Real-Time Karting Performance Monitoring via DAQ System with RTK-Enhanced GPS

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Abstract: Measuring instantaneous speed and engine parameters and accurately assessing trajectories is paramount in evaluating racing performance in motorsports. DAQuino is a general-purpose acquisition system that can configure these specific sports applications. This paper deals with an application of such a DAQ, based on RTK-enhanced GPS, suited for the telemetry acquisition of a kart's parameters and driver performance assessment. The proposed system measuring the kart's position with a maximum error of a few centimetres can assess the effectiveness of the trajectories.

1 INTRODUCTION

Karting, which had its inception in the United States during the 1950s, has steadily risen to prominence as a widely embraced motorsport discipline (Chaldanbayev, 2022). This thrilling form of racing centres around competitive events featuring open-wheeled vehicles characterized by their absence of bodywork, unforgiving solid suspension, and a fixed differential (Figure 1). As with many sporting endeavours, karting operates within a comprehensive framework of rules and regulations, meticulously crafted to safeguard fair competition, and uphold the sport's fundamental integrity (Nakamura et al., 2020).

Governing bodies operating at various echelons, ranging from national bodies to international federations, meticulously enforce these regulations. These entities undertake the essential task of overseeing the sport, ensuring conformity with standardized rules, and fostering an equitable environment for all participants (Bucur, 2019).

Figure 1: Kart vehicle.

The physical demands imposed by the world of karting necessitate that drivers maintain a state of

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exceptional endurance and physical fitness. The remarkable acceleration encountered during karting races subjects’ drivers to substantial G-forces, exerting significant strain on their bodies. Consequently, the cultivation of superior physical endurance, stamina, and muscular strength assumes paramount importance in the pursuit of elevated performance within the realm of karting (Potkanowicz & Mendel, 2013). To cope with their physical condition, drivers engage in cardiovascular exercises, strength training, and neck exercises to enhance their stamina, muscle strength, and neck stability (Matsumura et al., 2011; Yamakoshi et al., 2010).

Furthermore, karting also requires psychological and concentration abilities as drivers need to make split-second decisions, adapt to changes in race conditions such as weather and surface, vibration impacts, and strategically respond to the actions of their opponents. Mental strategies play a vital role in karting, allowing drivers to stay focused, make quick and effective decisions, and remain resilient in challenging situations (Iannuzzi et al., 2018; Yamakoshi et al., 2010).

Such vehicles can reach more than 200 km/h speeds depending on the type and class. Usually, they are powered by two-stroke gasoline engines ranging from 120 cc (junior classes) up to 250 cc (Super-kart class). Furthermore, in amateur classes, it is common to find a notable absence of a gearbox, further simplifying the operation and enhancing accessibility for newcomers to the sport. Combining these unique features and characteristics sets karting apart as a distinct and exciting branch of motorsports (Calderón et al., 2013; Hruska et al., 2017; Lot & Dal Bianco, 2016).

In the realm of modern sports analysis, precision and real-time data acquisition have become paramount for athletes and enthusiasts alike. In this article, we delve into the innovative adaptation of the DAQuino Digital Acquisition Board, a multipurpose data acquisition system (Bonaiuto et al., 2018) that can be tailorable for the specific sport application and that has been already successfully employed in other sport applications as kayaking (Bonaiuto et al., 2020) and swimming (Lanotte et al., 2018). In this case, such a system has been tailored to attach to the unique requisites of karting applications. Therefore, the comprehensive assessment of trajectory data and real-time speed metrics, coupled with the precise insights garnered from engine telemetry, emerges as an invaluable tool in the critical evaluation of racing performance.

In the ever-evolving world of sports and performance analysis, precision data acquisition has emerged as the cornerstone of athletic excellence (Kirkbride, 2013). In this era of cutting-edge technology, where every fraction of a second and every degree of movement can mean the difference between victory and defeat (Hughes et al., 2019; McGarry, 2009). Born from a previous exploration of its potential, DAQuino has undergone a transformation tailored to the unique requirements of karting applications. But its significance extends far beyond the racetrack, offering a versatile toolkit for sports and activities where trajectory tracking, and data-driven insights hold the key to unlocking true potential (Bonaiuto et al., 2020).

