Advanced Surveying Techniques for Measuring the Marathon Course

Maria TSAKIRI, Dimosthenis STATHAS and Orthodoxia ARABATZI, Greece

Key words: course measurement, total station, terrestrial laser scanning, certification

SUMMARY

The Marathon is a highlight of major athletics sport events. The precise measurement of the course is essential to ensure that the event conforms to IAAF (International Association of Athletics Federation) strict guidelines. This paper discusses these specific guidelines and reviews the common techniques currently adopted in measuring a course for certification. Considering this as a fundamental surveying problem, the paper proposes a suitable measurement technique using terrestrial laser scanning technology. It is demonstrated, by way of experiments, that the technique can be used to define the shortest possible route in a relatively automated way. Comparison of the results is performed using standard surveying procedures.

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1. INTRODUCTION

The marathon is the epitome of athletics sport events because it is the only sport that athletes of all abilities can participate on an equal footing. Elite athletes are interested in winning the race in a record-breaking time while the majority of runners are concerned in making a new ‘personal best’. With the pressure of modern international athletic competitions comes a demand for fast and precise road course measurements for distance definition. The IAAF (International Association of Athletics Federation) regulations emphasise the requirement of not only producing "accurate" courses but also ensuring that courses are not short in order to guarantee that every possible path a runner can take through the course is at least the stated distance.

Unlike track races where running courses are ovular and of a standardised construction, road races courses vary tremendously. For this very reason marathon times were referred to as “world best” times not world records. However, since August 2003, IAAF has adopted World Best as World Records (http://www.iaaf.org/WCH03/news/Kind=512/newsId=22373.html) In fact, the marathon course did not always have its current nominal length. For the 1908 London Olympic games the marathon distance was changed to 41.834 km so that the event could finish in front of the royal box. It took another 16 years before the distance of 42.237km was introduced, with the 1924 Paris Olympics being the first to hold the now official marathon distance. Even today, although the nominal length of marathon races is defined by IAAF standard and world record times and ‘fastest’ times are recorded, there is no standardisation of road racing records because of the wide variety of courses. It is up to the runners to pick the courses that they know will suit them or are known to produce fast times. It is, therefore, critical to provide reliable techniques that can measure road courses with results that are easily reproducible.

Although there are many ways to measure a course, the calibrated bicycle method has been the preferred to all others because of the speed with which it can be performed, the robustness of the technique and the instrumental precision of about 10cm. The basic method of measurement is to compare the number of revolutions of the bicycle wheel needed to cover the course with the number of revolutions required to cover a standard calibration course. Nevertheless, there are a number of issues pertaining to this technique, including the requirement of a special counter to record the revolutions of the front wheel, the repeated calibration of the bicycle and the need to use a short course prevention factor when determining the official distance in order to ensure the course is at least the advertised distance. Furthermore, to be statistically verifiable, this technique requires repeated bicycle measurements of the course. For example, the Atlanta Olympic Marathon course was measured by a team of 29 cyclists.

This paper reviews course measurement techniques and some of the specific guidelines involved with measuring a course for certification. Then it is demonstrated how state-of-the-art surveying techniques can be used to accurately perform the measurement of a marathon course with relatively automated procedures. Specifically, the use of terrestrial laser scanning technology that can sample in few seconds millions of three-dimensional points on a surface is adopted to produce a DTM (Digital Terrain Model) of the course. This virtual course enables the selection of the shortest possible route (SPR) that can be defined following all tangent lines and to within the 0.3m IAAF standard of curbs and road edges. In this paper, results from a segment test road course, which comprises a variety of curves and gradients, are shown to demonstrate the feasibility of the proposed technique. The course is laid out and marking points are established which are measured using total station surveying and terrestrial laser scanning. Finally, a comparison is performed to verify statistically that the course length is at least the stated distance.

2. CURRENT IAAF PROCEDURE FOR MEASURING THE MARATHON COURSE DISTANCE

In the ensuing discussion the IAAF regulations for defining and measuring the road courses are reviewed.

