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Snow Layer Prediction Model using Back Scattering Co-efficient

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Abstract: In this study, the objective is to estimate the physical parameters of each snow layer at a given certain altitude, which is according to the problem will always be between other altitudes, whose profile data is entirely provided. The provided data for the target profile will also consist of the number of layers, height of each layer, the back-scattering coefficient and the altitude. The goal is to estimate the interval [y_{min}, y_{max}] for each parameter, which are sphericity, diameter and density of the snowflakes. We are using here a multilayer snow profile and then applying the back scattering coefficients to calculate the snow layer altitude and height. Further, by correct prediction we can preserve the snow layers by continuously monitoring the snow model at the correct altitude throughout the year. Our aim demonstrates the comparatively better way to predict the best snow profile at right altitudes.
Keywords: Linear Interpolation, Normalisation, Gaussian, Back Scattering, Back Scattering Coefficient

I. INTRODUCTION

The Arctic region has undergone a serious climate change in the near decade. A lot of ice region has melted due to global warming. Unlike Antarctic Sea ice arctic region is highlighted for decline due to serious change in sea ice thickness [1]. Also, a huge loss of multi-year ice is observed and replaced by first year ice which is a lot of concern [2]. It has a resulted in decline of the Spring snow depth [3]. These changes have significantly affected the entire environment of eco system and marine environment with navigation system for water animals.[4][5] Similarly, NoSREx campaign was conducted near the Arctic Region to the Sodankylä-Pallas testbed for measuring the ever-declining ice bed of Sodankylä region. The landscape is generally flat and there are small hilly parts where the ice beds appear to be getting extinct in the recent years (NoSREx Data Report).[6][7]

II. RESEARCH OBJECTIVES

In this project we will give the context of the problem, describe how we determine the boundaries of the target profiles through interpolation and the ideas about increasing the performance of the model. We will conclude with the main challenges encountered, the methods that were tried and the possible extensions. We are given the data of 7 altitudes for 4 different dates. Each profile consists of assimilated data and results of snow evolution model (crocus). Therefore, we have the following parameters: (h, g1, g2, g3, ρ, σ). So, if we consider a snow-pack with k layers of snow, where k is known:

1) $h = (h_1, ..., h_k)$ is the height of each layer
2) $g1 = (g_1^1, ..., g_1^k)$ and $g2 = (g_2^1, ..., g_2^k)$ are the sphericity of the snowflakes at each layer
3) $g3 = (g_3^1, ..., g_3^k)$ and $\rho = (\rho_1, ..., \rho_k)$ are the diameter and the density of the snow flakes
4) σ is the back-scattering coefficient at a given altitudes at a given date

We need to estimate ($g1_{min}, g1_{max}, g2_{min}, g2_{max}, g3_{min}, g3_{max}, \rho_{min}, \rho_{max}$) for the target pro-file, whose number of layers may be different from the given profiles. The only data provided for the target profile are: number of layers, back-scattering coefficient and the height of each layer. The position of the arctic research centre and the location of the site is given below in Fig 1 and Fig 2. The data taken from the research centre is given below in Fig 3 and Fig 4.

