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I HAVE FOUND “X”

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PROFESSOR OF MATHEMATICS (STATISTICS)

Inaugural Lecture Series 357
University of Benin
January 15, 2026

ISSN 1597-0590

First published 2026

By

University of Benin Press
Ekehuan Campus
University of Benin
Benin City.

DEDICATION

This Inaugural lecture is dedicated to the Almighty God and to my family.

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PROTOCOL

The Vice Chancellor
The Deputy Vice Chancellors
The Registrar
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Provost, College of Postgraduate Studies
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Members of the University Governing Council
Deans and Directors
Professors and Members of the University of Benin Senate
Academic and Non-Teaching Staff of the University
My Lord Spiritual and Temporal
Great University of Benin Students
Gentlemen of the Press
Distinguished Guests
Ladies and Gentlemen

I welcome you all to 357th in the Inaugural Lecture Series of the University of Benin. My Inaugural Lecture is titled: I Have Found ''X''

SYNOPSIS

The Inaugural Lecture shows noble contributions in the areas of nonparametric statistics namely – Kernel Density Estimation (KDE) and its applications, Quality Control and recently, Data Science.

The choice of the bandwidth in KDE is examined using different methods for both the Univariate and Multivariate cases. This was done from the higher order derivatives approach, the hybrid approach and using boosting and bagging to reduce the two components of the error term (Asymptotic Mean Integrated Squared Error (AMISE) – $Bias^2$ and the variance respectively.

New control charts were introduced in quality control for producers/manufacturers to maintain standards during the course of producing goods for daily human needs. These include the Bivariate control chart, Hotelling'sv T^2 control limits and the permutation approach in obtaining control limits.

Finally, the application of KDE was shown in the areas of Agriculture, Material Science and Meteorology combining effectively with Data Science.

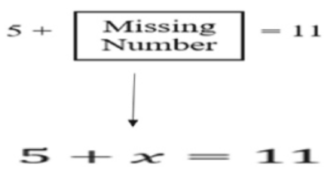
1.0 INTRODUCTION

Mathematics is the 'language' of science which gives birth to theories, methods and models in various fields of life like Finance, Medicine, Insurance, Engineering, Agriculture, Linguistics and Statistics.

Statistics is a science that deals with the collection, analysis and interpretation of data for the purpose of guided decision making when a problem is put before us. Data is a collection of facts or figures which can be very useful in decision making. A set of data to a mathematician is used to find parameters like mean, median, variance, standard deviation etc. The mathematician can also use a set of data to model. For a statistician, he is interested not just in the data, but the arrangement of the data, the distribution (pictorial view) of the data, the smallest value and largest value when arranged in ascending or descending order, the range etc.

Data can be of two simple forms – discrete and continuous. Discrete data is when it can be listed or countable like 2,3,5,7,9,11; while continuous data is the type that is in form of a range eg height of everyone in this Akin Deko Auditorium is between 1.5m – 1.9m. We have primary data, which is used by the person who collected the data and secondary data, which is made use of by someone else who did not collect the data. Collection of data can be in different forms like experimental data in labs, field data from surveys and even some from the use of questionnaires.

As a toddler, we were taught basic numerals (numbers), alongside pattern of numbers and the use of alphabets (letters) to represent a missing number or an unknown number.



This led to the task of finding the value of the letter “X” in our day to day activity. Hence, this Inaugural lecture: **I have found “X”**. This can be likened to looking at A as equivalent of 1, B as equivalent of 2 and so on, such that X is the equivalent of 24. That is the simplest illustration of X and people should stop looking for X. The value of X is not ’fixed’ but a representation of an unknown. It is a dependent variable whose value changes with every problem.

This simple “X” has crept into basic family expenses like upkeep‘ If for instance, the total(exact) money spent monthly by a household is X but ’Oga’ normally gives ’Madam’ X^* every month. This means that there is a difference called R – residual. i.e.

$$R = X^{*} \quad X$$

If this R (the difference between what is given to madam) and the exact amount spent monthly is positive, Madam doesn’t complain because the money given to her is in excess (surplus). But if, the difference between what is given to madam and the exact amount spent monthly is negative, Madam would complain because the money given to her cannot meet the essential needs of the family (less than what is needed). This X^* (money given to Madam by Oga), represents the estimated family upkeep by Oga, from the family revenue X.

Another example is to imagine a conversation between a husband and wife:

Wife: Honey, I think you have to review the monthly allowance for running the house oh, because every day I go to the market, it is as if I misplaced money because prices of everything keeps going up.

Husband: Can you do a list of what you think we spend monthly‘

Wife: It would be difficult because we buy items like Rice and Beans in bags that lasts like 3 – 4months.

Husband: Then divide the amount for the rice and beans into three to get the monthly cost.

Wife: If I divide into three, how do I now buy a bag?

Husband: The money can be given for the bags of rice and beans once but omitted in the next 2 months or I would still give the monies as if you would be the one to save them till it gets complete at the third month to buy. This is after buying the first bags

After some days, the wife gives the husband a list which they debate on and the man sums up the total and gives to the wife. Three months later, since money was given to buy the first bags of rice and beans, the wife again says that she is confused as the money was still not enough.

The above scenario between the husband and wife can be likened to "X", the unknown amount required for the upkeep of a family monthly. This X in the above example of husband and wife has variables like rice, beans, yam, plantain, meat, fish, eggs, tomatoes, pepper, egusi, ogbonor, gas etc. If for any reason the wife forgot to list some items like bread or electricity cost etc., the value of X would only be an estimate (approximate) of the actual value of X. These items can be represented as a simple model: $X = x_1 + x_2 + x_3 + \dots + x_n$, where each of the x_i, $i = 1,2,3, \dots,$ n represents the items listed above.

The interesting part of this problem is, how do we find X? As early as in our primary school days, we used a book called Lacombe for intermediate primary (for primary 3 and primary 4) where we were taught simultaneous equations in two unknown variables in two equations eg

$$3x + 4y = 11 \qquad (1)$$

$$5x - y = 3 \qquad (2)$$

This kind of problem can be solved simultaneously by the elimination and substitution methods. Not trying to scare anyone in this gathering, it is this kind of problem we encounter at Secondary School level, Undergraduate University courses like numerical analysis for those in the sciences, business mathematics for social sciences, etc.

QUOTE: *In our day to day activities, we consciously and unconsciously encounter X as a solution to our daily challenges*

In reality, “X” is any problem or quantity that has not been found. To the financial analyst, it can be shares index in a stock market. To an electrical engineer, it can be the amount spent on power (electricity) consumption monthly. To the medical researcher, it can be dose of a particular drug to be administered to a sick patient. To the agriculturist, it can be the yield (output) for a crop in a particular farming year. And finally, to me a statistician, it can be the probability density function (pdf) of a data set.

Given a set of data $x_1, x_2, x_3,$ x_n; we are interested in finding (drawing) a probability density function (pdf) (x)which is assumed not to be from any known family of distributions e.g. Binomial distribution, Hypergeometric distribution, Normal distribution, Exponential distribution, Weibull distribution, among many others. The data is allowed to ’speak’ for itself and this kind of problem is known simply as nonparametric density estimation. The one that is tied to a particular family of distribution is referred to as the parametric density estimation. Several methods exist in the nonparametric density estimation to find the density estimate (x). These includes the histogram method- which is the oldest, general weight function, naive estimator and the kernel density estimator which shall be the focus of this presentation.

