ACCURACY OF VIDEO ANALYTICS AND ONBOARD GPS DEVICES FOR DATA COLLECTION AT ROUNDABOUTS

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ABSTRACT

Roundabouts significantly reduce the number of vehicle conflict points at intersections while simultaneously reducing the speed of vehicles through intersections, thereby reducing crash frequency and severity. Accurately measuring the positions and speeds of vehicles traversing a roundabout in the field is challenging, but required to analyse operations at roundabouts. This paper reports on an investigation into different methods of measuring the positions and speeds of vehicles travelling through a roundabout. Ideally, continuous speeds, i.e., speeds measured at short intervals, are required for an accurate understanding of a vehicle's movement through a roundabout. Comparisons are made between several devices and technologies that can provide the necessary vehicular trajectory data in roundabouts. These include external devices and/or technologies tracking the vehicle (speed gun, area radar scanning, video recording, and video analytics) and onboard devices using satellite positioning systems (Mobile Smartphone, VBox Sport, Garmin Handheld, and DL1 Club). These devices vary in terms of specifications, data recording frequencies, speed, and positional accuracy. The study showed that of the devices that were tested, GPS tracking, using specifically the VBox Sport device, and video analytics using UAV-based video footage provide the highest levels of accuracy.

1. INTRODUCTION

The modern roundabout, a circular intersection operating with the yield-at-entry rule, provides safety and efficiency benefits over typical intersections like stop-controlled and signalised intersections (Rodegerdts *et al.*, 2010). A research project has been undertaken by the South African National Roads Agency Ltd (SANRAL) to investigate the design and operations at roundabouts across South Africa.

Roundabouts significantly reduce the number of vehicle conflict points at intersections while simultaneously reducing the speed of vehicles, thereby reducing crash frequency and severity. The roundabout is an effective method of speed control, and it is, therefore, important to investigate the relationship between speed and the geometric characteristics of a roundabout. Being able to accurately measure vehicle speeds and positions is useful and important when collecting speed data at various points in a roundabout.

Collection of vehicle trajectory and speed data at roundabouts is a cumbersome task to complete manually. Speeds through a roundabout are required to be recorded at intervals of less than a second to get adequate trajectory and speed data. Alternative means of determining vehicular data were considered and investigated during the project.

Advancements in technology have introduced devices and technologies capable of accurately tracking the speeds of vehicles, these include external tracking technologies, as well as onboard devices using satellite positioning. Table 1 illustrates the external and onboard devices considered in this study, briefly discussed in Sections 2 and 3.

Table 1: Position and speed measurement devices and technologies

External Tracking Technologies	Onboard Tracking Devices
Fixed View Cameras	Mobile Phone
Ground Level Radar Tracking	Garmin Handheld GPS
Unmanned Aerial Vehicle (UAV) Video	Driver Performance Device: DL1 Club
Radar – Speed Guns (Bushnell Radar Gun)	Driver Performance Device: Vbox Sport

The purpose of this paper is to evaluate these technologies and devices in terms of their accuracy and applicability for the research of driver and vehicle behaviour within roundabouts.

2. EXTERNAL DEVICES AND TECHNOLOGIES

The benefit of external devices is that they are able to evaluate the movement of all vehicles manoeuvring a roundabout. Video, video analytics and radar technologies were investigated to determine the most suitable external device and technology approach. An in-field study of external devices was conducted considering their respective advantages and disadvantages to determine the device and/or technology most suitable for use. The devices that recorded video footage all required the use of post process video analytics software, which are also investigated in this section.

2.1 Fixed View Video Cameras Mounted on Poles

Video cameras (standard GoPro cameras) were installed on high masts on an approach to a roundabout at between 10 and 14 m heights as illustrated in Figure 1. These cameras introduced issues related to the field of view, vehicle occlusion, and the number of pixels per vehicle on the far side approach which negatively impacted the quality of the footage. Video analytics software requires a minimum number of pixels, typically between 30 and 40 pixels per object, for the object to be recognisable.

An alternative approach to the standard view cameras was introduced and tested. This involved the use of 360° video cameras (GoPro Max and the Insta 360), installed on high masts on approach to the roundabout in closer proximity as shown in Figure 2. Any section of the 360° view can be exported for analysis in single/fixed view software. The issues of vehicle occlusion and the number of pixels per vehicle were resolved because the camera was placed closer to the intersection and at a better angle. The method did, however, introduce the issue of warping of the image that required sophisticated software to resolve.

