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Enhancing Student Engagement in Robotics through Competitive Challenges

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Abstract - Student engagement in robotics will improve innovation and technical skills among aspiring engineers. This paper discusses strategies to improve student involvement in robotics through participation in the VEX Robotics Competition, with a spotlight on the KFUPM Robotics Team (KRT). The paper explores the design, control mechanisms, and development of two VEX V5 competitive robots, highlighting the teamwork and problem-solving skills gained throughout the process. The main features of robot development, including hardware challenges, autonomous programming, and competition strategies, are argued. By analyzing the team's experience, this paper illustrates major challenges, such as weight distribution, coding complexities, and optimization of autonomous functions, while presenting successful solutions. Additionally, exploring the competition experience explains how hands-on robotics competitions enhance critical thinking, collaboration, and resilience. The results prove the importance of strategic planning, and an active learning environment in encouraging students to actively participate in robotics.

Keywords: Student Engagement, Robotics Education, VEX Robotics Competition, Hands-on Learning, Autonomous Programming, Teamwork and Problem-Solving, Sensor Integration, Engineering Skills Development,

1 INTRODUCTION AND BACKGROUND TO VEX COMPETITION AND KRT

Educational robotics has become an important tool for enhancing STEM education, providing students with hands-on experiences that promote problem-solving, teamwork, and technical skills [1]. Robotics competitions, such as VEX Robotics, play a significant role in developing computational thinking, engineering proficiency, and collaboration among participants [2]. VEX competition has become more popular worldwide, leading to increased student engagement and encouraging long-term interest in STEM fields [3]. Research highlights the positive impact of these competitions on motivation, self-confidence, and active participation [4].

Educational robotics makes learning more engaging by offering hands-on experiences that boost problem solving, teamwork, and motivation. Studies have shown that it increases student participation and interest in STEM [5]. Robot-assisted learning keeps students engaged, improves knowledge retention, and makes education more interactive and enjoyable [6]. For example, in 2017, 18,000 teams from 40 countries participated in different types of challenges during the VEX competition, highlighting its importance in robotics education [7]. Educational robotics continues to demonstrate its ability to boost student engagement and improve learning outcomes in different educational settings [8]. While robotics can enhance learning, it also presents challenges such as distractions and cognitive overload. Some students spend more time troubleshooting than learning concepts [9]. Robotics education requires strong instructor support. Without proper guidance, students struggle with complex programming and hardware, leading to frustration rather than engagement [10].

The VEX V5 competition fosters STEM skills by challenging students to design and fabricate innovative robots to achieve the theme's goals. Each year, the theme of the competition changes to challenge the students to build a new robot that can perform the tasks in the theme. The 2024-2025 High Stacks challenge, which is played in the field of 12 × 12 dimensions, contains five mobile goals, four fixed goals, 24 blue rings, 24 red rings, 2 positive corners, 2 negative corners, and a ladder in the middle of the field. The round time was separated into an autonomous period of 30 s and a Driver Controller period of 1.5 minute. In each round, there were red and blue teams. Each team has two robots with 24" x 24" x 24" and 15" x 15" x 15" dimensions. There were two positive and two negative corners. If the robot can move a mobile goal to the positive corner, all points of the rings in the goal will be doubled, and if it moves the goal to the negative corner, all rings will be negative points. In the Autonomous period, both robots should move and try to score points by taking the rings with the same color as their team and score it in any goal; there are other tasks in which if the robots make it, the team will get extra bonus points. In the Driver Controller period, the team should score the rings as much as possible and move the mobile goal that countians the maximum number of rings to the positive corner to double their points. Subsequently, if the robot can climb the ladder, it will provide additional points. There are three stages, and as it climbs higher, extra points are obtained. For clarity, the field of competition is presented in Figure 1.

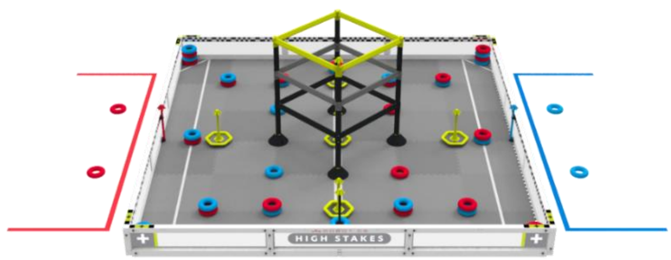

Fig. 1: The High Stakes Competition Field.