2.1 Road Races

The majority of running courses are taking place over non-linear routes such as city streets or undulating countryside roads. For this reason, the IAAF Handbook states (rule 165) that "*the course shall be measured along the shortest possible route that a competitor could follow within the section of the road*".

The "short possible route" (SPR) concept is relatively recent. The earliest course measurement rule was to measure "one metre from the curb in the running direction" (Wallingford, 2000) which simply meant to measure parallel to one edge of the road, on the side of the road where runners are intended to run, at clearance of about 1m from the curb or road edge (Figure 1a).

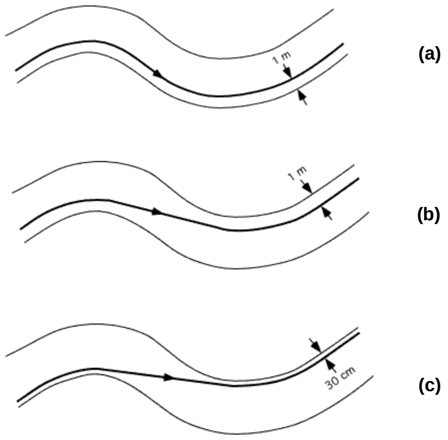

Figure 1: Evolution of the "short possible route" concept

By the time of the 1976 Olympic Marathon, course measurement had evolved so that measurers were following a path closer to the actual path taken by runners, using tangent lines when measuring between alternating right and left turns. However, a clearance of 1m was still maintained from curbs and road edges (Figure 1b). Currently, the measurers follow all tangent lines that come to within 0.3m of curbs and road edges as shown in Figure 1c. The 30cm offset from curbs is exactly the same offset as specified in rules for track measurement. Calculations show that for every 90° turn, a measurement at 30cm from the curb (instead of the 1m clearance used previously) alters the path length by about 1.1m (*ibid*, 2000).

For the creation and certification of a road racecourse, two basic measurement procedures must be followed; the “lay-out” procedure and the “validation” process of the course. The former is used when setting out a new course. However, when this procedure is followed properly it will produce a course that is slightly long but will have at least the correct length. IAAF has set a safety factor, which is called the “short course prevention factor” (SCPF) and is equal to 1:1000, so that a 10km race would be measured at 10,010m and a marathon at 42,237m. While this factor does not provide a true reflection of the actual course length, it does guarantee that the actual length is not less than the advertised course length. It is important to note that if a record has been achieved in a course that has been found to be shorter of its advertised length then the record is not accepted.

The validation process is followed by the nominal measurer determining the true length of the course and providing a certification. The IAAF handbook (rule 240.3) states that the uncertainty in road running courses should not exceed 0.1% of the distance of the course (*i.e.* 42m for a marathon). Considering that the determination of the true length is predominantly a surveying problem, this level of accuracy is rather difficult to achieve.

Other IAAF regulations define the relative location of the start and finish line that should not be greater than 30% of the course distance apart, for races over standard distances, and the decrease in elevation between the start and finish should not exceed 0.1% of the race distance. Furthermore, many national athletic bodies, such as the Association of International Marathons and Road Races (AIMS) and the United Kingdom “South of England Athletic Association” (SEAA), describe explicitly the maximum amount of off-road surface that can be used in official running events. For example, a marathon race should not include more than 2.6km of off-road surface because it may be impossible to issue a certificate of course accuracy (http://www.seaa.org.uk).

2.2 Measuring the Course

Although there are many ways to measure a course, the calibrated bicycle method is the preferred one by the official measurers. In fact, the IAAF Official Handbook (IAAF, 2002) does not enforce any specific technique but states that the calibrated bicycle method is the recommended for measuring road courses. Other national athletic bodies however, such as the United States of America Track and Field (USATF) do not recognise techniques such as automobile odometers or even standard surveying practices including electronic distance meters (EDM) and aerial survey maps (RRTC, 2003).