A further alternative that was tested was by mounting the 360° video cameras on the centre island as illustrated in Figure 3. At this position the camera angle resulted in the background view continuously drifting over time and could not provide a stable view for video analytics. The main issue with this approach was that it required the installation of a very high post on the central island.

Figure 1: View from standard fixed view action camera

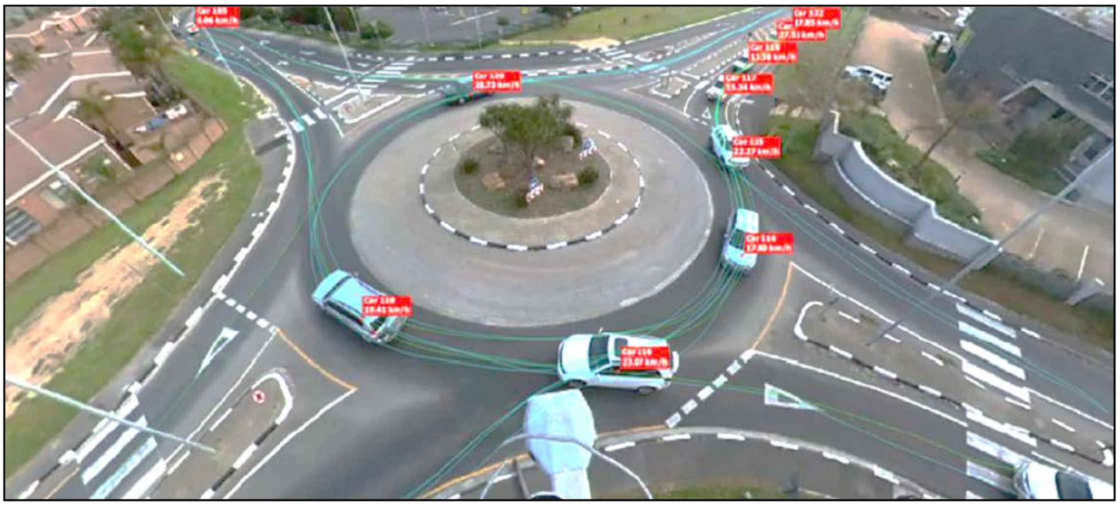

Figure 2: View from 360° camera mounted outside roundabout

Figure 3: View from 360° camera mounted on central island

2.2 Ground Level Radar with Vehicle Tracking

Several radar experiments were conducted to evaluate the capability of radar devices to track vehicle movements and produce coordinated paths through the roundabout. Radar uses radio waves to determine the distance and speeds of objects relative to the device. A radar beam normally follows a linear path allowing distances and speeds to and from the radar device to be accurately determined along this path (as in a radar gun used for speed law enforcement). A radar device (Smartmicro) made use of multiple firing beams to provide a wide field of view as illustrated in Figure 4. The limitation of the device was that although it could track vehicles accurately along each of the individual beams, it was less accurate for vehicles moving perpendicular to the beams. This often resulted in vehicles being “lost” as they circulated through roundabout.

