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A new approach to accuracy assessment of land-cover classification in UAV-based Remote Sensing

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SUMMARY

A new approach to accuracy assessment in land-cover classification using Weighted confusion matrix was considered in this work. It were shown main advantages of Weighted confusion matrix and its accuracy coefficients, such as: Overall accuracy, User's accuracy, Producer's accuracy and Weighted average of the weights for each class. It was noted, that Weighted confusion matrix gives different weights for different mistakes of classification. This property of Weighted confusion matrix is very important, when not all mistakes are equally serious. It was noted, that Weighted confusion matrix gives more precise accuracy assessment of image classification than Confusion matrix. It was also considered an numerical example of calculation of accuracy coefficients of Weighted confusion matrix. This proposed new approach to accuracy assessment of image classification in UAV-based Remote Sensing can be applied in forest classification, environmental monitoring, exploring for oil and gas, numerous agricultural and ecological tasks

Introduction. Nowadays with large capacity for development and improvement of unmanned aerial vehicles (UAV), we achieve images with a very high resolution and sufficient precision. These images can be applied in forest monitoring, vegetation classification, oil and gas industry, building of thematic maps (Figure 1). That's why the accuracy assessment is necessary to evaluate the quality of maps before they are used for further scientific investigations (Alpert and Alpert, 2020). This paper describes the method for accuracy assessment in land-cover classification using Weighted confusion matrix and accuracy coefficients. It is shown, that Weighted confusion matrix gives more precise accuracy assessment of image classification than Confusion matrix (Congalton, 1991).

Figure 1 *Most important practical tasks, that can apply proposed approaches to accuracy assessment: monitoring, classification and assessment of different territories*

Confusion matrix and accuracy coefficients.

Let $$X = \begin{pmatrix} x_{11} & \cdots & x_{1r} \\ \vdots & \ddots & \vdots \\ x_{r1} & \cdots & x_{rr} \end{pmatrix}$$ is a Confusion matrix, (1)

where element x_{ij} – number of test samples that actually belong to C_i and is classified into C_j, $i, j = 1, 2, ..., r$; r – number of classes (categories);

$\sum_{j=1}^{r} x_{ij} \equiv x_{i+}$ – marginal sum of i-th row; (2)

$\sum_{i=1}^{r} x_{ij} \equiv x_{+j}$ – marginal sum of j-th column; (3)

$n = \sum_{i=1}^{r} \sum_{j=1}^{r} x_{ij}$ – total number of observations. (4)

Accuracy coefficients:

1) $A_0 = \sum_{i=1}^{r} x_{ii} / n$ – Overall accuracy; (5)

2) $O_j = \dfrac{x_{jj}}{x_{+j}}$ – Producer's accuracy; (6)

3) $C_i = \dfrac{x_{ii}}{x_{i+}}$ – User's accuracy. (7)

But Confusion matrix has some disadvantages. Confusion matrix needs in large samples and can not take into account the "seriousness" ("roughness") of errors.

The Weighted confusion matrix. Weighted confusion matrix can be used, when not all classification errors and mapping mistakes are equally serious. Weighted confusion matrix gives partial credit for incorrect classification. This approach uses a Weights matrix W for Confusion matrix, that contains weights for each element in the Confusion matrix. Weighted confusion matrix takes into account the "seriousness" ("roughness") of errors of Confusion matrix (Cohen, 1968).

Weight's matrix is defined as:

$$W = \begin{pmatrix} 1 & w_{12} & \dots & w_{1r} \\ w_{21} & 1 & w_{23} & w_{2r} \\ \dots & \dots & \dots & \dots \\ w_{r1} & w_{r2} & \dots & 1 \end{pmatrix}, \qquad \begin{matrix} w_{ii} = 1, \quad \forall i; \\ w_{ij} \in [0,\dots,1], \quad \forall i \neq j. \end{matrix} \tag{8}$$

where diagonal elements must be "1", and the off-diagonals elements must be in the range [0,…,1]. Elements of the Weight's matrix (weights) are assigned by evaluator. A value "0" indicates that there is no credit for this mistake, and as the values of off-diagonal elements increase towards "1", the mistake is considered decreasingly serious. If all off-diagonal elements are "0", this reduces to the unweighted case, when all errors are equally serious. Let's note, that Weight's matrix isn't symmetric.