Historically, several kinds of bicycle wheel revolution counters have been used in the calibrated bicycle method, but currently the only simple and reliable counter used for this purpose is the Jones-counter (Jewell, 1961). The latest version is called the Jones-Oerth (JO) counter, developed around 1990, and is the device currently used in official course measurements (IAAF, 2002). It differs from the original Jones counter only in minor design alterations. It possesses a six-digit readout (up to 999,999 counts).

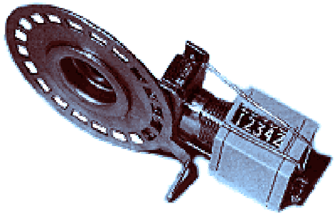

Figure 2: Jones counter

The original Jones counter was designed so that one revolution of the bicycle wheel equated to 20 counts. For the Jones-Oerth (JO) counter the number of revolutions per count is approximately 23.64 counts. Each count represents approximately 8 to 10cm on the ground. The basic method of measurement is to compare the number of revolutions of the bicycle wheel needed to cover the course with the number of revolutions needed to cover a standard calibration course. Although not stated specifically in the guidelines, experience has shown that it is preferable to use with the JO counter a standard thin-tired bike rather than a mountain bike with typical wheel size of 28-630 or 25-622, referring to the width of the tire and the diameter of the wheel respectively.

2.3 Steps in Measuring the Course

There are seven basic steps involved in measuring a run course using the JO counter on a bicycle. According to the IAAF guidelines initially a calibration course must be laid out. The calibration course must be a straight stretch of paved road of at least 500m in length (other national athletic bodies may suggest shorter calibration lengths). The measurement of the calibration course may be performed using a steel tape (a fibre tape is not suitable) at a tension of 20 Newtons and at about 20°C temperature. If temperatures vary, an appropriate correction term should be taken into account. Alternatively, EDM instruments may be used to obtain the length of the calibration course and lay out the marks of the course. It is evident that this course plays essentially the same role as any benchmark length for surveying instrumentation check (eg EDM calibration baseline).

The second step involves the calibration of the bicycle over the calibration course. At least four rides should be made on the course (two in each direction) and a record of the JO counter is made at the beginning and end of each ride. The rider takes care to ride in as straight a line as possible. The values obtained from this exercise allows calculation of a “working constant” which is derived from the number of counts/km times the SCPF of 1.001.

With the calibrated bicycle and the working constant, the full racecourse is measured following the shortest possible route to establish tentative start and finish marks. Although IAAF requires only one measurement, a second measurement of the course is recommended as a check. At this stage also, the number of counts are calculated to cover the split points that are laid down on the course. The regulations however do not require split points at certain distances. In earlier Olympic marathon courses such as the 1976 marathon measurement, a multiple sets of marks methodology was used, which means that every measurement of both the calibration course and race course was a "layout" measurement that attempted to produce a course of desired distance (http://www.rrtc.net/montreal-1976.html). Nowadays, only one set of marks is used, which means that only the first measurement of a course is a "layout" measurement that generates a tentative course and produces marks on the road. Every subsequent measurement generates only numbers depicting estimated values for the length of the tentative course. Then, after all measurements have been performed, a single adjustment is made to correct the course to the desired distance.

A recalibration of the bicycle is followed over the calibration course repeating the same procedure to estimate the “finish constant”. The “constant of the day” is calculated by using the average of the “working constant” and the “finish constant”, although many national bodies (eg RRTC, 2003) insist on using the larger of the two constants.

The measured distance of the race course is then recalculated using the “constant of the day”. For two or more measurements of the course, the proper measured length is the smallest value. However, the two measurements should not differ by more than 0.8% otherwise a third measurement should be taken for course certification. The final step involves the final adjustments to the course. If the proper measured course length differs from the desired length, then additions to the course are added preferably at the finish. Once all the measurements have been completed, the proper set of marks is made permanent.