The Histogram method

$$\hat{f}(x) = \frac{Number\ of\ observations\ with\ bin}{n} \times \frac{1}{Height\ of\ bin} \qquad (3)$$

The kernel density estimator is defined as:

$$\hat{f}(x) = \frac{1}{n\,h}\sum_{i=1}^{n} K\left(\frac{X - x_i}{h}\right) \qquad (4)$$

where n is the sample size, $K(\blacksquare)$is a kernel function which is symmetric and satisfies certain conditions, while h is the bandwidth. When using equation (4), we are faced with two basic problems viz

(i) The choice of the kernel function and (ii) the choice of the bandwidth

Some Kernel functions

Gaussian Kernel → $K(t) = \frac{1}{\sqrt{2\pi}} exp\left\{\frac{-t^2}{2}\right\}$

Epanechnikov Kernel → $K(t) = \frac{3}{4}.max\{1 - t^2, 0\}$

Uniform Kernel → $K(t) = \frac{1}{2}\ I(-1 \le t \le 1)$

Biweight Kernel → $K(t) = \begin{cases} \frac{3}{4\sqrt{5}}\left(1 - \frac{1}{5}t^2\right)^2, & -\sqrt{5} \le t \le \sqrt{5} \\ 0, & Otherwise \end{cases}$

All these kernel functions must be symmetric and satisfy the following conditions

(i) $\int k(t)dt = 1$ (ii)$\int tk(t)dt = 0$ (iii) $\int t^2k(t)dt < \infty$

Recent works have shown that the problem of the choice of the kernel has been resolved via central limit theorem (CLT), while that of the choice of the bandwidth remains a task that has attracted so much work worldwide. This problem of the choice of bandwidth constitutes most of my research work, though I have worked in some other areas like quality control and recently data science which I veered into because it is the 'key'to the world's problems.

During the course of finding this bandwidth, we started with what we call the univariate case and later the multivariate. The univariate case deals with a single type of variable while the multivariate deals with multiple variables though we mainly focus on the bivariate (two variables) at most. Works on this area of statistics became popular with the advent of computers in the early 80's because it is not easy to solve manually.

Authors like Silverman (1986) introduced the Rule of Thumb (ROT) for finding the bandwidth as h_{ROT}. Rudemo (1982) and Bowman (1984) worked on Least Squares Cross Validation (LSCV) method for finding the same bandwidth as h_{LSCV}. Scott & Terrell (1987) used the Biased Cross Validation (BCV) scheme as h_{BCV}.

We shall briefly illustrate how the choice of bandwidth is key in density estimation. Consider a data set of forty car battery lives in years, were several bandwidths (h) are used to estimate the density function and comparing it with the histogram method. The results can be seen in the figures displayed below.

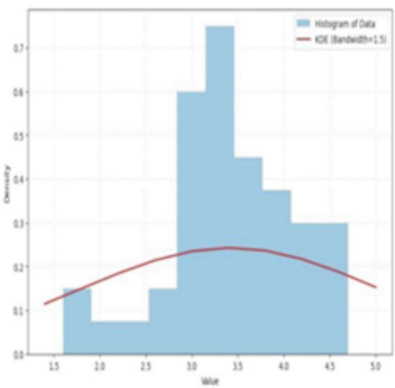


Figure 1: Kernel Density Estimate Using a Bandwidth of 1.5 against the Histogram.

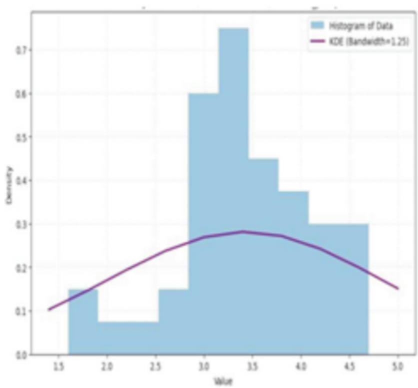


Figure 2: Kernel Density Estimate Using a Bandwidth of 1.25 against the Histogram

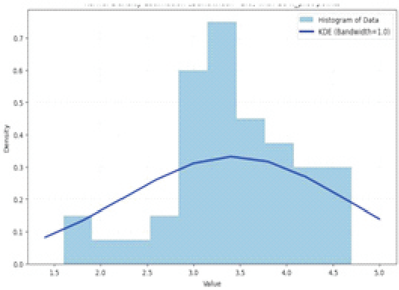


Figure 3: Kernel Density Estimate Using a Bandwidth of 1.0 against the Histogram.

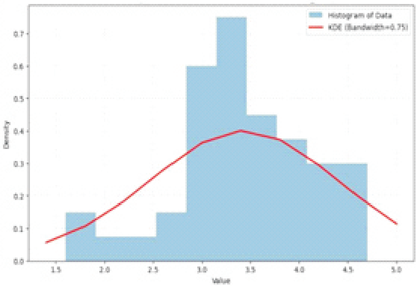


Figure 4: Kernel Density Estimate Using a Bandwidth of 0.75 against the Histogram.

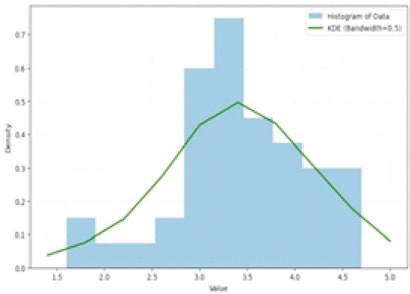


Figure 5: Kernel Density Estimate Using a Bandwidth of 0.5 against the Histogram.

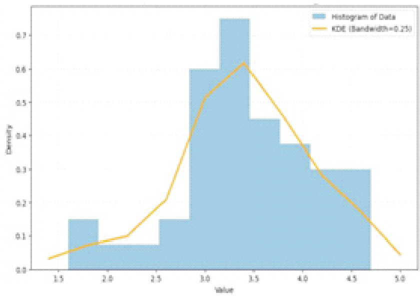


Figure 6: Kernel Density Estimate Using a Bandwidth of 0.25 against the Histogram.

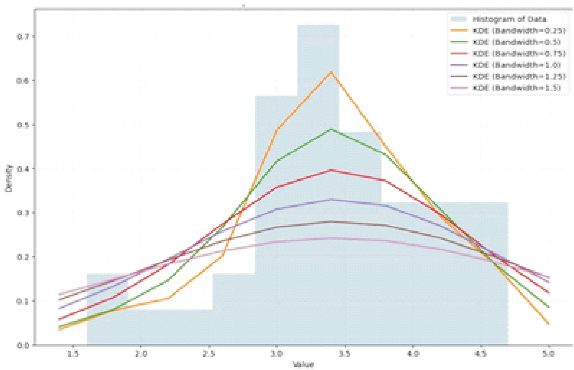


Figure 7: Kernel Density Estimates Using Different Bandwidths against the Histogram.

Figures 1 to 6, shows the density estimates using various bandwidth sizes (0.25, 0.5, 0.75, 1.00. 1.25, 1.5), in comparison with the histogram method for the same data. Figure 7, shows all the density estimates in comparison with the histogram. The results show that the smaller the bandwidth size, the closer it depicts the histogram chart. This brings us to the problem of finding an ideal choice of the bandwidth which has been my focus all through my research in Kernel Density Estimation.

2.0 MY CONTRIBUTIONS TO KNOWLEDGE IN KERNEL DENSITY ESTIMATION (KDE)

Ishiekwene and Afere **(2001)** introduced Higher Order Window Width Selectors for Empirical Data.

The problem of a data-based window width selector for the Kernel density estimation is considered in terms of higher order derivatives. A generalised expression for the Mean Integrated Squared Error (MISE) as well as the window widths are obtained alongside with their efficiency.

An appreciable reduction in the values of MISE (i.e. both bias and Var) is realised. The test graphs of the Kernel density function using various higher order window widths obtained were plotted for different sets of data.

These higher order choices of window widths were found to behave better than the conventional order two and order four suggested by Jones and Signorini (1997). Also, it was found at their MISE's were dropped as the order increases. This shows improvement over orders two and four. Their test-graphs also behaved better until a point where all the graphs became the same from order ten above. It was also noticed that the MISE's after order ten became almost the same value.

Finally, their efficiency dropped as the order increases. This is not beneficial thus extensive work continues to find a "breaking-point" between the MISE and the efficiency so as to determine which higher order window width choice is "best " or which order gives the best test-graph.

The use of a single fixed window width limits the characterizing smoothing impacts on the non-parametric theory. Thus, the automatic method shown above gives a variety of window widths which shows the various smoothing effects and one has the option of choosing the best test graph.

ISHIEKWENE & OSEMWENKHAE **(2006)** did A Comparison of Fourth-Order Window Width Selectors in Kernel Density Estimation (A Univariate Case)

The choice of an ideal window width in kernel density estimation was proposed using a fourth-order derivative kernel method. It was found to be exactly the same with that of Jones and Signorini [1997]. Its efficiency, asymptotic mean integrated squared error (AMISE) and graphs are looked at using three sets of data. A comparison between this method's efficiency, AMISE and graphs and that of the conventional order-two is done and is clearly seen that the superiority of this method over that of order-two is interesting.

