Toward Fair and Thrilling Autonomous Racing: Governance Rules and Performance Metrics for the Autonomous One

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***Abstract*—This letter is the second report from a series of IEEE TIV's Decentralized and Hybrid Workshops (DHWs) on Intelligent Vehicles for Education (IV4E). It outlines the prospect of The Autonomous One (TAO), a future autonomous racing competition modeled after Formula One to advance IV4E by pushing the boundaries of artificial intelligence. Existing autonomous races face challenges, including compromised fairness and low participant enthusiasm. These issues limit spectator engagement, thereby reducing the races' educational value. To prevent similar flaws in organizing TAO, our focus lies in setting governance rules from an organizer's perspective. In these DHWs, we analyzed the rules of existing autonomous races and suggested rule-making guidelines for TAO. To improve fairness, we recommend a balanced scoring system with rigorous monitoring of participating teams' performances. To discourage consistent victories by a single team, we suggest that leading teams share their source codes, thereby setting the championship-level performance as the baseline in the next season and accelerating the evolution of all participating teams' abilities. For enhancing suspense and spectator interest, an on-site adaptive rewarding scheme should be deployed to create thrilling turnarounds. Our strategies aim to maintain fairness, increase spectator interest, inspire competitiveness, and ultimately contribute to the advancement of IV4E in organizing TAO.**

***Index Terms*—Autonomous racing, intelligent vehicles for education (IV4E), the autonomous one (TAO).**

Manuscript received 28 June 2023; revised 15 July 2023; accepted 21 July 2023. Date of publication 26 July 2023; date of current version 22 September 2023. This work was supported by in part by the National Natural Science Foundation of China under Grant 62103139 and in part by the Natural Science Foundation of Hunan Province under Grant 2021JJ40114. *(Corresponding authors: Siji Ma; Fei-Yue Wang.)*

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Color versions of one or more figures in this article are available at https://doi.org/10.1109/TIV.2023.3298914.

Digital Object Identifier 10.1109/TIV.2023.3298914

I. Introduction

MOTOR racing emerged shortly after the invention of automobiles, and similarly, autonomous racing has evolved alongside the development of intelligent vehicles and autonomous driving technologies [1]. In recent years, autonomous racing events have seen a remarkable increase [2]. It is primarily university teams that are participating in these events, which highlights the crucial role of autonomous racing in promoting education on intelligent vehicle technology and nurturing student talent from an early stage.

When examining past autonomous racing events, it becomes apparent that certain teams consistently dominate. For example, the Zurich ETH team won the Formula Student Driverless (FSD) competition in 2017, 2018, and 2019, while the PoliMOVE team has continuously claimed victory in the Autonomous Challenge (IAC) championships held in January 2022, November 2022, January 2023, and June 2023 [3], [4]. While the success of these teams can be attributed to a large participant pool, strong technical mentoring, significant sponsorship, and highly motivated students, the continued dominance of the same teams may risk diminishing the diversity and unpredictability of competition, potentially discouraging new teams from joining, further compromising the educational purpose of organizing autonomous racing events. Additionally, due to turnover or graduation, membership within these leading teams is not static. If new members perceive their role as merely making only minor changes to the groundwork laid by their predecessors, especially in areas such as algorithmic theory, the educational value of these competitions may not be fully realized.

In addition to international races like FSD and IAC, there has been a rise in small-scale and local autonomous racing events. In the context of these events, gray markets have emerged where students deceitfully purchase competition kits tailored to specific race regulations, including ready-to-use software and hardware solutions. Such markets undermine the fairness and educational value of autonomous racing events.

The aforementioned issues pose challenges to the integrity and competitiveness of autonomous racing events, thus potentially compromising their fundamental role in fostering intelligent vehicle education. To ensure fairness and competitiveness in the future of The Autonomous One (TAO) races [1], specific strategies need to be implemented. This letter outlines potential strategies for achieving these goals. Recently, a series of Decentralized and Hybrid Workshops (DHWs) on Intelligent Vehicles for Education (IV4E) were conducted on May 26, June

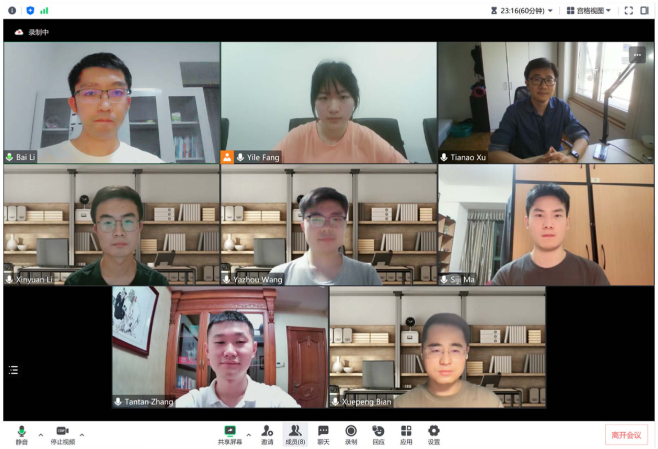

Fig. 1. Screencast of online meeting in DHW held on June 4, 2023.