3. STANDARD SURVEYING PRACTICE FOR COURSE MEASUREMENT

Clearly, the preferred by the IAAF regulations technique for road course measurement is the “calibrated bicycle method” (IAAF rule 165.1). However, any equipment can be used that is certified by an appropriated Weights and Measures authority (IAAF rule 148).

A total station that contains an integrated EDM unit is approved to be used in laying out a course measurement using standard surveying practice. Such an instrument provides high accuracy measurements but the lay-out procedure is very laborious and time consuming. The surveying method involves reconnaissance of the route staying 30cm from the kerb in the running direction and taking the shortest distance between two points on curved roads. The course layout is implemented on the asphalt using HILTI nails as benchmarks. The marked points form effectively a traverse, where measurements for all curved areas are performed by a steel tape and for all the straight lines by a total station (no horizontal angle measurements are performed). To achieve greater accuracy using the total station, the method of the “three tripods” is followed, whereby centring errors are minimised. Furthermore, the instrument and target heights are set in such values so that sighting of the measured line would almost be parallel to the ground, following the undulations of the road course. The above method, although very accurate, is very cumbersome and therefore not operationally applicable. For example, the marathon course measurement for the 1982 Athletics European Championship in Athens required a crew of seven surveyors working continuously for 10 days (Balodimos, 1982).

Without doubt, the greatest advantage of the calibrated bicycle method is its speed. The SPR is relatively simple to traverse and effectively a course can be measured during the time it takes to cycle this. The bicycle method became the exclusive measuring technique in major athletic events in the early 80s. For example, the 1976 Olympic marathon measurement was the first documented example of a marathon course measured by both calibrated bike and the surveying method by professional survey teams. The 1980 Moscow Olympic course was measured using only the surveying method. Starting with the 1984 Los Angeles Olympics, road courses have been measured using only the bicycle method.

4. COURSE MEASUREMENT EXPERIMENT

A test site for a road course measurement experiment was selected at the ring road of the {which university} Technical University campus in Athens. The selected section of the road, although not longer than 500m, was chosen because it is a typical non-linear route with turns, straight stretches and elevation differences. Even though the length of the test course is not realistic, it is adequate to transit a SPR across the road. A longer course was avoided because of regular disruption due to local traffic. The test course was measured using the bicycle method, standard surveying with a total station and terrestrial laser scanning techniques.

4.1 Standard Surveying Method

The surveying method was implemented mainly for verification. After reconnaissance of the test course, the shortest possible route was laid out using 39 HILTI nails. In all straight lines, the nails were positioned at the beginning and end of the line. Staking of the chord traverse in the curved areas was performed every 3m, as indicated by the a priori geometric calculations for radii of curvature varying from 15m to 150m. The selected course was measured independently using a 50m steel tape and a Leica TC1800 total station (quoted accuracy of ±2mm±2ppm in distance and 1" in angles). Prior to measurements, the total station was calibrated. The direct measurement of all curved and straight lines using tape and total station gave a total length of the test course at 436.907m ±18.5mm.

The (x, y, H) coordinates of all 39 points were computed in a local 3D cartesian system and the slope distances between the points were computed as, $D = \sqrt{\Delta x^2 + \Delta y^2 + \Delta H^2}$. The resulted total length of the test course using the computed coordinates was defined as 436.878 m ±30.8mm. The difference of 29mm between the two computations is statistically not significant at 95% confidence interval.

4.2 Bicycle Method

To provide an indication of the precision of the bicycle method, initially a calibration baseline was measured using two GPS receivers (Javad, Legacy) as well as a 50m steel tape.

The calibration baseline was a straight, flat stretch of road of 300m in length, as suggested by the USATF Course Manual (RRTC, 2003) chosen on the university campus. The height difference between the two sides of the calibration baseline was negligible. The two GPS receivers were set up for 30min, receiving data from 8 satellites. The data processing resulted in a calibration baseline length of 300.001 with an internal precision of ± 0.0015m. The bicycle test was performed by a young athlete from a local cyclist association. A JO counter was attached to a race bicycle. The bicycle tyres were warmed up prior the measurements, as specified in the USATF Course Manual. The temperature was 14ºC and remained unchanged for the four repeat measurements (two for each side). The pre-calibration values are shown in Table 1.

