中国测绘学会

全国十大科技创新人物

主要附件

（理事推荐用）

姓　　名 李清泉

工作单位 深圳大学

推荐人（理事）王丹、万剑华、卢秀山、张勤

填表日期 2019 年 7 月 16 日

附属材料：

获奖、专利证明

目录

国家技术发明奖

证　书

为表彰国家技术发明奖获得者，特颁发此证书。

项目名称：道路路面动态检测关键技术及装备

奖励等级：二等

获 奖 者：李清泉（武汉大学）

中华人民共和国国务院

2015 年 12 月 16 日

证书号：2015-F-303-2-04-R01

国家科学技术进步奖

证　书

为表彰国家科学技术进步奖获得者，特颁发此证书。

项目名称：空间信息网络服务技术及产业化

奖励等级：二等

获 奖 者：李清泉

2005年11月20日

证书号：2005-J-226-2-09-R02

国家科学技术进步奖

证　书

为表彰国家科学技术进步奖获得者，特颁发此证书。

获 奖 者：武汉大学对地观测与导航技术创新团队

中华人民共和国国务院

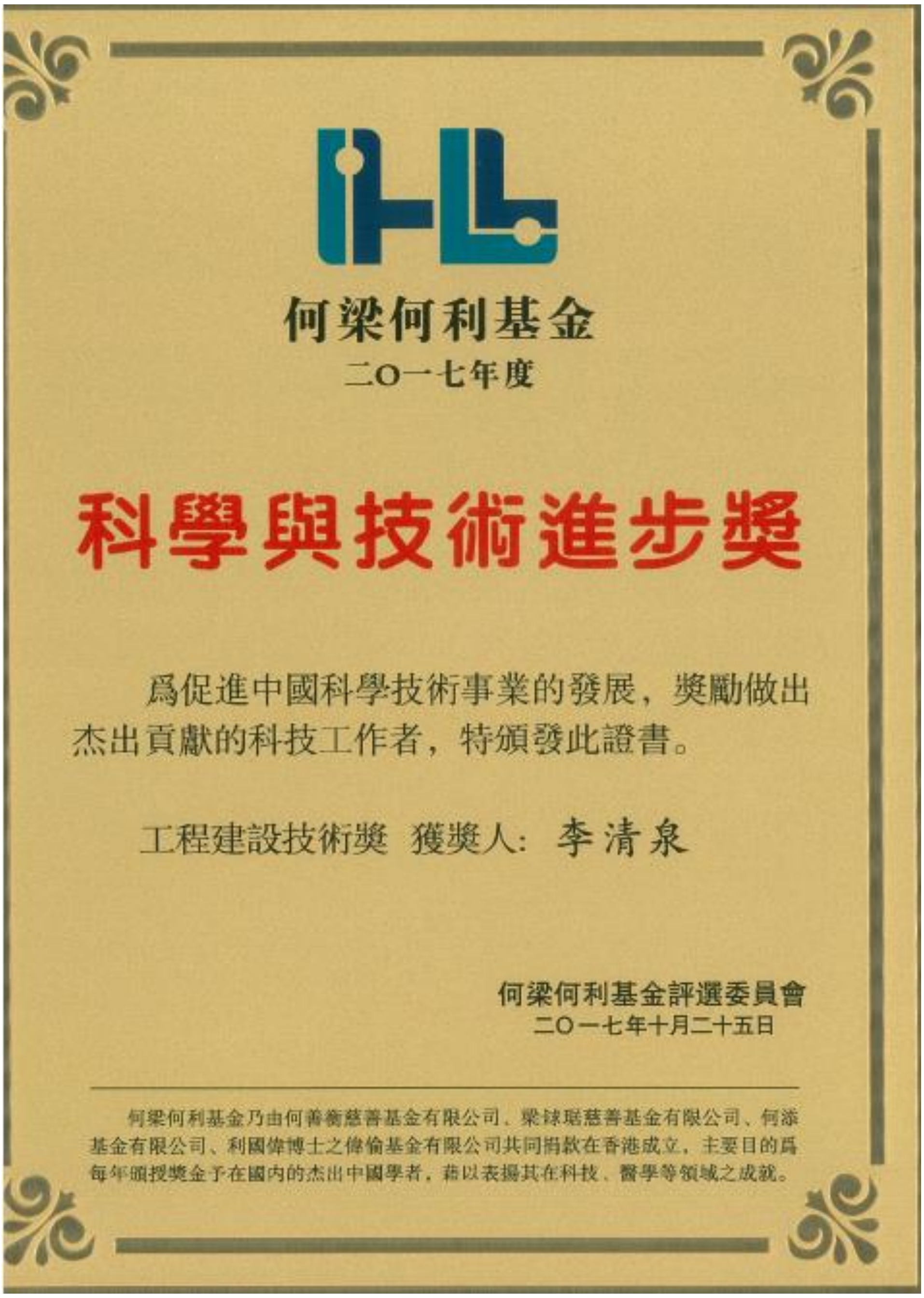
2014年12月12日

证书号：2014-J-207-1-02

国家科学技术进步奖获奖项目目录（通用项目）

序号	编　号	项目名称	主要完成人	主要完成单位	推荐单位
13	J-213-1-01	超深井超稠油高效化学降粘技术研发与工业应用	刘中云，秦　冰，林　涛，王世洁，郭继香，梁尚斌，韩军华，罗咏涛，肖贤明，李本高，赵海洋，李子甲，任　波，杨祖国，雷　斌	中国石油化工股份有限公司西北油田分公司，中国石油化工股份有限公司石油化工科学研究院，中国石油大学（北京），中国科学院广州地球化学研究所	中国石油化工集团公司
14	J-208-1-01	国家电网智能电网创新工程		国家电网公司	国有资产监督管理委员会