1, June 4, and June 18, 2023 (Fig. 1). The key findings and discussions from these DHWs inform our understanding and potential strategies for improving autonomous racing events.

In the remainder of this letter, Section II reviews current governance rules of autonomous racing competitions. Insights and discussions from the DHWs are summarized in Section III. Finally, our conclusions are presented in Section IV.

II. Review of Rules in Existing Autonomous Races

This section reviews the governance rules and metrics applied in existing autonomous races.

A. Roborace

Roborace, founded by Formula E and Kinetik in 2015, is the world's first international championship for autonomous racing [5], [6]. From 2016 to 2018, Roborace trialed its technology and race formats, parallel to the prestigious Federation Internationale de l'Automobile (FIA) Formula E World Championship events.

In 2019, Roborace launched Season Alpha, marking a new phase in the autonomous racing competition. The season's inaugural event unfolded at Spain's Circuito Monteblanco, featuring the first-ever wheel-to-wheel race between two fully autonomous vehicles from Arrival and Technical University of Munich (TUM) [7].

In Season Beta (2020–2021), seven teams participated in the races. The format of races in that season was solo sprints in a time attack manner, with the purpose to collect experiences for wheel-to-wheel races in the future. A highlight in Season Beta was the introduction of Roborace Metaverse – a real-time mixed-reality component that blended virtual objects into actual racetracks. These objects took on various forms, categorized essentially into obstacles that needed to be avoided, and collectibles that were to be acquired (Fig. 2). Another highlight was that the entire season was divided into missions, each with unique objectives and rules. These missions progressively introduced new object types and increased the dynamics and complexity of the objects' behaviors. One such addition was "ghost cars", which had to be overtaken for bonus points but were penalized if hit. The competition rules and mission plans were continually adapted based on the outcomes of preceding missions and the technical progress made by the competing teams [8]. This governance approach allows the racing rules to adapt flexibly based on event outcomes and audience feedback.

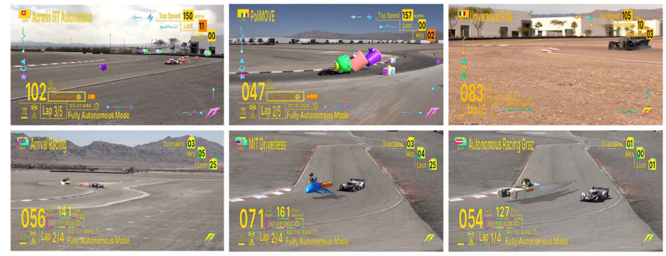

Fig. 2. Missions powered by mixed-reality Metaverse system at Las Vegas Motor Speedway during Season Beta of Roborace [7].

B. Indy Autonomous Challenge

The IAC is a worldwide contest that started in October 2021. Its goal is to encourage university students studying science, technology, engineering, and mathematics to develop innovative autonomous vehicle software for unmanned racecars, further enhancing the safety and performance in motorsports and urban transportation [9]. The IAC uses the Dallara AV-21 as a standard model, similar to Roborace's DevBot platform [10]. This means the difference between each team is the unique autonomous driving software stack that enables perception, planning, and control on the racetrack.

The IAC includes two different competitions: the Time Trial Competition and the Passing Competition. In the Time Trial Competition, one autonomous racecar at a time drives around the track. Teams have to follow race control orders and drive four laps: one for warming up, two for performance, and one for cooling down. Performance is rated by the average speed across the two performance laps. A special twist is that there are pylons placed on the track after the performance laps, acting as obstacles that the racecar must avoid. The racecar needs to bypass these pylons at a minimum speed of 60MPH [11].

