Program to Determine the Terrain Roughness Index using Path Profile Data Sampled at Different Moving Window Sizes

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ABSTRACT
In this paper development of a program to determine the terrain roughness index using path profile data sampled at different moving window sizes is presented. Relevant mathematical expressions and algorithm to determine terrain roughness index from elevation data captured at different moving window sizes are presented. The desktop program is written in Visual Basic for Application. The program enables users to sample the elevation data at a given window size and then determine the terrain roughness parameters at any other window size that is multiple of the original sampling window size. Sample 58.5523249 Km study path location that started at a latitude of 5.48717 and longitude of 7.04193 and ended at a latitude of 5.82096 and a longitude of 7.45042 was used to demonstrate the effectiveness of the software. Specifically, Geocontext online elevation profile software is used on the study path to capture N = 512 path profile data at an initial window size of 3.75 seconds which is equivalent to a distance of 114.5838061 m. The roughness index is computed at four (4) other sampling window sizes of 30 seconds, 1 minute (60 seconds) , 5 minutes (300 seconds) and 10 minutes (600 seconds). Among other things the program showed the window sizes and their corresponding terrain roughness index along with the elevation profile table and graph for each of the sampling window size. The results show that as the widows size increases the total number of sample data points decreases. Also, the largest terrain roughness index value of 52.89 m is observed with window size of 300 seconds whereas the lowest largest terrain roughness index value of 33.55 m is observed with window size of 600 seconds. The idea presented in this paper is useful for wireless network designer who relies on terrain roughness value for the determination of the multipath fade depth for detailed link design.

Keywords
Multipath, Fading Depth, Terrain Roughness Index, Elevation Profile, Geographic Reference System, Sampling Window

1. INTRODUCTION
Multipath fading is the losses in signal strength which occurs when signals travel through different paths before they reach the receiver [1, 2,3,4,5,6,7]. The multipath effect will always occur when there is a change in the path of the different components of the signal. As a result of the changes in the signal path, different components of the signal travel through different paths and path lengths before they reach the receiver. In all, at the receiver, the overall signal strength is reduced due to the multipath effect [8,9,10,11].

Notably, the nature of the path elevation profile has been identified as one of the causes of multipath in wireless signal communications systems. Due to the coarse nature of the ground surface signals are reflected at some points as they hit the ground and this ground reflection of signals causes the multipath effect [12,13,14]. Consequently, in a bid to account for the impact of terrain roughness on multipath fading, the International Telecommunication Union (ITU) Recommendation ITU-R P.530-17 incorporated terrain roughness index as part of the parameters for computing multipath fade depth [15].

Basically, the terrain roughness index is the standard deviation of elevation values obtained from the elevation data point captured around the signal path [16,17,18]. However, the approach presented by ITU-R P.530-17 model for computing the terrain roughness index adopted very large distance between elevation data points used in computing the terrain roughness index. As such, researchers in many cases compute terrain roughness index based on elevation data point with a smaller distance between elevation data points [19].

Furthermore, today, there are available online tools for capturing elevation profile data at a different time or distance resolutions. As such, in his paper, the focus is the development of relevant algorithms for a program that will enable users to determine the terrain roughness index of a given area based on the elevation profile data of the area. In the program, it is assumed that the elevation data is captured by an elevation profile data capturing tool that provides information of the distance and elevation of data points along the signal path. It is also assumed that the tool enables the user to select the time interval or distance interval between consecutive elevation data point it will capture and also the interval is the same between all the elevation data points. While the algorithm is presented here , the program is written in Visual Basic for Application (VBA). The requisite mathematical expressions and algorithms used in the program are presented in the succeeding section. The program enables the user to determine the terrain roughness index at higher resolutions that are multiples of the original resolution used to capture the elevation profile data.