Beyond the karting circuit, the applications of this system are far-reaching. Real-time kinematics (RTK) technology, integrated into the DAQuino system, revolutionizes precise location measurements. RTK GPS, when paired with an RTK base station, provides highly accurate positioning by incorporating real-time correction data into Global navigation satellite system (GNSS) receivers (Moon et al., 2018; Ng et al., 2018). This technology has found use in a diverse range of sports, including skiing and role skiing, cycling, and urban transport, where it enhances performance analysis, safety measures, and navigation capabilities (Desai et al., 2021; Ligocki et al., 2020; Moon et al., 2018; Supej, 2010).

Within the confines of this scholarly paper, we introduce a tailored and meticulously engineered iteration of an acquisition system, purpose-built specifically to cater to the unique requirements of karting vehicles. This sophisticated system has been thoughtfully crafted to facilitate the seamless collection and subsequent in-depth analysis of pertinent data emanating from the kart, thereby making a significant contribution to the enhancement of performance within the domain of karting.

2 DATA ACQUISITION SYSTEM

The DAQuino Digital Acquisition Board consists of a master node that can host GPS, Inertial Measurement Unit (IMU), and other kinds of sensors. Furthermore, via a custom radio channel, the system can be connected to up to eight slave boards where specific sensors can be hosted.

For this application, DAQuino (Figure 2) has been customized by equipping it with proper transducers for the measurement of engine speed (revolutions per minute – RPM – at a sampling rate of 25 Hz) and the temperature of both cooling liquid (1 Hz) and exhaust

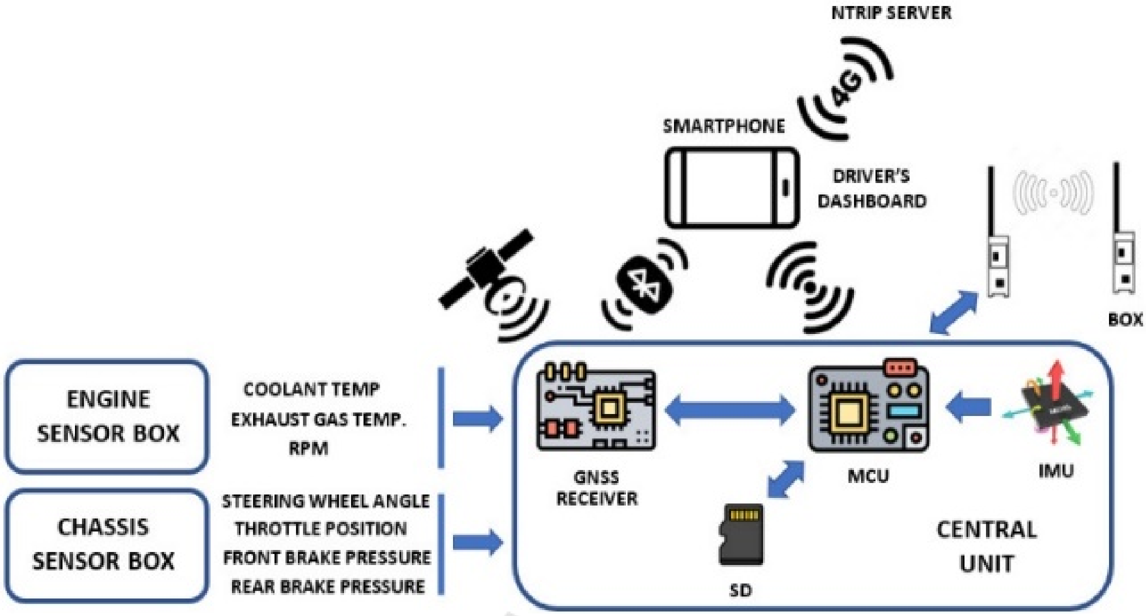

Figure 2: Block scheme of the DAQuino system customized for karting.

gases (10 Hz). The IMU (Nine DoF – Degree of Freedom) has been set at a sampling frequency of 200 Hz, allowing a reasonable estimation of the slip angles too. Figure 3 illustrates the hardware of the DAQuino system that is located on the kart in front of the driver's seat.

Some of the acquired data (e.g., instantaneous speed, lap time, cooling liquid temperature, etc.) are made available to the driver through a webpage on a small tablet that can be placed on the steering wheel (Figure 4) and that communicates with the system installed onboard the kart via a Wi-Fi link.

