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Quantitative Grading of Spun Yarns for Appearance

Yong K. KIM[a,*], Kenneth D. LANGLEY[a], Filiz AVSAR[b]

[a]*Department of Textile Sciences, University of Massachusetts Dartmouth*
North Dartmouth, MA 02747 U.S.A.
[b]*Lawson-Hemphill, Central Falls, RI 02863 U.S.A.*

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Abstract

The general appearance of a yarn is one of the primary qualities affecting its commercial value. The method of grading spun yarns by subjective visual examination has long been recognized as a practical quality assessment tool in yarn manufacturing and fabric forming industries.

In this paper, we want to report an objective and quantitative method for grading spun yarn appearance derived from optical yarn diameter measurements. Our study found that quantitative yarn characteristics derived from the optical yarn diameter measurement are determining factors for a human vision system to differentiate a good yarn from a bad one in terms of appearance. These characteristics are the optical yarn diameter, the yarn diameter CV%, thick place size, thin place size, nep size and yarn diameter distribution. We obtained a robust numerical metric (objective discriminatory appearance index) for yarn appearance grade, which is a linear combination of the numerical characteristics derived from the optical yarn diameter data of the USDA graded Ne 20 (29.5 Tex) Grade A, B, C and D yarns described in ASTM D2255−90.

Key Words: Yarn appearance, Optical yarn diameter, Yarn grade, Objective yarn grading system

1. Introduction

The method of grading spun yarns by visual examination has long been recognized as a practical quality assessment tool in the yarn manufacturing and fabric forming industries. The general appearance of the yarn is one of the primary qualities affecting its commercial value, as this characteristic influences the character of the end product. [1]

Yarn uniformity is generally assessed with evenness testers. The quantitative statistical parameters obtained from the instruments to describe irregularity are not simply related to the yarn quality or its salability. Overall expression for appearance quality of yarn cannot be expressed as a simple function of CV of yarn unevenness and the number of imperfections. [2]

Kazama observed that appearance as perceived by the naked eye is influenced not by the size of such variations, but by the character of the area, which deviates from the mean diameter. He defined over level ratio (OLR) as a criterion to define the perceived yarn appearance unevenness. OLR is defined as the ratio of an uneven segment length exceeding a diameter level to the total yarn length tested. Kazama reported that the appearance of the OLR curves depends on the type of unevenness. [3, 4, 5]

Typically yarn appearance quality is assessed by visually comparing the test yarn with the available appearance standards. The most widely used standard for grading yarns for appearance is ASTM D 2255−90, Standard Test Method for Grading Spun Yarns for Appearance.

Table 1 Summary of the Yarn Appearance Parameters.

Parameters	Definition
Yarn Diameter	The average optical yarn diameter value.
Yarn Diameter CV%	Coefficient of variation of the diameter.
Diameter Density Function	Criterion that determines the percent of the measured yarn diameter values that lie between −40% and +40% of the measured Grade A yarn diameter.
Thick Place Size	Thick place diameter (+50% and +100% of Grade A diameter), alfa-thick and the duration.
Thin Place Size	Thin place diameter (-40% of Grade A diameter), alfa-thin and the duration.
Nep Size	Neps diameter (+200% and +400% of Grade A diameter), alfa-neps and the duration.

* Corresponding author: E-mail: ykim@umassd.edu, Fax: +1−508−999−8452

Yarn specimens wound on inspection boards are compared with photographs of specimens representing the appearance grades. [6]

There are inherent difficulties in quantifying visual perception of yarn quality due to the subjective nature of the assessment. This study aims to understand and quantify the yarn characteristics that trigger the human vision system to differentiate a good yarn from a bad one in terms of appearance. The parameters shown in Table 1 will be used to establish an objective and quantitative method for grading spun yarn appearance. [7]

2. Experimental Procedures

2. 1 Materials

This study used 29.5 Tex (Ne 20) Grade A, Grade B, Grade C and Grade D ring spun yarns supplied and graded by the United States Department of Agriculture Experimental Station, Clemson, South Carolina. There were 10 bobbins from each grade. An approximately 10–meter long yarn leader was tied to beginning end of yarn on each test bobbin to determine the exact starting point of yarn diameter acquisition.