2. METHODOLOGY
2.1 The Theoretical Background On Terrain Roughness Index
Terrain roughness index can be determined from path profile data with respect to the distance in kilometres and the elevations in meters. Basically, the terrain roughness index (S_a) is the standard deviation of the elevation for the various

path profile data points considered . Assuming there are N elevation (E_n) data points in the path profile where n = 1,2,…N, then the terrain roughness index (S_a) is given as [15];

$$S_a = \sigma = \sqrt[2]{\left(\frac{\sum_{n=1}^{n=N}(E_n - \bar{E})^2}{N-1}\right)} \quad (1)$$

Where the average elevation $\bar{E}$ is given as [15];

$$\bar{E} = \frac{\sum_{n=1}^{n=N}(E_n)}{N} \quad (2)$$

In this study, it is assumed that the path profile data is captured at a given constant value moving window size (for instance, one sample every 10 seconds) such that the distance, δ_w between sampling point in the given window size, w is equal. The path length, d which is the distance between the starting point (with n = 1) of the profile data sampling to the last point (with n = N) on the data sampling is given as ;

$$d = d_N - d_1 = N(\delta_w) \quad (3)$$

Where d_n is the distance from data point 1 to data point n, and $d_1 = 0$. Hence,

$$d = d_N = d_N - d_1 = N(\delta_w) \quad (4)$$

If the elevation at the required distance point p is not available where d_p denotes the distance at point p and E_p denotes the elevation at point p, then interpolation of the two nearest profile points to point d can be used to obtain the elevation, E_p as follows;

$$E_p = E_n + \left[\left(\frac{d_p - d_n}{d_{(n+1)} - d_n}\right)\left(E_{(n+1)} - E_n\right)\right] \quad (5)$$

Where are E_n and $E_{(n+1)}$ are the elevations while d_n and $d_{(n+1)}$ are the distance of the points nearest to the profile point p and $d_n \leq d_p \leq d_{(n+1)}$.

2.2 The Theoretical Background On The Sampling Window Sizes

In geographic reference system 1° (that is , 60 minutes or 3600 seconds) of latitude is equivalent to a distance of 110 Km. Smaller resolution in seconds and minutes can be used whereby 1 second is equivalent to a distance of 30.56 m. In the elevation data capture software tool, the elevation points are captured at a given constant time unit called the sampling window of size, w. It is assumed that the data sampling mechanism moves at a constant speed along the path and captures elevation data every w time units. Since the speed is constant and the sampling window size (time) is also constant, then the distance from one sample point, n to the next sample point n + 1 is constant and it is denoted as δ_w , where w represents the sampling window size (time) used. For instance, sampling window size (time) w= 1 second means δ_{1sec}= 30.56 m. Other sampling sizes and their corresponding sampling distance sizes can be obtained from the 1 second window size values. For instance $\delta_{30\,sec} = 30\,(\delta_{1sec}) = 916.67$ m and $\delta_{1\,min} = \delta_{60\,sec} = 60\,(\delta_{1sec}) = 1833.6$ m . In this paper, the second will be used as the reference time unit to relate the distance among different sampling window sizes.

Now, consider a situation where the software tool is used to capture the elevation data at a window size of $w_1$seconds which has corresponding sampling distance of δ_{w1} and then, the roughness index parameter is needed at a different sampling size $w_2$seconds (where $w_2 \geq w_1$), then the number (denoted as K_{w21}) of w_1 sample points that will make up one w_2 sample point is given as ;

$$K_{w21} = \frac{w_2}{w_1} \quad (6)$$

Hence,

$$\delta_{w2} = (K_{w21})\delta_{w1} = \left(\frac{w_2}{w_1}\right)\delta_{w1} \quad (7)$$