The Passing Competition is a single-elimination tournament where the racecars compete head-to-head in a series of rounds. Two racecars participate in each round, alternating as leader (defender) and follower (attacker). Passes are attempted at increasing speeds until one or both cars fail. In each match, both cars are given a passing attempt at the round's speed level. After a pass attempt finishes, roles are reversed, and the new attacker attempts to pass the new defender. If both cars manage to overtake successfully, a new round starts at a higher speed. If only one car succeeds, it wins the round. If both fail, the round is a draw with the top-seeded team advancing [12].

As listed in Table I, IAC had organized five on-site contests by the end of June 2023. Particularly, the first-ever road course time trial competition was hosted on the renowned Monza Formula One circuit in June 2023. More than 10000 spectators watched

TABLE I
COMPETITION RESULTS OF IAC (BY JUNE 30, 2023)

Date	Champion Team Name	Competition Type	Competition Site	Gross Team Number	Maximum Speed
2021.10	TUM Autonomous Motorsport	Time Trial Competition	Indianapolis Motor Speedway, USA	9	157 MPH [1]
2022.01	PoliMOVE	Passing Competition	Las Vegas Motor Speedway, USA	9	173 MPH [2]
2022.11	PoliMOVE	Passing Competition	Texas Motor Speedway, USA	6	140 MPH [3]
2023.01	PoliMOVE	Passing Competition	Las Vegas Motor Speedway, USA	9	180 MPH [4]
2023.06	PoliMOVE	Time Trial Competition	Monza Circuit, Italy	5	169.8 MPH [5]

[1] https://www.autoweek.com/racing/more-racing/a38069263/what-missed-indy-autonomous-challenge-main-event/
[2] https://www.indyautonomouschallenge.com/polimove-wins-the-autonomous-challenge-at-ces
[3] https://www.indyautonomouschallenge.com/tms-results
[4] https://www.indyautonomouschallenge.com/ces-2023-results
[5] https://www.indyautonomouschallenge.com/indy-autonomous-challenge-sets-autonomous-speed-records-at-monza-temple-of-speed

TABLE II
COMPETITION RESULTS OF FSD (BY JUNE 30, 2023)

Date	Champion Team Name	Champion Affiliation	Gross Team Number	Leading Rate in Score*
2017	AMZ Driverless	ETH Zurich	15	204.33% [6]
2018	AMZ Driverless	ETH Zurich	17	183.80%
2019	AMZ Driverless	ETH Zurich	20	107.98%
2021	KA-RaceIng Driverless	Karlsruhe Institute of Technology	17	114.41%
2022	StarkStrom Augsburg	Augsburg University of Applied Sciences	19	158.02%

* The index "Leading Rate in Score" is defined as the ratio of the score of the first-place team to the score of the second-place team. This index represents the extent that the first-place team takes the lead, serving as an indicator of competition competitiveness.
[6] https://www.formulastudent.de/fsg/results/

Fig. 3. Team PoliMOVE won championship of first-ever road course time trial competition of IAC on Monza Formula One circuit in June 2023 [14].

as PoliMOVE, a local team representing Politecnico di Milano, won on a Formula One circuit (Fig. 3) [13].

C. Formula Student Driverless

The FSD competition has been an integral part of the renowned Formula Student Germany competition since 2017 [3]. This unique category aims to challenge teams of university students to conceive, design, fabricate, develop, and compete with small, formula-style racecars without human drivers. The purpose of this challenge is not merely to create the fastest vehicle but to present a complete package encompassing design, performance, cost, and financial and sales planning [14].

The competition has been consistent from its 2017 rules through the latest released 2023 rules [15], [16], which easily renders a fixed competitive hierarchy (Table II). To promote a fair and competitive playing field, FSD organizes both dynamic and static events in its competition. Dynamic events such as the Skidpad, Acceleration, Autocross, and Trackdrive test the performance of the autonomous system in each racecar. At the same time, static presentations on the Business Plan, Cost & Manufacturing, Engineering Design, and Autonomous Design challenge the participating teams to explain their design philosophies and the steps they took in the process of building their autonomous racecar. The static events emphasize aspects such as a comprehensive business model for the prototype racecar, an understanding of manufacturing processes and costs, engineering design, and autonomous driving capability. A special rule in FSD is that each competing racecar is allowed a lifespan of no more than three years, a stipulation that encourages continuous innovation. In contrast to competitions like Roborace or IAC, FSD places strict restrictions on participant eligibility. Team members must be degree-seeking undergraduate or graduate students with the exclusion of PhD students or equivalent. The stipulation of these rules serves to maintain fairness and upholds the educational intent of the competition, fostering growth and learning in the realm of autonomous vehicle development among university students.