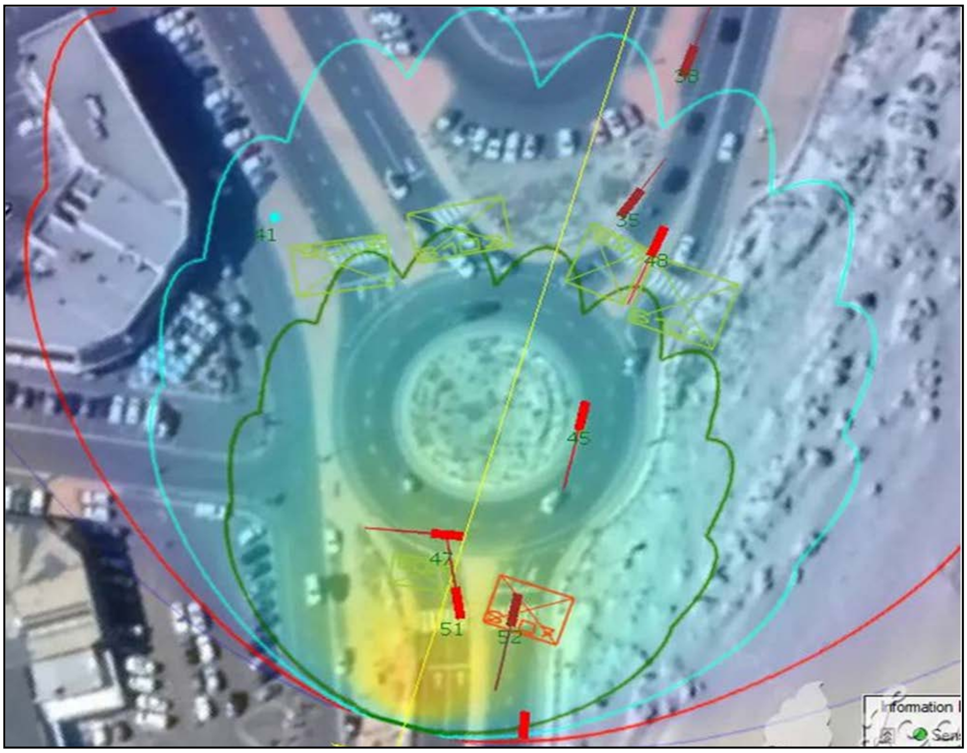

Figure 4: Radar with multiple firing beams

2.3 Video From High Vantage Point Using UAVs

The issues identified with post-mounted videos can be effectively mitigated by using UAVs (Unmanned Aerial Vehicles), also called drones, as illustrated in Figure 5. To obtain a sufficient field of view and to minimize vehicle occlusion, it was necessary to fly the UAV at a height of between 100 m and 125 m above ground level. Drone regulations in South Africa do not allow flying a drone over a public road and the drone had to remain a distance of 50 m away from the roundabout.

A significant limitation of using UAVs for traffic observation was that flight time was limited by the capacity of the battery, typically to only 20 to 30 minutes. Recording of long periods of video footage required battery changes, resulting in lost recording time, or the use of multiple UAVs per site.

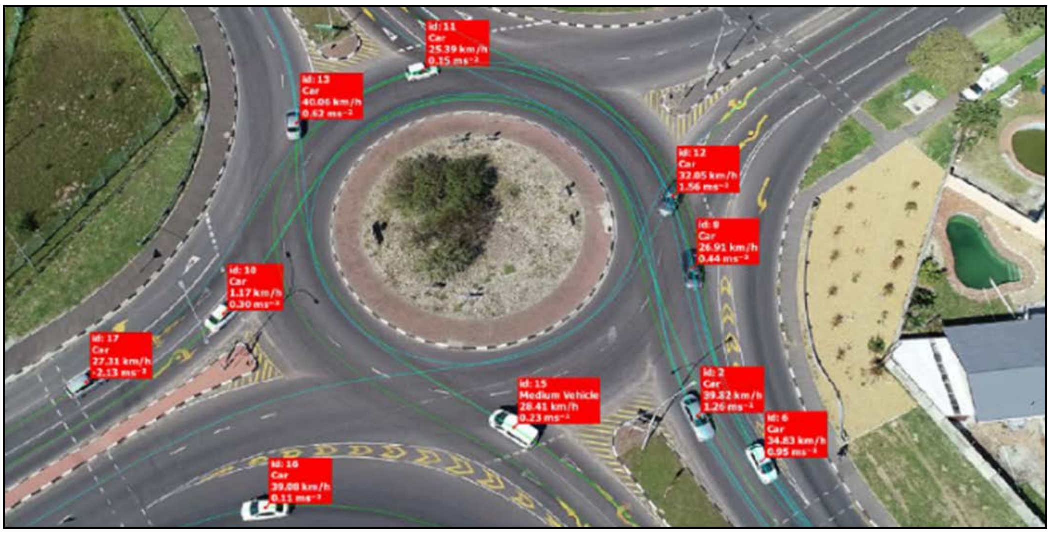

Figure 5: View from a high vantage point using UAV

The quality of the video footage is an important consideration for video analytics, which needs to trace vehicles as accurately as possible. One of the main concerns was the warping or distortion that could be caused by the camera lenses used on the UAVs. A test was devised to investigate this possible issue by means of a test image which consisted of dots printed on an A0 size paper. The dots were spaced at 25 mm intervals. For the purposes of the roundabout project, a scale of 1:200 was used which meant that each dot interval represented 5 m on the ground. A camera of a UAV was placed directly above the centre of the A0 paper, and the test image was photographed. The dots on these images were digitised by software to determine x-y coordinates of the centres of all the dots on the image. A camera model was then used to transform the coordinates to the horizontal ground plane and these coordinates were compared to the actual scaled coordinates on the test image.

