**表1** **特征表**

**Table 1** The characteristic of different features

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| Feature method | Local/Global | Characteristic |
| SIFT[14] | Local feature descriptor | SIFT (scale-invariant feature transform) feature is a set of interest points of some local appearance based on the object, is irrelative to the size and rotation of the image, and has a rather high tolerance of light, noise, micro-viewing angle change. |
| GIST[15] | Global feature descriptor | GIST (global feature descriptor) describes the macroscopic characteristics of the image and ignores the local characteristics of the image. |
| LBP[16] | Local feature descriptor | LBP (local binary patterns) are the operators for describing the local texture features of images in the field of machine vision. They have significant advantages such as rotational invariance and gray invariance. |
| HOG[17] | Local feature descriptor | HOG (histogram of oriented gradient) composes the features by calculating and counting the gradient histogram of the local area of the image. |
| SURF[18] | Local feature descriptor | SURF (speeded up robust features) is an improved version of SIFT, which uses Haar wavelet to approximate the gradient operation in the SIFT method, and the integral graph technique for fast computation. The computation speed of SURF is 3-7 times faster than that of SIFT. |

**表2** **核函数表**

**Table 2** Kernel functions

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| Kernel function | The formula of kernel function | Characteristic |
| Linear  kernel |  | Be suitable for orthogonally normalized data. |
| Polynomial kernel |  | Be very suitable for orthogonally normalized data. |
| Gaussian kernel |  | Be very sensitive to parameters. |
| Exponential kernel |  | A variety of gaussian kernel, adjust L2 to L1 for the distance between vectors to reduce the dependence on parameters, the scope of application is relatively narrow. |
| Laplacian kernel |  | Equivalent to the exponential kernel, less sensitivity to parameters. |
| Sigmoid  kernel |  | Come from neural networks, often be used as "activation functions". |
| Anova  kernel |  | Be suitable for multi-dimensional regression problems. |
| Histogram cross  kernel |  | Often be used for image classification, such as face recognition. |
| Quadratic rational  kernel |  | A substitute for Gaussian kernel, compared with Gaussian kernel, it takes less time and it is also very sensitive to parameters. |
| Wave kernel |  | Be used in the voice processing. |
| Logarithmic kernel |  | Usually be used for image segmentation. |
| Cauchy kernel |  | come from the Cauchy distribution, it can be applied to process high dimension data. |

图6.1-6.10是在IRMA数据集上进行的实验, 主要比较本文方法中的单特征多核方法(M1FM3KH表示HOG特征与三种核的组合)与其它对比方法在不同长度的哈希码下, 准确率与返回检索样本数和召回率与返回检索样本数的关系. 从中可以看出, 当只选择一种HOG特征和三种核函数进行组合时, 随着返回样本数的增加, 准确率大部分呈下降趋势, 召回率逐渐上升. 可以看出MFKH方法和SKLSH方法性能最优. 而M1FM3KH方法表现很不理想, 从中可以得出该单个HOG特征与这三种核函数的组合不好的结论.

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| 6.1 **图6.1在哈希码长度为16下, 返回检索样本数与准确率的关系**  **Figure 6.1** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 16 | 6.2 **图6.2在哈希码长度为16下, 返回检索样本数与召回率的关系**  **Figure 6.2** The relationship between the number of retrieved samples and the recall rate when the hash code length of 16 |

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| 6.3 **图6.3在哈希码长度为32下, 返回检索样本数与准确率的关系**  **Figure 6.3** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 32 | 6.4 **图6.4在哈希码长度为32下, 返回检索样本数与召回率的关系**  **Figure 6.4** The relationship between the number of retrieved samples and the recall rate when the hash code length of 32 |

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| 6.5 **图6.5在哈希码长度为64下, 返回检索样本数与准确率的关系**  **Figure 6.5** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 64 | 6.6 **图6.6在哈希码长度为64下, 返回检索样本数与召回率的关系**  **Figure 6.6** The relationship between the number of retrieved samples and the recall rate when the hash code length of 64 |

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| 6.7 **图6.7在哈希码长度为128下, 返回检索样本数与准确率的关系**  **Figure 6.7** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 128 | 6.8 **图6.8在哈希码长度为128下, 返回检索样本数与召回率的关系**  **Figure 6.8** The relationship between the number of retrieved samples and the recall rate when the hash code length of 128 |

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| 6.9 **图6.9在哈希码长度为256下, 返回检索样本数与准确率的关系**  **Figure 6.9** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 256 | 6.10 **图6.10在哈希码长度为256下, 返回检索样本数与召回率的关系**  **Figure 6.10** The relationship between the number of retrieved samples and the recall rate when the hash code length of 256 |

图6.11和6.12 是在IRMA数据集上进行的实验, 主要比较本文方法中的单特征多核方法(M1FM3KH表示HOG特征与三种核函数的组合)与其它对比方法在返回检索样本数为50时, 不同长度的哈希码下准确率与召回率的关系. 从图6.11可以看出当哈希码长度为大于等于32时, SKLSH方法准确率都高于其它对比方法. 从图6.12可以看出当哈希码长度为大于64时, SKLSH的召回率超过其它方法对比的方法(M1FM3KH中特征为HOG, 核函数为线性核,拉普拉斯核以及高斯核, 核参数分别为0.5, 10, 5).