2. 2 Procedures: Optical Yarn Diameter Measurement

The optical yarn diameter data were acquired for all the bobbins with a Electronic Inspection Board (manufactured by Lawson-Hemphill Inc., Central Falls, RI), which consists of the Constant Tension Transport (CTT) with linear charged coupled device (CCD) video camera attachment. The yarns were tested under 15 g of input tension. The CCD camera has a resolution of 1×2048 pixels. The scanning rate of the camera is constant which allows for measuring the diameter of approximately 0.5 mm of yarn at the test speed of 100 m/min.

2. 3 Yarn Inspection Board Preparation

The yarn, after the optical yarn diameter was measured, was collected and wound on a tube with Precision Lab Winder (manufactured by Lawson-Hemphill Inc., Central Falls, RI). To prepare the yarns for visual inspection as per ASTM D 2255–90, one bobbin from Grade B and one bobbin from Grade C, measured and collected in the manner described above, were wrapped around the 140 by 250 mm (5.5 by 9.5 in.) inspection boards (IBs) at even intervals (spacing 8.3 threads per cm) with the IB winder (manufactured by Alfred Suter Co., New York, NY).

2. 4 Data Reduction and Analysis

The yarn diameter characteristics of 100% Cotton Grade A, B, C and D Yarns were analyzed, using one-way descriptive statistics.

In addition, Thick Places, Thin Places and Neps (TTN) Characteristics were studied. There was no need to prepare IBs of Grade A and Grade D yarns for visual and quantitative characterization of TTNs. This is because of the clear visual differentiation of Grade A from Grade B and Grade C from Grade D. Thus, one IB from Grade B and one IB from Grade C were prepared in a manner described above. Thick places, thin places and neps (TTNs) were identified and marked. The average diameter and the duration length of these TTNs were obtained from the respective optical yarn diameter data files.

Finally, the diameter distribution function along the yarn length was calculated, using the average yarn diameter obtained from Grade A, B, C and D yarns. These distributions were then compared with the ASTM definition of Grade A, B, C and D yarns.

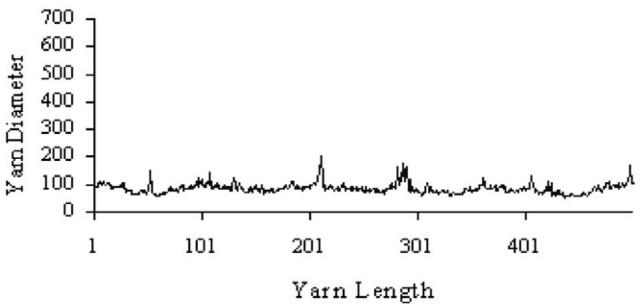
3. Results and Discussion

3. 1 Optical Yarn Diameter Characteristics

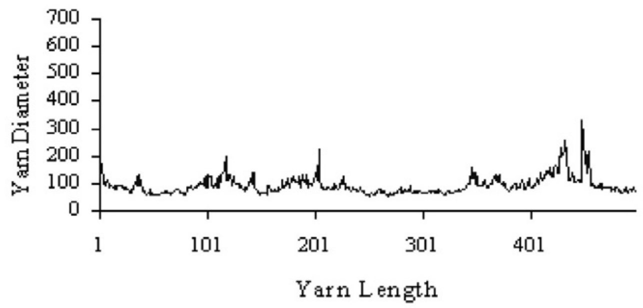
Using an optical measurement system, we acquired the yarn diameter data of Ne 20 Grade A, B, C and D bobbins. Each bobbin was tested for 92.664 meters (185328 diameter readings at sampling rate of 0.5 mm). Complete data sets (including the yarn leader diameter data) were saved in ASCII format for future reference. To determine the diameter characteristics, five bobbins from each grade were randomly selected from the data set. Table 2 provides the summary of the diameter characteristics for Grade A, B, C and D yarns. For Grade A, ten bobbins were measured to establish reference yarn diameter for the yarn group studied. The table shows that the yarn diameter and the CV% of yarn diameter increase as the yarn grade becomes lower, even though the yarns were of the same nominal yarn count. This is in accordance with yarn appearance descriptions in ASTM D 2255–90.

Table 2 Yarn Diameter Characteristics of Ne 20 (29.5 Tex) Grade A, B, C and D.