D. F1TENTH Autonomous Grand Prix

The F1TENTH Autonomous Grand Prix, previously known as the F1/10th Autonomous Racing Competition, is a pioneering platform for autonomous racing [17]. Incepted in 2016, the F1TENTH Autonomous Grand Prix has already spearheaded 13 competitions by June 2023 (Table III). Participating teams in this championship are tasked with constructing a 1:10 scale autonomous racecar as per given specifications and developing

TABLE III
COMPETITION RESULTS OF F1TENTH AUTONOMOUS GRAND PRIX (BY JUNE 30, 2023)

Date	Competition Site	Champion Team Name	Team Number
2016.10	Pittsburgh, USA	PRECISE Racing	5
2018.04	Porto, Portugal	TEAM Řeřicha	8
2018.10	Torino, Italy	Maciej Dziubinski & Karol Majek	8
2019.04	Montreal, Canada	University of North Carolina	7
2019.10	New York, USA/Columbia	SeoulTech / Unimore	10
2020.07	Berlin, Germany	TUfast TUfurious	13
2020.10	Las Vegas, USA	HiPeRT Modena	17
2021.09	Prague, Czech Republic	Scuderia Segfault	17
2022.05	Philadelphia, USA	ScatterBrain	38
2022.08	Lausitzring, Germany	ForzaETH	-
2022.12	Jeju Island, Korea	ACE2	7
2023.05	San Antonio, USA	Bercedes Menz Foxglove Racing Team	13
2023.05	London, UK	ForzaETH	22

its corresponding software to meet the competition restrictions. The primary goal of F1TENTH is to educate the participants on building safe and efficient autonomous systems. The allure of the one-tenth-scale platform lies in its convenience, allowing the participants to test with actual hardware swiftly, minus the risks and costs tied to a full-sized vehicle [18]. The competition primarily serves to stimulate learning and expedite industry advancements. To this end, it has predominantly held in-person competitions, barring a few virtual ones during the COVID-19 pandemic.

The competition features two main events: time trials and two-vehicle head-to-head competitions. In the time trials, each autonomous vehicle is required to complete a set course in the shortest possible time. Meanwhile, the two-vehicle head-to-head events entail a direct competition between two vehicles on the same course, highlighting both the agility and strategy of autonomous systems.

The crux of the competition lies in the software design aspect, making it a battle of algorithms, as the official rules state [19]. This stipulation means that the onboard hardware is restricted to ensure that no team gains an unfair advantage. However, there is still room for variation: racecars that fail to comply with this specification would be permitted to compete in the Open Class, though they are ineligible for awards.

Since its inception in 2016, the F1TENTH Autonomous Grand Prix has maintained a high level of consistency in its rules, with no major changes. It is an inclusive event, open to teams of all levels, with no restrictions on the composition of competing teams. In a bid to prevent the crystallization of championship rankings and enhance competitive spirit, the organizing committee encourages the winning teams to disclose their algorithmic source code each year. As evidenced in Table III, no team clinched the championship title consecutively. In this sense, the F1TENTH Autonomous Grand Prix has promoted a dynamic, competitive landscape in the field of autonomous racing.

E. Amazon Web Services (AWS) DeepRacer League

Launched in 2019, the AWS DeepRacer League distinguishes itself as the first autonomous racing league driven by a unique objective of promoting and benchmarking Machine Learning (ML) advancements through autonomous racing [20]. The structure of the AWS DeepRacer League includes three key components: monthly Virtual Circuit competitions, live Summit Circuit events held during AWS Summits, and a final showdown at the Re:Invent 2023 conference. This hierarchical structure ensures broader global participation by making the competition accessible and scalable. Most events in the AWS DeepRacer League are held virtually, thus reducing entry costs and logistical barriers. Meanwhile, the real-world application of ML models during the Summit Circuit competitions provides participants with a tangible, hands-on experience. Here, virtual models, which have undergone rigorous training and testing, are put to the ultimate test on standardized 1:18 scale AWS DeepRacer devices. Notably, AWS offers these kits at an affordable price point, facilitating easy access to hardware for budding autonomous racers. The league allows participants to submit multiple models to the scoring platform, supporting the iterative and experimental nature of ML. The submission that yields the best performance is used for ranking, offering flexibility to participants to iterate and improve their models.