Accuracy coefficients of the Weighted confusion matrix:

1) $A_{0w} = \sum_{i=1}^{r} \sum_{j=1}^{r} w_{ij} \cdot p_{ij}$ – Overall accuracy, (9)

where $p_{ij} = x_{ij} / n, \ i \neq j$ – proportion of observations in i-th row and j-th column; (10)

2) $C_{iw} = \frac{1}{p_{i+}} \sum_{j=1}^{r} w_{ij} \cdot p_{ij}$ – User's accuracy, (11)

where $p_{i+} = x_{i+} / n = \sum_{j=1}^{r} p_{ij}$ – proportion of mapped data in i-th row (i-th class); (12)

3) $O_{jw} = \frac{1}{p_{+j}} \sum_{i=1}^{r} w_{ij} \cdot p_{ij}$ – Producer's accuracy, (13)

where $p_{+j} = x_{+j} / n = \sum_{i=1}^{r} p_{ij}$ – proportion of reference data in j-th column (j-th class). (14)

The statistics $\bar{w}_{+j}$ shows proportion of each class in the mapped population;

The statistics $\bar{w}_{i+}$ shows proportion of each class in the reference population.

Weighted averages are defined as:

$\bar{w}_{i+} = \sum_{j=1}^{r} w_{ij} \cdot p_{+j}$ – Weighted average for i-th row; (15)

$\bar{w}_{+j} = \sum_{i=1}^{r} w_{ij} \cdot p_{i+}$ – Weighted average for j-th column. (16)

The sums of Weighted averages ranges from [1,…,r]. Sum of weighted averages is "1" in unweighted case, and sum of Weighted averages is "r" in the case where no misclassification is important.

Examples. Consider an example, where we conduct accuracy assessment of classification of 100 test samples from 3 classes.

$n = 100, \ r = 3.$

Class A means, that sample belongs to the class "Forest";
Class B means, that sample belongs to the class "Water";
Class C means, that sample belongs to the class "Buildings".
We should calculate accuracy coefficients for Weighted confusion matrix X.

Suppose, we have such Confusion matrix: $X = \begin{pmatrix} 20 & 12 & 10 \\ 8 & 15 & 7 \\ 10 & 14 & 4 \end{pmatrix}.$

1) The marginal sum of each row is defined as:

$$\sum_{j=1}^{r} x_{ij} \equiv x_{i+};$$

$x_{1+} = 20 + 12 + 10 = 42;$
$x_{2+} = 8 + 15 + 7 = 30;$
$x_{3+} = 10 + 14 + 4 = 28.$

2) The marginal sum of each column is defined as:

$$\sum_{i=1}^{r} x_{ij} \equiv x_{+j};$$

$x_{+1} = 20 + 8 + 10 = 38;$
$x_{+2} = 12 + 15 + 14 = 41;$
$x_{+3} = 10 + 7 + 4 = 21.$

3) Then we determine the next proportions of observations in *i*-th row and *j*-th column: $p_{ij} = \frac{x_{ij}}{n}$;

$$p_{11} = \frac{20}{100} = 0,2; \quad p_{21} = \frac{8}{100} = 0,08; \quad p_{11} = \frac{10}{100} = 0,1;$$
$$p_{12} = \frac{12}{100} = 0,12; \quad p_{12} = \frac{15}{100} = 0,15; \quad p_{12} = \frac{14}{100} = 0,14;$$
$$p_{13} = \frac{10}{100} = 0,1; \quad p_{13} = \frac{7}{100} = 0,07; \quad p_{13} = \frac{4}{100} = 0,04.$$

4) The Proportions matrix P is defined as:

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix} = \begin{pmatrix} 0,2 & 0,12 & 0,1 \\ 0,08 & 0,15 & 0,07 \\ 0,1 & 0,14 & 0,04 \end{pmatrix}.$$

5) The proportion of mapped data of each row is defined as:

$p_{1+} = 0,2 + 0,12 + 0,1 = 0,42;$
$p_{2+} = 0,08 + 0,15 + 0,07 = 0,3;$
$p_{3+} = 0,1 + 0,14 + 0,04 = 0,28.$

6) The proportion of reference data of each column is defined as:

$p_{+1} = 0,2 + 0,08 + 0,1 = 0,38;$
$p_{+2} = 0,12 + 0,15 + 0,14 = 0,41$
$p_{+3} = 0,1 + 0,07 + 0,04 = 0,21.$

7) Suppose, that we have the next Weights matrix:

$$W = \begin{pmatrix} 1 & w_{12} & w_{13} \\ w_{21} & 1 & w_{23} \\ w_{31} & w_{32} & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0,75 & 1 \end{pmatrix}.$$

8) The Overall accuracy for the Weighted confusion matrix is determined as:

$$A_{0w} = \sum_{i=1}^{r} \sum_{j=1}^{r} w_{ij} \cdot p_{ij} = 0,2 \cdot 1 + 0,1 \cdot 1 + 1 \cdot 0,15 + 0,75 \cdot 0,14 + 1 \cdot 0,04 = 0,595 \approx 0,6.$$