Grade	Number of Bobbin Tested	Grand Average Yarn Diameter (x 3.25 μm)	Average Std. Dev.	Mean CV%
A	10	68.4	9.32	13.62
B	5	79.9	15.97	19.99
C	5	80.1	19.61	24.47
D	5	97.9	31.94	32.54



(a) USDA Grade A, Ne 20



(b) USDA Grade D, Ne 20

Fig. 1 Optical yarn diameter profiles. See text for units of length and diameter.

Figure 1 shows the optical yarn diameter profiles. Each graph represents the 0.25 meter profile of a randomly selected bobbin from Ne 20 Grade A and D. These graphs show the yarn diameters for 500 consecutive 0.5 mm segments of yarn. Each diameter unit is equal to 3.25 μm. Each length unit refers to 0.5 mm of yarn. As the yarn grade deteriorates, the yarn diameter profiles become rougher as the spikes and peaks occur more frequently due to the changes in the yarn diameter.

3. 2 The Thick Place, Thin Place, and Neps Analysis

After measuring the yarn optical diameter (OD), the yarns were collected and wrapped on inspection boards as specified in ASTM D 2255–90. Two boards from Grade B and Grade C were randomly selected. These boards were visually analyzed under daylight-fluorescent lamp for the thick places, thin places and neps.

It was found from the visual inspection of the IBs that the discriminatory yarn diameter level that causes the human eye to distinguish a thick place from even area is +50%. We derived the thick place size and duration from the yarn diameter data files at levels of +50% and +100% of Grade A average yarn diameter (AD), respectively.

Similarly, thin place size and duration were determined from the optical yarn diameter data at the level of −40% of Grade A average yarn diameter.

The discriminatory yarn diameter level that causes the human eye to distinguish neps was determined to start at +200% of Grade A average yarn diameter. We chose two nep levels of +200% and +400%. The number of times the yarn diameter crossed over the neps diameter value and its duration were calculated from the data file.

3. 3 Diameter Distribution (OLR Curve)

OLR is defined as the ratio of deviation from the mean number of fibers or yarn diameter. For example, the ratio of the number of fibers which exceed by 20% the mean number of fibers in a cross section is calculated as $(L_1 + L_2) / L$ (Figure 2).

The over level ratio (OLR) defined by Kazama was used to determine the diameter distribution along the yarn length for each grade, using the average diameter of Grade A yarns as the zero level for all the grades (Figure 3).

Figure 3 shows that, in the case of Grade A bobbins, approximately 18% of the yarn segments have cross sections

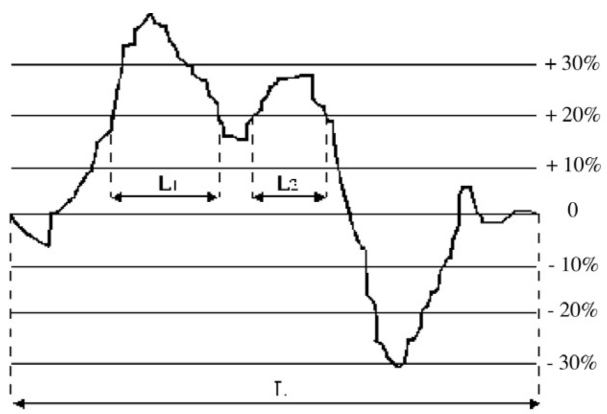


Fig. 2 Over level ratio at +20 % (1.2 times of average yarn diameter).

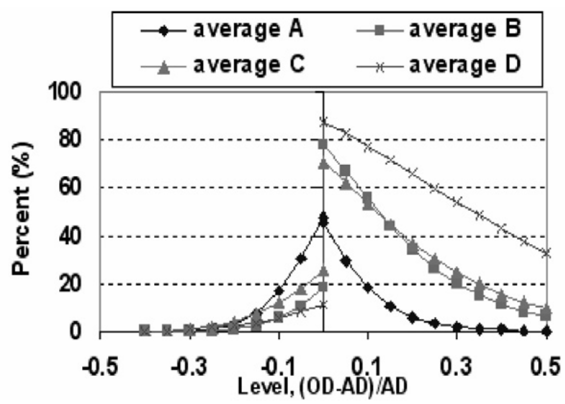


Fig. 3 Yarn diameter distribution (OLR) curves. Each grade curve represents five bobbin average values at the yarn diameter levels.