All the data acquired by the system are stored in an onboard SD memory and they can be downloaded to a computer located for example in the paddock via a Wi-Fi link at each lap for an immediate assessment of the race performances.

A special software program has been properly designed to post-process all the data acquired on the kart and show the relative results. Significant parameters calculated by the developed software include, among the others, lap time, speed in specific sectors, lap distance, average, top and bottom speed for each lap together with the engine speed, tyres slip angles and exhausted gas and cooling water temperatures.

Data from different laps can be superposed for direct comparison and they can be exported to a virtual globe software (e.g., Google Earth), for immediate visualization of the trajectories of each lap and the analysis of the telemetry in the different sections of the circuit.

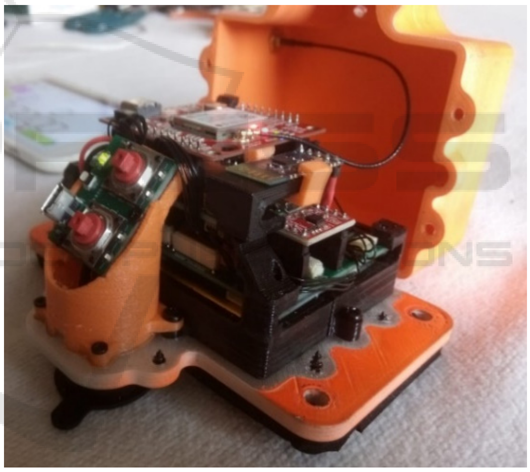

Figure 3: The DAQuino system that is tailored and located in front of the kart driver's seat.

Moreover, the installed GPS device (ZED-F9P by uBlox Switzerland) is a high performance multi-GNSS multi frequency device that exploits multi-band RTK (Gurusinghe et al., 2002) technologies for centimetres-level accuracy.

A comprehensive approach was employed to capture and record the instantaneous values of critical performance metrics throughout each lap's entirety.

Figure 4: Driver monitor mounted over the steer to immediate view of some driving parameters.

The precise measurement of lap duration, displacement, and average velocity, contributing to a holistic understanding of the kart's dynamic performance characteristics and race dynamics were measured (Table 1). Additionally, this encompassed the real-time measurement of speed, quantified in kilometres per hour, engine RPM, as well as the precise monitoring of water temperature and exhaust gas temperature, expressed in degrees Celsius (Table 2). This meticulous data collection process enabled a detailed examination of the kart's dynamic performance characteristics, offering a nuanced insight into its behaviour on the track.

To enhance the analytical capabilities of this research, advanced software tools were harnessed to consolidate and visualize the acquired datasets. This software provided the means to amalgamate the diverse data streams into a cohesive, informative figure. Notably, the software's interactive functionality permitted users to delve into the data with remarkable precision. With a simple click on the tracked trajectory line corresponding to each lap, investigators were empowered to access specific data points at precise moments of interest (Figure 5). This study feature facilitated an in-depth exploration of performance nuances, bolstering the accuracy and efficiency of our research endeavours and offering a dynamic and user-friendly approach to data analysis.

Table 1: Measurement of race duration (seconds), total displacement (meters), and average speed (km/h) for each lap.

lap	Time [s]	Distance [m]	Average speed [km/h]
1	49.242	796.3	58.2
2	43.143	795.8	66.4
3	42.076	797.9	68.3
4	41.508	797.1	69.1
5	41.255	797.3	69.6
6	41.189	799.0	69.8
7	40.688	796.8	70.5
8	40.921	799.1	70.3
9	40.944	801.0	70.4
10	40.741	799.5	70.6

Table 2: Instantaneous values were recorded for each minimum and maximum speed (km/h), RPM, water temperature, and exhaust gas temperature (in degrees Celsius) for each lap.