9) The User's accuracy for each class for the Weighted confusion matrix is determined as:

$C_{1w} = \frac{1}{0,42}(0,2 \cdot 1 + 0,12 \cdot 0 + 0,1 \cdot 1) = 0,7142 \approx 0,71 -$ User's accuracy for the class "*A*"- "Forest";

$C_{2w} = \frac{1}{0,3}(0,08 \cdot 0 + 0,15 \cdot 1 + 0,07 \cdot 0) = 0,5 -$ User's accuracy for the class "*B*"- "Water";

$C_{3w} = \frac{1}{0,28}(0,1 \cdot 0 + 0,14 \cdot 0,75 + 0,04 \cdot 1) \approx 0,52 -$ User's accuracy for the class "*C*"- "Buildings".

10) The Producer's accuracy for each class for the Weighted confusion matrix is determined as:

$O_{1w} = \frac{1}{0,38}(0,2 \cdot 1 + 0,08 \cdot 0 + 0,1 \cdot 0) = 0,53 -$ Producer's accuracy for the class "*A*"- "Forest";

$O_{2w} = \frac{1}{0,41}(0,12 \cdot 0 + 0,15 \cdot 1 + 0,14 \cdot 0,75) = 0,62 -$ Producer's accuracy for the class "*B*"- "Water";

$O_{3w} = \frac{1}{0,21}(0,1\cdot 1+0,07\cdot 0+0,04\cdot 1)=0,67-$ Producer's accuracy for the class "*C*"- "Buildings".

We can make a conclusion, that Overall accuracy for the Weighted confusion matrix is 60%. Maximum value of the User's accuracy is 71% for the class "A"-"Forest", maximum value of the Producer's accuracy is 67% for the class "C"-"Buildings".

11) Weighted average of the weights for each row is defined as:

$\bar{w}_{1+}=(w_{11}\cdot p_{+1})+(w_{12}\cdot p_{+2})+(w_{13}\cdot p_{+3})=1\cdot 0,38+0\cdot 0,41+1\cdot 0,21=0,59-$proportion of the class "*A*"- "Forest" in the mapped population;

$\bar{w}_{2+}=(w_{21}\cdot p_{+1})+(w_{22}\cdot p_{+2})+(w_{23}\cdot p_{+3})=0\cdot 0,38+1\cdot 0,41+0\cdot 0,21=0,41-$proportion of the class "*B*"-"Water" in the mapped population;

$\bar{w}_{3+}=(w_{31}\cdot p_{+1})+(w_{32}\cdot p_{+2})+(w_{33}\cdot p_{+3})=0\cdot 0,38+0,75\cdot 0,41+1\cdot 0,21=0,5175-$proportion of the class "*C*"-"Buildings" in the mapped population.

12) Weighted average of the weights for each column is defined as:

$\bar{w}_{+1}=(w_{11}\cdot p_{1+})+(w_{21}\cdot p_{2+})+(w_{31}\cdot p_{3+})=1\cdot 0,42+0\cdot 0,3+0\cdot 0,28=0,42-$proportion of the class "*A*"-"Forest" in the reference population;

$\bar{w}_{+2}=(w_{12}\cdot p_{1+})+(w_{22}\cdot p_{2+})+(w_{32}\cdot p_{3+})=0\cdot 0,42+1\cdot 0,3+0,75\cdot 0,28=0,51-$proportion of the class "*B*"-"Water" in the reference population;

$\bar{w}_{+3}=(w_{13}\cdot p_{1+})+(w_{23}\cdot p_{2+})+(w_{33}\cdot p_{3+})=1\cdot 0,42+0\cdot 0,3+1\cdot 0,28=0,7-$proportion of the class "*C*"-"Buildings" in the reference population.

Conclusions. Accuracy assessment of aerospace images is one of most important and actual task in remote sensing (Popov et al., 2015). This paper describes the method for accuracy assessment in land-cover classification using Weighted confusion matrix and accuracy coefficients. Weighted confusion matrix was considered with Confusion matrix. Advantages of Weighted confusion matrix and its accuracy coefficients, such as: Overall accuracy, User's accuracy, Producer's accuracy and Weighted average of the weights for each class were considered in this work too. It was shown, that Weighted confusion matrix gives different weights for different mistakes of classification. This property of Weighted confusion matrix is very important, when not all mistakes are equally serious. It was noted, that Weighted confusion matrix gives more precise accuracy assessment of image classification than Confusion matrix. It was also considered an numerical example of calculation of accuracy coefficients of Weighted confusion matrix. This proposed new approach to accuracy assessment of image classification in UAV-based Remote Sensing can be applied in forest classification, environmental monitoring, exploring for oil and gas, numerous agricultural and ecological tasks (Alpert, 2020).

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