Automatic Design and Correction of Ceramic Colours

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Problem Statement

This research focuses on producing glaze recipes which match a desired ceramic colour and correcting/fine tuning a ceramic colour. Currently the process is largely based on human operators.

Aim

Investigate two key problems in the ceramic industry
1. Reproduction of a desired colour from pigments: This process may currently take around 6 months and often over 300 experiments.
2. Correction of established ceramic colours: When a recipe for producing a desired ceramic colour is known, adjustments have to be made on a daily bases, due to the variability of the process. This involves heavy cost and consumes a lot of time.

Objectives

- Investigate the fundamental notions of colour theory (Pantone, CIE, RGB)
- Devise a coherent system to collect experimental data from the company in a standard format
- Implement mathematical models to improve the accuracy of the colour prediction and correction processes

Methods

- Software: R, MATLAB
- DATA cleaning and merging
- Used colorimeter (cost-effective) to measure the colour differences between the sample and standard (L, a, b)
- Used Commission Internationale de lEclairage L,a,b Coordinates (three-dimensional Lab colour space) to identify colour differences where L* indicating lightness, a* is the red/green coordinate, and b* is the yellow/blue coordinate. (Fig. 1)
- Implementation of the Taguchi Method using MATLAB
- Orthogonal arrays, ANOVA tests & Graphical user interface (GUI)
- Exporting Taguchi methods' results to Excel file
- Regression to predict L, a, b using data about pigments
- Cross-validation techniques to find out how good the model is

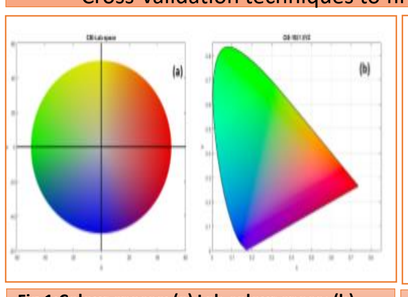


Fig.1:Colour spaces: (a) Lab colour space; (b) CIE-1931 XYZ.

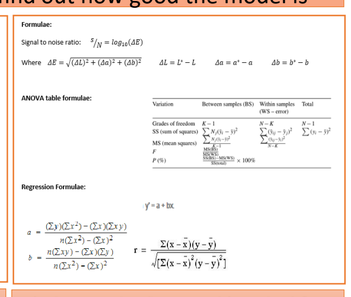
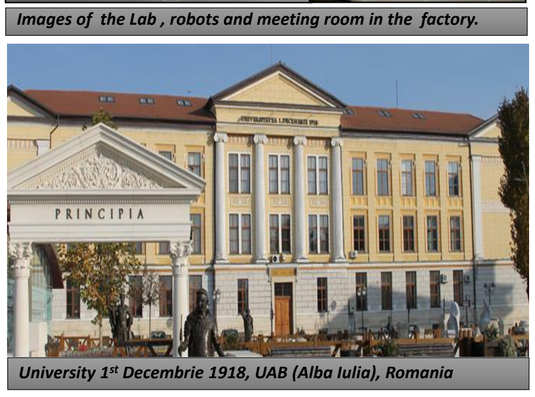


Fig.2: Formulae for Taguchi method & R.

Citadel in Alba Iulia (Romania).

The research was supported IPEC Alba Iulia (Romania), one of the world leading ceramics producers (1% of world output)

Images of the Lab , robots and meeting room in the factory.

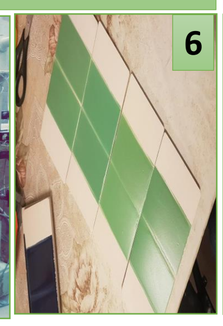


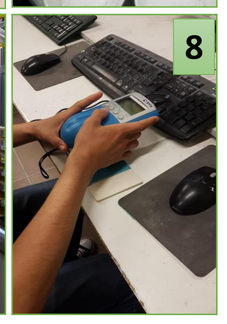
University 1st Decembrie 1918, UAB (Alba Iulia), Romania

Current Industrial Process

Key steps involved in making coloured ceramics

1. Machine producing the glaze
2. Weighing machine to weigh glaze and pigments concentration
3. Mixer to mix matte or glossy glaze, pigment & water (various quantities)
4. Mixtures poured into glasses with different pigment concentrations
5. Machine to make biscuits (tiles)
6. Biscuits are dipped into glaze mixtures (matte or glossy, containing various concentrations of pigments
7. Biscuits (Tiles) are fired in the oven for 6 hours
8. Colorimeter is used to measure the L, a, b of each tile after step 8.