Fig. 1 Position of the Arctic research Centre

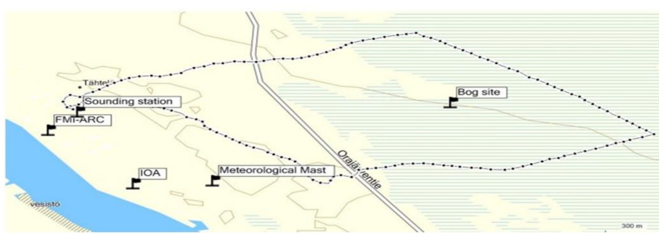

Fig. 2 Location of the site where the ice bed is to be measured

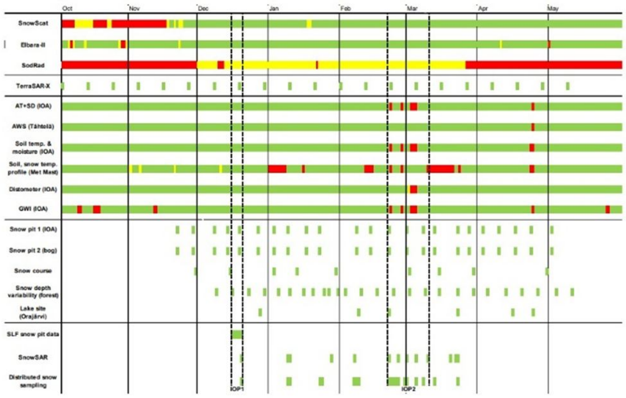

Fig. 3 Month based data from Research centre

Parameter	Value
Frequency range	9.199984–17.798512 GHz
Frequency step	3.072 MHz
Number of frequency steps	2800
Elevation range	30°–60°
Elevation step	10°
Number of elevation steps	4
Azimuth range	-62°…+34° (sector 1), -166° … - 142° (sector 2)
Azimuth step	6°
Number of azimuth steps	17 (sector 1); 5 (sector 2)
Measure modes	CC (internal cal loop), HH, HV, VH, VV
Sampling frequency	25000 Hz
Number of samples:	64
Scheduled daily measurement start times (UTC)	01:45; 05:45; 09:45; 13:45; 17:45; 21:45
Estimated duration of measurement	1 h 45 min (sector 1) + 30 min (sector 2)

Fig. 4 Azimuth and frequency data from centre

A. Data Visualisation

The data above shows the number of Azimuth angles that we can take during the experiment. And also, the elevation range with the azimuth step is provided with a monthly basis. Here the frequency steps are an important factor in implementing the ice detection model. As soil temperature with moisture plays a vital role in determining the ice pack layer depth in different seasons.

III. POSSIBLE SOLUTION FOR THE ESTIMATION OF THE UNKNOWN SNOW PROFILE

A. Averaged Coefficients Interpolation

Our first approach considers the following setting. We know at least two full snow profiles, and we are trying to estimate another snow profile with known number of layers and known heights of each layer. Precisely, we are trying to estimate for each layer of the profile the parameters *(g1, g2, g3, ρ).*

B. Linear Interpolation

As a first approach we will consider linear interpolation between the two known profile with given altitudes, to get the missing snow profile. The main difficulty is to take into account the different number of layers between the snow profiles. The first step is to normalise the total heights of every snow layer. Let's call $(h_1^1,..,h_n^1)$, the heights of the n layers of the known snow profile S_1, $(h_1^2,..,h_m^2)$, the heights of the m layers of the known snow profile S_2 and $(h_1^3,..,h_k^3)$ the heights of the k layers of the unknown snow profile S_3. We consider the following normalisation:

$$(h_1^{1'},..,h_n^{1'}) = \{ \frac{(h_1^1,..,h_n^1)}{\sum_{i=1}^n h_i^1} \}$$

We apply the same normalisation on the heights of the two other snow profiles. We now have snow profiles with the same total height but with different number of layers and different heights for each layer. We can't apply directly interpolation between parameters of S_1 and S_2 because of the different number of layers. We need to define a way to get a set of *4k* parameters for the snow profiles S_1 and S_2. First divide every layer of every snow profile into I very small layers with parameters corresponding to their depth and their snow profile. Second, define L_1 the number of small layers covering the 1^{th}layer of S_3. Third, take the L_1first layers of $S_1$and average their coefficients. Fourth, define L_2 the number of small layers covering the 2^{th} layer of S_3. Fifth, take the layers from index L_1 to $L_2 + L_1$ of S_1 and average their coefficients. Sixth, repeat this process for all layers of S_3. Seventh, repeat this process replacing S_1 with S_2. Eigth, taking a great value for l reduces the overlapping between the original layer and the small layers and thus gives results with greater precision. Once finished we have 2 sets of *4k* parameters and we can perform a simple linear interpolation between the new parameters estimated from S_1 and S_2. Let's define x_1 the altitude of snow profile S_1, y_1^i a parameter corresponding to the unknown layer i of S_3 estimated using the snow profile S_1, x_2 the altitude of snow profile S_2, y_2^i a parameter corresponding to the unknown layer i estimated using the snow profile S_2, x_3 the altitude of snow profile S_3 and y_3^i the parameter we want to estimate.