序号	编　号	团队名称	主要成员	主要支持单位	推荐单位
15	J-207-1-01	解放军总医院器官损伤与修复综合救治创新团队	陈香美，付小兵，蔡广研，姚咏明，谢院生，孙雪峰，张　旭，白雪源，吴　镝，魏日胞，张　利，马　哲，朱晗玉，韩为东，吴　杰	中国人民解放军总医院	总后勤部
16	J-207-1-02	武汉大学对地观测与导航技术创新团队	李德仁，刘经南，龚健雅，张良培，李清泉，施　闯，吴华意，王　密，陈能成，赵齐乐，陈晓玲，朱欣焰，眭海刚，廖明生，张　过	武汉大学	湖北省
17	J-207-1-03	中国航天科技集团公司第五研究院深空探测航天器系统创新团队	叶培建，孙泽洲，黄江川，张廷新，杨孟飞，张　熇，贾　阳，张洪华，饶　炜，陈建新，王晓磊，张　伍，彭　兢，吴学英，孟林智	中国空间技术研究院	国防科技工业局



何梁何利基金

二〇一七年度

科學與技術進步獎

为促進中國科學技術事業的發展，獎勵做出杰出貢獻的科技工作者，特頒發此證書。

工程建設技術獎 獲獎人：李清泉

何梁何利基金評選委員會

二〇一七年十月二十五日

何梁何利基金乃由何善衡慈善基金有限公司、梁銶琚慈善基金有限公司、何添基金有限公司、利國偉博士之偉倫基金有限公司共同捐款在香港成立，主要目的爲每年頒授獎金予在國内的杰出中國學者，藉以表揚其在科技、醫學等領域之成就。

为表彰在促进科学技术进步工作中做出重大贡献，特颁发此证书。

获奖项目：三维复杂空间目标集成建模关键技术与应用

获 奖 者：李清泉（第1完成人）

奖励等级：科学技术进步奖一等奖

奖励日期：2007年01月

证 书 号：2006-171

中华人民共和国教育部

教育部

二〇〇七年一月二十五日

测绘科技进步奖

证 书

为表彰测绘科技进步奖获得者，特颁发此证书。

项目名称：精密三维测量技术（装备）及集成应用

奖励等级：一等奖

获 奖 者：李清泉　　名次：序(01)