After pre-calibration, the cyclist performed two repeat measurements of the course. The cyclist was instructed to follow, as best as possible, the SPR which was already marked on the road. The first lap gave 4194.5 counts which is equivalent to 437.75m and the second lap gave 4215.5 counts which is equivalent to 440.05m for the length of the course (Table 1). These distances have been calculated without incorporating the SCPF factor. The difference between the two measurements is under the 0.8% allowed difference by the IAAF regulations and therefore a third measurement was not required. The difference between the two laps can be explained by the way the cyclist reads the course. While in the first lap the cyclist has already developed relatively high speed coming from a downhill, it is possible that he could not maintain the SPR as closely. In the second lap at the opposite direction, starting from a straight almost levelled stretch of road, the cyclist is more confident in following the SPR.

	Recorded Count	Elapsed Count
Start Count	26512.0	
End first ride	29385.5	2 873.5
End second ride	32260.0	2 874.5
End third ride	35134.0	2 874.0
End fourth ride	38007.0	2 873.0
Average counts for 300m		2 873.75
Counts / km		9 579.167
Counts /km with 1.001SCPF		9 588.75
Rough Layout constant		9 589

Table 1: Pre- calibration values

The mean of the two laps (ie 438.9m) differs from the corresponding distance measured by tape and EDM by 2.02m and 1.993m, respectively. Because it is difficult to follow the shortest possible route perfectly, the use of the SCPF factor of 0.1% has been incorporated into the calibration procedure so that even with the small errors in following the shortest possible route, this will never be shorter. The differences between the methods can also be explained by the fact that the nails for marking the short possible route were laid out at exactly 30cm from the kerb or edge of the roadway, so any manholes, storm drains, broken pavement and other hazards render it impractical to follow closely the marked route using the bicycle method. A post-calibration procedure was followed and a “constant of the day” was obtained at 9589 counts. Although this is not of any use in this exercise, the constant is necessary for the calculation of the official measured distance.

4.3 Terrestrial Laser Scanning Method

Terrestrial laser scanning is a very attractive 3D data acquisition tool and in spite of it being relatively new technology, it has already shown significant advantages for many application requiring object and surface modelling. Terrestrial laser scanners provide a dense set of three-dimensional vectors to unknown points relative to the scanner location, often termed "point clouds". The volume of points and the high sampling frequency of laser scanning offer users the capability of developing a smooth surface that accurately represents the scanned area, essentially a small-scale digital terrain model (DTM).

Data collection for the test site was performed using a Riegl LMS-Z360. This laser scanner has a range up to 200m and a field of view up to 90 degrees by 360 degrees. The manufacturers of the instrument quote a measurement resolution of 5mm and a typical averaged accuracy of 6mm.

Figure 3: Three set-ups of the scanner were used and registration of scans was performed using retroreflector targets

Three set-ups of the scanner were performed with an equivalent number of scans taken (Figure 3). A number of cylindrical retroreflectors of height 50mm by diameter 50mm were positioned onto the survey marks, as seen in Figure 3, to enable calculation of coordinates of the 39 marks. Also, some targets were scattered at suitable locations to facilitate registration between the different scans. All three scans were taken at an angular resolution of 120mdegrees, which is the recommended by the manufacturers to produce fast a DTM of adequate accuracy. In less than 6min, each scan had been acquired including the fine scan required for each target. The three scans had a size of 1.5Gb amounting to about 15 million points. The big size of the data files is due to the 360 degrees scene capture but in practice the scanner needs to acquire only the part of the scene that is of interest. If necessary, the number of points can be reduced based on an octree-filter and thus producing more manageable files for modelling.