Then: $$y_i^3 = y_i^1 + (x_3 - x_1)\frac{(y_i^2 - y_i^1)}{(x_2 - x_1)}$$

We can interpolate every parameter of every layer in this way and then obtain an estimation of the parameters of the unknown snow profile. The whole process is shown in the Fig 5.

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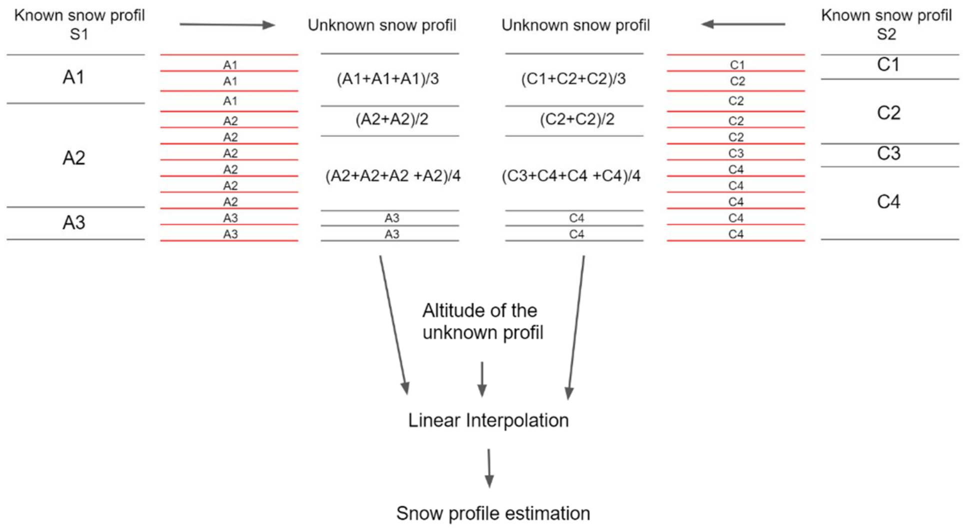
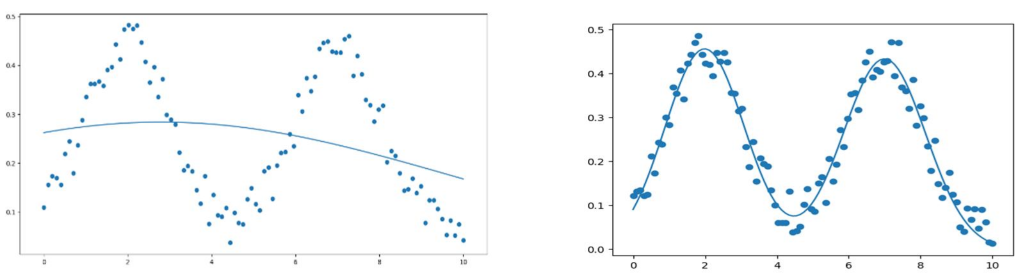