A histogram of the dot position errors is shown in Figure 6. Half of positional errors were less than 0.2 m (scaled to ground view), while over 95% of the errors were found to be smaller than 0.5 m (scaled) with a maximum error of about 0.7 m. These errors were considered acceptable for the purposes of the research.

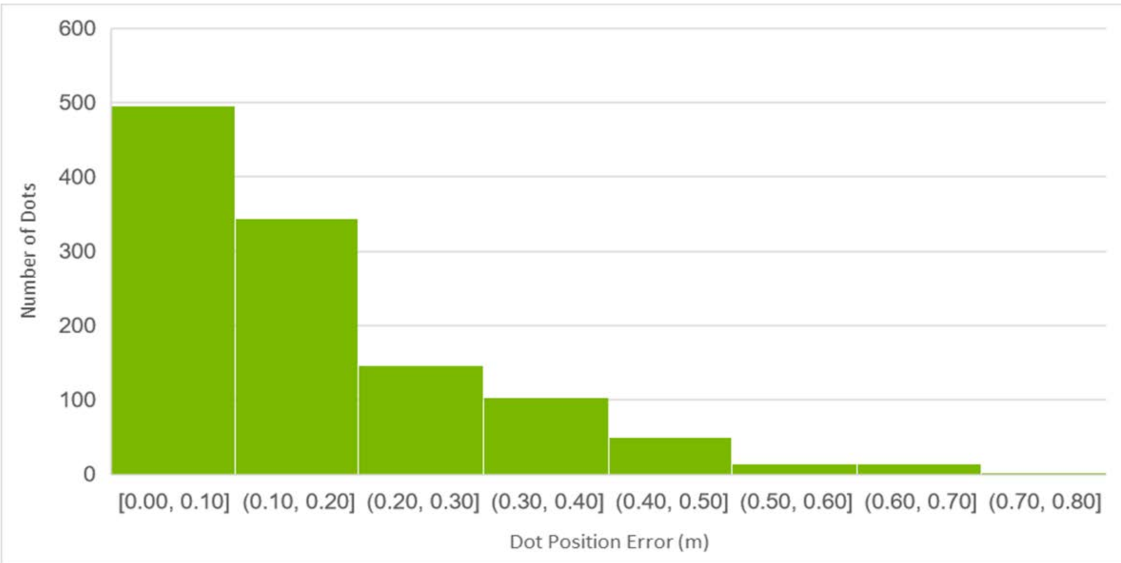

Figure 6: Dot position error – Full width image

Based on the field experiments with different UAV cameras it was concluded that camera specifications should be at least the following:

- Lens FOV 84° 8.8 mm/24 mm (35 mm equivalent) f/2.8 – f/11 auto focus.
- Mechanical Shutter Speed 8 – 1/2000 s.
- Electronic Shutter Speed 8 – 1/8000 s.
- Image Size 3:2 Aspect Ratio: 5472 × 3648.
- PIV Image Size 3840×2160(3840×2160 24/25/30/48/50/60p).
- Video Recording Modes H.265, 2.7K:2720×1530 24/25/30p @65Mbps.

Based on the field investigations of external devices, UAVs were found to be the best to use when collecting traffic data at roundabouts.

2.4 Video Analytics Software for External Devices

At the time of the study, various companies provided software for the post-processing of aerial videos. These included the following:

- DataFromSky – https://datafromsky.com/
- Street Simplified **–** https://www.streetsimplified.com/
- Hermes Traffic **–** https://hermestraffic.com/
- Intuvision **–** https://www.intuvisiontech.com/

The DataFromSky software was found to provide all the analysis that was required for the purposes of the roundabout research and was selected for the analysis of all video footage collected during the research. DataFromSky Viewer provided an easy-to-use interface for post processing video analysis and data extraction.