For instance, if w_1 is 5 seconds such that the $\delta_{w1} = \delta_{5\,sec} = 5(30.56) = 152.8$ m and if the roughness index is required at the sampling rate of $w_1 = 30$ seconds then, $K_{w21} = \frac{w_2}{w_1} = \frac{30}{5} = 6$ and so $\delta_{w2} = \delta_{30sec} = 6(152.8) = 916.8$. In practice, it is advised that the data capturing windows size be such that the required window sizes for computing roughness index are multiples of the original capturing windows size otherwise the data point will point at the location where there is no elevation data. In such case, interpolation may be used as specified in Equation 5. However, such occasion should be avoided. The total number of data points , N_2 when the data is resampled at the window size of w_2 from its original N_1 sampling at the window size of w_1 is given as ;

$$N_2 = \left\lfloor 1 + \left(\frac{N_1 - 1}{K_{w21}}\right)\right\rfloor \quad (8)$$

Where $\lfloor x \rfloor$ means integer part of x.

3. THE ALGORITHM FOR DETERMINATION OF THE TERRAIN ROUGHNESS INDEX USING PATH PROFILE DATA SAMPLED AT DIFFERENT MOVING WINDOW SIZES

The algorithm for the algorithm for determination of the terrain roughness index using path profile data sampled at different moving window sizes are given in following submodules:

Module 1: Read in the N original data points captured by the path profile data capture software toolset at window size w_0

Module 2: Generate data points at another window size , w_x based on the N original data points captured by the path profile data capture software tool

Module 3: Compute the average elevation for the data points at another window size , w_x

Module 4: Compute the roughness index for the data points at another window size , w_x

The detailed algorithm is as follows:

Module 1: Read in the N original data points captured by the path profile data capture software toolset at window size w_0

Step 1: INPUT the data capture window size , w_0, the number of data points , N

Step 2: w = w_0

Step 3: FOR n = 1 to N step 1

Step 4: READ the data point distance $\delta_{(\mathbf{w_0},n)}$ and **the data point elevation** $E_{(\mathbf{w_0},n)}$

Step 4: NEXT n

Step 5 CALL Module 2

Step 6: END

Module 2: Generate data points at another window size , w_x based on the N original data points captured by the path profile data capture software tool

Step 1: x = 1

Step 2: INPUT the required roughness index sampling window size , w_x

Step 3: COMPUTE $K_{w_x w_0} = \frac{w_x}{w_0}$

Step 4: INITIALISE i = 1 ***// counter for data points in*** **sampling window size ,** $\boldsymbol{w_x}$

Step 5: FOR n = 1 to N STEP $K_{w_x w_0}$

Step 6: READ the data point distance $\delta_{(\mathbf{w_0},n)}$ and **the data point elevation** $E_{(\mathbf{w_0},n)}$

Step 7: $\delta_{(\mathbf{w_x},i)} = \delta_{(\mathbf{w_0},n)}$

Step 8: $E_{(\mathbf{w_x},i)} = E_{(\mathbf{w_0},n)}$

Step 9: NEXT n

Step 10: N(x) = i // N(x) is the total number of sampled data points obtained when data is sampled at window size, $\boldsymbol{w_x}$

Step 11: IF ($\boldsymbol{w_x}$ **is the last window size to be considered) THEN**

Step 11.1: X_N **= x**

Step 11.2: CALL Module 3

Step 11.3: ELSE

Step 11.4: x = x + 1

Step 11.5: GOTO Step 2

Step 11.6: ENDIF

Step 12: RETURN

// Compute the roughness index , Sa for the Xn different window sizes , $\boldsymbol{w_x}$ **where x = 1,2,…,Xn**

Module 3: Compute the average elevation for the data points at another window size , w_x

Step 1: x = 1

Step 2: $\boldsymbol{Sum_x}$ **= 0** ***// Initialise*** $\boldsymbol{Sum_x}$ **to 0**