中国测绘地理信息学会

证书号：2017-01-01-01　　2017年 11 月 9 日

测绘科技进步奖

证 书

为表彰测绘科技进步奖获得者，特颁发此证书。

项目名称：精密三维测量技术（装备）及集成应用

奖励等级：一等奖

获奖单位：武汉武大卓越科技有限责任公司　　名次：序(03)

中国测绘地理信息学会

证书号：2017-01-01-01　　2017年 11 月 9 日

CHINA ASSOCIATION FOR GIS

GIS

地理信息科技进步奖

证 书

项目名称：复杂动态交通环境下网络导航与物流配送关键技术与应用

奖励等级：壹等奖

获 奖 者：李清泉　　名次：序(1)

证书号：2014-01-01　　2014年9月10日

中国地理信息产业协会

获奖项目：车载路面快速检测与测量技术及产业化

获奖单位：武汉武大卓越科技有限责任公司

（第2完成单位）

奖励等级：科学技术进步奖一等奖

奖励日期：2009年01月

证 书 号： 2008-166

中华人民共和国教育部

教育部

二〇〇九年一月二十日


测绘科技进步奖

证书

为表彰测绘科技进步奖获得者，特颁发此证书。

项目名称：智能路面综合检测装备研发及产业化

奖励等级：一等奖

获奖单位：武汉武大卓越科技有限责任公司 名次：序(01)

