北京交通大学

博士学位论文

基于动态光学传递函数的随机运动模糊图像快速复原方法

FAST RESTORATION METHOD FOR RANDOM
MOTION-BLURRED IMAGE BASED ON DYNAMIC OPTICAL
TRANSFER FUNCTION

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北京交通大学

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致谢

摘要

成像技术在军事、工业、民用等领域具有广泛的应用。然而，待测场景与时延成像系统之间存在相对运动，气动光学效应等原因都会造成图像随机运动模糊，影响机器视觉系统的成像性能。图像复原算法是一种可以改善图像质量的有效手段，然而，应用最为广泛的盲复原算法因采用了迭代运算而存在运算量大、耗时长的缺点，难以满足各领域对退化图像快速复原的技术要求，而线性复原算法因现有像质评价函数或方法的各种局限性而无法实际应用。因此，建立一种新的像质评价模型，将其与线性复原算法相结合，是实现随机运动模糊图像快速复原的有效手段。

本课题"基于动态光学传递函数的随机运动模糊图像快速复原方法"的研究目的在于：严格推导随机运动动态光学传递函数（Dynamic Optical Transfer Function，DOTF）模型，将其用于准确描述随机运动模糊图像的像质退化规律，提出一种从退化图像中提取 DOTF，并将其与线性复原算法相结合的图像复原算法，从而回避迭代运算，实现随机运动模糊图像快速复原。本课题的研究为随机运动模糊图像提供一种快速复原手段，研究成果对于提高时延成像系统实时成像性能具有积极的促进作用。课题的主要研究内容有：

1. 为了解决现有像质评价函数或方法不能用于指导图像快速复原，建立了一个新的像质评价函数。首先分别在空域和频域严格推导了随机运动 DOTF 模型，根据两种方法得到的 DOTF 模型相同，实现了二者之间的相互验证；然后在静止、匀速运动和高频简谐振动三种典型运动状态下，将本文模型化简为现有模型形式，验证了本文 DOTF 模型适用于随机运动；最后通过严格的数学推导，发现本文随机运动 DOTF 模型是气动光学点扩展函数的傅里叶变换，说明本文随机运动 DOTF 模型可用于描述气动光学随机运动模糊图像像质退化规律。

2. 针对盲复原算法运算量大，运算时间长的问题，提出了一种随机运动模糊图像快速复原方法。首先推导了随机运动模糊图像的频谱模型，然后利用退化图像向导部分在背景均匀条件下所具有的边界补充特性和背景等效静止特性，提出了一种从退化图像向导部分提取 DOTF，并与线性滤波复原方法相结合的复原方法，最后对该复原方法进行仿真，仿真结果表明，复原图像与原始图像之间的相关系数为 1，验证了该方法的有效性。

3. 分析了本文方法中各项误差因素对图像复原质量的影响规律。针对背景不均匀，图像传感器存在暗电流，以及伴随有随机噪声的三种情况，分别建立了随

机运动模糊图像复原模型并仿真，仿真结果分别为：对于背景不均匀的情况，复原图像与原始图像的相关系数随背景对比度的增大而变小；对于图像传感器存在恒量暗电流的情况，只要在复原环节将暗电流从退化图像中减去，复原图像与原始图像的相关系数就恒为 1；对于伴随有随机噪声的情况下，复原图像与原始图像的相关系数随噪声强度的增加而减小。这些结果表明为了获得更好的图像复原效果，需要尽可能满足背景均匀条件，降低噪声强度，并在复原环节将暗电流从退化图像中减去。

4. 对本文图像快速复原算法及相关理论进行了实验验证。首先根据相同运动参数下的 DOTF 测量曲线与理论曲线吻合，以及 DOTF 测量曲线随速度变化而在空间频率方向表现出的伸缩规律与理论分析相一致，验证了本文随机运动 DOTF 模型的正确性；然后根据软件得到的退化图像与实际采集得到的退化图像之间的相关系数为 0.9979，验证了向导部分的边界补充特性，根据背景随目标一起运动与不随目标一起运动情况下得到两幅退化图像之间的相关系数为 0.9994，验证了向导部分的背景等效静止特性；最后分别采用文本复原方法与现有快速复原方法复原同一幅退化图像，结果为：表征图像复原质量的 GMG 和 LS，本文方法均高于现有方法 5.77 倍以上，而复原时间却减少了将近 90%，结果表明本文方法不仅具有更好的复原效果，而且将运算速度提高近一个数量级