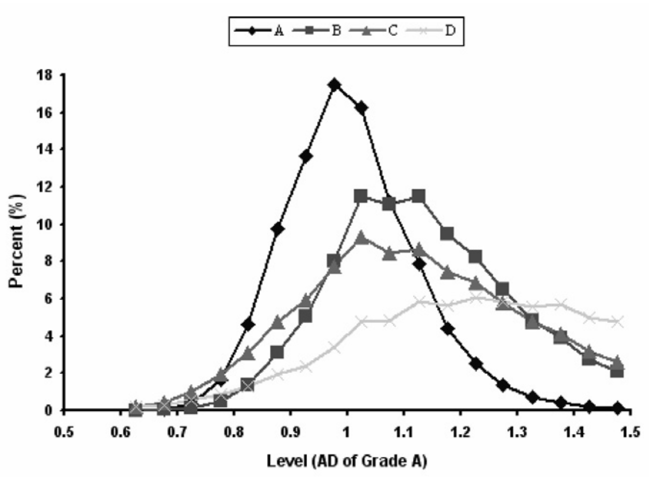


Fig. 4 Yarn diameter density function.

containing greater than 10% more fibers than the average for the yarn. An almost equal number of yarn segments have cross sections containing 10% fewer fibers than the average. It is observed, however, that the yarn diameter distribution changes significantly from being symmetrically distributed around its mean for Grade A, to more weight toward thicker diameter levels, as the yarn grade becomes lower.

The yarn diameter density function, as seen in Figure 4 shows the absolute percentage of yarn segments containing given OLR levels, was derived from the above. The average diameter of Grade A yarns was used as the zero level for all grades (Method I). This shows that Grade A has a symmetric diameter density distribution, while Grade B, C and D diameter density functions show shifts towards the right. For comparison, a second method was used in which the average diameter of each grade was used as the zero level of its respective grade (Method II). Compared with the results obtained with Method I, the Grade B, C, and D diameter distributions shifted towards the left in this case. In general, the results with Method II had poor agreement with visual assessment to inspection boards from the collected samples described in section 2.3. Thus, we used the percentage of the measured optical yarn diameter values that lies between –40% and +40% of the measured Grade A yarn diameter to quantify descriptions of the ASTM criteria numerically.

3.4 Development of Objective and Quantitative Yarn Grading System

In order to develop an objective and quantitative yarn grading method, it was required that the parameters that influenced the human perception in assigning appearance grade to a yarn be determined.

3.4.1 Determination of Yarn Appearance Parameters

The USDA graded test yarns were wrapped on the inspection boards and visually analyzed under the guidelines of ASTM D 2255–90 to determine the parameters that contribute to the yarn appearance and trigger human brain to assign a certain grade to a yarn. These parameters are as follows:

1. Yarn Diameter (*yd*): This is average yarn diameter value. ASTM D 2255–90 states that as the yarn grade gets progressively lower, the normal yarn diameter may become greater for a given yarn count.

2. Yarn Diameter CV% (*cv*): This is the coefficient of variation in yarn diameter. ASTM D 2255–90 states that as the yarn grade gets progressively lower, the overall yarn appearance becomes rougher.

3. Diameter Density Function-Method I: This is the criterion that determines the percent of the measured optical yarn diameter values between –40% and +40% of the measured Grade A yarn diameter. ASTM D 2255–90 states that Grade A has the best yarn appearance. The amount of deviation from the Grade A diameter distribution may be an indication of a worse grade.

4. Thick Place Size (*tk*): This is a combination of the following: The first is Discriminatory Yarn Diameter Level that causes human eye to distinguish a thick place. Two thick place levels were selected: +50% and +100% of the Grade A average yarn diameter. The second is the number of times the yarn diameter crosses over the thick place diameter value. This will be referred as Alfa-Thick. The third is how long the yarn diameter stayed above the thick place diameter value along the test length. This will be referred as Duration.

5. Thin Place Size (*tn*) : This is a combination of the following: The first is Discriminatory Yarn Diameter Level that causes human eye to distinguish a thin place. One level was selected: –40% of Grade A average yarn diameter. The second is the number of times the yarn diameter crosses under the thin place diameter value. This will be referred as Alfa-Thin. The third is how long the yarn diameter stayed under the thin place diameter value along the test length. This will be referred as Duration.