Both methods are higher order. (fourth order) window width choices in Kernel Density Estimation (KDE) which arguably are the best compared to order-two.

The window widths obtained are acceptable by standard (see Scott and Factor [1981]). The measure of discrepancy used in this work is the Asymptotic Mean Integrated Squared Error as shown by Marron and Wand [1992]. The result of the AMISE shows order - four behaved better by giving smaller values when compared with that of order - two. Also, the ratio of their efficiency as compared to the standard Epanechnikov kernel showed 87% efficient.

Finally, the graphs also support the fact that order - four behaved better than that of order -two. Since the graphs gave a true picture of the data used. In general, our proposed method is an equivalent of Jones and Signorini [1997] which arguably is the best window width choice than the conventional order-two choice.

In 2007, Osemwenkhae, and **Ishiekwene** utilised the Application of Adjustable Kernel Method in Test Evaluation.

The work was motivated by the appearance of heavy tails when estimating learners' performances in most psychological tests. Explaining this appearance of heavy tails poses a problem. Over-smoothing the target density by using large bandwidth may tend to remove this abnormal tail behaviour, but this result in masking some essential features in the distribution. Conversely, smaller bandwidth can result in under-Smoothing of the true density and thus gives a biased estimate of the density under study. Therefore, in any psychological test involving heavy tails. We observed that the adjustable kernel method is better for fitting this density than its fixed kernel method. However, when heavy tails are not suspected, fixed kernel method may be easier in assessing learners'performances

When heavy tails are suspected in a set of any psychological test, a better estimation scheme would be adjustable kernel method. Conversely, when heavy tails are not suspected, the adjustable kernel method easily decomposes to the fixed scheme if the sensitivity parameter, $\alpha=1$.

Osemwenkhae and **Ishiekwene** (2007b) Constructing Asymptotically MVUE in Univariate Kernels

The work considered the construction of asymptotically minimum variance unbiased estimator (MVUE) in univariate kernels. The method used are both analytical and empirical. The practice of going up till order four is seen not to produce MVUE in univariate kernels. The work concluded that this desirable property. Asymptotically MVUE is only possible at higher order value (specifically from 8 and beyond) of the smoothing parameter, h in kernel density estimation.

Osemwenkhae, **Ishiekwene** and Osagiede (2007) This study generalizes global errors for nonsymmetric kernels for any given order by using the most acceptable way for this measure-Mean Integrated Squared Error (MISE). It further obtains these MISE for some common nonsymetric kernels. This is aimed at removing the rigor of obtaining MISE for any specified order of the smoothing parameters when researchers are working on these important kernels.

The work removed the rigor of specifying the order of the bandwidth, h when estimating the global error - MISE. This was done by generalizing this important property of any nonsymmetric kernel. So, researchers no longer have challenges when considering these kernels.

Ishiekwene, Odiase and Ogbonmwan (2007c) looked at Bootstrap in Boosting Kernel Density Estimates.

This article proposes a re-sampling algorithm for boosting kernel density estimates. The algorithm is a bias reduction technique. Empirical studies were carried out and it was observed that the proposed resampling algorithm for boosting is better in terms of time complexity and removes the problem of function evaluation in existing boosting algorithms. The accuracy of the results of existing schemes is achieved by the proposed scheme in just a fraction of the time it takes the existing schemes.

It is clearly seen from the graphs that both schemes produce equivalent results but the proposed re-sampling scheme achieves the same results in a shorter time with less function evaluations. It shows that the proposed bootstrap re-sampling scheme is better in terms of time complexity and does not actually evaluate the functions like in the leave-one-out scheme. It is therefore recommended for use in place of the leave-one-out.

Ishiekwene, Ogbonmwan and Oyegue (2008) Considered the Choice of Smoothing Parameters in Boosting Kernel Density Estimates.

The work provided a scheme for choosing the smoothing parameter in boosting kernel density estimates. Several boosting algorithms were implemented using different choices of smoothing parameters and the "best" choice is found to be at order - four after considering different sets of data.

The values of h - the smoothing parameter obtained using orders m = 2,4,6,... 20, were displayed and were used for the different boosting algorithms for all three data set. Some selected smoothing parameter choices (namely, orders 2,4,18 and 20) were used in plotting estimates for the kernel density function for the three different data sets, and the density estimates on display gave fantastic results. In all, the order two choices showed some noises at the 'peaks' of all three density estimates. Thus, we recommend the use of higher orders greater than or equal to four smoothing parameter choices when using boosting algorithms in kernel density estimates. This also supports Jones and Signorini's [9] órder four choice of smoothing parameter arguably the "best". The estimates for the density curves were done for all three algorithms namely; Algorithm 1(Mazio and Taylor [11]), Algorithm 2 (**Ishiekwene** et.al 2007a [8]) and Algorithm 3 (**Ishiekwene** et.al 2007b [7]). The results showed that apart from the order two choice of the smoothing parameter, all other smoothing parameter choices are appropriate for any of the boosting algorithm employed. We therefore recommend the use of these higher order smoothing parameter choices in boosting in kernel density estimation.

Ishiekwene, Ogbonmwan and Osemwenkhae (2008) A Meshsize Boosting Algorithm in Kernel Density Estimation

The paper proposed a new algorithm for boosting in kernel density estimation (KDE). This algorithm enjoys the property of a bias reduction technique like other existing boosting algorithms and also enjoys the property of less function evaluations when compared with other boosting schemes. Numerical examples are used and compared with existing algorithm and the findings are comparatively interesting.

From the graphs for the three sets of data, we can clearly see that our proposed algorithm compares favourably if not arguably better than that of Mazio and Taylor (2004). Also, the results revealed the biás reduction targeted by both algorithms.

Since our algorithm does the same task with fewer function evaluations and in fact better in terms of time complexity, we are recommending it for use in boosting in KDE.

Ishiekwene and Nwelih (2011). Adaptive Kernel In The Bootstrap Boosting Algorithm In KDE

The work proposes the use of adaptive kernel in a bootstrap boosting algorithm in kernel density estimation. The algorithm is a bias reduction scheme like other existing schemes but uses adaptive kernel instead of the regular fixed kernels. An empirical study for this scheme is conducted and the findings are comparatively interesting.

We have shown that the adaptive kernel can be used in place of the classical fixed kernel in boosting in kernel density estimation. The charts- clearly reveals that the adaptive kernel method does better than the classical fixed kernel method in kernel density estimation. It is therefore recommended for use in place of the classical fixed kernel method in boosting in KDE having exhibited the qualities of bias reduction and revealing the data features at the tails.

Ishiekwene and Nwelih (2012) Adaptive Kernel in Meshsize Boosting Algorithm in KDE

The publication proposes the use of adaptive kernel in a meshsize boosting algorithm in kernel density estimation. The algorithm is a bias reduction scheme like other existing schemes but uses adaptive kernel instead of the regular fixed kernels. An empirical study for this scheme is conducted and the findings are comparatively attractive.

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shiekwene and Afere (2012) Higher-Order Hybrid Gaussian Kernel in Bootstrap Boosting Algorithm

This paper proposes the use of higher-order hybrid Gaussian kernel in a bootstrap boosting algorithm in kernel 'density estimation. The algorithm is a bias reduction scheme like other existing schemes but uses the higher-order hybrid Gaussian kernel instead of the regular fixed kernels. An empirical study for this scheme is conducted and the findings are rather impressive when compared with regular fixed kernels.

We have shown that the higher-order hybrid Gaussian kernel can be used in place of the classical fixed kernel in boosting in kernel density estimation. This clearly reveals that the higher-order hybrid Gaussian kernel method does better than the classical fixed kernel method in kernel density estimation. It is therefore recommended for use in place of the classical fixed kernel method in boosting in KDE having exhibited the qualities of bias reduction which translates to a reduction in the MISE.