KFUPM Robotics Team (KRT) is a robotics team fully led by students at King Fahd University of Petroleum and Minerals and supported by the Control and Instrumentation Engineering Department and the Smart Mobility and Logistics Center. The team was founded by three students: Hussain Algargous, Mohammed Alkhabbaz, and Mohsen AL Zamzam, who communicated with the department and the center to receive financial support and then communicated with the VEX franchiser in Saudi Arabia to provide robot kits. They also announced the format of the team to attract students to join. After selecting the members, the founders handled all tasks, such as coordination with the department, university, and competition organizing committee to register the team. The full team included Mohammed Almutawa, Mohamad Almahdood, Alyazan Fatani, Fadil Younes, Montather Alkhabbaz, Reda Alherz, Mohammed Alkadhim, Abdullah Batarfi, Ali Gafer, and Husam Noorwli, all contributing to different aspects of the team's success. The three founders played specific roles based on their experience: Hussain became the leader and coach, Mohammed became the treasurer and software team leader, and Mohsen managed public relations and became the hardware team leader. The collaboration of the three founders, who have experience in the field of robotics, has achieved great success in covering all tasks in a short time and smoothly.

2 ROBOT DESIGN AND MECHANISM DEVELOPMENT

The team members were divided into two sub-teams, each responsible for building one robot. The small robot named Slee5 and the large robot named Theeb have different tasks to do, but both collaborate to obtain as many points as possible. For clarity, both robots have the same task to collect the ring, meanwhile they have different implementation approaches.

The two robots are labeled as Slee5 and Theeb, which are presented in Figure 2. Both sub-teams began by constructing a base to ensure smooth wheel movements.

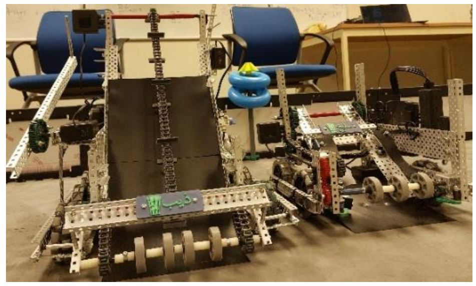

Fig. 2: The Final Version of Both Robots.

2.1 Slee5

The base of Slee5 was constructed as two standard wheels in the back, which were made of plastic to provide stability while moving, each of them were motorized, and two omni wheels in the front to provide smooth turning. The used Slee5 base is presented in Figure 3. The first version of Slee5 used a chain mechanism to collect the rings. It was collected from the front using a hook and then left them to the back of the robot. However, the chain mechanism with a hook was not so efficient in collecting, so the team added a collecting mechanism in front of the robot, which is a flex-wheel made of rubber, to improve collection by increasing the surface of the fraction with rings and then pushing them inside to leave it up by the chain and hook. The problem with this design was that the dimensions of the robot were small, as there was insufficient space for the hook to grab the ring. In the second version, the team changes the mechanism of collecting from the chain and hook mechanism to the arm mechanism, which is placed at the back of the robot at an angle of approximately 45°to collect the ring and then perform circular movement and place the ring at the goal. This mechanism has two main problems: the flex-wheel collecting mechanism was not applied, so it was not collecting quickly, and even if the arm collected the ring, it was not stable in the arm. In the final version, the flex-wheel mechanism is added to the robot again to make it faster and more accurate. To address the stability problem, a 3D part was designed and printed as a holder for the rings to ensure stable and efficient ring collection.

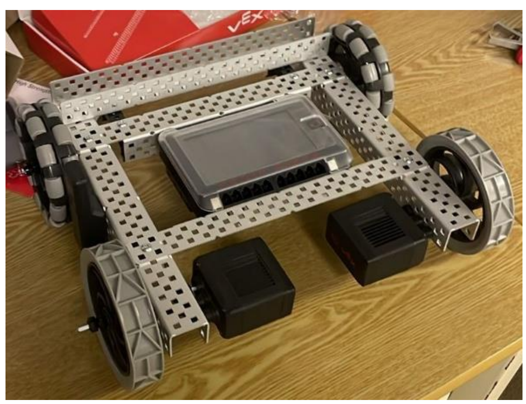

Fig. 3: The Base of Slee5 Robot.