证书号：2013-01-01-02 2013年10月11日

中国公路学会

科学技术奖证书

为表彰中国公路学会科学技术奖获得者，特颁发此证书

项目名称：道路路面综合检测关键技术及成套装备研究

奖励等级：一等

获 奖 者：武汉武大卓越科技有限责任公司

中国公路学会

2014年12月

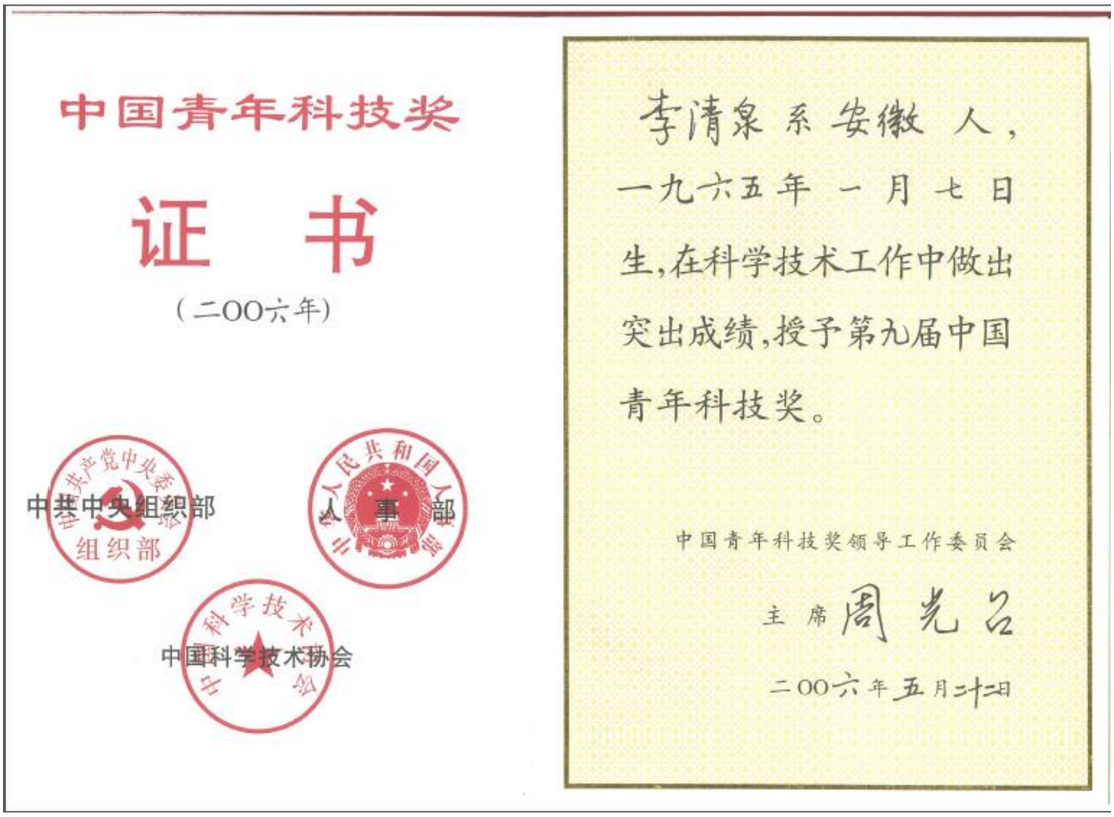
证书号：A14-1-009-001

李清泉同志：

荣获第十四届广东省丁颖科技奖，特发此证。

广东省科学技术协会

二〇一七年十二月



中国青年科技奖

证　书

（二〇〇六年）

中共中央组织部　　人　事　部

中国科学技术协会

李清泉 系 安徽 人，一九六五年一月七日生，在科学技术工作中做出突出成绩，授予第九届中国青年科技奖。

中国青年科技奖领导工作委员会

主　席　周光召

二〇〇六年五月二十二日

三、2018年高等教育国家级教学成果奖获奖项目名单

特等奖（2项）

序号	成果名称	完成人	完成单位
1	以课堂教学改革为突破口的一流本科教育川大实践	谢和平，步宏，张红伟，李中锋，冉桂琼，周琳，杨军，冉蓉，胡娜，夏建钢	四川大学
2	深度融合信息技术的高校人才培养体系重构与探索实践	杨宗凯，彭南生，刘建清，李鸿飞，吴砥，杨浩，曹阳，胡慧洁，郑伦楚	华中师范大学

一等奖（50项）

序号	成果名称	完成人	完成单位
1	入耳入脑入心 同向同行同频：以思政课为核心的课程思政教育教学改革与创新	许宁生，焦扬，陈锡喜，沙军，赵宪忠，褚君浩，姜智彬，刘淑慧，顾铮先，曹文泽，李梁，张黎声，李江，李国娟，吴强，桂永浩，顾钰民，宗爱东	复旦大学，上海交通大学，上海市教育科学研究院，同济大学，华东师范大学，上海外国语大学，东华大学，上海理工大学，华东政法大学，上海大学，上海中医药大学，上海工程技术大学，上海应用技术大学，上海政法学院
2	砥砺求索35年——情感教学理论的创立与实践	卢家楣，刘伟，贺雯，王俊山，陈宁	上海师范大学
3	国家试点学院APLIC教育学科创新人才培养模式探索	朱旭东，石中英，李家永，王晨，黄欣	北京师范大学