Ishiekwene and Afere (2013) Higher-Order Hybrid Gaussian Kernel in Meshsize Boosting Algorithm

In the paper, we used higher-order hybrid Gaussian kernel in a meshsize boosting algorithm in kernel density estimation. Bias reduction is guaranteed in this scheme like other existing schemes but uses the higher-order hybrid Gaussian kernel instead of the regular fixed kernels. A numerical verification of this scheme is conducted and the results are compared with the regular fixed kernels.

Higher-order hybrid Gaussian kernel has been used in place of the classical fixed kernel in boosting in kernel density estimation and the results compared. This clearly reveals that the higher-order hybrid Gaussian kernel method does better than the classical fixed kernel method in kernel density estimation. It is therefore recommended for use in place of the classical fixed kernel method in boosting in KDE having exhibited the qualities of bias reduction which translates to a reduction in the MISE (ie $bias^2$+ var).

Ishiekwene and Afere (2013b) Higher-Order Gaussian Kernel in Bootstrap Boosting Algorithm

The bootstrap boosting algorithm is a bias reduction scheme. The adoption of higher-order Gaussian kernel in a bootstrap boosting algorithm in kernel density estimation was investigated. The algorithm used the higher-order Gaussian kernel instead of the regular fixed kernels. A comparison of the scheme with existing fixed kernel methods indicated the results were better.

Higher-order Gaussian kernel had been substituted for the classical fixed kernel in boos-ting kernel density estimation. The plots of bias reduction and MISE revealed that the higher order Gaussian kernel method performed better than the classical fixed kernel method in the estimation of kernel density. Therefore, the higher order Gaussian kernel method should be used in place of the classical fixed kernel method in boosting in KDE having exhibited the qualities of bias reduction which translated to a reduction in the overall MISE.

Ishiekwene, Siloko and Ezeh (2013) Bootstrapping in Boosting Kernel Density Estimates

A new boosting algorithm which makes use of the bootstrap technique was introduced in this paper. It is a bias reduction technique which behaves better than existing algorithms in terms of time taken to execute the algorithm and avoids function evaluations that might be tedious to resolve. Studies show that this scheme achieved accurate results in a fraction of time it took existing scheme to achieve same result.

It is clearly shown that both schemes produce equivalent results but the proposed re-sampling scheme achieves the same result in half the time it took the existing method with less function evaluations. It shows that the proposed bootstrap re-sampling scheme is better in terms of time and does not actually evaluate the functions like in the leave-one-out scheme. Also, its bias is seen be smaller than existing schemes which the greatest achievement in this paper by implication of bias reduction is a reduction in the MISE. It is therefore commended for use in place of the leave-one-out scheme.

Siloko and **Ishiekwene** (2013). Smoothing Parameter Choices in Multivariate Kernel Density Estimates.

The choice of an ideal or appropriate smoothing parameter in multivariate kernel density estimation is considered by looking at six different methods. A comparative study of these six methods is done using simulated data. The higher-order smoothing parameter choice is seen to have behaved better than the others with the smallest bias value, mean integrated squared error (MISE) and also gave the best 3-D graph. It is clearly seen that the higher-order choice of the smoothing parameter gave the least MISE and also gave the best 3-D graph. We thus conclude that it should be used in place of all others when dealing with multivariate kernel density estimation.

Siloko and **Ishiekwene** (2014) Bias Reduction in Multivariate Kernel Density Estimation Via Higher-Order Kernel

The rules for choosing smoothing parameter are generally based on the relatively simple but important ideas of balancing bias and variance globally. We focused on how to reduce the bias term by using the generalised higher-order kernel in multivariate kernel density estimation particularly the. A comparison of the higher-order smoothing parameter choices and the data-driven choices shows a reduction in the bias term and the mean integrated squared error (MISE) with higher-order smoothing parameter than the data-driven smoothing parameter using sets of simulated data.

From the results, coupled with the 3-D plots and contour plots, it therefore an established fact that the order four choice of smoothing parameter would always do better than the data-driven choice of smoothing parameter in multivariate kernel density estimation just like it has been established in the univariate case.

Ikpotokin and **Ishiekwene** (2014) Constructing Hotelling's T2 Control Limits for Different a. Levels of Significance

When the quality of à product is controlled by combinations of two or more variables, a high-level decision quickly determines the out of control signals, while simultaneously, evaluating the variable(s) responsible for the false alarm rate (α) levels of significance. In this connection, bootstrap algorithm for constructing Hotelling's T2 control limits was developed and implemented using Visual Basic Code to resolve such problem. The results obtained using industrial production process data proved that the bootstrap control limit at different levels of significance performed better when compared with other existing methods. Akaike Information Criterion (AIC) was also applied to identify the variable(s) responsible for the out of control signals.

Using numerical examples from industrial production process, the bootstrap control limits obtained at different alpha levels of significance were better than values obtained previously from the Existing Method. The AIC method was used in identifying the quality characteristics responsible for out of control signals. Therefore, methodologies adopted and the data values for the bootstrap control limits and AICs obtained would assist Quality Managers to take decisions for monitoring future production purposes.

Ikpotokin[1] and **Ishiekwene**[2] (2014b) Identifying out of Control Signals in a Bivariate Control Chart via the Bootstrap Approach.

In manufacturing and service industries, most multivariate statistical quality control charts are usually used to determine whether a process is performing as intended or if there are some unnatural causes of variation upon an overall statistic. Once a multivariate control chart signals, identifying which or combination of the quality characteristics responsible for the signal has been a difficult task. To address this problem, a bootstrap approach in setting up control limits is presented, and the decomposition method is presented to identify which or combination of variables responsible for the signals in a bivariate case.

This study introduced the bootstrap approach as a means of determining the control limits of a T'2 control chart when observations do not follow a normal distribution. The multivariate quality control has become important as the growth technology has made it relatively easy to monitor many quality characteristics on each unit of product manufactured practice, there are not a few situations in which the simultaneous monitoring and control of two or more related characteristics is necessary. The decomposition approach of identifying out of control signal has been introduced. numerical example, the effectiveness of this approach has been shown. Therefore, the values of bootstrap control limit and decomposition (di) obtained in this study will assist the management to take decision for monitoring future pro purposes.

Siloko and **Ishiekwene** (2014) A Brief Review of Kernel Density Estimation with Applications to Data Analysis

Kernel density estimation is an important smoothing technique with direct applications such as exploratory data analysis and data visualisation. This review summarizes the most important theoretical aspects of kernel density estimation and provides a description of classical methods for computing the smoothing parameter. The performance of the kernel estimator will be considered based on the classical methods of obtaining the smoothing parameter and this will be fully illustrated by real data examples.

A very natural use of kernel density estimates is in the informal investigation of the properties of a given set of data. Kernel density estimates can give valuable indication of features such as skewness and multimodality in the data. In some cases that will yield conclusions that may be regarded as self-evidently true while in other cases all they will do is to point the way further analysis.

Despite these important roles played by kernel density estimation, there is the problem of selecting the most suitable smoothing parameter for the kernel density estimator. In this review, we only considered the cross-validation bandwidth selectors where the unbiased cross validation tends to select smaller smoothing parameter while the biased cross validation and the smoothed bootstrap method selects smoothing parameter that produced similar estimates in the univariate case. In the sets of data examined, the second and third data sets displayed one of the functions of kernel density estimation and that exploratory data analysis in which case these data sets were bimodal. In terms of data visualization, the kernel estimates especially in the bivariate case can be viewed using familiar perspective ('wire frame') or contour plots.

Afere and **Ishiekwene** (2014) On the Efficiency of Multivariate Spherically Symmetric Polynomial Kernels: A Biweight Kernel Perspective

The efficiency of d-dimensional spherically symmetric biweight kernel that have support on [-1,1] is presented in this work. We proposed a d-dimensional spherically symmetric biweight kernel and derived its generalized efficiency. This was done by eliminating the problem of first computing the second moment and its corresponding L2-norm in each U dimension before computing their efficiencies.

As the order of the efficiency increases, the efficiency decreases. The computation of the second moment and its L_2 norm of the spherically symmetric biweight kernel for each dimension before calculating their efficiencies are simplified.