2.2 Theeb

The base of Theeb was constructed as two standard wheels in the middle for stability in the moving and four omni wheels to provide smooth turning, and two motors on each side were connected with gears to connect all the wheels together to increase the torque of the robot. For improved clarity, the Theeb gear ratio used is illustrated in Figure 4. The addition of the base of the Theeb is a pneumatic mechanism to grab the mobile goal and score while moving. In the first version of Theeb, the chain mechanism was built separately from the base and then connected to the base. The main issue with this version is that it is not easy to connect the chain mechanism with the base, and it would require significant support. In the second version of Theeb, the team began building the chain mechanism on the base directly to make it stable and to not be perfectly fit with the dimension of the base and added the flex-wheels mechanism in the front, and it was perfect in collecting the rings. The problem with this version is scoring the rings in the goal because the chain throws the rings far from the goal. In the third version of Theeb, the team builds something like a roof as a limit for the rings, to ensure that it does not throw it away. The issue with the roof was not efficient because it decreased the scoring accuracy, and the rings were only placed on top of the goal without scoring them as points. In the last version of Theeb, a new mechanism was innovated to function as a hammer to push the rings inside the goal to make it count points that were working perfectly and score many rings in a short time.

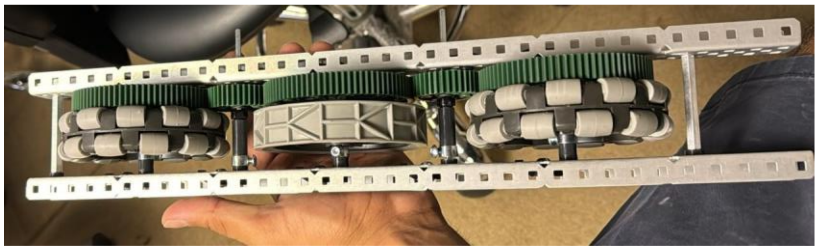

Fig. 4: The Gear Ratio for Theeb.

For both robots, there were other common problems and issues. One of the problems is weight distribution, which is a significant issue after building the robot because the weight of the side is different from the other side; therefore, the team bought lead fishing weight and then smelted it to fit inside the robot by making a 3D mold for it. All the problems faced with these robots improved their creative thinking to generate an amazing solution that could be more functional and easier to apply.

3 AUTONOMOUS AND CONTROL SYSTEMS

This section discusses the programming and problem-solving challenges faced during the VEX Robotics Competition. This covers our decision to use C++ for greater flexibility, debugging methods, and the benefits of VEX C++ classes in simplifying complex calculations. The following subsections explore sensor integration, autonomous programming, and control system optimization, demonstrating how the team applied theoretical concepts to real-world robotics. This experience helped improve coding skills, teamwork, and problem-solving abilities.

3.1 Coding Challenges and Problem-Solving

Participating in the VEX Robotics Competition provided a unique opportunity to explore programming and problem-solving, showing how robotics is a platform for applying theoretical knowledge to practical challenges. The first task was to determine the programming method for the robot; we opted to write the code in C++ rather than using VEXcode Blocks. This decision stemmed from our desire to have greater flexibility and control over the programming process, which allowed us to implement customized functions for the robot. Furthermore, C++ provided access to an extensive set of references and resources, such as the VEX API, which offered detailed explanations of the VEX-specific commands.

3.2 Key Coding Challenges

Robot programming presents a range of challenges that require strategic debugging methods. To address these challenges, we used the following approaches.

- Modular Testing: Each subsystem (e.g., drivetrain and sensors) was tested in isolation to ensure functionality before integration. For instance, the intake mechanism was tested separately to verify motor commands and alignment.
- Diagnostic Tools: Using printed statements (e.g., Brain.Screen.print("This Is How The Team Tested Some Functions")to display real-time feedback from the robot's sensors and motors helped identify mistakes.
- Iterative Refinement: Code was implemented incrementally, with frequent testing after each addition or modification to identify errors early. Consequently, the software team heavily used Git and GitHub tools.

3.3 Advantages of VEX C++ Classes

The C++ classes provided by the VEX API significantly simplified our work. For example: Drivetrain Class: Instead of manually implementing kinematic equations to control the movement of the robot, the software team utilized pre-built functions such as setRotation() and turnToAngle(). Without these, the software team would have had to calculate the wheel velocities, turning radii, and other factors mathematically, introducing room for error. For example, the robot has a differential drive, as shown in Figure 5.

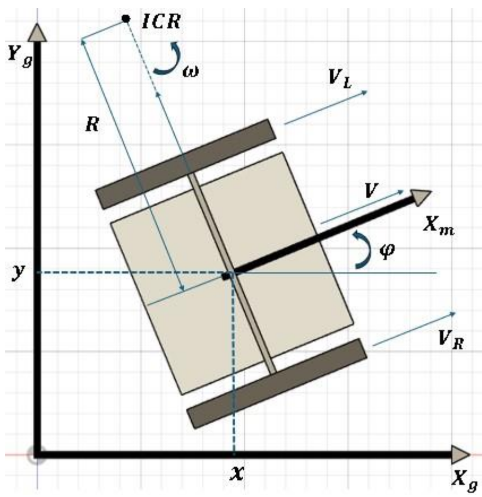

Fig. 5: Differential Drive Robot.