关键词：图像复原；DOTF；随机运动；快速算法

ABSTRACT

Imaging technology has been widely used in military, industrial, civil and many other fields. However, image will be random motion-blurred because of relative motion between the scene and the time-delay imaging system, aero-optical effect or other seasons, and imaging performance of the machine vision system will be affected. Image restoration algorithm is an effective way to improve quality of image. However, iteration is used, so the shortcomings of the most widely used blind restoration algorithms are large amount of computation and time-consuming, and it is difficult to meet the fast restoration requirements in many fields. Linear restoration algorithms have not been practical application because of the limitations of the existing image quality evaluation function or method. Therefore, establishing a new image quality evaluation model and combined with the linear restoration algorithm is an effective means of rapidly restoring random motion-blurred image. The subject of "a fast restoration method for random motion-blurred image based on DOTF" aims to strictly derive random motion Dynamic Optical Transfer Function (DOTF) model, and use it to accurately describe the degradation law of random motionblurred image, and then a restoration method which extract DOTF from the blurred image and combine with the linear filter algorithm is proposed. Iterative operation can be avoided in this restoration method, and the degraded image can be restored rapidly. These researches offer a technology scheme for rapidly restoring random motion-blurred image, and it is good for improving real-time imaging performance of time-delay imaging system. The main research contents include:

1. In order to solve the problem of the existing image quality evaluation function or methods can't be used for rapidly restoring random motion-blurred image, a new evaluation function was built. Firstly, we rigorously derived Random motion DOTF models in the space domain and in the spatial frequency domain separately, and they are mutual verified because the two DOTF models are exactly the same; secondly, Using our DOTF model, we rigorously derived previously known DOTF expressions for static, uniform motion and high frequency harmonic vibration, and according to the displacement function of the motion image is no limits to any motion type, our DOTF model can be developed for random motion was verified; at last, by strictly derivation, we found that our DOTF model is the Fourier transform of the existing aero-

optical point spread function, it is therefore concluded that our DOTF model can be also applied to describe the degradation rules of aero-optical random motion-blurred image.

2. The existing blind restoration methods have the characteristics of large computation and long operation time, in order to solve these problems, a fast restoration method for random motion-blurred image was proposed. Firstly, the spectrum model of degraded image was strictly derived, secondly, based on the border added and background equivalent static properties of the guide part of the degraded image, a restoration method of extracting DOTF from the guide part of the degraded image and combining with the linear filter algorithms was proposed; at last, our restoration method was simulated, the correlation coefficient between the restored image and original image is 1 proves the effectiveness of our method.

3. The rules of error impacts of our methods effect quality of the restoration image were analyzed. Restoration models were built for the background is not uniform, the image sensor has dark current, and there is random noise during imaging separately, and the restoration method was simulated for the different models. The simulation results show that: for nonuniform background, quality of the restoration image will be degraded with increasing of the contrast of the background; for constant dark current, quality of the restoration image will be unchanged as long as the dark current subtracted from the degraded image during the restoration process; for random noise, quality of the restoration image will be declined with increasing of the noise intensity. These results suggest that in order to get a high quality restoration image, a background with low contrast and low noise intensity will be chosen, and the dark current need to be subtracted from the degraded image during restoration.

4. The fast restoration method and the related theories are verified by experiments. Firstly, according to the measurement DOTF curves are agree to the theoretical ones at the same motion parameters, and the changing law of the DOTF curves in the spatial frequency direction with the change of velocity is agree to the theoretical result, the effectiveness of our DOTF model were verified; Secondly, secondly, according to the correlation coefficient between the blurred image degraded by software and the real degraded one is 0.9979 and the correlation coefficient between the blurred image with a Synchronous

motion background and the one without Synchronous motion background is 0.9994, the border added and the background equivalent static properties were verified; at last, The blurred images were restored by our restoration method and the existing ones, for quality of the restoration image, the GMG and LS of the images restored by our method are 5.77 times more than those of the images restored by the existing methods, and for operation time, the cost was cut nearly 90the advantages of our restoration method are not only improving the restoration quality, but also increasing the operation speed nearly one order of magnitude

KEYWORDS: Image restoration; DOTF; Random motion; Fast algorithm

序言

　　[鼠标左键单击选择该段落，输入替换之。内容为小四号宋体。] 学位论文的序或前言，一般是作者或他人对本篇论文基本特征的简介，如说明研究工作缘起、背景、主旨、目的、意义、编写体例，以及资助、支持、协作经过等；也可以评述和对相关问题发表意见。这些内容也可以在正文引言中说明。

目录

1 引言

这里是引言[1,2]。

这是 的示例文档，基本上覆盖了模板中所有格式的设置。建议大家在使用模板之前，除了阅读《用户手册》，这个示例文档也最好能看一看。

小老鼠偷吃热凉粉；短长虫环绕矮高粱。[1]

1.1 封面相关

封面的例子请参看 cover.tex。主要符号表参看 denation.tex，附录和个人简历分别参看 appendix01.tex 和 resume.tex。里面的命令都非常简单，一看即会。[2]

1.2 字体命令

苏轼（1037-1101），北宋文学家、书画家。字子瞻，号东坡居士，眉州眉山（今属四川）人。苏洵子。嘉佑进士。神宗 时曾任祠部员外郎，因反对王安石新法而求外职，任杭州通判，知密州、徐州、湖州。后以作诗"谤讪朝廷"罪贬黄州。哲宗时任翰林学士，曾出知杭州、颍州等，官至礼部尚书。后又贬谪惠州、儋州。北还后第二年病死常州。南宋时追谥文忠。与父洵弟辙，合称"三苏"。在政治上属于旧党，但也有改革弊政的要求。其文汪洋恣肆，明白畅达，为"唐宋八大家"之一。其诗清新豪健，善用夸张比喻，在艺术表现方面独具风格。少数诗篇也能反映民间疾苦，指责统治者的奢侈骄纵。词开豪放一派，对后代很有影响。《念奴娇·赤壁怀古》、《水调歌头·丙辰中秋》传诵甚广。