Step 3: FOR i = 1 to X_N **STEP** 1

Step 4: $\boldsymbol{Sum_x} = \boldsymbol{Sum_x} + E_{(\mathbf{w_x},i)}$

Step 5: NEXT i

Step 6: $\boldsymbol{AVG_x} = \frac{\boldsymbol{Sum_x}}{\mathbf{N(x)}}$

Step 7: IF ($\boldsymbol{x} \geq X_N$ **) THEN**

Step 7:1 CALL Module 4

Step 7.2: ELSE

Step 7.3: x = x + 1

Step 7.4: GOTO Step 2

Step 7.5: ENDIF

Step 8: RETURN

Module 4: Compute the roughness index for the data points at another window size , w_x

Step 1: x = 1

Step 2: $\boldsymbol{SumSq_x}$ **= 0** ***// Initialise sum of squared error,*** $\boldsymbol{SumSq_x}$ **to 0**

Step 3: FOR i = 1 to X_N **STEP** 1

Step 4: $\boldsymbol{SumSq_x} = \boldsymbol{SumSq_x} + \left(\boldsymbol{E_{(\mathbf{w_x},i)}} - \boldsymbol{AVG_x}\right)^2$

Step 5: NEXT i

Step 6: $\boldsymbol{S_{ax}} = \left(\sqrt[2]{\frac{\boldsymbol{SumSq_x}}{(\mathbf{N(x)-1})}}\right)$

Step 7: IF ($\boldsymbol{x} \geq X_N$ **) THEN**

Step 8: GOTO Step 9

Step 8.2: ELSE

Step 8.3: x = x + 1

Step 8.4: GOTO Step 2

Step 8.5: ENDIF

Step 9 RETURN

In the flowchart it is assumed that the window sizes, w_x are multiples of the original sampling window size w_0. In this case no interpolation is required.

A program is written in Visual Basic for Application to automate the computation of the relevant parameters once the required input data are keyed in.

Particularly, the following 4 sets of input data are required for the program ;

i. X_N, the number of sampling window sizes to be used
ii. Window sizes $w_0, w_1, w_2, \ldots w_{X_N}$
iii. N , the number of data points for the initial window size w_0
iv. For n = 1 to N input data point distance, $\delta_{(w_0,n)}$ and data point elevation $E_{(w_0,n)}$ of the initial window size, w_0

Among other things , the program output includes the following ;

i. Sampling Window Size Name, w_x where x = 0,1,2,… X_N

ii. Sampling Window Size in Time Unit (seconds)

iii. Sampling Window Size in Meters

iv. $K_{w_x w_0} = \frac{w_x}{w_0}$: the number of units of Window Size w_0 that make up 1 Window Size w_x

v. N_x : Total number of sampled data points for Window Size w_x

vi. For n = 1 to N_x output data point distance, $\delta_{(w_0,n)}$ and data point elevation $E_{(w_0,n)}$ of window size w_x

vii. Sumx : Sum of elevations for Window Size w_x

viii. AVGx : Average of elevations for Window Size w_x

ix. SumSqx: Sum of square error of elevations for Window Size w_x

x. Sax : Terrain roughness index for Window Size w_x

4. NUMERICAL EXAMPLE

The 58.5523249 Km study path location started at a latitude of 5.48717 and a longitude of 7.04193 and ended at a latitude of 5.82096 and a longitude of 7.45042. Geocontext online elevation profile software is used on the study path to capture N = 512 path profile data at an initial window size w_0 of 3.75 seconds which is equivalent to a distance of $\delta_{(3.75\text{ sec})} = 114.5838061$ m. Meanwhile the roughness index is required at the following four (4) sampling window sizes; 30 seconds, 1 minute (60 seconds) , 5 minutes (300 seconds) and 10 minute s(600 seconds). Accordingly, the program presented in this paper is used to compute the roughness index for the each of the given 4 different sampling window sizes

A portion of the originally sampled data using window size , w_0 of 3.75 seconds is shown in Table 1 while the elevation profile of the complete path is shown in Figure 1.