The AWS DeepRacer League's outstanding feature is its commitment to fostering a rich, community-centric learning environment. Through resources like the AWS DeepRacer Pit Stop [21], an online hub for knowledge sharing, and other resources including the AWS DeepRacer Reddit community, Developer Forum, Twitter, and Instagram, participants are equipped with comprehensive educational and training material. This encourages a culture of peer learning and experience sharing, vital for the growth and development of ML technology, resonating with the core tenets of IV4E. Moreover, the league presents an inclusive platform welcoming global participation. While it attracts a wide array of developers, from students to professionals, it also

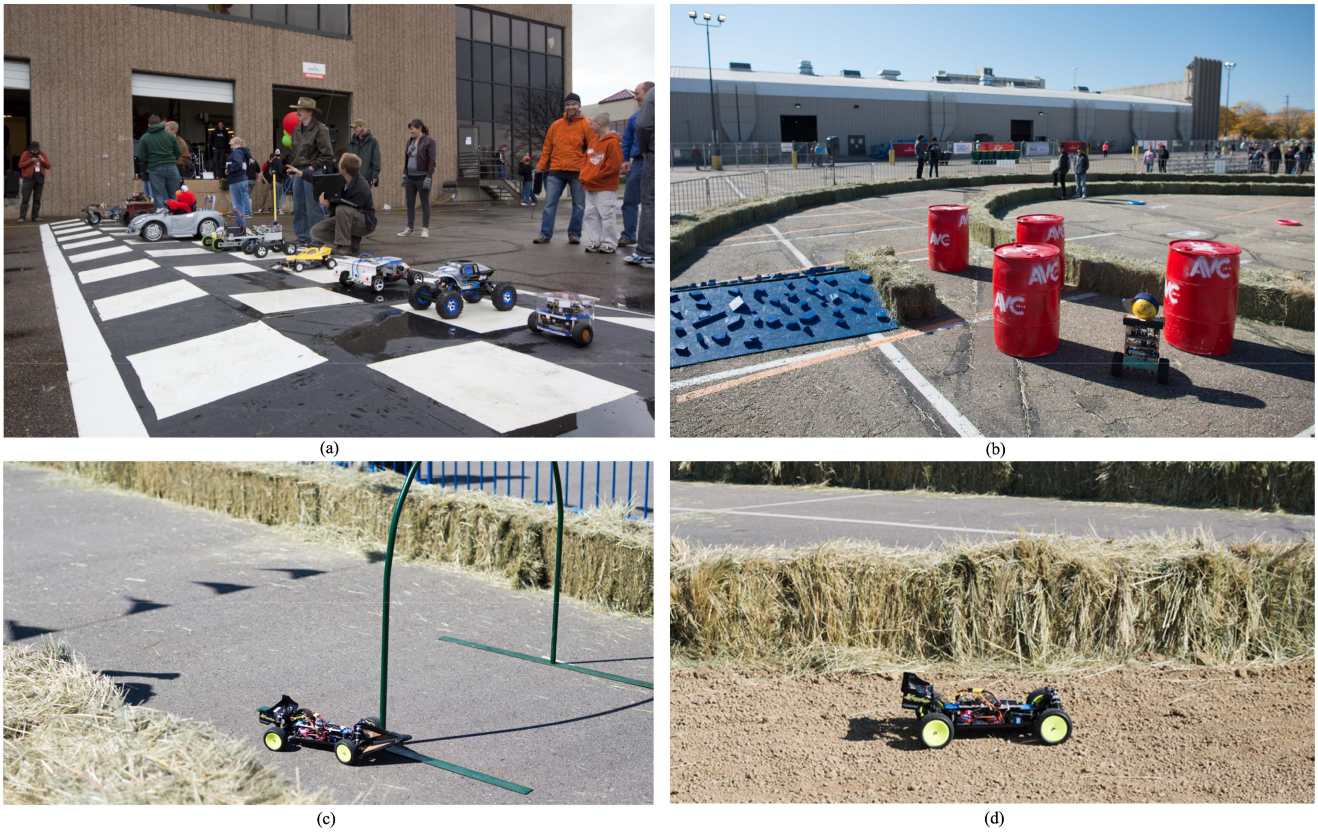

Fig. 4. Details of SparkFun Autonomous Robot Racing Challenges [24]: (a) Diversity of designs in participating racecars; (b) Layout of competition field; (c) Green hoop for awarding pass-through maneuvers; (d) An alternative pathway filled with scattered rocks.

upholds minimal restrictions on participant eligibility, further lowering entry barriers. Consequently, it stands as a testament to the democratization of ML, making it one of the easily accessible and effective platforms for learning, competing, and innovating in the field of autonomous racing.