The known coordinates of the survey points were used as control to enable georeferencing of the registered point cloud to the local geodetic system, as this was defined by the total station measurements. The least squares adjustment process for the georeferencing of the registered point cloud scans gave differences ranging from 3mm to 8mm for the coordinates of the known points. The above computations and relevant processing were performed in the propriety software package RiSCAN PRO (www.riegl.com). From the registered point cloud, the road was extracted and its DTM (digital terrain model) was computed using the software PolyWorks Modeler (www.innovmetric.com). Figure 4 presents a snapshot of the surface model of the course in two forms, textured and triangulated mesh models, both derived from decimated point clouds of 10cm. Such a terrain model can then be imported in any low-cost desktop software that allows digitisation of polylines. In this way, the short possible route can be defined easily by digitising straight lines connected to tangents and staying at 30cm from the kerb according to the regulations.

(a) Textured surface model (b) Triangulated mesh model

Figure 4: Snapshot of the surface model of the test road

An example of a short possible route defined on the model and extracted on a typical CAD environment is shown in Figure 5. The dashed line represents the benchmark SPR as defined by the staked points (A1 to A39) measured by surveying methods. The solid line represents the digitised polyline of the SPR from the laser scanner model. While the digitised line was defined without prior knowledge of the benchmark line, both coincide well at within five centimetres. In this figure, the two lines have been offset for clarity.

While the two lines of the figure are shown in a plan view, it is important to emphasise that the total distance of the route should be measured in three-dimensions (ie slope) and not onto the plane. In this example, the distance between points A2 and A34 measured on the benchmark line is 295.03m and on the digitised line is 296.70m. This difference is entirely due to the operator’s ability to truly define the SPR in the digital model. On the other hand, the survey marks were laid out based on geometric calculations but in reality, no athlete can follow this route exactly. When the same distance is calculated from the coordinates of the georeferenced point clouds it has been derived as 295.06m, which is within the IAAF regulations of 0.1% uncertainty in course measurements.