Ikpotokin'and **Ishiekwene** (2015) Performance Evaluation on Bootstrap Hotelling's T2 Control Chart for Bivariate Data

Statistical Process Control (SPC) is one of the mostly used techniques to monitor processes and to help in reducing variability and improving process performance. A basic assumption in theoretical statistical quality control is that the observations are independently and identically distributed; however, this assumption is usually violated in many production processes. Also, autocorrelated data are commonly present in many process control applications; this can seriously affect the performance of classical control charts if not properly accounted for. In this paper, a bootstrap T2 control chart is proposed for monitoring and controlling multivariate autocorrelated processes. To illustrate the power of the proposed control chart, its Average Run Length (ARL), Standard Deviation Run Length (SDRL) and Median Run Length (MRL) performance is evaluated against the statistical F-distribution T2 control charts, in bivariate autocorrelated processes. Illustrative examples shown that the bootstrap T2 control chart performs better than the F-distribution T2 control chart when it is used to detect small to moderate shifts, i.e., shift size $< 2\sigma$.

This study critically looked at the performance of the bootstrap Hotelling'scontrol ch whether or not the underlying distribution is known, and the assumption of normality satisfied. Using a numerical example, the bootstrap results obtained in this study at different mean shift levels has been shown to be better than the existing method when compared Generally speaking, the out of control ARL decreases with the increase of the the magnitude. This is because it is logically easier to identify a larger shift than a smaller shift. Finally, it was shown that the proposed control chart outperforms the F-distribution control chart in terms of ARL, SDRL and MRL. Therefore, the performance of bootstrap control chart obtained in this study will assist quality manager to take decision for monitoring future production purposes.

Siloko and **Ishiekwene** (2016). Boosting and Bagging in Kernel Density Estimation

Boosting is a bias reduction technique while bagging is a variance reduction method. These two methods aim at reducing the asymptotic mean integrated square error (AMISE). This study aims to show that bagging is a boosting algorithm in kernel density estimation since both techniques use large smoothing parameter(s): This relationship was verified by real and simulated data.

Boosting and bagging in kernel density estimation are bias, and variance reduction techniques characterized by using larger smoothing parametér(s) suggested a powerful new tool for addressing the curse dimensionality effects (Marzio and Taylor, 2004).Since large bandwidths reduce the variance term of the AMISE and increases the bias term, the study carried out two boosting steps to demonstrate the reduction of the bias and variance term that translated to a reduction in the AMISE using the over smoothed bandwidth. As can be seen, bagging can be considered as a boosting algorithm in kernel density estimation since both methods used larger smoothing parameter aimed at reducing the AMISE. Although boosting and bagging depend on larger smoothing parameter but we have demonstrated that their targets are different in terms of their contribution to the AMISE.

Ejakpovi, Siloko and **Ishiekwene** (2016) Performance of Some Higher Order Beta Polynomial Family Kernels

This article introduces two new higher-order kernels of the beta polynomial family when p = [5,6]. The most commonly used measure of discrepancy which is the mean integrated squared error (MISE)that shows how close an estimated density is to the targeted true density was considered for both kernels. We obtained their expressions and the asymptotic mean integrated squared error for the proposed higher order kernels was given. Different data sets of various sizes were used to illustrate the behaviour of the proposed procedure and the results obtained was quite interesting.

Ikpotokin and **Ishiekwene** (2017) On the Bootstrap Multivariate Exponentially Weighted Moving Average (BMEWMA) in Setting Control Limits and P-Values for Interpreting Out of Control Signals.

The effects of control limits that are too narrow increase the rate of false alarms, while those that are too wide may not be able to identify special causes of variability in any given process. It is of this view that control chart methodology that can detect small to moderate shifts in the mean vector should be developed so that the probability of detecting or not detecting false alarm rate should be minimized. The bootstrap multivariate exponentially weighted moving average is proposed in setting control limits, while p-value method was introduced to identify out of control signals.

This study specifically considered the BMEWMA method as a means of determining control limits from multivariate control charts. The intension is to reduce the rate of not discovering false alarm in any given process. Procedures that can carry out a systematic generation of bootstrap replications for two or more quality characteristics have been proposed in this work; it is straight forward but computer intensive. Using numerical example, control limits obtained from the proposed method performed very well when compared with the existing methods.

Ikpotokin, **Ishiekwene** and Ekhosuehi (2017) Performance Evaluation of Bootstrap Multivariate Exponentially-Weighted Moving Average (BMEWMA) Control Chart

A fundamental hypothesis in theoretical statistical quality control is that samples are independently and identically distributed; but this assumption is frequently violated in many production processes. Moreover, the presence of auto correlated data in many process control applications gravely affects the performance of classical control charts if not appropriately accounted for. In this paper, bootstrap T2 and bootstrap multivariate exponential weighted moving average (BMEWMA) control charts are proposed for monitoring and controlling multivariate autocorrelated processes. From numerical illustration, results obtained from the Average Run Length (ARL), standard deviation run length (SDRL), median run length (MRL) and percentiles run length (PRL) displayed in tabular and graphical forms, shows that the proposed bootstrap control methods performed better than the F-distribution T2 control method.

This study critically looked at the performance of the bootstrap Hotelling's T2 and BMWEMA control charts whether or not the underlying distribution is known, and the assumption of normality is satisfied. Using an empirical data set, the bootstrap results obtained in this study at different mean shift levels has been shown to be better than the existing method when compared.

Generally, out of control ARL, SDRL, MRL and PRL decrease with the increase of the shift magnitude. The BMEWMA detects a shift at least as quick as both the F-distribution T2 and the Bootstrap T2 charts. This is expected since the smoothing parameter (0.1) for the BMEWMA chart was chosen to detect small shifts. Finally, it was shown that the proposed control charts outperform the F-distribution control chart in terms of ARL, SDRL, MRL and PRL. Therefore, the performance of bootstrap control chart obtained in this study will assist in detecting small shift.

Siloko, **Ishiekwene,** and Oyegue (2017). The Effect of Smoothing Parameter in Kernel Aggregation. Canadian Journal of Pure and Applied Sciences, Vol. 11 (2), pp. 4255–4262.

Kernel density estimation depends on appropriate smoothing parameter selection in its implementation since the method is mainly for data exploration and visualization purposes. While considering the effect of the smoothing parameter, the form of aggregation employed will determine the size of the smoothing parameter required for better performance. This paper considered two aggregating methods with respect to the asymptotic mean integrated squared error (AMISE) as the criterion function by introducing the multiplier factor that regulates the selection of smoothing parameter in the multiplicative aggregation. The results of the forms of aggregation considered were compared using real life data.

The additive and multiplicative aggregations were considered with the later displaying better results than the former in terms of performance using the AMISE as the error criterion function. The multiplicative aggregation technique targets reduction in the AMISE without considering features such as multi-modality that might be present in a given data set due to the principle of over smoothing which means using larger smoothing parameters. As observed from the data sets considered, the additive aggregation retained the features of the data set such as bimodality while the multiplicative aggregation at times may smooth out this feature as a result of using larger smoothing parameters but with a reduction in the AMISE. The smoothing parameter used for the multiplicative aggregation was obtained using the bandwidth multiplier.

Ejakpovi, S.U., Siloko, I.U. and **Ishiekwene,** (2018). On the Efficiency of Beta Polynomial Higher Order Kernels. Journal of Mathematical Association of Nigeria (ABACUS, Mathematics Science Series) Volume 45 (1), pp. 175–179.

This paper deals with the efficiency of some higher order kernels of the Beta polynomial family and their hybrid. The generalized efficiency expression for the kernel functions was derived. Also, the efficiency expression was implemented for the different kernel functions. The results obtained showed that the hybrid kernel of the higher order kernels of the Beta polynomial family considered was more efficient than their respective higher order versions.

We proposed higher order kernel functions and its Hybrid from the classical Beta polynomial kernels and examined their efficiencies respectively. In terms of the efficiency, the proposed higher order kernels were closer to the optimal kernel which is the Epanechnikov kernel with respect to the mean integrated squared error despite the decrease of efficiencies values as the orders of the kernel functions increases. Another key contribution of this work is the fact that the Hybrid kernel outperformed the optimal kernel in terms of efficiency as presented above, and this simply suggests that the Hybrid kernel is also efficient.