Table 1 Portion of the originally sampled data using window size , w_0 of 3.75 seconds

Data Point Number , n	Distance (m)	Elevation (m)	Latitude	Longitude
1	0	73	5.48717	7.04193
2	114.583806	73.28502	5.48782349	7.04272894
3	229.167612	73.11905	5.48847697	7.04352788
4	343.751418	72.83546	5.48913045	7.04432682
5	458.335224	71.80804	5.48978394	7.04512576
6	572.91903	72.02904	5.49043742	7.04592471
7	687.502836	72.99104	5.4910909	7.04672365
8	802.086642	71.78662	5.49174438	7.0475226
9	916.670449	73.62459	5.49239785	7.04832155
10	1031.25425	73.39307	5.49305133	7.0491205
503	57521.0706	123.5818	5.81508361	7.44322134
504	57635.6545	123.7228	5.81573655	7.44402119
505	57750.2383	123.0307	5.81638948	7.44482103
506	57864.8221	121.9574	5.81704242	7.44562088
507	57979.4059	123.0356	5.81769535	7.44642073
508	58093.9897	121.6979	5.81834828	7.44722058
509	58208.5735	119.3775	5.81900121	7.44802043
510	58323.1573	116.0922	5.81965414	7.44882029
511	58437.7411	114.2163	5.82030707	7.44962014
512	58552.3249	109.8918	5.82096	7.45042