F. SparkFun Autonomous Robot Racing Challenge

The SparkFun Autonomous Vehicle Challenge is a truly unique event. Originating from a bet that navigating a vehicle autonomously around a building would be more challenging than it sounded [22], the competition ran annually from 2009 through 2018. Instead of taking place on a predefined racetrack, this contest followed a path around the periphery of a building, with boundaries defined by structural elements such as walls. Remarkably, the competition placed minimal constraints on the competing vehicles; the inaugural rule merely capped a vehicle's construction cost at $300, without imposing specific restrictions on its dimensions (Fig. 4(a)). In an effort to foster diversity and creativity, special awards were introduced from the very first year, like the Drunken Master and Best Dressed awards, with more special awards, such as the Kill Dozer and Best Use of Duct Tape awards, added over the years. The competition aimed to maintain the purity of the challenge, requiring photographic or video documentation of the vehicle's building process chronically, perhaps to prevent the unfair practice of simply buying a ready-to-use model. With a guiding purpose of nurturing students, the competition required that at least 80% of the work on the competing vehicle should be finished by students.

Over the course of ten years, the rules of the competition were continually refined, drawing on the experiences and lessons from each year's competition. For instance, in 2010, static obstacles were introduced to increase the challenge level. In 2011, a time reward mechanism was implemented, allowing teams to subtract 30 seconds from their total time by passing through a narrow arch. This added an exciting possibility of a last-minute turnaround for trailing teams, thereby keeping the suspense alive until the final moments of the competition. The competition began categorizing vehicles by type from 2013 onwards, responding to the huge variety of vehicles entered in previous years. This change was prompted by the fact that the minimal restrictions led to a wide range of vehicles participating, even including modified large-scale jeeps. First implemented in 2016, the concept of "shortcut" added an exciting strategic dimension to the competition. These shortcuts presented a quicker, albeit challenging, route which the trailing teams could leverage to turn the tables. The race circuit splintered into varied routes (Fig. 4(b)), some providing a direct path but on challenging terrain, others longer yet smoother. A green hoop for bonus points (Fig. 4(c)), scattered rocks (Fig. 4(d)), and even pitfall traps punctuated these routes, offering high-risk-high-reward shortcuts. The option to take the challenging path – the dirt track covered with debris and the fearsome Discombobulator, a massive gas-powered turntable, or the easier route with potential points offered by a green hoop and ramp, represented strategic choices [23]. These decisions brought suspense, competitive spirit, and joy to the spectacle, creating a thrilling environment for spectators and participants alike. The incorporation of shortcuts was therefore not just a tactical addition, but also a significant enhancement to the overall appeal of the competition.

The SparkFun Autonomous Vehicle Challenge may seem less regulated than competitions like the IAC, FSD, or Roborace, but its flexible strategy lowered the entry barrier and drew more participants. Over its ten-year run, the competition made annual adjustments to increase suspense, ensure fairness, and enhance spectator appeal, earning it a place of honor in the annals of competitions. The competition's official website presents a mix of humor and gravitas, reflecting the essence of SparkFun – truly making fun a significant part of the contest. Regrettably, the SparkFun Autonomous Vehicle Challenge retired after the 2018 season.

G. Formula Pi

Organized by Raspberry Pi, Formula Pi is an autonomous mini-racing competition aimed to encourage coding and problem-solving skills [25]. The event is structured in multiple rounds, challenging competitors' abilities in solo runs, obstacle avoidance, and interactive racing. Highly prioritizing fairness, meticulous attention is devoted to hardware maintenance, with thorough inspections carried out for aspects such as battery voltage and motor backlash. Likewise, the submitted codes are stringently managed, ensuring they are transferred to a randomly chosen robot for the competition. Furthermore, to promote continuous learning and improvement, the victorious team is obligated to share their winning code, serving to inspire and guide future competitors. The Formula Pi competition was conducted only once in 2018.

III. Discussions of Rule-Making Perspectives for TAO

This section shares insights from recent DHWs that analyzed the key features, highlights, and potential improvements of existing autonomous racing rules. The DHWs emphasized strategies for enhancing spectator engagement, promoting competitiveness, and ensuring fairness. The discussions in the DHWs would offer guidance for TAO, a contest similar to Formula One but without drivers. The purpose of organizing TAO is to leverage the power of autonomous intelligence for university student education [1]. In the remaining part of this section, the discussions from the DHWs are summarized into several subsections.