Siloko, Siloko, Oyegue, and **Ishiekwene** (2018). On the Efficiency of Beta Polynomial Family in Multivariate Kernel Density Estimation. Nigerian Journal of Science and Environment, Volume 16(1), pp. 174–179.

The efficiency of the beta polynomial kernels in the multivariate setting is the focus of this paper. The univariate kernel density estimation is of wide applications in nonparametric density estimation. The applications of kernel density estimation in terms of exploratory data analysis and data visualization are mainly in the multivariate context; however, the multivariate kernel function needs more smoothing parameters in its implementation. The univariate kernel form of the beta polynomial kernels has been extensively studied. We obtained the multivariate form of the beta polynomial kernel functions from their univariate counterpart using the product approach. The statistical properties of the multivariate kernel functions were compared with the univariate kernel functions and the results show that the efficiencies tend to be smaller with increase in the dimensions of the kernel function. The efficiencies also decrease with higher powers of the beta polynomial kernels.

The paper focused on the efficiencies of the beta polynomial kernels by considering higher values of the powers of apart from the known lower values of like the Epanechnikov, Biweight and Triweight kernels for the univariate and bivariate kernels only, although a generalization to higher dimensional cases is given. The bivariate kernels were obtained using the product strategy. The choice of a kernel function should be based on its degree of differentiability since kernel with higher values of tends to be smoother and possesses more derivatives unlike those with fewer derivatives that tend to be noisy. Also noted from the results is that the efficiency decreases as the dimension of the kernel function increases, and this was obviously seen in the Uniform and Gaussian kernels.

Siloko, **Ishiekwene,** and Oyegue (2018). New Gradient Methods for Bandwidth Selection in Bivariate Kernel Density Estimation. Journal of Mathematics and Statistics, Volume 6(1), pp. 1–8, http://dx.doi.org/10.13189/ms.2018.060101

The bivariate kernel density estimator is fundamental in data smoothing methods especially for data exploration and visualization purposes due to its ease of graphical interpretation of results. The crucial factor which determines its performance is the bandwidth. We present new methods for bandwidth selection in bivariate kernel density estimation based on the principle of gradient method and compare the result with the biased cross-validation method. The results show that the new methods are reliable and they provide improved methods for a choice of smoothing parameter. The asymptotic mean integrated squared error is used as the measure of performance of the new methods.

The methods presented are compared with the biased cross-validation method because they are based on a suitable estimate of the asymptotic mean integrated squared error (AMISE). The results presented show that the new methods are reliable and they provide improved methods for a choice of smoothing parameter. An advantage of the gradient methods is that they can easily computed provided the function f is at least twice differentiable. As for the bivariate case that sits between the univariate and higher dimensional kernel, and that $\boldsymbol{K}$ is a standard normal product kernel, the gradient methods based on their performance is at least as competitive as the existing biased cross-validation.

Siloko, Ikpotokin, Oyegue, **Ishiekwene** and Afere (2019). A Note on Application of Kernel Derivatives in Density Estimation with the Univariate Case. Journal of Statistics and Management Systems, Volume 22(3), pp. 415–423, https://doi.org/10.1080/ 09720 510.2018. 1524956.

The paper considered the application of kernel density derivatives to real life data. Kernel density derivatives estimation is very fundamental and critical in statistical data analysis especially for exploratory and visualization purposes. As a result of the wide range of its applications, appropriate estimation of the kernel derivatives from its function and locating some statistical features such as bumps and modes of a set of observation is of a great importance. We consider the first and second derivative of the Gaussian kernel and compare their results in terms of performance using asymptotic mean integrated squared error as the error criterion function. The results of the comparison show that as the derivative of the kernel function increases, the AMISE decreases with an increase in the smoothing parameter.

The first and second derivative in kernel estimation is about the point of inflexion of the function and the curvature of the function respectively. Higher derivatives order in kernel estimation is an AMISE reduction strategy that is characterizes with oversmoothing as the derivative order increases. As the order of the derivative increases, the smoothing parameter also increases respectively and this is due to the presence of the roughness of the r^{th} derivative of the kernel function and the roughness of the r^{th} unknown probability density function.

Siloko, Siloko, Ikpotokin, **Ishiekwene** and Afere (2019). On Asymptotic Mean Integrated Squared Error's Reduction Techniques in Kernel Density Estimation. **International Journal of Computational and Theoretical Statistics,** Volume 6(1), pp. 89–98, http://dx.doi.org/10.12785/ijcts/060110

The techniques of asymptotic mean integrated squared error's reduction in kernel density estimation is the focus of this paper. The asymptotic mean integrated squared error (AMISE) is an optimality criterion function that measures the performance of a kernel density estimator. This criterion function is made up of two components, and the contributions of both components to the AMISE are mainly regulated by the smoothing parameter. Kernel density estimation is of vitally importance in statistical data analysis especially for exploratory and visualization purposes. In performance evaluation, a method is better when it produces a smaller value of the AMISE; hence effort is being made to develop techniques that reduce the AMISE while ensuring that in practical implementation using real data, the statistical properties of the given observations are retained. We consider the kernel density derivative and kernel boosting as the AMISE reduction techniques. In kernel boosting, we introduce the optimal smoothing parameter selector for each boosting steps as the number of iteration increases. The presented results show that the AMISE decreases with higher kernel derivatives and also as the number of boosting steps increases.

The study is on the techniques of reducing the asymptotic mean integrated squared error using the kernel density derivative and kernel boosting approaches. Both methods depend on the smoothing parameter which must be larger than the classical second order smoothing parameter. Kernel density derivatives and kernel boosting may smooth away some desirable features of a data set such as multimodality but retained the characteristics of reducing the AMISE. While kernel boosting and kernel density derivative tends to produce smaller value of the AMISE, the proposed kernel boosting bandwidth selector produce AMISE values that are smaller than the AMISE values of the kernel density derivative method in kernel density estimation.

Siloko, Ikpotokin, Oyegue, Siloko and **Ishiekwene** (2019). Numerical Computation of Efficiency of Beta Polynomial Kernels Using Product Method. Journal of Applied Science and Technology, Volume 23 (1 & 2), pp. 33–39.

The efficiency values of beta polynomial kernel functions were computed using bivariate product approach, which involved multiplication of two univariate beta kernel functions. The statistical properties of bivariate beta kernel functions, in terms of roughness and variance, were evaluated to compute the efficiency values. The efficiency values of univariate form of beta polynomial kernels were also determined, and compared with values of bivariate beta kernel functions, since most applications of kernel estimators are in the bivariate form. The kernel estimator is a nonparametric density estimator with direct applications in data analysis and visualization. The computations showed that efficiency values tended to be smaller for bivariate beta polynomial kernel functions than for univariate kernel functions, due to effects of dimensionality associated with nonparametric statistics.

There was decrease in efficiency of kernel functions with increase in the dimension of the kernels, implying that the efficiencies of beta polynomial kernel functions were affected by dimension. The variations in efficiency values due to increase in dimension were faster in higher dimensions. The decrease in efficiency with increase in dimension was due to the difficulty associated with nonparametric statistics in dealing with multidimensional analysis. The problem of dimensionality effects were the difficulties associated with handling many variables concurrently in statistical processes, either in the industrial sector or decision making.

