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Feature Selective Validation Application to Effect Analysis of Coiling on the Impedance Profiles of Augmented Cables for IoT Infrastructure

*Olusegun E. Ogundapo
Department of Electrical and Electronics Engineering, American University of Nigeria, Yola, Nigeria
segundapo@gmail.com

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ORIGINAL RESEARCH

Abstract— The increasing demand for Power-over-Ethernet (PoE) applications in Internet of Things (IoT) infrastructure has led to a rise in the use of augmented cables as it is cost-effective. Augmented category 6 (Cat 6a) cable is now the standard for new installations requiring the aforesaid functions. Cat 6a cables for POE applications are required to be able to withstand the effects of repeated coiling they would be subjected to during installation. There is a paucity of literature on the effect of coiling on the impedance profiles of augmented cables across their length. The drawback of the available pieces of literature is that the effect of coiling is based on the frequency of operation. Examining the effect of coiling on the impedance profiles of Cat 6a cables across their length can help determine their physical integrity and aid fault location. Therefore, a method that can be used to examine the effect of coiling on impedance profiles of augmented cables across their length using the Feature Selective Validation (FSV) technique is provided. The ability of the FSV to accurately present the comparison between two data sets as a comprehensible output makes it better than other common methods. Three Cat 6a cables from different manufacturers were selected for the experiment. The Cat 6a cables were exposed to two rounds of coiling and uncoiling to imitate the stress anticipated from handling during installation. The FSV results revealed the cables with the lowest and highest impedance profile variations from the stress tests. The approach presented showed that it can be used to undertake an objective quantification of the effect of coiling on the impedance profiles of the cables across the length.

Keywords— augmented cables, Cat 6a cables, coiling, feature selective validation, impedance profile

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1 INTRODUCTION

The standard for new installations requiring POE is Cat 6a (Zimmerman, 2021; Vincent, 2023). The standard requirements for enhanced performance using Cat 6a cables have been defined by the American National Standards Institute/ Telecommunications Industry Association known as ANSI/TIA-568.2D (Tellas, 2018). The Cat 6a cables are rated for a maximum frequency of 500 MHz at 10 Gigabit per second (10 Gbps) Ethernet (Solomon and Kim, 2021). The driving force behind the use of Cat 6a for new installations is the ability to deliver both data and power simultaneously which is a vital requirement for Internet of Things (IoT) devices (Finnegan and Baillargeon, 2016; Froechlich, 2020). Cat 6a cable is future-proof and backward-compatible (Vincent, 2023). It also provides a cost-effective Ethernet solution for connecting wireless access points, enterprise, health care and educational facilities applications (Vincent, 2023; Finnegan and Baillargeon, 2016).

The demand for Ethernet over Cat 6a cabling continues to grow due to POE application requirements for access controls, surveillance cameras, intelligent lighting, monitoring sensors, and wireless fidelity (WIFI) access points (Shailesh, 2018; Jones and Tremblay, 2019). POE using twisted pair cables for IOT devices and wireless access points is an integral part of smart building automation as it is cost-saving (Shailesh, 2018; Hafski, 2021). Building automation is now an element of the smart cities concept (Hassan *et al.*, 2021). The use of POE for the already mentioned functionalities requires a reliable cabling network. There is the problem of coiling that can impose some degradation on the cables due to poor packaging and during the installation process (McLaughlin, 2019; Marchant and Schumacher, 2023). The coiling can also lead to kinking and damage which can inflict degradation on the cables especially when they are substandard (Copp & Oliver, 2021).

Previous works in the literature on the effect of coiling on the impedance profiles of Cat 6a cables is scanty and those available are based on frequency rather than length which does not reveal their physical integrity. They only deal with performance of the cables (Froechlich, 2020; Marchant and Schumacher, 2023). The examination of the impedance profiles of augmented cables across length is therefore vital to study the effect of coiling on them which can determine their physical integrity and help in fault location. In this research, three Cat 6a cables were selected for the test. The selected cables were subjected to two coiling and uncoiling tests to imitate the expected bending stress during installation. The FSV which is a standardized tool that has been used to objectively compare two data sets in various fields (Zeng *et al.*, 2016; Bai *et al.*, 2023) will be applied in this paper. The FSV has been established to perform better in accuracy and comprehensiveness than common comparison methods like relative error and root mean square error (Wang and Zhao, 2019). It would be used to evaluate the variations between the impedance profiles to find out their resilience

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*Corresponding Author

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or otherwise to the coiling stress test. The method presented can be used to study the effect of coiling on the impedance profiles of cables across the length. It can also help determine their physical integrity and enable cable installers to make objective decisions.