If we want to move it for some distance, or to turn it with some angle ϕ, we would have to directly deal with the following kinematic equations with respect to the global frame (i.e., X_g and Y_g):

$$p(t) = \begin{bmatrix} x(t) \\ y(t) \\ \varphi(t) \end{bmatrix} \tag{1}$$

where $p(t)$ is the robot's pose vector, which includes its position and orientation within the global reference frame. Here, $x(t)$ and $y(t)$ describe the robot's location along the horizontal and vertical axes respectively, while $\varphi(t)$ specifies its heading angle.

$$\begin{bmatrix} \dot{x}_m(t) \\ \dot{y}_m(t) \\ \dot{\varphi}_m(t) \end{bmatrix} = \begin{bmatrix} v_{x_m} \\ v_{y_m} \\ \omega \end{bmatrix} \tag{2}$$

where $\dot{x}_m(t)$ and $\dot{y}_m(t)$ represent how fast the robot moves forward and sideways relative to its own body, and $\dot{\varphi}_m(t)$ corresponds to its rate of rotation. The local velocity components v_{xm} and v_{ym} quantify movement in the robot's forward and lateral directions, while ω is used to denote how quickly the robot is turning. We can perform the following simplification:

$$\begin{bmatrix} \dot{x}_m(t) \\ \dot{y}_m(t) \\ \dot{\varphi}_m(t) \end{bmatrix} = \begin{bmatrix} v \\ 0 \\ \omega \end{bmatrix} \tag{3}$$

with the model is simplified based on the assumption that the robot only moves along its forward direction, making the lateral component $\dot{y}_m(t)$ equal to zero. The variable v is used to describe this straight-line velocity, while ω continues to represent the angular motion. The tangential and angular velocities are defined as follows:

$$v(t) = \frac{r\omega_R + r\omega_L}{2} \tag{4a}$$

$$\omega(t) = \frac{r\omega_R - r\omega_L}{L} \tag{4b}$$

where (4a) defines the forward speed of the robot, $v(t)$, in terms of the angular velocities of its left and right wheels, while (4b) explains how the difference between wheel speeds leads to rotational movement. This relationship also introduces r, the wheel radius, along with ω_R and ω_L, which are the angular velocities of the right and left wheels, respectively. The variable L is introduced here to represent the spacing between the two wheels, often referred to as the wheelbase or track width. Consequently, in the global frame, using a rotation matrix for the transformation:

$$\begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \dot{\varphi}(t) \end{bmatrix} = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ 0 \\ \omega \end{bmatrix} = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ 0 & 0 \\ -\frac{r}{L} & \frac{r}{L} \end{bmatrix} \begin{bmatrix} \omega_L \\ \omega_R \end{bmatrix}$$

By performing an inverse operation, we can determine the wheel rotation speed required to obtain the desired motion or rotation. This mathematical process highlights the complexity of rigid-body kinematics, where even a simple movement or rotation requires detailed calculations of pose vectors, velocities, and transformations. However, the VEX drivetrain class significantly simplifies this by encapsulating these calculations within the prebuilt functions. Instead of manually implementing the equations, we can execute commands such as turnToAngle() or driveFor() to effortlessly achieve precise movements. This not only saves time, but also provides a practical demonstration of how theoretical kinematic principles translate into real-world applications, making the experience both educational and efficient.

3.4 Integration of Sensors

Sensors are integral to the functionality of the robot, particularly during autonomous periods. They allowed the robot to interact intelligently with its environment and make real-time adjustments based on feedback. In one of the robots, we primarily relied on an accelerometer to track motion, particularly during the autonomous period. Initially, when we connected the sensor, the robot moved extremely slowly, hindering its ability to complete tasks within a limited timeframe. Speed is crucial in autonomous gameplay. Therefore, one of the team members took the initiative to fine-tune the gains of the PID controller to achieve a faster response. By carefully adjusting the proportional, integral, and derivative terms, we were able to balance stability and speed, ensuring precise and efficient motion. This process not only improved the robot's performance but also served as a practical way to relate the theoretical concepts of feedback control to real-life applications. Witnessing how these adjustments directly influenced the robot's behavior showed the importance of control systems and feedback theory, concepts that five of the team members had previously studied in the Introduction to Robotics & Autonomous Systems course with Dr. Sami El Ferik.