lap	Min lap Speed [km/h]	Max lap Speed[km/h]	Min water T [°C]	Max water T [°C]	Min exhaust Gas T[°C]	Max exhaust Gas T[°C]	Min RPM	Max RPM
1	38.4	88.2	51	52	342	621	6192	15629
2	39.8	95.1	50	53	281	637	7513	15752
3	41.8	96.9	50	51	289	622	7119	15637
4	43.7	97.4	50	52	311	629	7616	15649
5	43.5	97.9	48	49	322	623	7544	15710
6	44.4	98.2	49	50	346	606	7689	15588
7	44.8	98.3	48	50	313	608	7628	15669
8	43.8	98.4	51	52	347	611	7072	15864
9	44.4	98.6	51	52	328	641	7363	15818
10	44.5	98.1	51	52	0	620	7486	15764

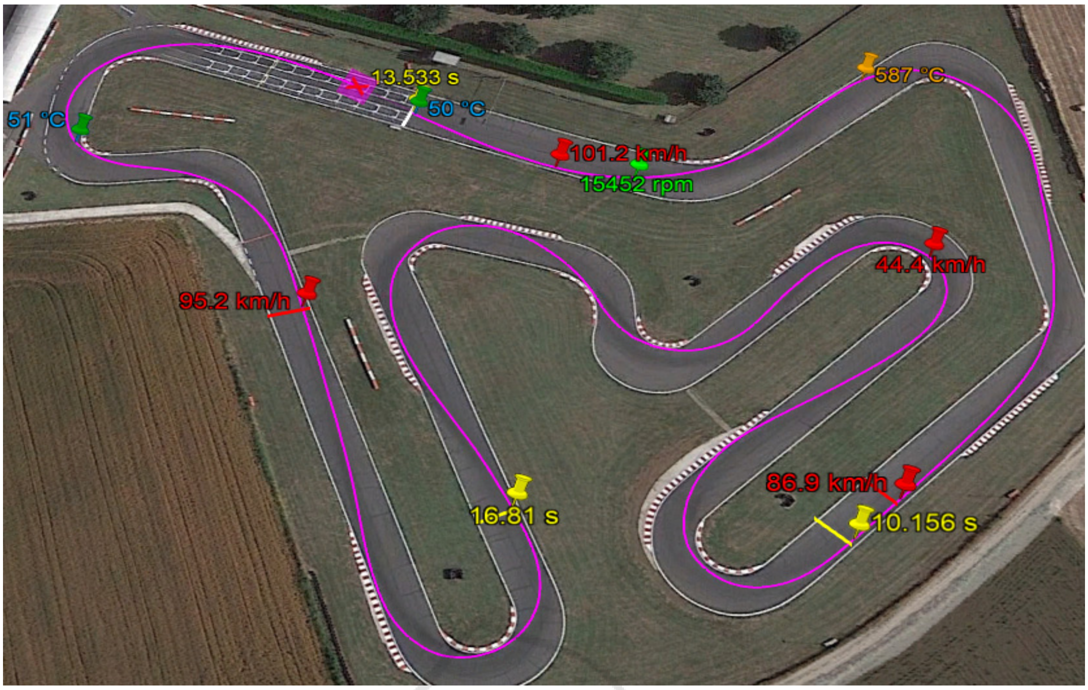

Figure 5: The kart's trajectory (tracking magenta line) was recorded by the system with some parameters recorded by the system in specific track points: the time obtained for each subsection of the track (yellow), the kart's speed in some random track points (red), RPM (green), water temperature (cyan), exhaust gas temperature (orange).