2 MATERIALS AND METHODOLOGY

2.1 CABLES FOR THE EXPERIMENT

The cable materials used for the experiment are three augmented category 6 (Cat 6a) from different manufacturers. They are all foiled, unshielded twisted copper cables. The cables have four twisted pairs each namely: orange, green, blue and brown.

2.2 EXPERIMENTAL PROCEDURE

The experiment was carried out using the DSX-5000 cable analyzer that can handle the testing and certification of Cat 6a cables (Fluke Networks, 2022). The measurements were implemented using the International Organization for Standardization/International Electrotechical Commission (ISO/IEC) 11801 Class EA which allows measurements up to 500MHz for Cat 6a cables (Fluke Networks, 2022). The tester has two major components: the "main" and "remote". The two main parts have hollows for connecting permanent link adapters (Fluke Networks, 2019). The permanent link adapters from the main and remote parts are connected to one patch cord each. The end of each patch cord is then connected to the standard registered jack 45 (RJ45) connector (Fluke Networks, 2019). The other end of the RJ45 connectors has 8 pin holes used for connecting the four twisted pairs (8 wires) from the cables to be examined (Fluke Networks, 2022; Fluke Networks, 2019).

The cables to be tested were connected to the RJ45 connectors pin holes using the standard T568B wiring standard (Panek, 2019). The standard T568B wiring standard used for the test labels the four pairs as pair 1,2 (orange), pair 3,6 (green), pair 4,5 (blue) and pair 7,8 (brown). The test results are stored in the main part of the cable analyzer. To extract the results to a personal computer or laptop, a test management software from the cable analyzer manufacturer called the "Link Ware" must be installed. A universal serial bus (USB) is used to transfer the laboratory results stored in the main part of the tester to the laptop. The analyzer measures the impedance profiles of the Cat 6a cables using an inbuilt High-Definition Time Domain Reflectometry (HDTDR). The measurements were carried out as follows:

Measurement 1 (M1): cable of 30m length unwound from the reel and stretched out for measurement

Measurement 2 (M2): The cable used in M1 is coiled using about 30cm diameter and then stretched out for measurement

Measurement 3 (M3): The process in M2 is repeated.

The schematic representation of the cable test system is shown in Fig.1.

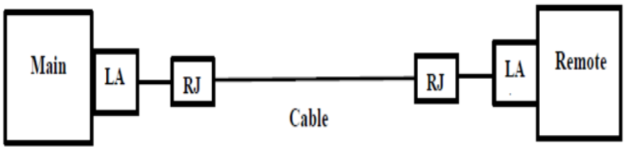

Fig.1: Schematic representation of the measurement procedure using the cable analyzer

Note: LA is the permanent link adapter, RJ is the registered jack 45 connector, and "Cable" is the Cat 6a cable under examination.

2.3 THE FEATURE SELECTIVE VALIDATION METHOD

The FSV was introduced to have an objective method of comparing data sets devoid of human subjective judgment (Zeng *et al.*, 2016; Bai *et al.*, 2023). The FSV is robust and has proven to be credible in automatically quantifying the similitude between two data sets (Zeng *et al.*, 2016; Wang and Zhao, 2019). The features mentioned above of FSV have made its use in different fields possible to quantify complex data from different sources (Wang and Zhao, 2019; Chen, 2021; Zhang and Duffy, 2021). The FSV has two major comparison components: amplitude difference measure (ADM) and feature difference measure (FDM). The ADM deals with differences in amplitudes of the data, while the FDM handles the differences in the characteristics of the data. It does the comparison on a point-by-point basis. The FSV combines the ADM and FDM to give the global difference measure (GDM) which indicates the overall quality of comparison (Chen, 2021). Six qualities of agreement used in FSV are: very poor, poor, fair, good, very good and excellent (Wang and Zhao, 2019; Bai *et al.*, 2023). A table showing the interpretation scale for the FSV-GDM is presented in Table 1 (Zeng *et al.*, 2016; Bai *et al.*, 2023).