二等奖（400项）

序号	成果名称	完成人	完成单位
1	"本硕一体·全科·融通"的卓越小学教师培养模式改革实践	吕立杰，陈旭远，解书，马云鹏，唐丽芳，于伟	东北师范大学
373	面向计算思维能力培养的虚拟实验体系与在线实验模式探索	李凤霞，陈宇峰，李冬妮，余月，赵三元，李林，计卫星	北京理工大学
374	青藏高原多民族地区医学机能实验平台搭建及实验教学改革与创新实践研究	刘永年，张伟，李建华，吴穹，刘辉琦，曹学锋，王生兰	青海大学
375	信息化背景下物理系列课程的教学模式创新与实践	张汉壮，倪牟翠，王磊，张涵，崔田，马琰铭，孙敬姝	吉林大学
376	构建三模块五平台虚拟仿真实验教学体系，培养"研究者+实践者"心理学人才	张卫，刘学兰，莫雷，曾祥炎，田丽丽，许思安，郑希付，迟毓凯	华南师范大学
377	"通用-通识-专用"三位一体、信息化混合式大学英语教育探索与实践	胡杰辉，冯文坤，伍忠杰，刘淑珍，李京南，俞博，张文鹏，张丽，楚军，邹涛	电子科技大学
378	全国地方高校优课联盟在线开放课程建设与应用	李清泉，黎军，王晖，孙忠梅，张凡，周毅，陈晔，吴燕玲，蔡艳嫦，章天金，吴华洋，朱汉祎，费跃农，吴晓凤，薛英忠，姚凯，傅霖，王志强，王晓钧	深圳大学，苏州大学，湖北大学，黑龙江大学，南方医科大学
379	我国数字解剖学教学体系创建与推广	刘树伟，张绍祥，徐以发，李振平，李振中，谭立文，孟海伟，李七渝，张娜，王莉，汤煜春，吴毅，孙守华，刘真，魏昱，李贵宝，冯蕾，吴凤霞，毕玉顺，李伟涛	山东大学，中国人民解放军陆军军医大学，山东数字人科技股份有限公司，中国解剖学会
380	校企协同、创新引领，打造"两交叉四融合"菁英班实践育人新模式	徐忠锋，管晓宏，王小华，陈立斌，段玉岗，罗新民，吴莹，陈磊，曹猛，高腾	西安交通大学
381	基于校企协同的"订单+联合"大核电人才培养体系创新与实践	夏虹，陈泰，陆道纲，彭敏俊，刘正，李体强，高璞珍，矫彩山，田凯，谭思超，李向宾，李金阳，马福秋，崔媛，王海涛	哈尔滨工程大学，中国广核集团有限公司，华北电力大学

161843

证书号第3167528号

发明专利证书

发 明 名 称：一种全波形数据的噪声回波剔除方法及系统

发　明　人：李清泉；朱家松；汪驰升；王丹；丁凯

专　利　号：ZL 2016 1 0900186.5

专利申请日：2016年10月14日

专 利 权 人：深圳大学

地　　　址：518054 广东省深圳市南山区南海大道3688号

授权公告日：2018年11月30日　　　　授权公告号：CN 106556824 B

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告之日起生效。

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申长雨

国家知识产权局
2018年11月30日

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16O113

证书号第3062041号

发明专利证书

发 明 名 称：一种激光雷达测深数据的海底底质反射率提取方法及系统

发 明 人：李清泉；丁凯；朱家松；汪驰升

专 利 号：ZL 2016 1 0416807.2

专利申请日：2016年06月14日

专 利 权 人：深圳大学

地 址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2018年09月07日　　授权公告号：CN 105954732 B

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国家知识产权局
2018年09月07日

北京市海淀区地方税务局 印花税代扣专用章 国家知识产权局

第1页（共1页）

证书号第3071372号

发明专利证书

发明名称：一种移动物体的定位定姿方法和系统

发 明 人：李清泉;张亮;毛庆洲;刘勇;陈智鹏;熊智敏

专 利 号：ZL 2016 1 0126054.1

专利申请日：2016年03月04日

专 利 权 人：深圳大学

地 址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2018年09月14日　　　授权公告号：CN 105628026 B

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专利证书记载专利权登记时的法律状况。专利权的转移、质押、无效、终止、恢复和专利权人的姓名或名称、国籍、地址变更等事项记载在专利登记簿上。

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国家知识产权局
2018年09月14日

第1页（共1页）

153204

证书号第2806557号

发明专利证书

发明名称：一种动态环境下轨道检测平台的三维定位定姿方法及系统

发 明 人：李清泉；陈智鹏；毛庆洲；刘勇；熊智敏；张亮

专 利 号：ZL 2016 1 0010650.3

专利申请日：2016年01月08日

专利权人：深圳大学

授权公告日：2018年02月06日

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中华人民共和国国家知识产权局
2018年02月06日

第1页（共1页）

证书号第3049199号

发明专利证书

发 明 名 称：一种非接触的钢轨表面伤损检测方法及其装置

发　明　人：李清泉；熊智敏；毛庆洲；刘勇；张亮；陈智鹏

专　利　号：ZL 2015 1 0896242.8

专利申请日：2015年12月08日

专 利 权 人：深圳大学

地　　址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2018年08月28日　　授权公告号：CN 105548197 B