坡仙擅长行书、楷书，取法李邕、徐浩、颜真卿、杨凝式，而能自创新意。用笔丰腴跌宕，有天真烂漫之趣。与蔡襄、黄庭坚、米芾并称"宋四家"。能画竹，学文同，也喜作枯木怪石。论画主张"神似"，认为"论画以形似，见与儿童邻"；高度评价"诗中有画，画中有诗"的艺术造诣。诗文有《东坡七集》等。存世书迹有《答谢民师论文帖》、《祭黄几道文》、《前赤壁赋》、《黄州寒食诗帖》等。画迹有《枯木怪石图》、《竹石图》等。

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[1]韩愈（768-824），字退之，河南河阳（今河南孟县）人，自称郡望昌黎，世称韩昌黎。幼孤贫刻苦好学，德宗贞元八年进士。曾任监察御史，因上疏请免关中赋役，贬为阳山县令。后随宰相裴度平定淮西迁刑部侍郎，又因上表谏迎佛骨，贬潮州刺史。做过吏部侍郎，死谥文公，故世称韩吏部、韩文公。是唐代古文运动领袖，与柳宗元合称韩柳。诗力求险怪新奇，雄浑重气势。

[2]你说还是看不懂？怎么会呢？

易与天地准，故能弥纶天地之道。仰以观於天文，俯以察於地理，是故知幽明之故。原始反终，故知死生之说。精气为物，游魂为变，是故知鬼神之情状。与天地相似，故不违。知周乎万物，而道济天下，故不过。旁行而不流，乐天知命，故不忧。安土敦乎仁，故能爱。范围天地之化而不过，曲成万物而不遗，通乎昼夜之道而知，故神无方而易无体。

有天地，然后万物生焉。盈天地之间者，唯万物，故受之以屯；屯者盈也，屯者物之始生也。物生必蒙，故受之以蒙；蒙者蒙也，物之稚也。物稚不可不养也，故受之以需；需者饮食之道也。饮食必有讼，故受之以讼。讼必有众起，故受之以师；师者众也。众必有所比，故受之以比；比者比也。比必有所畜也，故受之以小畜。物畜然后有礼，故受之以履。

履而泰，然后安，故受之以泰；泰者通也。物不可以终通，故受之以否。物不可以终否，故受之以同人。与人同者，物必归焉，故受之以大有。有大者不可以盈，故受之以谦。有大而能谦，必豫，故受之以豫。豫必有随，故受之以随。以喜随人者，必有事，故受之以蛊；蛊者事也。

有事而后可大，故受之以临；临者大也。物大然后可观，故受之以观。可观而后有所合，故受之以噬嗑；嗑者合也。物不可以苟合而已，故受之以贲；贲者饰也。致饰然后亨，则尽矣，故受之以剥；剥者剥也。物不可以终尽，剥穷上反下，故受之以复。复则不妄矣，故受之以无妄。

有无妄然后可畜，故受之以大畜。物畜然后可养，故受之以颐；颐者养也。不养则不可动，故受之以大过。物不可以终过，故受之以坎；坎者陷也。陷必有所丽，故受之以离；离者丽也。

2 研究背景

[鼠标左键单击选择该段落，输入替换之。内容为小四号宋体。] 引言（或绪论）简要说明研究工作的目的、范围、相关领域的前人工作和知识空白、理论基础和分析、研究设想、研究方法和实验设计、预期结果和意义等。应言简意赅，不要与摘要雷同，不要成为摘要的注释。一般教科书中有的知识，在引言中不必赘述。

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附录 A

附录标题

[内容为五号宋体。] 附录是作为论文主体的补充项目，并不是必须的。论文的附录依序用大写正体英文字母 A、B、C······编序号，如：附录 A。

This is my second palace that has a key.

上文提到 Knuth 留下了后门 \special，但是直接用它来插入图形不够含蓄优雅，于是 LaTeXv2.09 推出了 epsf 和 psfig 宏包。之后 David P. Carlisle (1961–) [1] 和 Rahtz 推出了面向 LaTeX 2_ε 的 graphics 和 graphicx 宏包；后者基于前者，语法更简单，功能更强大，所以一般推荐用它。

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[1]1995 年曼彻斯特大学数学博士，剑桥博士后，1998 年加入数字算法公司 (Numerical Algorithms Group)。

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一、作者简历

二、发表论文

[1] e

[2] yi

三、参与科研项目

[1] e

[2] yi

[3] san

四、专利

[1] e

[2] yi

[3] san

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<p align="center">表 1.1   数据集页</p>

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