Fig. 5 Process of Linear Interpolation for snow profiles

C. Fitting Mixture of Gaussian to Generate Back-Scattering Coefficients

For increasing the performance of the model, we need to take into account the back-scattering coefficient value. In this section we present a method to obtain a parametric model based on generating back-scattering coefficients for randomly chosen set of parameters. First, we need to generate a great number of σ randomly and uniformly using the function model. We consider a maximum of 50 layers for a snow profile, meaning that the parameters space will be of dimension 250 [for each layer i : (hi, ρ, g1, g2, g3)]. The parameter space will be constrained by known empirical maximum and minimum values for the parameters. We consider g1 ∈ [−99, 0] (no units), g2 ∈ [0, 99], (no units), g3 ∈ [0.2, 3] (mm), ρ ∈ [0.2, 0.6] (no units) and a total height between 0.2 and 4 (m). The units given here are the ones used in the model. Using those data, we might fit a mixture of Gaussian using a non-linear least square regression as in Fig 6. Fig 5 data was generated using a linear combination of Gaussian function and adding a small random Gaussian noise. Two different sets of initial values for the non-linear least-square algorithms are chosen.



(a) Failed Regression due to bad choice of initial parameters (b) Successful Regression by choosing proper parameters

Fig. 6 Process of Linear Interpolation for snow profiles

D. Using the mixture and the interpolation

As mentioned earlier, the interpolation does not take into account the back-scattering coefficient. we propose here a strategy to take the back-scattering coefficient into account as well as the profile estimated using the interpolation and the mixture of Gaussian fitted. The interpolation process returns an estimated profile p_0. Using the fitted mixture of Gaussian G, we can assign a back-scattering coefficient to any profile p as $G(p) = \sigma$. Let's call p_u the unknown true snow profile and σ_u the back-scattering coefficient of the unknown snow profile. p_0 is an estimation of the unknown snow profile but we expect: $G(p_0) = \sigma_0 \neq \sigma_u$. We want to find a new profile p_0^* close to p_0 such that $G(p_0^*) = \sigma_u$. Let's define: G'(p) = G(p) - σ_u

Now the set $(p: G'(p) = 0)$ corresponds to the set of snow profiles for which $(p) = \sigma_u$. Finding a new profile p_0^* such that $G(p_0^*) = \sigma_u$ is now equivalent to finding a root of the function G'. However, the search must be constrained given that for the unknown profile, we know the number n of layers and the height of each layer$(h_1 \dots \dots h_n)$.

The problem we're solving can be written by giving an initial profile p_0 and a given n_u, knowing the number of layers n_u and their heights $(h_1^u \dots \dots \dots h_n^u)$ find a profile p_0^* such that

$$(h_i^{0*}, g_{1i}^{0*}, g_{2i}^{0*}, g_{3i}^{0*}, \rho_{1i}^{0*}, \dots \dots, h_{50}^{0*}) = 0 \text{ for } i \in [n_u + 1,\ 50]$$

$$h_j^{0*} = h_j^u \text{ for } j \in [1,\ n_u]$$

Finally, we can transform it into a minimisation problem, finding a root of G' is equivalent to finding a local minimum of defined as $G'_{abs}(p) = |G'(p)|$.

$$\text{Solve for } p_0^* = local \operatorname{arg\,min} G'_{abs}(p)$$

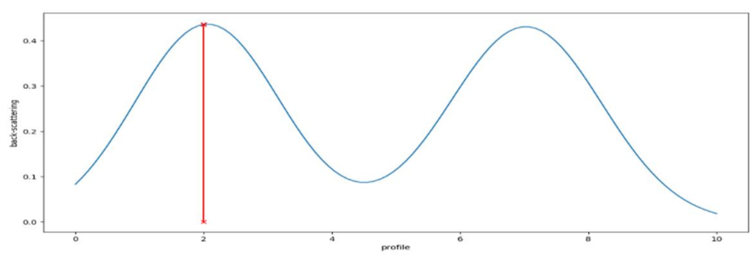
$$(h_i^{0*}, g_{1i}^{0*}, g_{2i}^{0*}, g_{3i}^{0*}, \rho_{1i}^{0*}, \dots \dots, h_{50}^{0*}) = 0 \text{ for } i \in [n_u + 1,\ 50]$$