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国家知识产权局
2018年08月28日

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152474

证书号第3040353号

发明专利证书

发 明 名 称：一种基于众包的WiFi位置指纹地图构建方法及其系统

发 明 人：李清泉;周宝定

专 利 号：ZL 2015 1 0702867.6

专利申请日：2015年10月26日

专 利 权 人：深圳大学

地 址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2018年08月21日 授权公告号：CN 105263113 B

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2018年08月21日

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162202

证书号第3095624号

发明专利证书

发明名称：一种适应低速及变速测量的平整度检测装置及方法

发　明　人：李清泉;张德津;曹民;王新林;林红

专　利　号：ZL 2016 1 0970181.X

专利申请日：2016年10月28日

专利权人：武汉武大卓越科技有限责任公司

地　　址：430223 湖北省武汉市东湖开发区武大科技园4路6号

授权公告日：2018年10月02日　　授权公告号：CN 106638242 B

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2018年10月02日

第1页(共1页)

证书号第3098203号

发明专利证书

发 明 名 称：基于线扫描三维点云的物体表面变形特征提取方法

发 明 人：李清泉；曹民；张德津；林红；陈颖

专 利 号：ZL 2016 1 0027930.5

专利申请日：2016年01月15日

专 利 权 人：武汉武大卓越科技有限责任公司

地 址：430223 湖北省武汉市东湖新技术开发区武大科技园4路6号

授权公告日：2018年10月02日　　授权公告号：CN 105809668 B

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2018年10月02日

第1页（共1页）

证书号第2948131号

发明专利证书

发 明 名 称：一种隧道检测多传感器集成平台

发　明　人：李清泉；章丽萍；曹民；周瑾；谢俊；徐学文

专　利　号：ZL 2015 1 0870169.7

专利申请日：2015年12月01日

专 利 权 人：武汉武大卓越科技有限责任公司

地　　　址：430223 湖北省武汉市东湖新技术开发区武大科技园4路6号

授权公告日：2018年06月05日　　　授权公告号：CN 105352550 B

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局长
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2018年06月05日

第 1 页 (共 1 页)

证书号第2743652号

发明专利证书

发 明 名 称：复杂光环境下基于线结构光的大断面测量方法

发　明　人：李清泉；曹民；曲旋；王新林；卢金；陈颖

专　利　号：ZL 2015 1 0491323.X

专利申请日：2015年08月11日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2017年12月19日

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中华人民共和国国家知识产权局
2017年12月19日

第1页（共1页）

证书号第2663638号

发明专利证书

发明名称：一种逐步求精的路面裂缝检测方法

发　明　人：李清泉；张德津；曹民；陈颖；林红；卢金

专　利　号：ZL 2015 1 0205343.6

专利申请日：2015年04月27日

专利权人：武汉武大卓越科技有限责任公司

授权公告日：2017年10月20日

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局长
申长雨

2017年10月20日

第1页（共1页）

证书号第2803337号

发明专利证书

发明名称：隧道快速综合测量系统

发 明 人：李清泉；曹民；章丽萍；孙小进；谢俊

专 利 号：ZL 2015 1 0085599.8

专利申请日：2015年02月16日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2018年02月02日

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2018年02月02日

第1页（共1页）

证书号第2340936号

发明专利证书

发明名称：车用里程随动测量装置

发明人：李清泉；张德津；曹民；王新林；闽斌云；孙小进；孙海华

专利号：ZL 2014 1 0422014.2

专利申请日：2014年08月26日

专利权人：武汉武大卓越科技有限责任公司

授权公告日：2017年01月11日

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中华人民共和国国家知识产权局
2017年01月11日

第1页（共1页）

证书号第2426440号

发明专利证书

发 明 名 称：融合影像梯度信息和分水岭方法的裂缝检测方法

发　明　人：李清泉；毛庆洲；靳华中；曹民；张德津；陈振兴；周瑾
章丽萍

专　利　号：ZL 2014 1 0268332.8

专利申请日：2014年06月17日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2017年03月22日