Siloko, Ukhurebor, Siloko, Enoyoze, Bobadoye, **Ishiekwene,** Uddin and Nwankwo (2021). Effects of some Meteorological Variables on Cassava Production in Edo State, Nigeria via Density Estimation. Scientific African, e00852, https://doi.org/10.1016/j.sciaf.2021.e00852

Agricultural productivity depends on weather variables because crop yield and animal productivity are directly affected by these variables. Due to the significant roles of weather variables in agriculture and the environment; studying their effects is therefore unavoidable because this will help in the general performance and evaluation of agricultural productivity. The effect of weather variables on agricultural productivity globally is a major issue due to the fact that the existence of humanity is directly dependent on agricultural products. This study employs the nonparametric statistical approach in investigating the interactions between temperature and relative humidity and their direct effects on cassava production in Edo State, Nigeria. The statistical analysis of the variables for purposes of exploratory and visualization is examined owing to the fact that underlying structures of the variables form the basis of decisions and policies making by weather experts. The study investigates the interactions between temperature and relative humidity and their effects on cassava production for a period of six years which is from 2014 to 2019 in Edo State, Nigeria using kernel method. The results obtained revealed that quality cassava yields annually is associated with higher relative humidity and lower temperature and vice-versa with 2014 producing the best yield while 2017 produced poorly for the period under consideration

This paper investigates the effects of temperature and relative humidity on cassava production in Edo State, Nigeria using kernel method for a six-year period. The investigation show that cassava yields in Edo State is determined by higher relative humidity and lower temperature and vice-versa. The results of the study show that the years of best yield are attributed to higher probabilities which usually resulted in producing minimum AMISE values while lower probabilities is an indication of poor yield with large AMISE values. The investigation also revealed that the value of correlation coefficient is a major performance indicator of cassava production capacity in the State. For correlation coefficient values within the range of - 0.45 and - 0 .47, the production capacity will be high while values outside the range tend to produce large AMISE values which denotes low cassava yield.

Siloko, Ukhurebor, **Ishiekwene,** Siloko, Uddin, and Enoyoze (2021). Statistical Estimation of Some Meteorological Variables Using the Beta Kernel Function. Ethiopian Journal of Environmental Studies and Management, Volume 14(4), pp. 474–486, https://ejesm.org/doi/v14i4.7

The study of meteorological variables is imperative due to their usefulness in our daily activities. Climate change which is now a global issue has received considerable large volume of research owing to the fact that its effects cut across all aspects of life. It is generally known that the effects of climatic change pose a great threat to agricultural activities in Africa continent and the world at large. Temperature and relative humidity are inversely related and this inverse relationship as investigated using real life data shows its devastating effect on the environment if neglected without urgent control measure. Hence, this study investigates the relationship between temperature and relative humidity using the beta kernel function with the asymptotic mean integrated squared error (AMISE) as the criterion function. The results of the study using real data reveals that temperature and relative humidity greatly determine climatic fluctuations which can adversely affect the environment.

Temperature and relative humidity are inversely related and this inverse relationship as investigated using real life data shows its devastating effect on the environment if neglected without urgent control measure.

The probability of their interaction is high using the statistical tools of nonparametric density estimation. Activities that could result in depletion of the Ozone layer should be avoided and environmentalists should as a matter of urgency sensitize the citizenry on the importance of urgent need of maintenance of the environment. Government at all levels in every nation should come up with stringent policies that regulate the activities of individuals and industries towards the maintenance of the environment to reduce the effects of climatic fluctuations.

Siloko, Ejakpovi, Ukhurebor, Siloko and **Ishiekwene** (2022). Comparison of Kernel Density Function in Detecting Effects of Daily Emission of Sulphur (IV) Oxide from an Industrial Plant. *Ethiopian Journal of Science and Technology,* Volume 15(1), pp. 53–66, https://dx.doi.org/10.4314/ejst.v15i1.4

Air pollution is a major concern of environmentalists because of the importance of air to man and other living organisms. This paper is about the investigation on the effects of daily emission of Sulphur (IV) oxide from an industrial pollutant using a nonparametric estimator which is the kernel estimator. Nonparametric estimators are free from distributional assumptions owing to the fact that most real-life data are not from a particular family of distribution. The functionality of this estimator is contingent on the smoothing parameter also called the bandwidth that determines the degree of the smoothness applied when analyzing the data. The bandwidth is extrapolated by minimizing the asymptotic mean integrated squared error which is the objective function of the kernel estimator. In this investigation, we selected some kernel functions of the beta family with the Gaussian kernel and obtained their bandwidths or smoothing parameters with respect to their distribution. The result of the analysis showed that an increase in number of tons of Sulphur (IV) oxide was associated with higher concentration level of the gas which suggests a potential danger of the gas to humans, animals and plants in the environment.

This paper discusses the potentials of kernel estimators in detecting the effects of the volume of Sulphur (IV) oxide released into the atmosphere daily from an industrial plant. The rising level of the effects of the gas is displayed in the kernel estimates and the regions of high number of tons of the gas with adverse effects in the environment are vividly shown. When the number of tons emitted daily is above 20 tons, the prescribed concentration levels of the gas in the atmosphere will be exceeded which resulted in increase in probabilities values. The increase in probabilities values associated with increase in the number of tons emitted daily is an indication that human lives, plants and animals shall experience the negative effects of the gas in the environment. Hence; appropriate government authority should enact laws that should regulate the emission of Sulphur (IV) oxide into the environment.

Siloko, Siloko, Ojobor, Wasan, Enoyoze, **Ishiekwene,** Ikpotokin, and Ogbeide (2023). A New Multivariate Product Kernel Function of the Beta Polynomial Family. Journal of Statistics Applications and Probability, Volume 12 (3), pp. 1385–1398, http://dx.doi.org/10.18576/jsap/120340

Multivariate analysis of data is of wide applicability in data science especially in big data analytic due to the volume of concealed information to be analyzed. Accurate analysis of multivariate variables is pertinent because predictions from analyzed data are good statistical indicators for making helpful decisions economically and industrially. One of the statistical analytic tools for analyzing multidimensional observations is the kernel density estimator in data exploration and visualization. The functionality of the kernel depends on the kernel function and bandwidth which influences smoothness of estimates. Several kernel functions and bandwidth selectors exist in literature; however novel estimators are being introduced to handle complex circumstances. This paper introduces a new multivariate beta kernel functions whose derivation is contingent on the product techniques. The performances of the newly introduced and existing kernels are evaluated with a known objective function and the numerical results distinctly indicating that the introduced family transcended the traditional beta family.

This paper introduces a new multivariate beta family from its classical kernels with the aid of the multivariate product construction techniques. On numerical evaluation with the AMISE as performance measure, the introduced kernel has established its superiority over the classical kernels in empirical verification and data application with emphasis on the univariate and bivariate cases. Features retention is a vital aspect of multivariate kernel density estimation especially in bivariate estimation primarily for extraction of information in decision making and future prediction. Multivariate kernel estimate provides enormous information with reference to essential features of data, hence the proposed kernel functions like their classical counterparts also retained the statistical properties of the data investigated.

Siloko, Siloko, Ojobor, Agwemuria, **Ishiekwene,** Ikpotokin, Ogbeide and Enoyoze (2024). A new second-order kernel of the beta polynomial family in density estimation. International Journal of Computing Science and Mathematics, Volume 20(4), pp. 273–289, https://doi.org//10.1504/IJCSM.2024.10065595.

Data exploratory analysis and data visualizations are the main functions of kernel density estimation. The kernel density estimation techniques depend fundamentally on the bandwidth that determines its smoothness and a kernel function. In this paper, a novel second order beta kernel from its classical counterpart with improved performance is introduced. The improvement of the newly introduced kernel family is ascribed to their possession of additional powers of derivatives since they are polynomial families. Although several techniques of kernel construction exist in literature, the proposed kernels were derived by modifying the additive higher order kernel construction rule. A real data and different sample sizes were employed in authenticating and validating the efficacy of the proposed kernels' performances using the asymptotic mean integrated squared error (AMISE) as the measure of accuracy. The results of the proposed kernels were compared with existing kernels with the proposed kernels outperforming the traditional kernels family.

A new beta kernel family with superior performance is proposed using the additive higher order construction techniques. The performance of the proposed beta kernel functions is authenticated numerically with the AMISE as the performance metric. Empirically, the outcomes of the newly introduced kernel functions show superiority and improvements over the classical beta kernel functions. In exploration of intrinsic characteristics of data, the introduced kernel functions also demonstrated dominance over the traditional kernels in revealing the statistical composition of the data examined.

Ejakpovi, Siloko, Ojobor and **Ishiekwene** (2025). Probability density function estimation using a new series nonparametric estimator with data applications. Global Academic and Scientific Journal of Multidisciplinary Studies (GASJMS), Volume 3(3), pp. 91–98, https://doi.org//10.1528/zenodo.15588414

In the paper, we studied a new nonparametric density estimation method. We proposed this estimator in series univariate form that incorporates the kernel density estimator and kernel density differential estimator and derived its normality and variance. We have also compared the asymptotic normality of the mean integrated squared error (AMISE) of the proposed estimator, kernel density estimator and bias reduced kernel estimator. The results obtained have shown that the proposed estimator, Hermite series kernel density estimator one has better performance than the kernel density estimator and bias reduced kernel estimator when real data are applied.