6. Neps Size (*n*): This is a combination of the following: The first is the Discriminatory Yarn Diameter Level which causes human eye to distinguish neps. Two neps levels were selected: +200% and +400% of the Grade A average yarn diameter. The second is the number of times the yarn diameter crosses over the neps diameter value. This will be referred as Alfa-Neps. The third is how long the yarn diameter stayed above the neps diameter value along the test length. This will be referred as "Duration".

3.4.2 The Yarn Appearance Matrix

The USDA graded test bobbins were tested on EIB and the prepared Inspection Boards were visually analyzed under the guidelines of the ASTM D 2255–90 to determine the six parameters that contribute to the yarn appearance and trigger human brain to assign a certain grade to a yarn. These parameters formed the normalized yarn appearance matrix shown in Table 3.

For normalization, raw data were converted in approximately 0 to 100 scale except diameter density. The diameter density is the percent of measured optical yarn diameter values lie between −40% and +40% of the reference Grade A yarn diameter. A statistical analysis, using the reference diameters and CV%, shows that the raw diameter density of Grade A, for example, is 92.6%, while that of Grade D is 55.5%. It was determined that this scale should be reversed to have the matching trends of other parameter characteristics; "the lower the better."

Statistical estimation of 95% confidence intervals for these parameters for individual grade shows that some parameters have clearly separated intervals for different grades. However, others have overlapping intervals for different grades. To develop a discriminatory index function for an objective grading system from the normalized parameters, weights for the parameters are assigned according to their importance to the grade in accordance with the assessment criteria of ASTM Appearance Grades.

Table 3 Yarn Appearance Parameter Matrix.

Bobbin	Yarn Dia.	CV%	Dia. Density	+50% Thick Place	+100% Thick Place	+200% Neps	+400% Neps	-40% Thin Place
A1	69.96	33.95	57.17	0.029	0.0020	0.0004	0.00	0.00
A2	67.76	34.65	56.43	0.015	0.0027	0.0085	0.01	0.00
A5	70.10	33.50	57.20	0.036	0.0024	0.0018	0.00	0.00
A7	68.33	32.20	56.87	0.015	0.0007	0.0005	0.00	0.00
A10	67.26	35.53	57.24	0.026	0.0025	0.0002	0.00	0.00
B1	79.61	51.50	65.48	7.62	0.4772	0.0667	0.28	0.00
B2	79.03	48.73	63.30	5.30	0.2954	0.1003	0.02	0.00
B5	80.74	49.43	64.82	7.67	0.5599	0.1188	0.09	0.00
B6	81.27	51.23	67.28	10.99	0.7688	0.0682	0.04	0.00
B10	78.68	49.05	63.87	5.56	0.2516	0.0391	0.01	0.00
C1	79.91	61.85	70.04	14.01	1.70	0.16	0.04	8.27
C2	80.45	65.58	71.62	16.70	2.75	0.31	0.12	66.06
C5	80.12	59.45	69.28	12.96	1.24	0.10	0.30	1.90
C7	80.68	58.70	69.97	14.36	1.36	0.23	0.12	5.40
C10	79.47	60.30	68.98	12.80	1.54	0.11	0.00	17.33
D1	101.23	92.30	100.74	94.35	99.95	112.26	105.0	95.56
D4	96.43	74.68	96.13	83.34	48.37	14.20	4.05	12.83
D5	95.93	73.38	95.22	80.05	46.10	11.36	0.49	27.52
D9	96.53	74.50	96.31	83.82	52.89	12.24	1.50	18.04
D10	99.71	91.88	98.28	84.46	90.99	101.32	78.60	83.20

Table 4 Weighting Values for Appearance Parameters.

Appearance Parameter		Assigned Weighting Values
Average Diameter	**(ad)**	**0.05**
Diameter CV%	**(cv)**	**0.30**
Adjusted Diameter Density	**(add)**	**0.20**
+50% Thick Place	**(50tk)**	**0.15**
+100% Thick Place	**(100tk)**	**0.10**
+200% Neps	**(200n)**	**0.10**
+400% Neps	**(400n)**	**0.05**
-40% Thin Place	**(40tn)**	**0.05**

Table 4 shows the weighting value of each parameter we used for this study. Great weight was assigned to those parameters associated with the contrast between thick and thin areas: Diameter CV%, Adjusted Diameter Density, +50% and +100% Thick Places, and –40% Thin Places. +200% and +400% Neps was given a lower weight in that it is mostly important in distinguishing between Grades A and B.