A. Building Vibrant Competition Communities

The AWS DeepRacer League exemplifies how nurturing a vibrant competition community can level the playing field for participants. It lowers the entry barriers, fostering increased involvement, which indirectly intensifies competition. An elevated level of competitiveness lessens the likelihood of complacency among reigning champions and recurrent dominance, adding suspense and excitement to the competition.

Organizing such a community involves three key aspects. First, the organizers should provide education through tailored tutorials and guides that cover crucial competition elements like localization, perception, prediction, planning, and control [2], [26], [27], [28]. Secondly, the community should have a section allowing participants to freely share and exchange their competition experiences and learned lessons. Finally, if the competition involves miniaturized racecars, the community should offer an official, monitored trading platform, which not only sells standardized hardware kits with unique identification numbers but also oversees the circulation of second-hand competition hardware.

B. Easing Participation via Module Standardization

In addition to nurturing a vibrant community filled with enriched knowledge and experiences, lowering the entry barrier can be further achieved by focusing on the critical elements of the competition. Our strategy is to direct attention toward what truly matters in these races – the onboard algorithms that leverage the intelligence in autonomous racecars. Other aspects, particularly hardware, can be standardized or modularized, following the footsteps of competitions like Roborace and IAC, or even less restrictive like the SparkFun Autonomous Robot Racing Challenge.

Moving forward with the upcoming TAO races, we plan to embrace and enhance this philosophy of focusing on truly competitive elements. The strategy is to empower participants to excel in their areas of expertise, even if they are only familiar with a subset of the required algorithmic modules for autonomous vehicles. To facilitate this, we provide a set of standardized baseline modules (just as Autoware [29] did) that participants can plug into and supplement with their own algorithms. A practical example might be a participant with specialized knowledge in motion planning. He would employ the default algorithms for positioning, perception, prediction, and tracking control while writing his unique source codes in the motion planning module. A reflection of this idea was seen in our previously organized 2022 Trajectory Planning Competition for Automated Parking (TPCAP) [30]. This idea should be amplified in the future TAO races, which enable the incorporation of mixed teams characterized by three key features: 1) Team members spanning multiple universities and nationalities, 2) Each member concentrating solely on specific algorithm design aspects, and 3) Formation of such eclectic teams is facilitated through the online community mentioned in Section III.A. This idea would largely lower the entry barrier for individual participants, further elevating the competition level in autonomous racing.

C. Intensifying Head-to-Head Races

Head-to-head events exemplified by IAC have demonstrated smooth racing operations. However, the intensity of such competitions tends to be subdued due to the establishment of excessively large minimum allowable lateral and longitudinal distances between vehicles. These measures, while being prudent, can be perceived as overcautious. To improve the allure and competitiveness of future races, a gradual increase in close-proximity vehicular interactions should be implemented, whilst still upholding safety regulations. Alternatively, one may boost the number of racecars concurrently competing on the same racetrack. This idea could induce temporary alliances among racecars from different teams to cooperatively block a more threatening competitor from overtaking. Another idea is to allow each team to field two or more racecars, thereby encouraging within-team collaboration. The aforementioned measures can boost the suspense of the races and prevent teams from resting on their past achievements, thereby continuously motivating all participating teams to strive for excellence.

D. Enriching Dynamic Events on Racetrack

In its beta season, Roborace introduced the Metaverse-based approach, incorporating virtual and dynamic elements on the racetrack, thereby enhancing the suspense even in single-player time-trial races. Although critics have pointed out potential visibility issues for spectators due to the introduction of virtual objects [31], the affordability and safety improvements that these virtual objects bring to the race cannot be ignored [32], [33].

In terms of expanding this innovative technique, one may bring intelligence to the virtual objects' motions. For instance, a virtual obstacle could learn online to be more "cunning" over time, enhancing its ability to challenge a racing car on the track [34], [35]. Also, experienced human Formula One drivers may be invited to remotely manipulate the virtual objects, converting them to rivals on the track alongside the competing racecars [36]. This idea further intensifies the competitive nature of races, pushing both human and artificial intelligence to their limits [37]. It is speculated that the temporal gap between the initial instance of an autonomous racecar outperforming a human driver, and the last occasion of a human driver defeating an autonomous racecar, would not be substantially long.