Table 1. FSV interpretation scale for the GDM

Value of FSV-GDM	**FSV-GDM Interpretation**
$1.6 \leq GDM$	Very Poor
$0.8 \leq GDM < 1.6$	Poor
$0.4 \leq GDM < 0.8$	Fair
$0.2 \leq GDM < 0.4$	Good
$0.1 \leq GDM < 0.2$	Very Good
$GDM < 0.1$	Excellent

3 RESULTS AND DISCUSSION

3.1 MEASUREMENT RESULTS

The impedance profiles of pairs (1,2), (3,6), (4,5) and (7,8) of cable 1 across their lengths are shown in Figs. 2,3,4 and 5 respectively. Similarly, the impedance profiles of pairs (1,2), (3,6), (4,5) and (7,8) for cable 2 across their lengths are shown in Figs. 6,7,8 and 9 respectively. Finally, the impedance profiles of pairs (1,2), (3,6), (4,5) and (7,8) of cable 3 across their lengths are shown in Figs. 10,11,12 and 13 respectively. The plots in Figs. 2 to 13 indicate that none of the cable impedance profiles exceed the standardized limit of +/-15% of 100 ohms (115/85 ohms). An observation of Figs. 2 to 13 shows that there are variations between Measurements M1, M2 and M3.

However, the variations between the measurements cannot be quantified with the human eye. The FSV method will be applied to have an objective comparison of the degree of variations between the measurements. This is to evaluate their resilience or otherwise to the coiling stress tests.