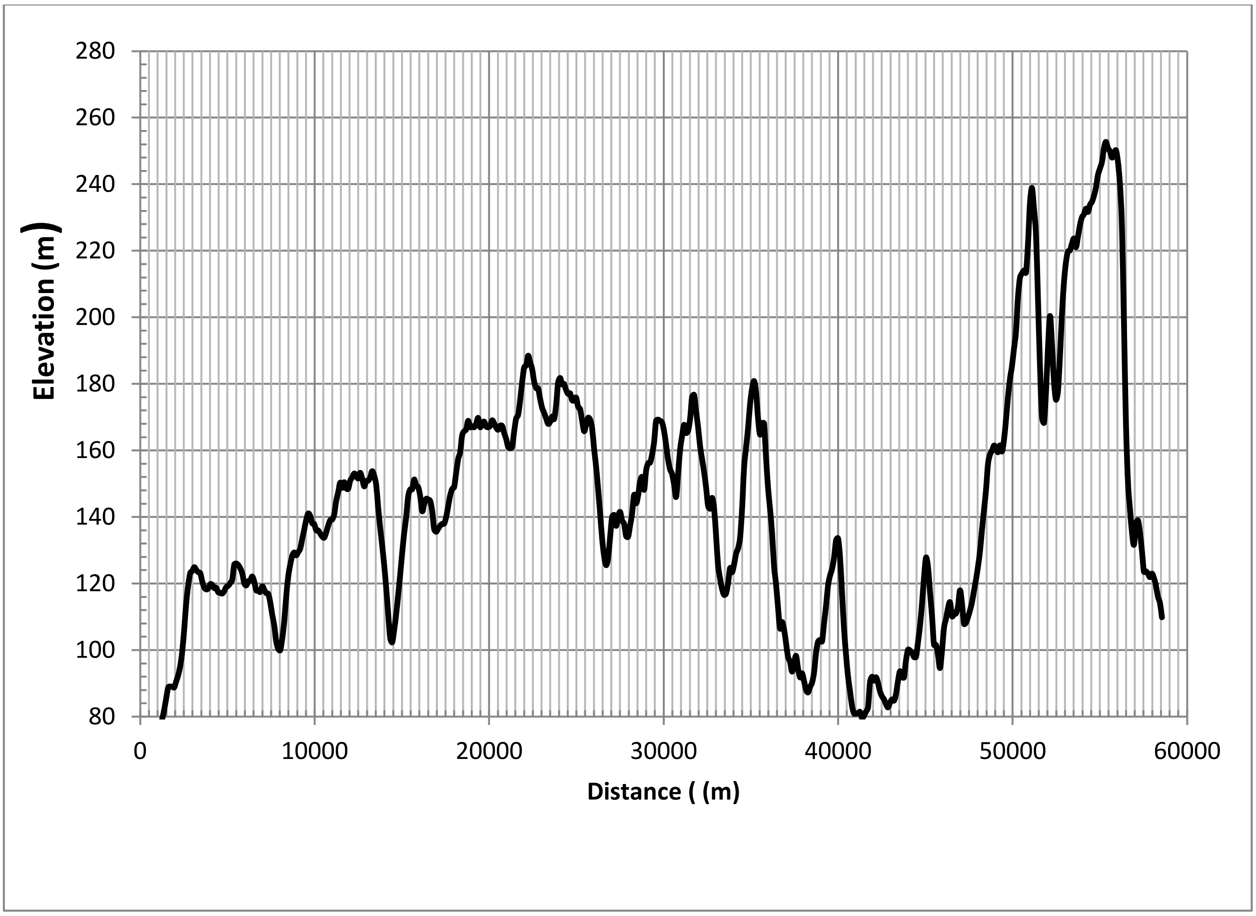

Figure 1 The elevation profile of the complete path

The results in Table 2 show the output of the window sizes and the corresponding terrain roughness index. The larger the widow size the larger the value of $K_{w_x w_0}$ and the smaller is the total number of sample data points . The largest terrain roughness index value of 52.89 m is observed with a window size of 300 seconds whereas the lowest largest terrain roughness index value of 33.55 m is observed with a window size of 600 seconds.

The program also displays the elevation profile table and graph for the various sampling window sizes. Table 2 and Figure 2 show the elevation profile table and graph for the sampling window size , w_2 of 1 Minute (60 seconds). A total of 32 data sampling points are captured with sampling window size of 60 seconds.

Similarly, Table 23 and Figure 3 show the elevation profile table and graph for the sampling window size , w_3 of 5 Minutes (300 seconds). A total of 7 data sampling points are captured with sampling window size of 300 seconds.

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Table 2 The output of the program showing the window sizes and the corresponding terrain roughness index

Sampling Window Size Name	Sampling Window Size in Time Unit (seconds)	Sampling Window Size in Meters	Total Number Of Sample Data Points (N_x)	$K_{w_x w_0}$	Sumx	AVGx	SumSqx	Sax
w0	3.75	114.58	512	1	72768.61	142.13	785007.32	39.19
w1	30	916.67	64	8	9220.89	141.86	104735.52	40.45
w2	60	1833.34	32	16	4628.01	140.24	53846.96	41.02
w3	300	9166.70	7	80	1060.41	132.55	19583.69	52.89
w4	600	18333.41	4	160	611.10	122.22	4502.30	33.55

Table 2 The elevation profile of the window size , w_2 of 1 Minute (60 seconds)

Data Point Number , n	Distance (m)	Elevation (m)For Window Size 1 Minute (60 Seconds)	Data Point Number , n	Distance (m)	Elevation (m)For Window Size 1 Minute (60 Seconds)
1	0	73.00	17	29333.45	158.86
2	1833.34	89.00	18	31166.80	167.74
3	3666.68	118.83	19	33000.14	134.40
4	5500.02	126.07	20	34833.48	166.77
5	7333.36	116.95	21	36666.82	106.52
6	9166.70	130.52	22	38500.16	90.25
7	11000.05	139.27	23	40333.50	106.39
8	12833.39	149.23	24	42166.84	91.88
9	14666.73	110.91	25	44000.18	100.14
10	16500.07	145.31	26	45833.52	94.63
11	18333.41	159.51	27	47666.86	114.44
12	20166.75	169.09	28	49500.20	163.16
13	22000.09	184.97	29	51333.55	225.02
14	23833.43	173.68	30	53166.89	219.82
15	25666.77	169.87	31	55000.23	244.79
16	27500.11	141.56	32	56833.57	135.54