In this study, we conclude that the results obtained from the Hermite series kernel density estimator are better that the kernel density estimator and bias reduced kernel estimator. We showed this by computing the asymptotic mean integrated squared error (AMISE) and the rates of convergence. The work showed the Statistical qualities and performance parameters of the estimators, it becomes evidential that the Hermite series kernel density estimator one has the least asymptotic mean integrated squared error (AMISE) when compared with the other exiting estimators under real data applications.

Ejakpovi, Siloko & **Ishiekwene,** did a Comparative Study of Kernel Density Functions in Detecting the Malleability of material Viscosity in a chemical Process.

Viscosity is the internal intermolecular flow of a material (fluid or gas) in a chemical process. The flow characteristics of the material viscosity determines the malleable nature of the material in predicting its value. This paper focuses on the material viscosity in a chemical process using a nonparametric method, which is the kernel density estimator whose potentials is domicile in its smoothing parameter and kernel function. The smoothing parameter applied on the material viscosity is the improved rule-of-thumb (IROT) smoothing parameter algorithm which evolved from the derivatives of the kernel density estimator. The beta kernel functions were used to achieve the levels of the material movement using the smoothing parameter. The results showed that the material has two major regions of high viscous resistance amidst other low regions during the chemical process.

The paper dealt with the potentials of the kernel density estimator in detecting the regions of material viscosity during a chemical process with the aid of the improved rule-of-thumb (IROT) smoothing parameter selector. The rising and falling bumps of the estimates depict the slow and quick level of material flow as reflected in the malleability of the material viscous data. Therefore, it is imperative for product manufacturers to determine material viscosity before embarking on the chemical process to ensure the durability of their finished products.

At the beginning of this lecture, we set out to find 'X' the unknown in all situations. Thus we did by using simple illustrations of our day to day activities, then looking at the problem of finding the bandwidth choice in both univariate and multivariate kernel density estimation, the use of control charts in our manufacturing/production process and finally, application of kernel density estimation with data science to areas like agriculture, meteorology, environment and material science.

3.0 RECOMMENDATIONS

The problem of density estimation has clearly been discussed extensively and we have been able to show how the problem of finding an ideal bandwidth (windowwidth or smoothing parameter) has received great attention worldwide. We have also seen its application in various fields of human lives. Agriculture and climate issues are now being addressed using the density estimation methods combined with Data Science.

Now that governments everywhere are trying to do new things outside the conventional methods, we must embrace the use of density estimation and data science to do forecasting/predicting so as to achieve data driven solutions to problems as they arise instead of relying on 'historical methods'.

Specifically, government and its agencies are encouraged to put in place policies that would ensure that manufacturers are adhering to quality control standards, maintain acceptable climatic conditions for safe agricultural and environmental conditions for its populace.

4.0 CONCLUSION

Data on its own is useless unless when properly analysed and interpreted. We have seen how univariate set of data is used in constructing density estimates via different methods and different means of choosing the bandwidth which is very crucial in the construction of the density estimates. We also dealt with the multivariate case of kernel density estimates using various choices of bandwidths. The quality of goods in a production process also received attention by constructing new versions of control charts that are used to monitor production processes so as not to go out of control.

Application of kernel density estimates was seen in the fields of agriculture, meteorology, material science and environment.

ACKNOWLEDGEMENT

To God Almighty be all the glory and praise for making this day a reality and come to pass.

Also, I sincerely appreciate the Management of University of Benin led by our Vice Chancellor, Prof. Edoba Bright Omoregie, SAN and other principal officers: Prof. C. C. Osubor (DVC, Administration), Prof. V. O. Igbineweka (DVC, Academics), Prof. B. A. Ayinde (DVC, Ekehuan Campus), Mr Ademola Bobola (Registrar), Prof. (Mrs) J. Aba (Librarian) and Mr. O. I. U. Osifo (Bursar).

To my parents, Late Chief E. D. Ishiekwene of blessed memory and my mum Mrs F. O. Ishiekwene who is aged and can't travel to witness this day. My wonderful siblings, Chief Anthony Chukwuemeke, Stella Nkechi, Bernard Amechi, Francisca Ifeoma, Daniel Chukwuma and Priscilla Ndidi for all your love and support.

To my supervisor at both M.Sc and Ph.D levels, Rtd. Prof. S.M. Ogbonmwan and members of staff of Statistics Department – Prof. J.E. Osemwenkhae (Director of Academic Planning), Prof. J.I. Mbegbu, Prof. N.Ekhosuehi, Prof. F.O. Oyegue, Prof. A. Iduseri (current HOD), Prof. F. Ewere, Dr S.A. Osagie, Mr. F.C. Ezeh, Mr. L.I. Osawe, Mr. C.O. Odijie and the newly employed staffs (Dr. L.C. Nzei, Mr. K. Uadiale and Mr. I. Izuagbe), Mrs D.I. Oseghale, Mrs Akpemuwa, Dr Innocent Akata and others. I say thank you for making the department a peaceful place for academic work.

Let me also appreciate my academic children, Prof. Israel. U. Siloko, Dr O. Ikpotokin, Dr Simeon .U.Ejakpovi and Mrs S.I. Siloko. You guys are wonderful and fast-growing children.

My special thanks to the Vice Chancellor University of Delta, Agbor (Unidel), Prof. (Mrs) S.C. Chiemeke, the Registrar, Barr. R. Omagbemi for opportunity of sabbaticals and my Unidel 'Team' Desmond Ekokotu, Okpako Ejaita, Okeh Dono, Andy Emuobonuvie, Jaboro Grandy, Ideh

Kingsley, Mr Williams Eghebi, Charles Egbenusi, Mamus Okposo, Mr. Azani Nwabuoku, Miss Oke Ohoriemu, Frank Odiri Eghajivie, Frank & UK Okoh, Ben Adeyemi, Dr Amahi, Ngozi Uriah, Igwe P^2, Mr Kazeem, Barr. Dike, Dr (Mrs) R.N. Nwaka - my HOD, Dr Ehiwario, Dr Meka Fortune, Dr Azagbakwe and other staff of Mathematics & Statistics Department, Unidel. Also, my sabbaticals colleagues – Prof. N.P. Okolie, Prof. J.U. Iyasele, Prof. M.N.O. Ikhile, Prof. Ben Iyozor, Prof Sam Ike and Prof Oladipupo. Thanks for being there for me all the time.

Members of University of Benin Senior Staff Club, Dr Adaze .E.(President), Dr Owin Olowo (IPP), Prof. Adams (Igwe), Prof Ozor, Prof Yuka, Prof Charles Imarenghiaye, Prof Onoselase, Prof George Eriyamremu, Prof E. Ogujor, Folarin Dimowo, Dr Emeka Iroh (Lala), Mrs T. Omage-Umeh, Chief Martins (Oniha of Igueben), Mr Ekeruke (Alaboi), Mr Roland Ikhuobase, Tony Obahiagbon, Dr Mike Chijuka. I say a big thank you for the love and friendship.

Members of UMT – Nnamdi Okafor, Ehigbai, Mama Anna, Leo Okosor, Okpere, Tuchi, Desmond Olie and Dr. Efe, Solo50, I say you are worthy friends.

Michael Ehinze for the typesetting and editing of this work, I am indeed grateful.

To my ’Boys’ all over the world, Theo, Cole, Victor, Ayi, Shegun, OluB, Momoh JP, OnosD, Otus, Ovo, Tega and many others. I say, remain good and keep the family strong.

Finally, to members of my immediate family led by my lovely wife, Barr. Vivian Akpesiri Ishiekwene, my kids – Ifeoma Christabel, Onyeka Christine and Ugochukwu Charles. You guys have been so loving and wonderful ’home squad’ that I can depend on any day and any time. I say a big thank you for your show of love.

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