$$h_j^{0*} = h_j^u \text{ for } j \in [1,\ n_u]$$

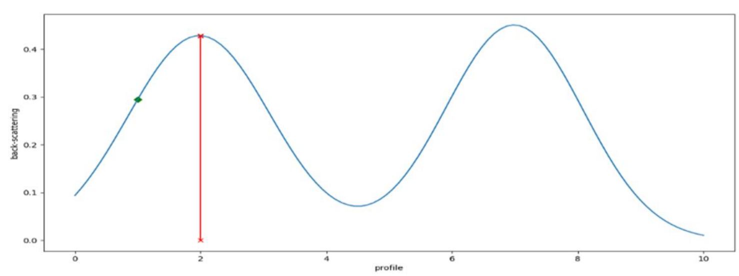
We can now choose a minimisation algorithm adapted for C_0 function and linear constraint, possibly taking advantage of the fact that we can compute analytically the gradient of G_{abs} where it's defined. For example, we could choose the Newton-CG algorithm.

IV. OBSERVATION OF THE OUTPUT

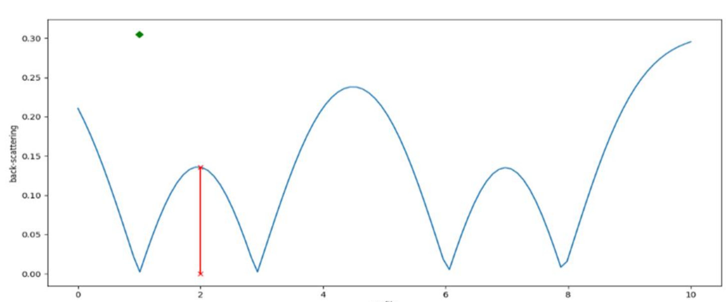
The newly obtained profile p_0^* satisfies the knowledge we have on the unknown profile p_u and we expect it to be closer to the true profile than the profile estimated using average interpolation algorithm. Fig 7 illustrates the algorithm on a toy example, with one parameter to estimate and for a set of data generated using linear combination of Gaussian with a small random Gaussian noise. The curve represents the fitted data as in Fig 6.



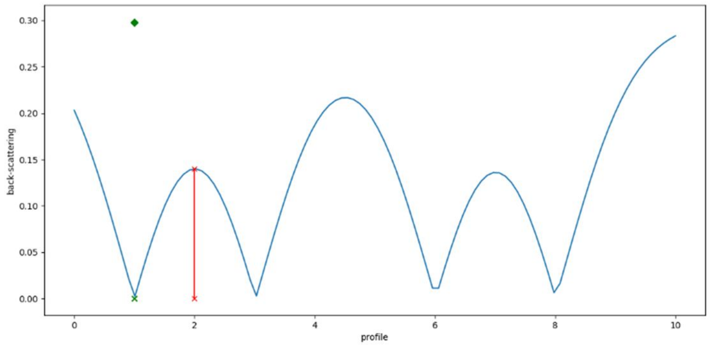
(a) Estimated parameter p_0 using averaged interpolation and back scattering coefficient (y-axis) σ_0



(b)The green diamond point signifies the back scattering coefficient σ_u corresponding to the unknown profile



(c)Subtracting σ_u to the fitted mixture of Gaussian and finding the absolute value



(d) the green dot for x = 0 corresponds to the new profile p_0^* after minimization of the function G'_{abs}

Fig. 7 Illustration of the Algorithm using averaged interpolation

V. CONCLUSIONS

One of the main challenges was to find the way to approach the problem. In the beginning we were looking for the ways to map the pixel intensities with the physical parameters of the snow layer. We came up with the graphical approach, but since the conditions changed where the images were not a concern, the approach gave a near perfect estimation of snowflakes. Also, to improve the estimated parameters, we provided all together with the back-scattering coefficients and the heights.