3.5 Autonomous Period Programming

Programming the Autonomous Period was one of the most intellectually demanding aspects of the competition. This short-period phase required the robot to operate entirely on pre-programmed instructions, relying solely on sensor inputs for decision-making. A key strategy employed was to optimize the movement paths of the robot to minimize unnecessary actions. By defining specific waypoints, the robot was able to navigate the field systematically and efficiently, thereby reducing the time required to complete the tasks. In addition, the software team implemented a proportional-integral-derivative (PID) controller to enhance the accuracy of the robot. The PID controller enabled the robot to approach targets, such as stakes or mobile goals, without overshooting or oscillating around the desired position. Tuning the controller involves adjusting the proportional, integral, and derivative gain values to achieve an optimal balance between the speed and stability.

A major achievement in the tournament during this phase was the successful completion of the Autonomous Win Point (AWP) task, which required scoring three rings of the alliance's color and avoiding contact with restricted zones. This accomplishment was particularly rewarding, as it demonstrated the effectiveness of the team coding strategies and the seamless integration of sensors into the robot's operation.

4 COMPETITION EXPERIENCE

Mental preparation was the most important factor for this competition because it was the first competition with this environment for ten out of thirteen members of the team, and it was against seventeen other universities that some of them had experience in this competition, exceeding seven years. Dr.Mujahed al-dhaifallah, chairman of the Control and

Instrumentation Engineering Department, and Dr. Sami el ferik, director of the Smart Mobility and Logistics Center, provided motivational speeches to boost team confidence before the competition began. Photographs of the team are presented in Figures 6 and 7. The coach reinforced the team's spirit before departure, ensuring that KFUPM's debut was competitive. Moreover, before each round, the coach gave a short speech to encourage drivers and their assistants to focus on the round.

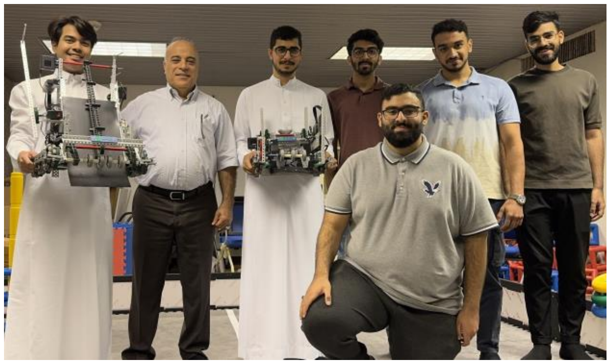

Fig. 6: Dr. Sami Visting the Team While Working.

Fig. 7: The Last Picture with Dr. Mujahed Before Traveling to The Competition.

During the competition, teams were assigned different roles. The most important role was to watch and record the rounds of other teams. Recording competitors' rounds allowed the team to develop different strategies, leading to key victories, especially against top-ranked teams, which led to reaching quarter finals but lost against the competition champion.

One of the skills the team maintained was professionalism and sportsmanship in both victory and defeat, reinforcing respect as a core principle. One of the KRT team principles is to show respect to all teams in all situations, even in the last round, which led to the elimination of the team; all members shake hands with the winning team. Moreover, filing drivers of robot positions was a challenge for the team because of the fear of bearing this high responsibility, but encouragement from coaches and all the supporters from professors and chairman decreased this fear in members and bore this high responsibility.

The initial participation of the team was impressive for the university students and encouraged them to join the team. In this competition, the team reached the qualifier quarter finals, but the opposing team was a competition champion with more than 10 years of experience in this competition. On the other hand, in the Robot Skills sector, which allows only one team to be on the field alone and collect as much as possible, the team ranks second in robot skills and the 6th place in world rankings directly after the competition. For clarity, Figure 8 presents the team after winning second place in the Robot Skills competition.

Fig. 8: The Team After Winning Second Place in Robot Skills.

5 CONCLUSION

Participation of the KFUPM Robotics Team in the VEX Robotics Competition showed the impact of hands-on learning on student engagement. Through iterative design improvements, programming challenges, and strategic gameplay, students were able to apply theoretical knowledge to real-world robotics problems. The experience highlighted the importance of teamwork, adaptability, and continuous learning, reinforcing key engineering principles such as control systems, sensor integration, and software optimization. Despite competing against experienced teams, KRT successfully reached quarterfinals and secured second place in the Robot Skills category.

This study emphasizes that fostering student engagement in robotics requires not only technical support, but also mentorship, encouragement, and a structured learning approach. Future participation in robotics competitions should focus on refining robot designs, improving coding efficiency, and enhancing autonomous decision-making capabilities. By providing students with hands-on experience, competitive exposure, and a collaborative learning environment, robotics education can play a pivotal role in preparing future engineers for the rapidly evolving technological landscape.

6 ACKNOWLEDGMENTS

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