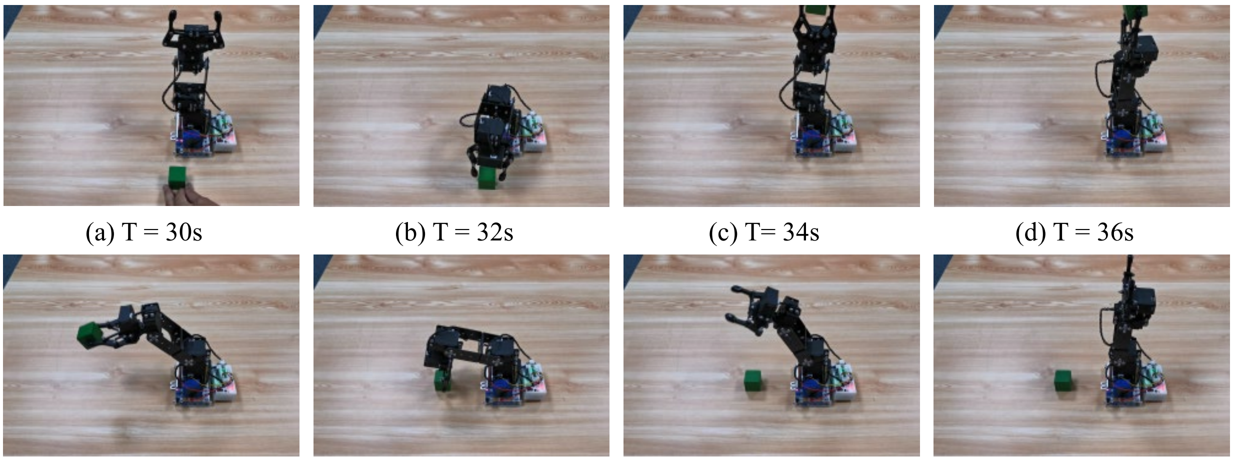
(a) T = 11s (b) T = 12s (c) T= 14s (d) T= 16s

(e) T = 19s (f) T = 22s (g) T = 25s (h) T = 27s

Figure 5. Case study II: path following/tracking of a four-wheeled robot based on infrared sensing

3.3. Construction 3 (4-DoF robot arm): pick-and-place

In this case study, a 4-DoF robot arm with a gripper at the end is designed to perform automatic cargo handling, as well as counting the number of handled cargos. This will not only encourage the students to consider the realization of basic functions (e.g., pick-and-place) but also pay attention to human-machine interaction when developing robots. As shown in Figure 6, (a) a wooden cube is placed next to the infrared sensor mounted on the robot arm; (b-f) the robot arm gradually complete the action of grabbing, turning and placing; (h-j) then, the robot arm restores to its initial posture, meanwhile reports the cumulative number of wooden cubes transported.