VI. ACKNOWLEDGMENT

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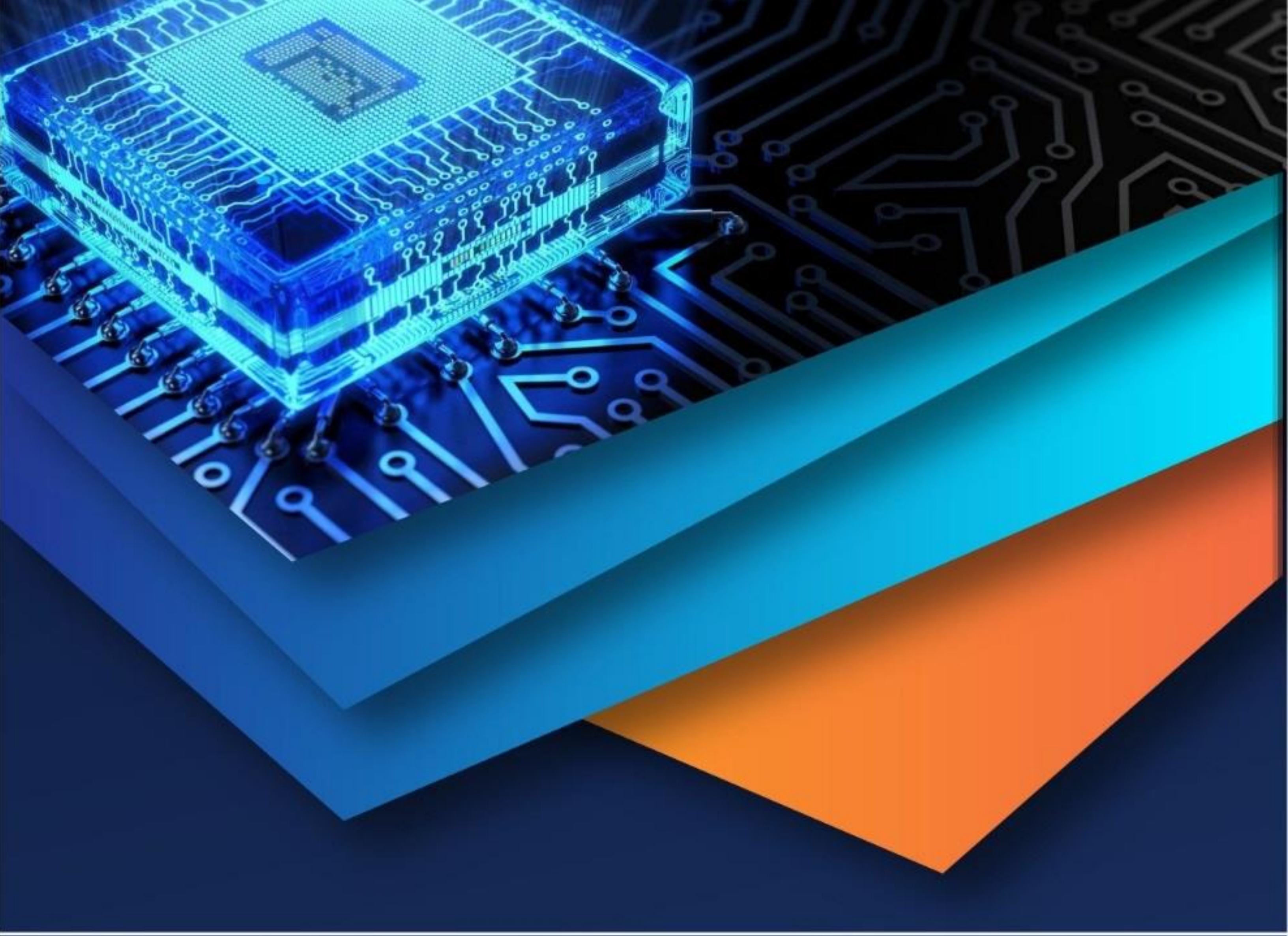

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