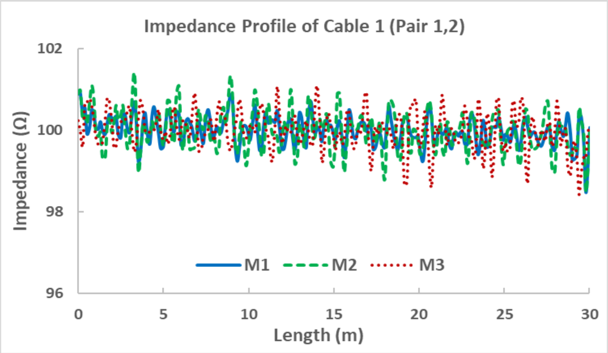

Fig. 2: Impedance profile for pair (1,2) of cable 1

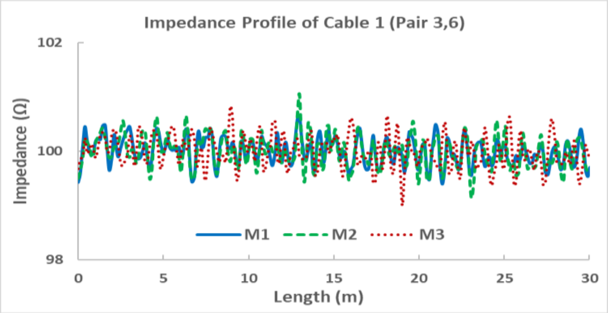

Fig. 3: Impedance profile for pair (3,6) of cable 1

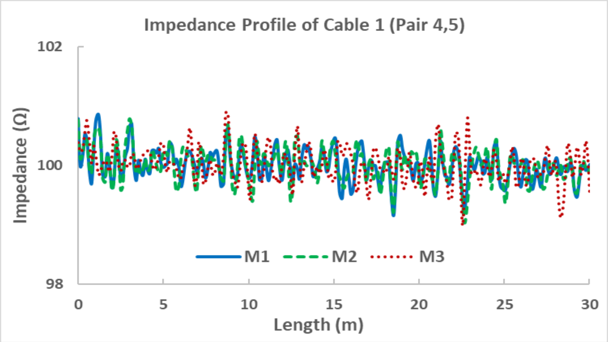

Fig. 4: Impedance profile for pair (4,5) of cable1

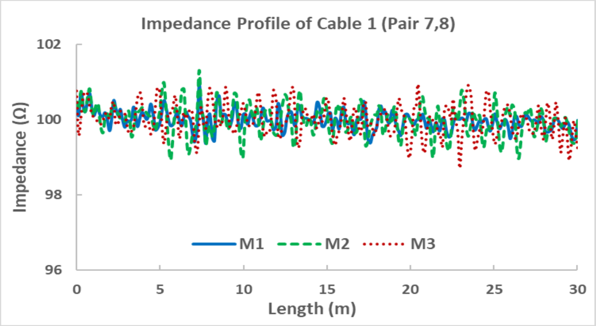

Fig. 5: Impedance profile for pair (7,8) of cable 1

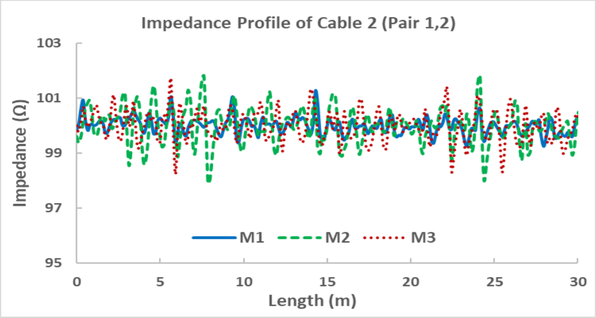

Fig. 6: Impedance profile for pair (1,2) of cable 2

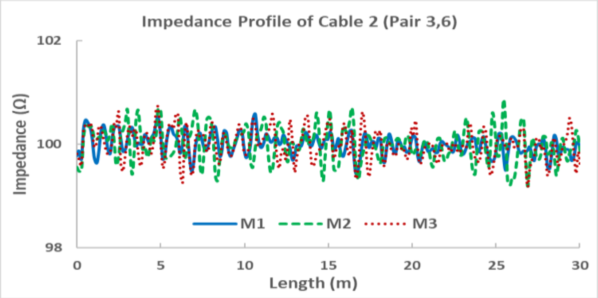

Figure 7: Impedance profile for pair (3,6) of cable 2

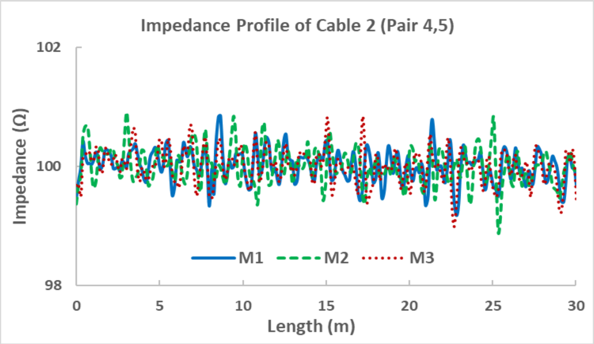

Figure 8: Impedance profile for pair (4,5) of cable 2

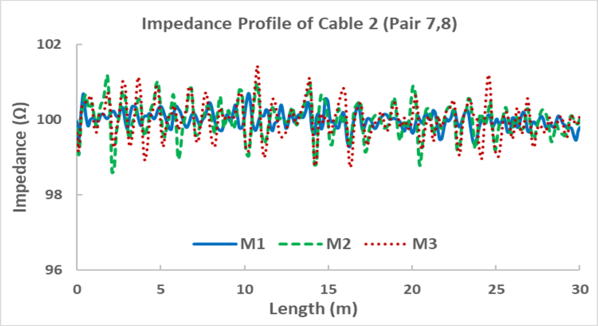

Fig. 9: Impedance profile for pair (7,8) of cable 2

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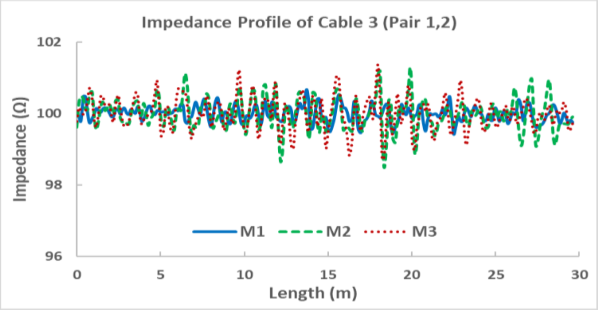