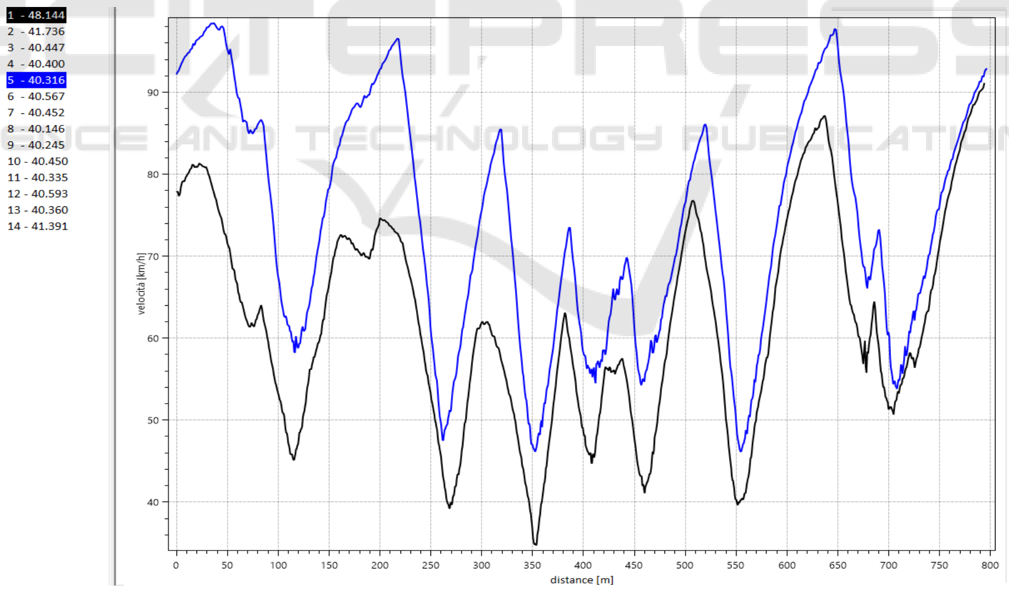

Figure 6: Speed data for kart across two laps (the 1st lap in black and the 5th lap in blue).

The power of specialized software to not only collect and store a wealth of performance data but also to transform it into meaningful visual representations. This facilitates the design and generation of dynamic graphs for each of the monitored parameters over time. One of its standout features is the ability to select specific laps for comparative analysis. This means that researchers have the flexibility to choose laps of interest and directly compare the performance metrics they wish to scrutinize. Figure 6, for instance, illustrates the variation in vehicle speed during the first and the fifth laps, providing a visual representation of how speed evolves throughout the race.

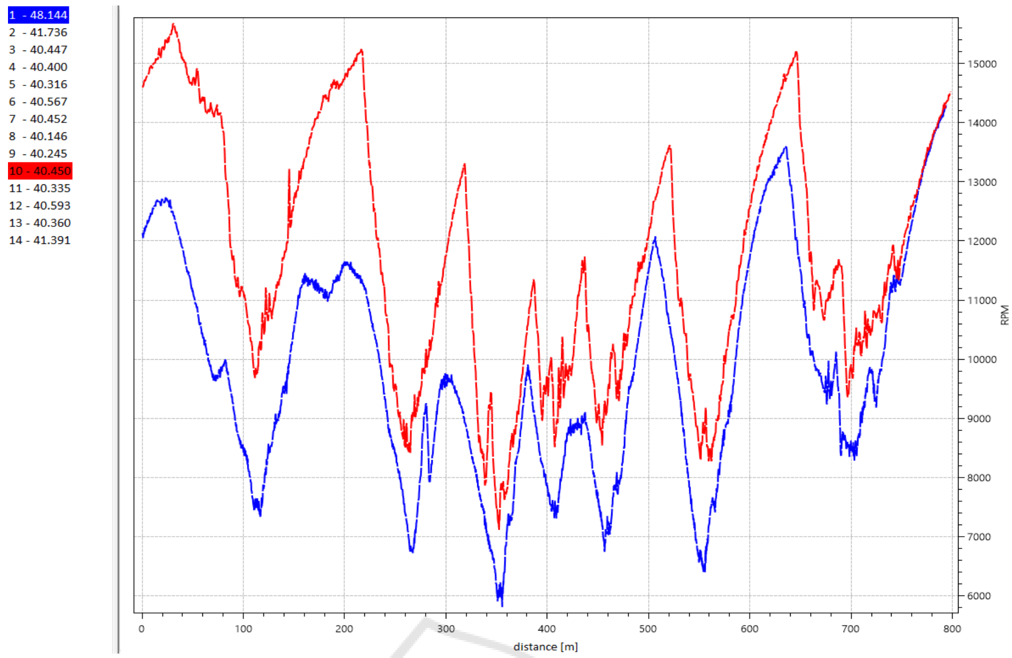

Figure 7: RPM data for kart across two laps (the 1st lap 1 in blue and the 10th lap in red).