Predictive analysis (L, a, b)

Regression and Cross Validation

Data Preparation
- Collecting and Reading data from different files and merging into one
- Structuring, organizing data for data visualization
- Ensuring data is valid, complete, uniform, consistent and accurate

Prediction of L, a, b using Multiple Linear Regression Model
- To explain the relationship between L, a, b (outcome variables) and the pigments (independent variables).
- To figure out which variables in particular are significant predictors of the outcome variable
- To predict L, a, b

Checks: Multi-co- linearity, assumptions, correlations between independent variables and also between independent and dependent, confidence-intervals etc.

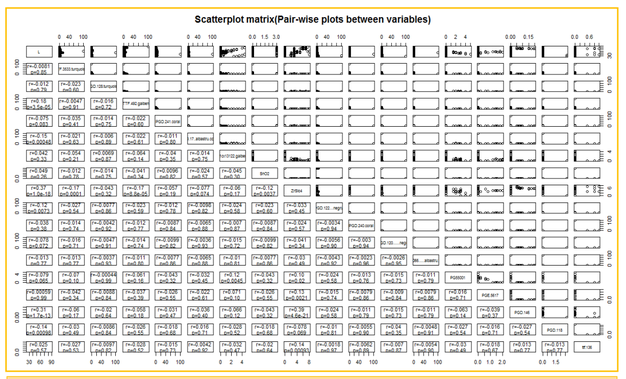


Fig. 9 : Scatter-plot matrix to show the linear relationship between variables.

```
> model1<-lm(L ~ ., data = selectedData)
> summary(model1)

Call:
lm(formula = L ~ ., data = selectedData)

Residuals:
    Min      1Q  Median      3Q     Max
-51.85 -14.73    0.12   10.42   40.26

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                46.8372     1.0505   44.59  < 2e-16 ***
TTF.3533.turquoise          0.1951     0.1444    1.35   0.1772
PGD.128.turquoise           0.0389     0.1556    0.25   0.8028
TTF.492.galben              0.9318     0.1451    6.42 3.0e-10 ***
PGD.241.coral              -0.2034     0.1536   -1.32   0.1859
PGD.17..albastru.cobalt    -0.4624     0.1555   -2.97   0.0031 **
Xlcx13122.galben            1.2033     1.1532    2.78   0.0057 **
SnO2                        4.0240     1.3857    2.90   0.0038 **
Zr5io4                      2.6669     0.3180    8.39 4.7e-16 ***
PGD.122....negru            0.4148     0.1551   -2.68   0.0077 **
PGD.240.coral              -0.1108     0.1567   -0.71   0.4798
PGD.120.......negru        -0.2239     0.1564   -1.43   0.1529
PGD.066......albastru.verzui  0.0093     0.1567    0.06   0.9527
PG5001                     -2.9749     1.0557   -2.82   0.0050 **
PGE.5617                   -3.0688     2.8749   -1.07   0.2863
PGD.146                   113.3875    25.7146    4.41 1.3e-05 ***
PGD.118                    -6.3365     2.3964   -2.64   0.0084 **
ttf.136                    -4.3084     7.0994   -0.61   0.5442
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 15.6 on 520 degrees of freedom
Multiple R-squared:  0.299,     Adjusted R-squared:  0.276
F-statistic:    13 on 17 and 520 DF,  p-value: <2e-16
```

Fig. 10: Output shows Regression coefficients, p- and F values

Cross-validation

- To check how accurate the predictive model would perform in practice
- To measurie the predictive performance of above statistical models
- Techniques which are used include hold-out, leave-one-out and k-fold cross-validation.

Implementation of Taguchi Method

Taguchi Method

- Robust design technique developed by Japanese statistician Genichi Taguchi.
- Implemented here to investigate how different factors affect the mean and variance of a process performance characteristic that defines how well the process is functioning.
- Based on orthogonal arrays which are utilised to organise the factors affecting the process and the levels at which they should be varied.
- Tests pairs of combinations instead of testing all possible combinations like the factorial design.
- Allows us to study the effect of individual factors on the performance and to determine which factors most influence the product quality with a minimum amount of experimentation and which ones have less, particularly important in case of formulation of colours, thus saving time and resources.

Orthogonal Arrays

- Study the entire factor space with only a small number of experiments
- Special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output.
- Selected by the number of variables and the number of levels due to the variability of the process.
- Commonly used standard orthogonal arrays are L4, L8 with level 2 t o design experiments.

1	1	2
1	2	1
2	1	1
2	2	2

Fig. 3: Orthogonal array for L4

1	1	1	2	2	2	2
1	1	2	1	2	1	1
1	2	1	1	1	2	1
1	2	2	2	1	1	2
2	1	1	1	1	1	2
2	1	2	2	1	2	1
2	2	1	2	2	1	1
2	2	2	1	2	2	2

Fig. 4: Orthogonal array for L8.