A field study was undertaken to determine the accuracy of the DataFromSky video analytics software. The study involved a correlation analysis of the speeds calculated by DataFromSky and speeds manually calculated from fundamental principles. The following process was followed to perform the correlation analysis:

- UAV video footage was obtained from a test site with the correct camera specification and flight height of ±120m and ±50m away from the roundabout while maintaining a steady position.
- The videos were then processed by means of the DataFromSky software and travel times and distances of all vehicles were obtained.
- Markers were then identified on the roundabout like the painted arrows on the roadway, which were used as reference points. The distances between these reference points were measured by means of a scaled measuring tape in the image field. A sample of vehicles was then manually tracked on the videos as they travelled between the markers, and the corresponding travel times were determined. This provided a number of accurate speeds and travel time estimates evaluated manually in the image field for comparison with speeds and travel times estimated by DataFromSky.

The results for 80 vehicles that were measured and tracked as outlined above are indicated in Figures 7 and 8, comparing average speeds and travel times. The graphs show a close relationship between the field measurements and the results from the DataFromSky software. A correlation analysis yielded correlation coefficients of 0.9953 (for average speed) and 0.9998 (for travel times), signifying a strong correlation between the results from the field and the output from DataFromSky. The accuracy of the software was therefore considered appropriate.

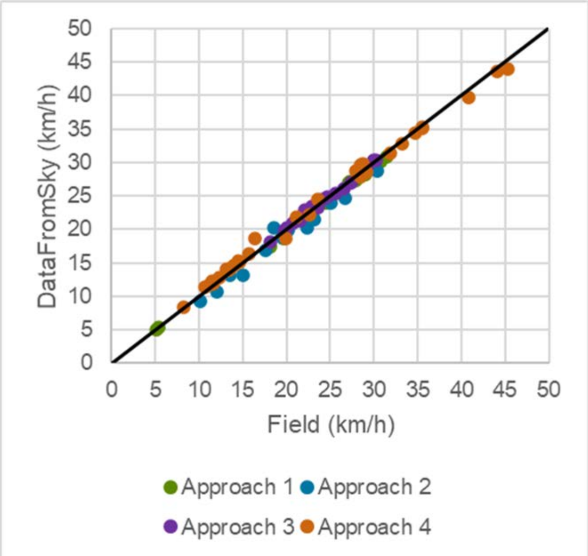

Figure 7: Average speed (km/h): Field vs DataFromSky

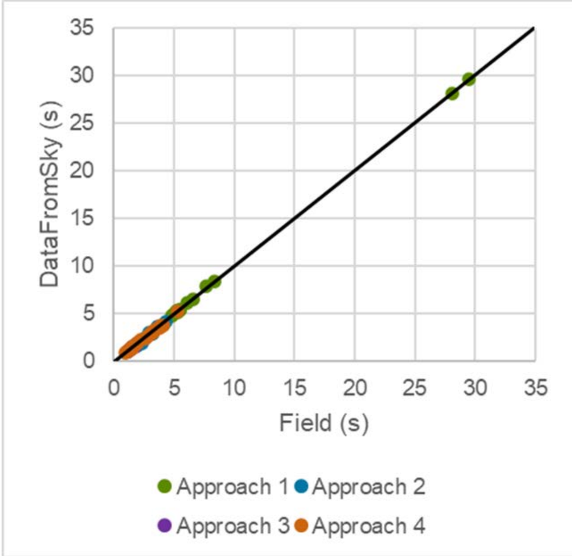

Figure 8: Travel times (s): Field vs DataFromSky

3. ONBOARD TRACKING DEVICES

The UAV video methodology together with the DataFromSky video analytics software was selected as the most appropriate method of observing traffic through roundabouts for most of the purposes of the research project. One of the objectives of the overall SANRAL roundabout project, however, was to obtain the fastest speeds that vehicles can traverse a roundabout with a reasonable degree of safety when there are no other vehicles in or near the roundabout. Due to cost implications, the video observations were only undertaken during peak periods with the purpose of recording traffic interactions during higher demand periods. During such periods, drivers do not traverse the roundabout as fast as possible. Fastest speed analyses are used to evaluate the fastest path that can be traversed around a roundabout.

Hence, an alternative method of using on-board GPS tracking devices with the use of a test vehicle for determining the fastest speeds was investigated. This test vehicle was used during off-peak periods when there were very few vehicles at roundabouts, such as during the quiet periods over weekends or at night. The tests were undertaken at relatively high speeds, but the speeds were not so high that at any stage of the test runs were the speeds considered to be unsafe or reckless. The speeds would be representative of a prudent driver who is in a hurry to reach a destination without being reckless.