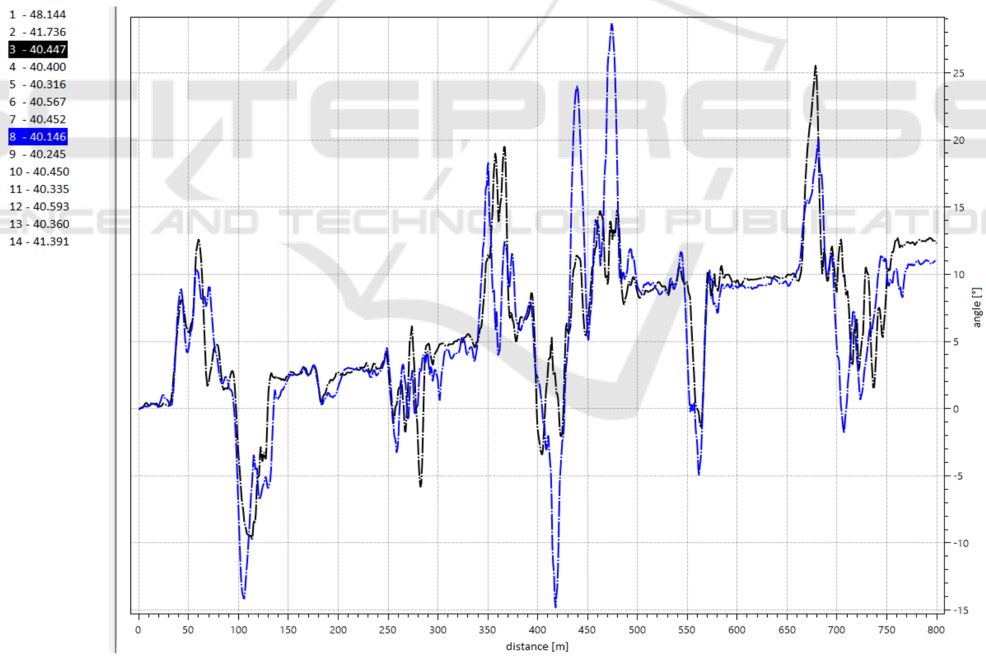

Figure 8: Slip angle data for kart across two laps (the 3rd lap in black and the 8th lap in blue).

Similarly, Figure 7 shows the RPM values in the first and tenth laps, allowing for a direct comparison of engine performance between these two specific laps in the race.

Another ability of the system is to measure the tyres' slip angle that most often occurs during changing the directions and curves. This information aids to the driver's ability to control the kart and understand the breaking force to observe the vehicle performance. In Figure 8 the variation of tyres' side-slip angle over the distance of the circuit is depicted, while Figure 9 shows some technical details of this tyres' feature and the applied force on the tyre in motion and the effect that can occur the slip angle.

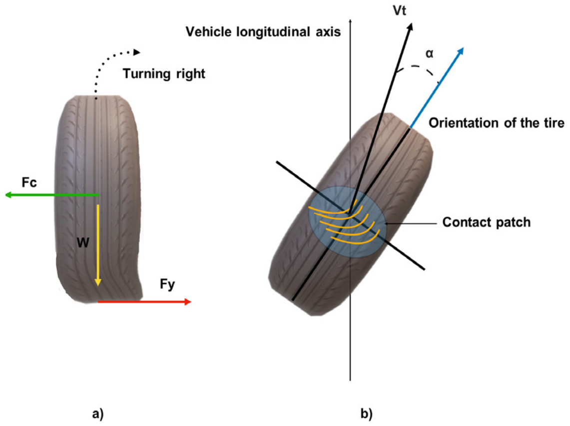

Figure 9: The parameters that have effect to occur slip angle in the axes of the tyres in motions.

These illustrative figures not only enhance the reader's understanding of our research but also underscore the valuable capabilities of the software in generating customized visualizations for in-depth analysis.

3 REAL-TIME KINEMATICS

RTK has emerged as a promising technology that offers precise location measurements. This technology utilizes a family of low-cost GPS navigation receivers, which, when connected to an RTK base station, can achieve highly accurate positioning. The key advantage of RTK GPS is its ability to incorporate correction data into the GNSS receivers, significantly improving, in this way, their position accuracy. The RTK base station plays a crucial role as a stationary GNSS receiver with a known location to receive correction data via receivers. The RTK technology offers a significant improvement over traditional GPS systems by providing real-time correction data. With an RTK base station within a radius of approximately 40 km, the RTK rover can benefit from high-precision positioning capabilities (Broekman & Gräbe, 2021; Skoglund et al., 2016).