Signal-to-noise Ratio (S/N)

- Quantify variation between the target and obtained values, Taguchi uses signal-to-noise ratio (S/N ratio). As the obtained colour should be as close as possible to the standard colour (for S/N "lower is better")

N-way ANOVA

- Helps choosing the pigments with significant influence on the desired colour.
- If the effect of one pigment is significant, its **level should be the same as in the best combination of factors**, but if it is not significant, its level should be the lowest one to reduce costs.

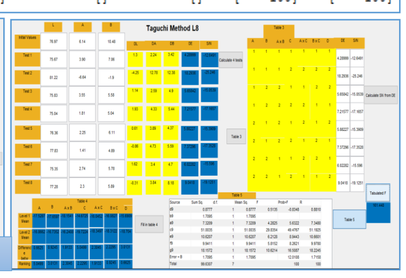
'Source'	'Sum Sq.'	'd.f.'	'Mean Sq.'	'F'	'Prob>F'	'R'
'A'	[2.3445]	[1]	[2.3445]	[32.0489]	[2.6418]	[2.7268]
'B'	[0.0732]	[1]	[0.0732]	[]	[]	[]
'AB'	[20.0553]	[1]	[20.0553]	[274.1557]	[23.2411]	[23.3262]
'C'	[26.2900]	[1]	[26.2900]	[359.3825]	[30.4925]	[30.5776]
'AC'	[1.8544]	[1]	[1.8544]	[25.3489]	[2.0717]	[2.1568]
'BC'	[8.4382]	[1]	[8.4382]	[115.3504]	[9.7293]	[9.8144]
'D'	[26.9224]	[1]	[26.9224]	[368.0279]	[31.2281]	[31.3131]
'Error + B'	[0.0732]	[1]	[0.0732]	[]	[0.5956]	[0.0851]
'Total'	[85.9779]	[7]	[]	[]	[100]	[100]

Figures 5 & 6: ANOVA tables for Taguchi (T4 ^ and T8)

'Source'	'Sum Sq.'	'd.f.'	'Mean Sq.'	'F'	'Prob>F'	'R'
'D'	[0.8603]	[1]	[0.8603]	[3.1400]	[2.1658]	[3.1778]
'B'	[0.2740]	[1]	[0.2740]	[]	[]	[]
'A'	[25.9392]	[1]	[25.9392]	[94.6685]	[94.7981]	[95.8101]
'Error + B'	[0.2740]	[1]	[0.2740]	[]	[3.0362]	[1.0121]
'Total'	[27.0735]	[3]	[]	[]	[100]	[100]

Graphical user interface (GUI):

- Built using MATLAB software, so it would be easier for the non-programmer users to use the Taguchi method for their experiments.



Figures 7 & 8: ANOVA tables for Taguchi (T4 & T8)

Summary

- Investigated the fundamental notions of colour theory (Pantone, CIE, RGB)
- Reviewed key literature in the area of ceramics colouring using pigments
- Collected data from the company in a standard, coherent format
- Analysed the data using Mathematical and Computational tools
- Suggested and tested predictions to be tested in the factory laboratory
- Contributed to a research article to be published in an international journal
- Used mathematical techniques (Taguchi method, ANOVA, etc) and software to predict L, a, b and used different cross validation techniques to determine how good the model is.
- Prepared a presentation for the URSS conference at the University of Derby

Future work

To investigate:
- Further use of data mining and machine learning techniques to solve the problem of automatic design and correction of ceramic colours.
- Deep learning techniques.

Acknowledgement

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References

[1] Dr. A. Birlutiu. 2018. *Evaluarea modelelo*. [ONLINE] Available at: http://adrianabirlutiu.uab.ro/cursuri/MIRF/2018curs5.pdf. [Accessed 1 September 2018].
[2] Edwin de Jonge, Mark van der Loo. 2013. *An introduction to data cleaning with R*. [ONLINE] Available at: https://cran.r-project.org/doc/contrib/de_Jonge+van_der_Loo-Introduction_to_data_cleaning_with_R.pdf. [Accessed 15 August 2018].
[3] G. Casella, S. Fienberg, I. Olkin. 2013. *Springer Texts in Statistics*. [ONLINE] Available at: http://www-bcf.usc.edu/~gareth/ISL/ISLR%20Seventh%20Printing.pdf. [Accessed 1 August 2018].
[4] Ovidiu Bagdasar, Ioan-Lucian Popa, Minsi Chen, Adriana Birlutiu. 2017. *Qualitative Case Study Methodology: Automatic Design and Correction of Ceramic Colors*. [ONLINE] Available at: http://adrianabirlutiu.uab.ro/pubs/conf/2017sinaia.pdf. [Accessed 10 July 2018].
[5] A.O. Castela a, A.T. Fonseca b, P.Q. Mantas c. 2010. *Development of coloured glazes for tile applications using Taguchi's method*. [ONLINE] Available at: https://www.sciencedirect.com/science/article/pii/S0955221910002463. [Accessed 16 August 2018].

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