(a) T = 30s (b) T = 32s (c) T= 34s (d) T = 36s

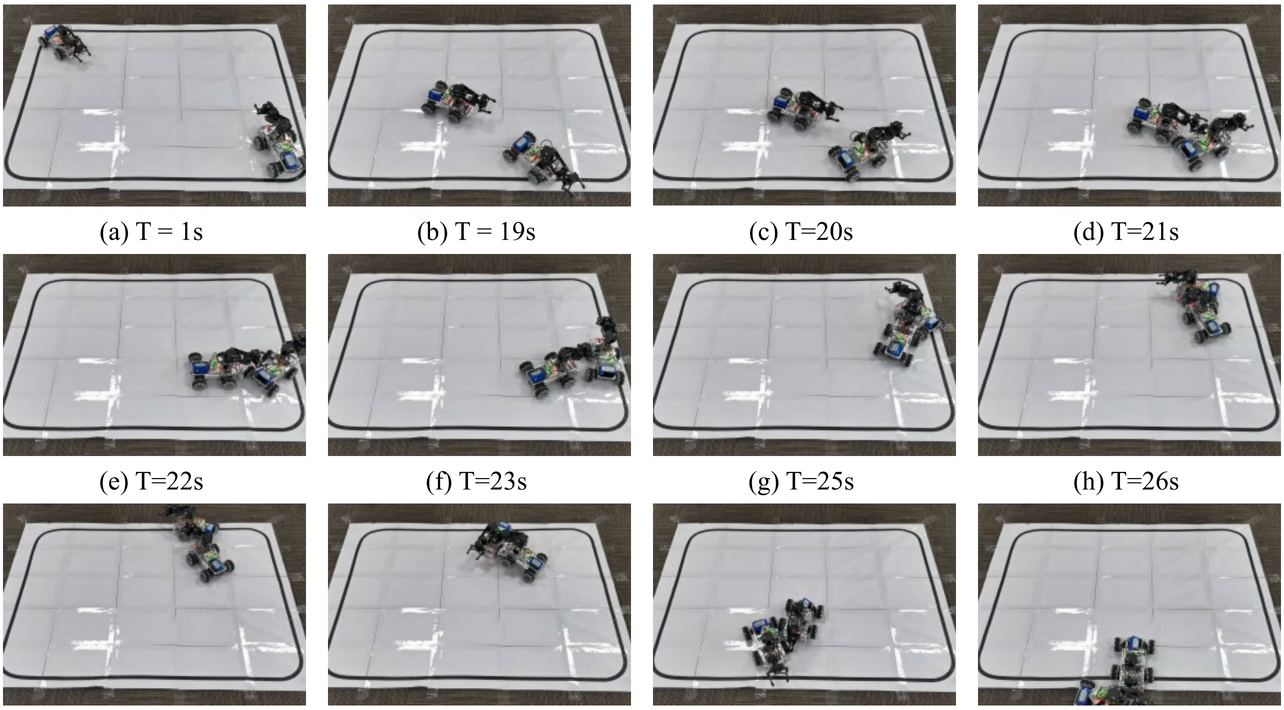
(e) T = 37s (f) T = 38s (h) T = 39s (i) T = 40s

Figure 6. Case study III: pick-and-place with a 4-DoF robot arm

3.4. Construction 4 (four-wheeled robot & 4-DoF robot arm): territory scramble

In this construction, a 4-DoF robot arm is assembled on a four-wheeled robot, by which it can perform not only all-direction mobility but also manipulation. Based on this construction, a case study of territory scramble is proposed to encourage the students to further learn and develop robotic skills.

The rules of territory scramble are that (i) two or multiple (<4) robots start the initial positions at the corners of the site; (ii) one loses when its vertical projection is outside the battle area; (iii) the game will end in a draw if the robots tangle up or have no contact with each other for more than one minute. In Figure 7, a demonstration of the territory scramble is presented with two identical reconstructed robots. It can be seen that (a) two robots started from the initial positions; (b-c) Robot I automatically moved towards the site centre while Robot II detected the boundary and adjusted the direction to move away from the boundary; (d-e) Robot I detected the other robot and rushed towards it, then clamped it with its gripper; (f-j) Robot II, though impaired in movement, was still programmed to turn and adjust direction when pushed to the edge, however being clamped, it could not get away from its opponent; (k-l) Robot II was further pushed by Robot I and was not able to turn this time at the boundary due to Robot I's obstruction, and was eventually pushed out of the field.



(a) T = 1s (b) T = 19s (c) T=20s (d) T=21s

(e) T=22s (f) T=23s (g) T=25s (h) T=26s

(i) T=28s (j) T=30s (k) T=36s (l) T=38s

Figure 7. Case study IV: territory scramble of two reconstructed robots (a four-wheeled robot and a 4-DoF robot arm)

4. Conclusion and Future Work

In this paper, a reconfigurable, powerful, and affordable robot platform, Daran Robot, is designed and developed for STEM education. Daran Robot's modular design meets the needs of STEM education that requires students to participate in design. The aluminum parts ensure that the robot's body is strong enough to be stable for most of the experiments the students want to do. At the same time, the structure's excellent wear resistance also ensures Daran Robot's durability. The status of the servomotors (e.g., current, PID parameters) can be acquired and the setting parameters can be modified online, which allows the students to further learn and develop the robots using Daran Robot. Daran Robot also provides all library function codes and related communication protocols for users with an open-sourced basis, which allows the user to further develop various functions conveniently and freely.

Apart from the four constructions and corresponding classical applications presented in this paper, various case studies can be found in the Daran Robot education package which will update periodically. In the next stage, the Daran Robot will be further developed in the Robotic Operation System (ROS), which will allow the users to expand their knowledge to an even higher level.

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Links to additional recourses

- Demonstration videos: https://youtu.be/XDyk3zA5vgs
- Daran website: https://www.daran.tech/#/download_centre

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