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| 6.11 **图6.11在返回检索样本数为50时, 哈希码长度与准确率关系**  **Figure 6.11** The relationship between the length of the hash code and the accuracy rate when the number of retrieved samples is 50 | 6.12 **图6.12在返回检索样本数为50时, 哈希码长度与召回率关系**  **Figure 6.12** The relationship between the length of the hash code and the recall rate when the number of retrieved samples is 50 |

图7.1-7.10是在IRMA数据集上进行的实验, 主要比较本文方法中的单特征多核方法(M1FM3KH表示GIST特征与三种核的组合)与其它对比方法在不同长度的哈希码下, 准确率与返回检索样本数和召回率与返回检索样本数的关系. 从中可以看出, 当只选择一种GIST特征和三种核函数进行组合时, 随着返回样本数的增加, 准确率大部分呈下降趋势, 召回率逐渐上升. 与图6.1-6.10相比, 在其它条件不变的情况下, 当特征由HOG特征改为GIST特征时, 此时的M1FM3KH在准确率和召回率上并没有其它对比方法好, 由此可以得出不同的特征对各个方法的准确率和召回率有很大的影响, 以及该单个GIST特征与这三种核函数的组合不好的结论. 从图6.1-6.10和7.1-7.10可以看出单个特征多核的组合形式并不理想.

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| 7.1 **图7.1在哈希码长度为16下, 返回检索样本数与准确率的关系**  **Figure 7.1** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 16 | 7.2 **图7.2在哈希码长度为16下, 返回检索样本数与召回率的关系**  **Figure 7.2** The relationship between the number of retrieved samples and the recall rate when the hash code length of 16 |

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| 7.3 **图7.3在哈希码长度为32下, 返回检索样本数与准确率的关系**  **Figure 7.3** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 32 | 7.4 **图7.4在哈希码长度为32下, 返回检索样本数与召回率的关系**  **Figure 7.4** The relationship between the number of retrieved samples and the recall rate when the hash code length of 32 |

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| 7.5 **图7.5在哈希码长度为64下, 返回检索样本数与准确率的关系**  **Figure 7.5** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 64 | 7.6 **图7.6在哈希码长度为64下, 返回检索样本数与召回率的关系**  **Figure 7.6** The relationship between the number of retrieved samples and the recall rate when the hash code length of 64 |

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| 7.7 **图7.7在哈希码长度为128下, 返回检索样本数与准确率的关系**  **Figure 7.7** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 128 | 7.8 **图7.8在哈希码长度为128下, 返回检索样本数与召回率的关系**  **Figure 7.8** The relationship between the number of retrieved samples and the recall rate when the hash code length of 128 |

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| 7.9 **图7.9在哈希码长度为256下, 返回检索样本数与准确率的关系**  **Figure 7.9** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 256 | 7.10 **图7.10在哈希码长度为256下, 返回检索样本数与召回率的关系**  **Figure 7.10** The relationship between the number of retrieved samples and the recall rate when the hash code length of 256 |

图7.11和图7.12是在IRMA数据集上进行的实验, 主要比较本文方法中的单特征多核方法(M1FM3KH表示GIST特征与三种核的组合)与其它对比方法在返回检索样本数为50时, 不同长度的哈希码下准确率与召回率的关系. 图7.11呈现的是返回样本数为50时, 不同长度的哈希码下准确率的变化情况. 图7.12呈现的是返回样本数为50时, 不同长度的哈希码下召回率的变化情况, 从图7.11和7.12中可看出M1FM3KH的准确率和召回率实验结果并没有SKLSH方法好. 说明该M1FM3KH方法的组合并不好(其中M1FM3KH中特征为GIST, 核函数为线性核, 拉普拉斯核以及高斯核, 核参数分别为0.5, 10, 5).

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| 7.11 **图7.11在返回检索样本数为50时, 哈希码长度与准确率关系**  **Figure 7.11** The relationship between the length of the hash code and the accuracy rate when the number of retrieved samples is 50 | 7.12 **图7.12在返回检索样本数为50时, 哈希码长度与召回率关系**  **Figure 7.12** The relationship between the length of the hash code and the recall rate when the number of retrieved samples is 50 |

图8.1-8.10是在IRMA数据集上进行的实验, 主要比较本文方法中的多特征多核方法(M2FM3KH表示GIST特征和HOG特征与三种核函数的组合)与其它对比方法在不同长度的哈希码下, 准确率与返回检索样本数和召回率与返回检索样本数的关系. 当选择的特征为HOG特征和GIST特征与三种核函数进行组合时, 与图6.1-6.10和7.1-7.10相比, 当特征由HOG特征或GIST特征改为HOG特征和GIST特征的组合时, M2FM3KH在哈希码长度大于等于32时, 准确率超过了其它对比方法, 当哈希码长度为256时, 返回检索样数分别为10, 20, 30时, 最高准确率可以达到百分之百, 而当特征只有一种时, 返回样本数为10时, 最高准确率只有百分之七十. 由此可以看出不同的特征包含的信息不同, 将两种不同的特征信息考虑进来后可以进一步增加图像的特征信息量, 将这两种特征和三种核函数进行融合后可以更好地提高图像检索的准确率.