3. 5 Linear Discriminatory Function for an Objective Yarn Appearance Grading System

The discriminatory linear function is derived by linear combinations of weighted yarn appearance parameters according to significance:

$$\begin{aligned} DI = & 0.05*(ad) + 0.30*(\mathrm{cv}) + 0.20*(add) + 0.15*(50tk) \\ & + 0.10*(100tk) + 0.10*(200n) + 0.05*(400n) \\ & + 0.05*(40tn) \end{aligned} \quad (1)$$

The discriminatory index, DI, was calculated from the linear function for the bobbins listed in Table 3 using the assigned weight values. The descriptive statistics of DI for Grade A, B, C and D set-up bobbins are given in Table 5, which shows that the discriminatory index values increased as the yarn grade became lower.

It is observed that the average and standard deviation of the Discriminatory Index increased as the yarn grade deteriorated. This agrees with ASTM D 2255–90. Grade A has the lowest Discriminatory Index average and standard

Table 5 Discriminatory Index for USDA Yarn Grade.

Discriminatory Index Statistics					95% confidence interval for mean	
sample	grade	mean	stdev	std. error	Lower limit	upper limit
N=5	Grade A	25.02	0.37	0.16	24.70	25.35
N=5	Grade B	33.15	1.05	0.47	32.23	34.08
N=5	Grade C	39.66	2.56	1.14	37.42	41.91
N=5	Grade D	77.52	16.13	7.22	63.38	91.66

deviation. Grade A is also clearly separable from its nearest grade, which is Grade B. Although the Grade C index lower limit is close to the Grade B index upper limit, the difference between the upper and lower limits is greater for Grade C yarns than for Grade B yarns. This may be caused by the higher contrast between the thick and thin places in Grade C yarns as stated in the ASTM D 2255–90. Grade D has the highest index average and standard deviation. This grade is clearly separable from its nearest grade, which is Grade C.

3.6 Verification of the Linear Discriminatory Index

To verify the applicability of the Linear Discriminatory Index, the test bobbins were randomly selected from the bobbins of known grade acquired from the USDA experimental station. Bobbin 9 of Grade A, B, C and Bobbin 2 of Grade D were selected for the trial. Table 6 shows the normalized yarn appearance matrices and DIs for these test bobbins, respectively.

Table 6 Discriminatory Indices for Verification Tests.

	Selected Bobbins (95% Confidence Interval)		**Test Bobbins**
Yarn Grade	**Disc. Index Lower Limit**	**Disc. Index Upper Limit**	**Test Index I**
Grade A	**24.70**	**25.35**	**24.81 (A9)**
Grade B	**32.23**	**34.08**	**32.99 (B9)**
Grade C	**37.42**	**41.91**	**37.52 (C9)**
Grade D	**63.38**	**91.66**	**68.71 (D2)**

The grades determined by the DI agreed well with USDA appearance grading for all the tested bobbins. Thus, the developed discriminatory index can be used for an objective yarn appearance grading system.

4. Conclusions

This study developed a methodology to objectively quantify the same yarn characteristics that cause the human vision system to differentiate a good yarn from a bad yarn during.

The quantified parameters derived from the optical yarn diameter data set were used to delineate an objective discriminatory function for spun yarn appearance grading system. These yarn appearance parameters were determined to be optical yarn diameter, yarn diameter, CV%, thick place size, thin place size, nep size and diameter density function.

By using the linear combinations of the weighted yarn appearance parameters, a Discriminatory Index (DI) was developed to objectively grade yarns for appearance. One bobbin from each yarn grade set was randomly selected to test the Discriminatory Index. It was observed that the discriminatory indices of the test yarns predicted the USDA grading, as did the visual inspection results.

We only used 100% cotton Ne 20 yarns. The developed approach will be applied for different yarn linear densities such as Ne 10, Ne 30, and Ne 40 in near future.

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