RTK GPS technology has demonstrated beneficial use in outdoor sports such as Skiing and cycling. RTK GPS enables detailed slope mapping and grooming, allowing cyclists to analyse their performance on different terrains and optimize their training and enhance safety through avalanche detection systems and provide accurate navigation for skiers, particularly in challenging mountainous environments (Sharma et al., 2018; Skaloud et al., 2004; Supej, 2010). Moreover, in urban transport, the application of RTK GPS for vehicle tracking is beneficial for studying factors such as rapid acceleration and deceleration, helping to improve transportation systems and optimize traffic flow (Supej & Čuk, 2014). These examples highlight the diverse range of sports and activities where RTK GPS technology is proving valuable in terms of performance analysis, safety enhancement, and navigation in sports. Its refresh rate has been set to 25Hz. The onboard tablet is connected via a 4G data link to an NTRIP Server (Networked Transport of RTCM via Internet Protocol) to download the parameters useful for the position correction that are transmitted to the GPS device via a Bluetooth radio link to implement the embedded RTK procedures.

Figure 10 illustrates two distinct trajectories derived from identical GPS data. The first trajectory, depicted in red, shows the results when the Real-Time Kinematic (RTK) correction system is operational, while the second trajectory, represented in yellow, demonstrates the outcome when this system is intentionally deactivated.

4 CONCLUSIONS

The paper introduced an innovative adaptation of the DAQuino system, meticulously tailored to address the specific requisites of karting applications. This enhanced system, equipped with precision sensors, is adept at capturing critical performance metrics. These encompass the measurement of motor RPM, the monitoring of temperature levels in both the cooling liquid and exhaust gases, and the comprehensive acquisition of kinematic data through a cutting-edge 9 DoF IMU. The utilization of this IMU facilitates the estimation of slip angles, a pivotal parameter in karting performance analysis.

Furthermore, the system boasts a GPS component, bolstered by an RTK position correction mechanism, ensuring the retrieval of position data with centimetre-level accuracy. The incorporation of these advanced features, coupled with an impressively high data update rate, renders this system eminently suitable for a spectrum of sporting applications where precise trajectory tracking holds paramount importance. Examples of such sports encompass but are not limited to canoe slalom, skiing, cycling, and more, where the quest for accuracy in tracing and analysing trajectories stands as a critical component of performance assessment and improvement.

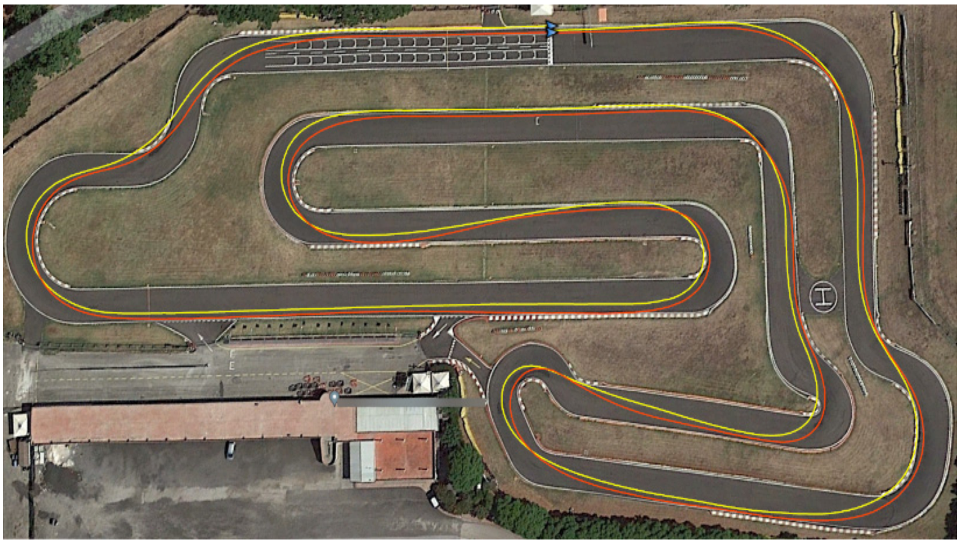

Figure 10: Trajectories recorded by the system differentiate between those acquired with RTK correction (in red) and those obtained without it (in yellow).

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