Several in-vehicle tracking devices were investigated and these are illustrated in Figure 9 and discussed in the following sections.

Figure 9: Onboard tracking devices: A – Mobile phone, B – Garmin handheld GPS, C – VBox Sport GPS, and D – DL1 Club GPS

3.1 Mobile Phone

Mobile phones with built-in GPS modules, (See Figure 9A), are common and readily available tracking devices. A study by García-Ramírez *et al* (2020) found a strong relationship between data from a VBox Lite tracking device and Samsung Galaxy S5 and S6 smartphones. For speeds up to 51.9 km/h, the model had a correlation coefficient of 0.97. They found that speed measurement errors varied between 2.21 km/h and 11.81 km/h. These larger errors, however, were considered too high for the purposes of the SANRAL roundabout research. Mobile phone devices were not considered further in device tests, and other devices were therefore evaluated.

3.2 Garmin Handheld Device

A Garmin GPSMAP 60CSx GPS (See Figure 9B) was available and evaluated during the investigation. This device can record trajectory data in 1 second intervals, with an accuracy of 3 m, 95% of the time, and a speed accuracy of 1 km/h (Al-Gaadi, 2005). This device is typically used for hiking and route determination.

3.3 VBox Sport

The Vbox Sport (developed by Racelogic, see Figure 9C) is a GPS tracking device for analysis of driving performance, as well as for use in accident reconstruction (Ciępka and Janczur, 2019). The device has an internal and external antenna that can be mounted on the top of a vehicle and is battery operated. Speeds are calculated using the Doppler effect and based on the shift in the GPS carrier signal, rather than the triangulated position. The Vbox Sport records positions and speeds at a frequency of 0.1 seconds. According to the brochure, positions can be recorded with a precision of ±5 m and speeds of ±0.1 km/h.

3.4 DL1 Club Device

The DL1 Club (Race Technology, see Figure 9D) is a GPS tracking device for enhancing driver performance and is also used for accident reconstruction (Ciępka and Janczur, 2019). The device has an antenna that is mounted on the vehicle roof and needs an external power source. One of the issues with the device is that it was not always possible during the tests to determine if the device was actually logging data. According to Race Technology (2013), it records at a frequency of 0.01 seconds with positions within ±3 m and speeds within ±0.3 km/h.

3.5 Testing and Comparisons

An investigation was undertaken to compare the latter three described devices (Garmin 60CSx, VBox Sport and the DL1 Club). A test-vehicle run was conducted on a road section with all three loggers active. The test route was approximately 400 metres in length and covered two ninety-degree turns and U-turn manoeuvre, and speeds varied between 0 km/h and 60 km/h.

The speed measurements obtained from the three devices are shown in Figure 10. Although the speeds are reasonably similar, it was evident the Garmin (green line) speed measurements were the least similar to the VBox Sport (blue line) and the DL1 Club (orange line) speeds. The Garmin speeds are also reported less frequently. The speed measurements of the VBox Sport and the DL1 Club were similar over large sections of the route, but the DL1 Club often indicated unrealistically high-speed spikes. The Garmin device does not record data frequently enough for manoeuvring roundabouts at high speeds and was not further analysed.