E. Asking Leading Teams to Release Source Codes

To prevent the dominance of consecutive championship titles by the same team, and also to curb its demoralizing effect on other participating teams, it should be mandatory to request the leading teams to release their on-board source codes by the end of a race season. This strategy ensures that the championship-level performance becomes the baseline in the competition of the next season, which could accelerate the evolution of each participating team, further motivating all teams, including the champion team, to be well-engaged in this competition. While the ethos of open-source sharing is indeed commendable, some teams may still show reluctance towards disclosing their solutions, driven by concerns over intellectual property losses. To mitigate this issue, it is suggested that the competition committee offers assurances to the leading teams, who are required to release their source codes, by providing them the opportunity to concurrently publish their work in reputable international journals (such as IEEE TIV) at the time of code disclosure.

F. Setting Risky Rewards for Exciting Turnarounds

A unique contribution of the SparkFun Autonomous Robot Racing Challenge is the introduction of a "cut-in" paradigm, which provides an opportunity for trailing racecars to stage comebacks. Comebacks are vital components of narrative and filmic suspense on the racetrack. Before a competition ends, if a racecar in second place lags 60 seconds behind the first-place racecar, it is unlikely to muster a comeback under normal circumstances, leaving few possibilities for the audience to anticipate. A cut-in paradigm allows trailing racecars to take risks in exchange for the possibility of catching up, thus making a race thrilling and unpredictable. The cut-in paradigm also pressures the leading teams to continually refine their algorithms, as they cannot overlook such potential threats from behind. To discourage consecutive victories, the cut-in paradigm should be disabled for the previous season's champion team if it still takes the lead in a race of the current season. This idea is similar to the rule of the Drag Reduction System in the Formula One races, which encourages a racecar close behind another racecar to overtake with extra power, thus adding suspense to the race [38].

Taking the cut-in paradigm a step further, we propose a more advanced implementation that leverages online feedback control. In essence, this would involve a real-time adjustment of the racing situation and the allocation of suitable cut-in chances to trailing racecars, in response to the progress of the competition and evolving circumstances. The application of Metaverse technologies, as mentioned in Section III.D, could aid in the instantaneous creation of virtual alternative cut-in routes [39], [40]. These routes would offer trailing racecars a strategic choice: take a calculated risk to shortcut their way forward or maintain their current trajectory. Regardless of which decision to make, this addition would increase competition spectacle and enrich the racing experience.

G. Archiving In-Race Progress for Transparency

Fairness and transparency are critical to the success of any competition. A supervision system should be deployed to prevent a participating team from buying an off-the-shelf solution before applying it to the competition directly. The supervision process could involve collecting development and production logs from each team during the competition to keep track of their progress and identify unfair operations. All collected logs should be released after the race for community oversight. Moreover, to hold teams accountable for their work, all used on-board codes should be archived. This allows for potential complaints or allegations of code issues to be addressed by referring to the archived codes.

H. Diversifying Awards

To maintain suspense and engagement in any racing event, diversifying the award categories is needed [41], as exemplified by the SparkFun Autonomous Robot Racing Challenge. However, it is also important to avoid subdividing the race into too many specific scenarios, otherwise both the audience's attention and competitors' focus are distracted. An effective idea is to have a single racetrack and a uniform set of rules while varying the evaluation criteria to define different awards. Such diversity in awards would encourage more innovative strategies and foster a wider range of skills among participants, making the competition dynamic and captivating.

I. Instituting Balanced Scoring Strategies

To create a dynamic, fair, and engaging autonomous racing competition, the introduction of balanced scoring mechanisms is needed. This can be realized by awarding initial score bonuses to new entrants, indirectly penalizing the preceding season's leading contenders. This strategy pushes victors to consistently innovate, discourage complacency, and cultivate a spirit of relentless competition. If a team consistently retains championships, this penalty escalates over successive seasons, thus forming a feedback controller akin to the Balance of Performance (BoP) mechanism in motorsports [42].

Additionally, it is crucial to support novice teams by offering them extended participation opportunities, even when their prospects of clinching the championship are slim. For example, initiating revival races allows these teams to gain hands-on experiences and grow rapidly within their debut seasons.

IV. Conclusion

This letter has extensively explored autonomous racing competitions, analyzing their merits and the improvement opportunities for advancing intelligent vehicle technologies. We have proposed several recommendations to enhance the appeal, competitiveness, and fairness of TAO. Typical strategies include fostering closer vehicular interactions, diversifying awards, instituting balanced scoring strategies, and implementing dynamic virtual elements on the racetrack. Particularly, virtual-reality technology or metaverse technology has significant potential to enrich competition scenarios and therefore deserves to be better utilized.

As competitions such as TAO become mature, we anticipate a significant influence on the evolution of the intelligent vehicle industry, potentially propelling us toward a future where intelligent vehicles become an integral part of life.

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