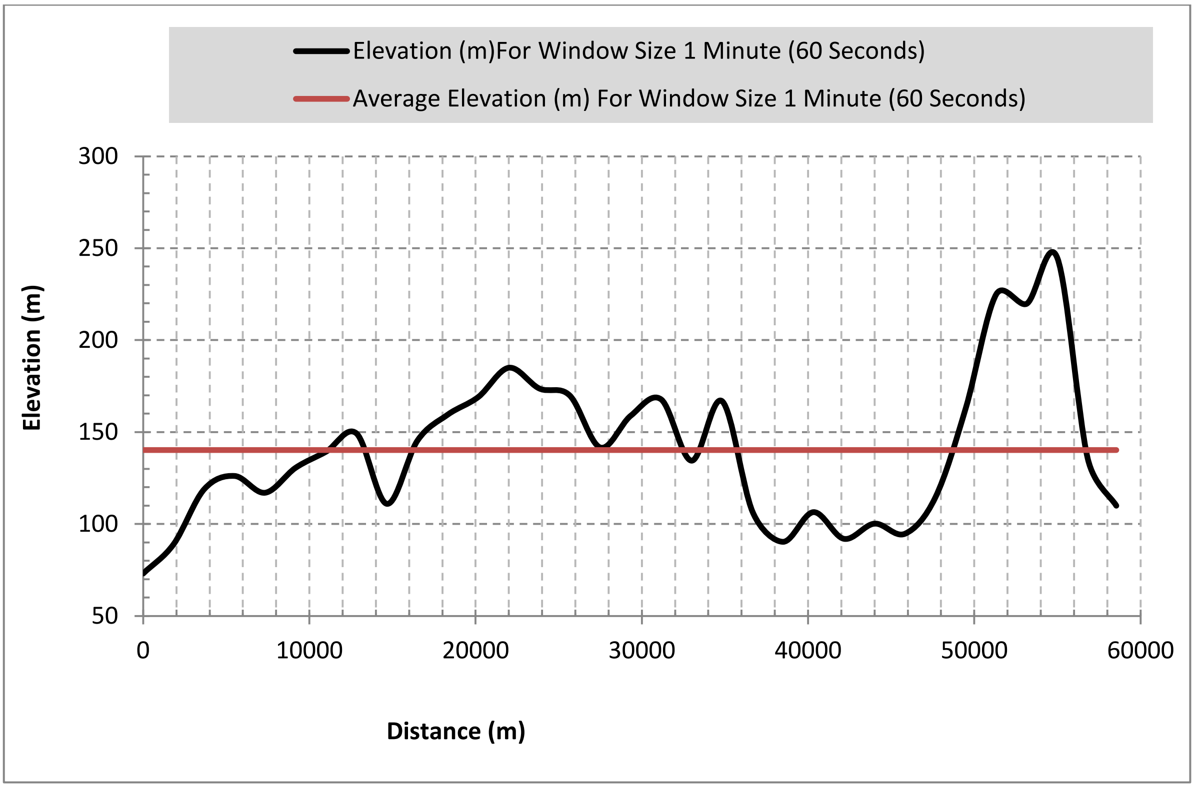

Figure 2 The elevation profile of the window size , w_2 of 1 Minute (60 seconds)

Table 3 The elevation profile of the window size , w_3 of 5 Minutes (300 seconds)

Data Point Number , n	Distance (m)	Elevation (m) For Window Size 5 Minutes (300 Seconds)
1	0	73
2	9166.704	130.5188
3	18333.41	159.505
4	27500.11	141.5607
5	36666.82	106.5168
6	45833.52	94.63456
7	55000.23	244.7859