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| 8.1 **图8.1在哈希码长度为16下, 返回检索样本数与准确率的关系**  **Figure 8.1** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 16 | 8.2 **图8.2在哈希码长度为16下, 返回检索样本数与召回率的关系**  **Figure 8.2** The relationship between the number of retrieved samples and the recall rate when the hash code length of 16 |

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| 8.3 **图8.3在哈希码长度为32下, 返回检索样本数与准确率的关系**  **Figure 8.3** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 32 | 8.4 **图8.4在哈希码长度为32下, 返回检索样本数与召回率的关系**  **Figure 8.4** The relationship between the number of retrieved samples and the recall rate when the hash code length of 32 |

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| 8.5 **图8.5在哈希码长度为64下, 返回检索样本数与准确率的关系**  **Figure 8.5** The relationship between the number of retrieved samples and the accuracy rate at the hash code length of 64 | 8.6 **图8.6在哈希码长度为64下, 返回检索样本数与召回率的关系**  **Figure 8.6** The relationship between the number of retrieved samples and the recall rate at the hash code length of 64 |

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| 8.7 **图8.7在哈希码长度为128下, 返回检索样本数与准确率的关系**  **Figure 8.7** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 128 | 8.8 **图8.8在哈希码长度为128下, 返回检索样本数与召回率的关系**  **Figure 8.8** The relationship between the number of retrieved samples and the recall rate when the hash code length of 128 |

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| 8.9 **图8.9在哈希码长度为256下, 返回检索样本数与准确率的关系**  **Figure 8.9** The relationship between the number of retrieved samples and the accuracy rate when the hash code length of 256 | 8.10 **图8.10在哈希码长度为256下, 返回检索样本数与召回率的关系**  **Figure 8.10** The relationship between the number of retrieved samples and the recall rate when the hash code length of 256 |

表8, 表9, 表10分别在IRMA数据集, Ultrasound数据集以及Cifar10数据集上进行的实验, 主要验证核哈希方法和深度哈希方法(DSPH)在不同长度的哈希码下的训练时间, 从这三个表中可以看出深度哈希方法所需的训练时间是远远大于核哈希方法.

**表8 IRMA 数据集训练时间表**

**Table 8** Training Schedule on IRMA Dataset

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Method | IRMA (training time/seconds, N=2123) | | | |  |
|  | 8-bits | 12-bits | 24-bits | 32-bits | 48-bits |
| MFKH | 1.1696 | 1.3054 | 0.9257 | 0.9127 | 0.8484 |
| SH | 0.0304 | 0.0213 | 0.0102 | 0.0135 | 0.0134 |
| SKLSH | 0.0022 | 0.0019 | 0.0024 | 0.0042 | 0.0032 |
| KLSH | 9.1315 | 8.7274 | 9.0654 | 9.5908 | 9.3706 |
| MFMKH(M2FM3KH) | 52.3631 | 29.2412 | 25.8159 | 40.2627 | 32.7781 |
| DPSH | 3886 | 4151 | 4462 | 3952 | 3955 |

**表9 Ultrasound 数据集训练时间表**

**Table 9** Training Schedule on Ultrasound Dataset

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| --- | --- | --- | --- | --- | --- |
| Method | Ultrasound(training time/seconds, N=1982) | | | |  |
|  | 8-bits | 12-bits | 24-bits | 32-bits | 48-bits |
| MFKH | 0.4559 | 0.6755 | 0.4754 | 0.4908 | 0.4848 |
| SH | 0.0182 | 0.0102 | 0.0100 | 0.0142 | 0.0131 |
| SKLSH | 0.0020 | 0.0024 | 0.0026 | 0.0038 | 0.0034 |
| KLSH | 8.2570 | 8.2191 | 9.1177 | 8.7301 | 9.6035 |
| MFMKH(M2FM3KH) | 7.7621 | 20.6588 | 22.6186 | 20.0926 | 11.8208 |
| DPSH | 4266 | 4100 | 4109 | 4454 | 4698 |

**表10 Cifar10 数据集训练时间表**

**Table 10** Training Schedule on Cifar10 Dataset

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| --- | --- | --- | --- | --- | --- |
| Method | Cifar10(training time/seconds, N=5000) | | | |  |
|  | 8-bits | 12-bits | 24-bits | 32-bits | 48-bits |
| MFKH | 4.3227 | 4.4727 | 4.6554 | 4.4021 | 4.7814 |
| SH | 0.2916 | 0.0264 | 0.0323 | 0.0408 | 0.0393 |
| SKLSH | 0.0050 | 0.0234 | 0.0269 | 0.0272 | 0.0404 |
| KLSH | 107.0237 | 106.6893 | 108.6299 | 109.4304 | 110.6830 |
| MFMKH(M2FM3KH) | 272.0450 | 235.7176 | 144.1333 | 148.3040 | 134.6403 |
| DPSH | 24318 | 11107 | 99089 | 97439 | 94195 |