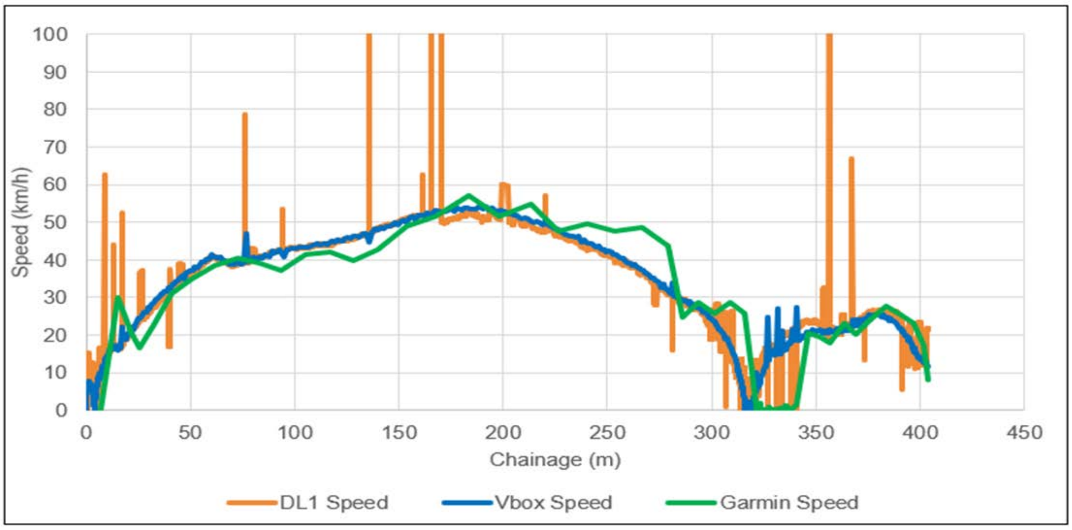

Figure 10: Speed profile comparison - VBox Sport vs DL1 Club vs Garmin 60CSx

The actual vehicle trajectories reported by the VBox Sport (blue line) and the DL1 Club (orange line) are compared in Figure 11 for a 125 m section of the test route in one 90-degree turn. Figure 12 shows the last 100m of the test route in the U-turn. The VBox Sport reported a smoother path and a better spatial representation of the actual path that was followed. The DL1 Club stopped recording on the return leg of the test route as is evident in Figure 11, resulting in only one orange line, while both in- and outbound paths are indicated for the VBox Sport.

Figure 11: Initial 125 m of test section

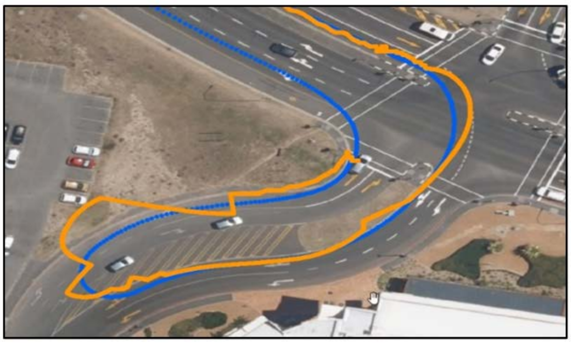

Figure 12: Final 100 m of test Section

Based on this comparison it was decided to evaluate the VBox Sport further by comparing the device with UAV videos and the DataFromSky software. These tests involved driving through a roundabout with the onboard VBox Sport active while simultaneously recording video footage using a UAV. Then the post processed DataFromSky results were used to obtain the path information of the test vehicle. This video path data was then compared with that extracted from the VBox Sport. The data was corrected to ensure that the start times of the respective paths coincided and that the time intervals corresponded.

The recorded speeds using the VBox Sport and that from the UAV are compared in Figure 13. The VBox Sport speed profile is shown as blue dots and the DataFromSky is shown as red dots. It is notable from the figure how similar the speed profiles are. This is regardless of the performed manoeuvre and/or where the test vehicle was, either on the approaches or while travelling through the roundabout.