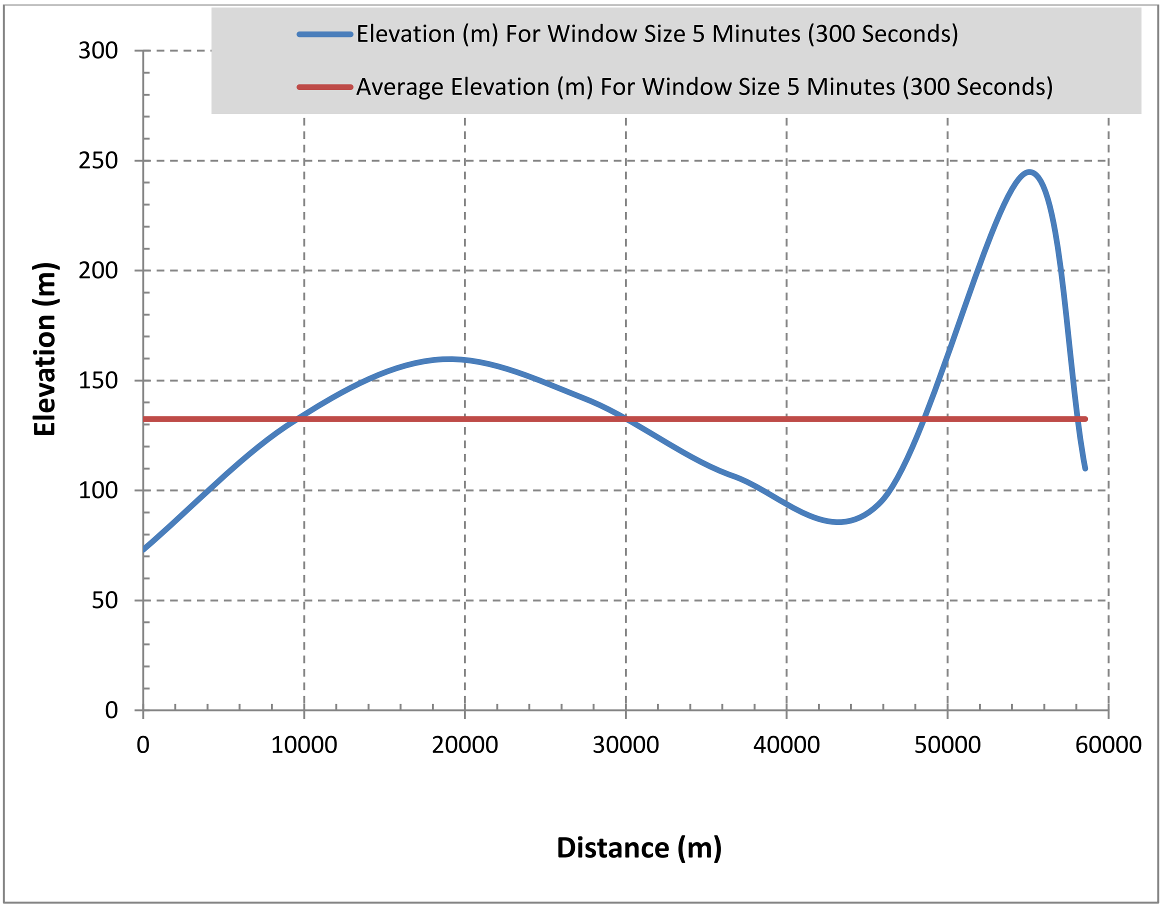

Figure 3 The elevation profile of the window size, w_3 of 5 Minutes (300 seconds)

5. CONCLUSION

Mathematical expressions and algorithm along with a program to determine terrain roughness index from elevation data captured at different moving window sizes are presented. The elevation data profile is captured using an online elevation profile data software which captures elevation data at a given regular time or distance interval (window sizes). The program enables users to sample the elevation data at a given window size and then determine the terrain roughness parameters at any given window size that is multiple of the original sampling window size. The program is written in Visual Basic for Application (VBA) and it is a desktop application. Sample path profile is used to demonstrate the effectiveness of the program to determine the essential terrain roughness parameters for different sampling window sizes.

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