Fig. 10: Impedance profile for pair (1,2) of cable 3

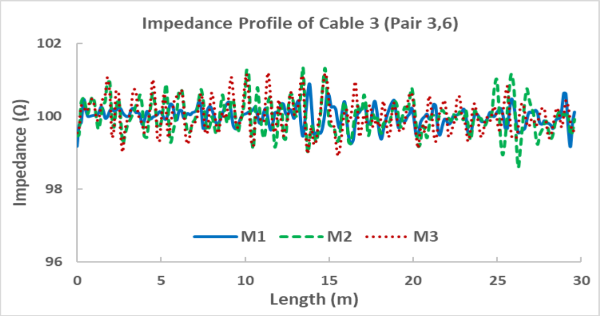

Fig. 11: Impedance profile of pair (3,6) of cable 3

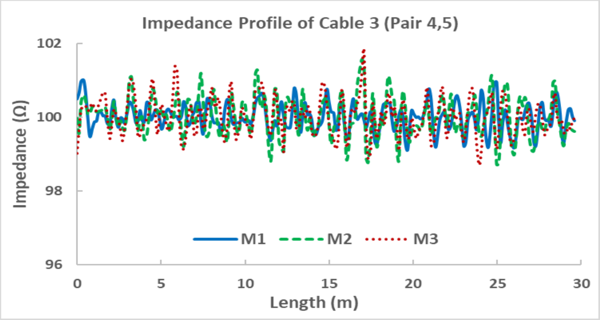

Fig.12: Impedance profile for pair (4,5) of cable 3

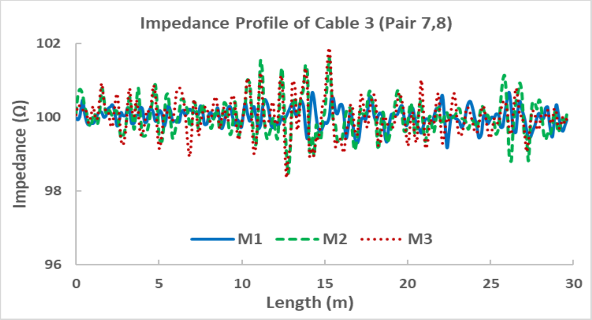

Fig. 13: Impedance profile for pair (7,8) of cable 3

3.2 FSV COMPARISON RESULTS

The summary of the M1 and M2 measurements comparison using the FSV is shown in Fig.14. Fig. 14 shows that cable 1 presented the least variations between impedance profiles M1 and M2 in all four pairs. This indicates that cable 1 gave the best resilience to the coiling stress for measurements M1 and M2 comparison. Similarly, the FSV GDM comparison between impedance profiles M1 and M3 is presented in Fig. 15. Fig.15 shows that cable 1 gave the least variations between the M1 and M3 comparison for pair (1,2) and pair (7,8). Cable 2 on the other hand, gave the least variations between M1 and M3 comparison for pair (3,6) and pair (4,5). In summary, cable 1 presented the best resilience to the coiling tests as it gave the least variations for the impedance profiles comparison between M1 and M2 for all pairs of the cable. Cable 1 also gave the least variations between M1 and M3 for pair (1,2) and pair (7,8).

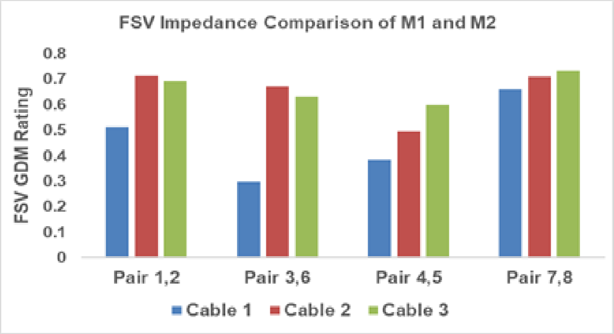

Fig. 14: Comparison of M1 and M2 measurements for the three cables using the FSV

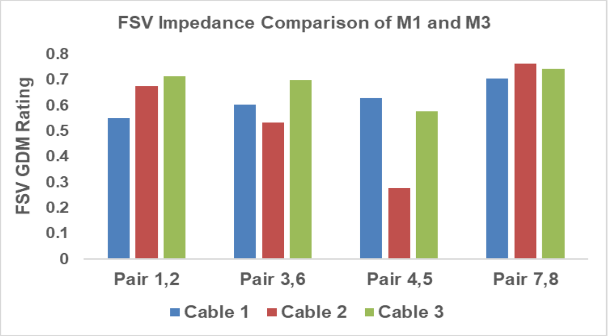

Fig. 15: Comparison of M1 and M3 measurements for the three cables using the FSV

4 CONCLUSION AND RECOMMENDATION

This paper has presented a method of performing an objective quantification of the effects of coiling on augmented cable impedance profiles across their lengths. This is to determine the resilience of the augmented cables to the coiling stress anticipated during installation. The FSV GDM results show that cable 1 gave the best resilience to the coiling stress tests as it presented the least variations between impedance profiles M1 and M2 for all four pairs. It also gave the least variations between impedance profiles M1 and M3 for pair (1,2) and pair (7,8). However, none of the impedances of Cat 6a examined exceeded the standard limits. Cable engineers can use the method presented in this paper to analyze the effect of coiling on the impedance profiles of augmented cables across the length which can reveal their physical integrity and aid fault location. The method is recommended when cable engineers need to make objective decisions and can be extended to evaluate other parameters. Future work can examine the coiling effect on the foiled, shielded Cat 6a cables. This will help study

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how the shielding of cables affects the impact of coiling on them.

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