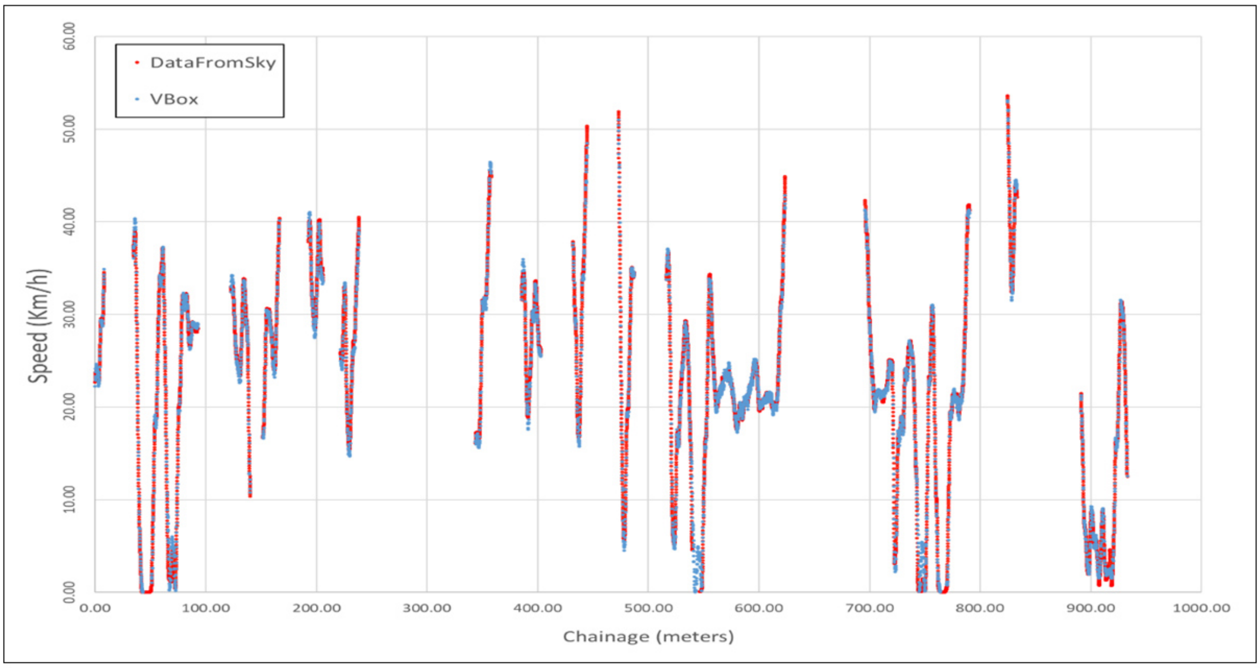

Figure 13: Speed profile comparison - DataFromSky vs VBox Sport

The speeds obtained from the VBox Sport and from UAV footage through DataFromSky are also compared in Figure 14 which shows a close correlation between the video analytics and VBox Sport speeds. A correlation analysis indicated a correlation coefficient of 0.9968. The greatest differences are observed for speeds below 10 km/h. The reasons for the differences were not clear but could be attributed to the amplification of the dot position error of the UAV at low speeds. For the higher speeds, most of the speed differences were lower than 0.3 km/h. The purpose of the in-vehicle device was in fact to measure the fastest speeds through the roundabout. Fastest speeds through a roundabout are typically speeds well above 10 km/h and the error was not considered an issue for continued use of the VBox Sport.

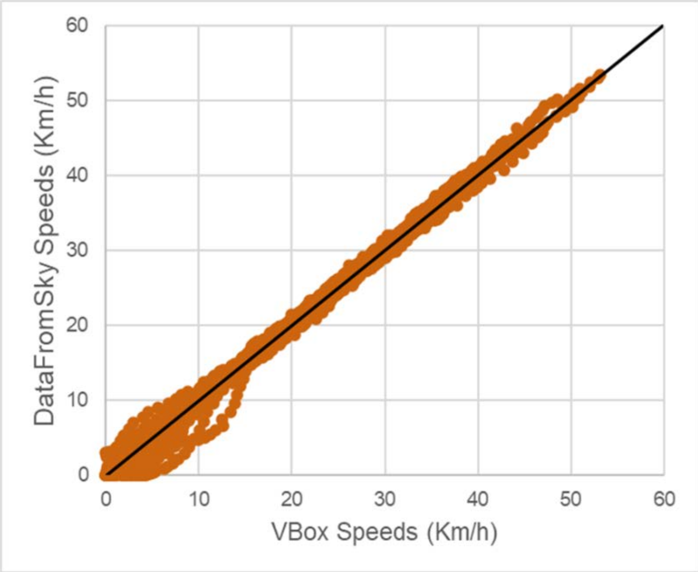

Figure 14: Correlation analysis - VBox Sport vs DataFromSky

4. CONCLUSIONS

The SANRAL research project to investigate design and operations at roundabouts across South Africa required accurate positional and speed data of vehicles travelling through roundabouts. This study focussed on identifying suitable tracking devices and technologies that can be used at roundabouts.

The investigations showed that UAV video footage together with the DataFromSky analytics software were the most suitable and accurate tools for the collection of trajectory data for all vehicles manoeuvring roundabouts. Various on-board devices were also evaluated for measuring the fastest speeds of an individual test vehicle during periods of uninterrupted flow. The VBox Sport was determined as the most suitable device for this purpose.

Both UAV footage and the VBox Sport device have now successfully been used for the collection of data at a large number of roundabouts around South Africa. Without these devices, it would have been very difficult and even unlikely to collect the quality data that were possible with the devices. The use of the devices made a significant contribution to the quality of the research and can be used in future research of vehicle trajectory analysis at roundabouts, and certainly other road infrastructure facilities.

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