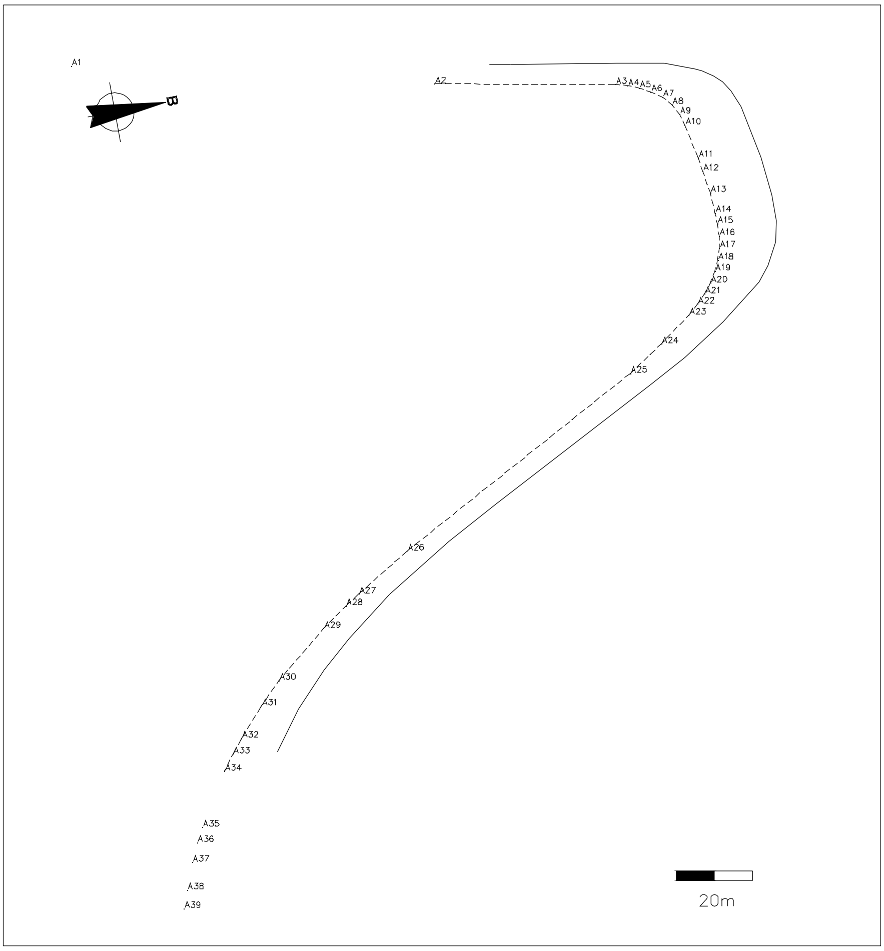

Figure 5: Short possible route defined by standard surveying and laser scanning

5. CONCLUDING REMARKS

Under the IAFF regulations, the bicycle method is the accepted method for road course measurements. While the method is clearly faster than the other two described in this paper, it can provide only a single value that refers to the distance of the route. However, its repeatability is questionable aswith this method there is no permanent record of the traversed path and in case of future use of the same road, new calculations must be performed. Positioning sensors, such as GPS receivers, that can be attached to a bicycle and provide the ridden path over the course route are not always practical to use because of the common problems that cause obstruction of line-of-sight between the receiver and satellites. GPS can be used for observing the length of the calibration baseline, although, conventional surveying is much suitable for this task.

Standard surveying using total station and steel tape, although accepted by IAAF, is extremely time consuming for traversing non-linear routes. In this paper, the surveying method was used for defining a benchmark shortest possible route, but in practice there is no such path laid out. Sometimes, the method is used to define the splits of the course, but the marked line indicating the route to the athletes in running events is in no way a geometrically laid out line.

The experiment described in this paper has shown that measurement of course distances for running events is possible using terrestrial laser scanning. The derived DTM can be used to define a number of short routes and compare them before the optimum route is chosen. Distance measurements can be easily performed in CAD environment. The captured point clouds allow for a virtual model of the route to be created where all nearby features are evident. This information is metric and can be read similar to a topographic map, while additional information such as height profiles can also be extracted. This permanent 3D record of the road course can be used to check the route at any time; prior to the event to decide, for example, upon the coned area and the locations of the refreshments based on features such as intersections or places where the road is wider. After the event is held, the virtual model of the path can be useful in situations of record dispute or use of the same course for a different event. Finally, the IAFF regulations define that application for certification must include a detailed map of the course. Such a 2D plan view of the course is easily composed in a CAD environment from 3D point cloud data which will contain all key points (start, finish, turn-arounds, cone positions, etc.) and can be located exactly year after year. The main impediment for the terrestrial laser scanning method is the rather slow procedure in setting-up the instrument. The authors of this paper see most benefit in a mobile laser scanning system. Considering that for about 500m of a course three set-ups of the scanner were required, a marathon course would be covered with at least 85 scans. Therefore, the method is currently very slow for operational application. However, there are applications already reported (eg www.geodata.at) whereby the scanner is mounted on suitable pod on a vehicle allowing for fast data acquisition. Supplementary sensors such as GPS receiver would provide the necessary information for georeferencing of the point cloud.

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BIOGRAPHICAL NOTES

Dr Tsakiri joined as a lecturer the National Technical University of Athens in 2000 after having held academic positions at Curtin University of Technology in Australia. Her principal areas of research include high precision GPS and terrestrial laser scanning applications.

Dr Stathas is Associate Professor at the National Technical University of Athens. He has been an academic staff at the same university since 1976. His research interests focus on high precision surveying techniques and engineering surveying applications.

Mrs Arabatzi is Research Associate at the National Technical University of Athens since 1981. Her research interests include precise heighting and engineering surveying applications.

CONTACTS

Maria Tsakiri
Department of Surveying Engineering
National Technical University of Athens
9 H. Polytechniou Street
Zographos Campus Athens 15780
GREECE
Tel. + 30 210 772 2735
Fax + 30 210 772 2728