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2017年03月22日

北京市海淀区地方税务局 印花税 代扣专用章 国家知识产权局

第1页（共1页）

证书号第1903969号

发明专利证书

发明名称：基于深度和灰度图像的路面裂缝检测装置和方法

发明人：李清泉；毛庆洲；熊智敏；曹民；张德津；周瑾；章丽萍

专利号：ZL 2014 1 0269998.5

专利申请日：2014年06月17日

专利权人：武汉武大卓越科技有限责任公司

授权公告日：2016年01月20日

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中华人民共和国国家知识产权局
2016年01月20日

第1页（共1页）

证书号第1693096号

发明专利证书

发 明 名 称：一种堆场实时动态三维测控系统

发　明　人：李清泉；曹民；黄俊能；张德津；张志刚

专　利　号：ZL 2012 1 0348000.1

专利申请日：2012年09月19日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2015年06月10日

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中华人民共和国国家知识产权局
2015年06月10日

第 1 页（共 1 页）

证书号第1509503号

发明专利证书

发 明 名 称：一种城市基础设施快速检测系统

发　明　人：李清泉；曹民；张德津；何莉；曲旋；王新林；马斌

专　利　号：ZL 2012 1 0132397.0

专利申请日：2012年05月02日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2014年10月29日

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2014年10月29日

第1页（共1页）

证书号第1562462号

发明专利证书

发 明 名 称：激光测速仪平行度精确测量装置及测量方法

发　　明　　人：李清泉；曹民；毛庆洲；张德津；章丽萍；谷伟华；曾星

专　　利　　号：ZL 2011 1 0275036.7

专利申请日：2011年09月16日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2015年01月07日

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局长
申长雨

中华人民共和国国家知识产权局
2015年01月07日

第1页（共1页）

证书号第1366328号

发明专利证书

发 明 名 称：激光束调节平行系统及其调节方法

发 明 人：李清泉；毛庆洲；曹民；张德津；曾星；章丽萍；韦仕仕

专 利 号：ZL 2011 1 0211062.3

专利申请日：2011年07月26日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2014年03月26日

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局长
申长雨

中华人民共和国国家知识产权局
2014年03月26日

第1页（共1页）

证书号第968265号

发明专利证书

发 明 名 称：激光动态弯沉测量车

发　明　人：李清泉;毛庆洲;付智能;曹民;张德津

专　利　号：ZL 2010 1 0561720.7

专利申请日：2010年11月18日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2012年06月06日

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局长 田力普

中华人民共和国国家知识产权局

2012年06月06日

第1页（共1页）

证书号第974261号

发明专利证书

发 明 名 称：高精度时空数据获取的多传感器集成同步控制方法和系统

发　明　人：李清泉；毛庆洲；高庆武；陈小宇；章丽萍

专　利　号：ZL 2010 1 0252860.6

专利申请日：2010年08月10日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2012年06月20日

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局长

2012年06月20日

第 1 页（共 1 页）

证书号第905630号

发明专利证书

发 明 名 称：基于动态规划的路面裂缝检测方法

发　明　人：李清泉；邹勤；毛庆洲；付智能

专　利　号：ZL 2010 1 0252859.3

专利申请日：2010年08月10日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2012年02月01日

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局长 田力普

2012年02月01日

第 1 页（共 1 页）

证书号第777126号

发明专利证书

发 明 名 称：地面车载移动检测系统

发　明　人：李清泉；毛庆洲；李必军；曹民；张德津

专　利　号：ZL 2009 1 0177893.6

专利申请日：2009年10月14日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2011年05月11日

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局长 田力普

中华人民共和国国家知识产权局

2011年05月11日

第1页（共1页）

证书号第1115754号

发明专利证书

发 明 名 称：地理位置数据采集系统

发　　明　　人：李清泉；李必军；李雪冬；夏舸；周志安；贾昆；张德津；曹民

专　　利　　号：ZL 2009 1 0162435.5

专利申请日：2009年08月04日

专 利 权 人：武汉武大卓越科技有限责任公司
中国电信股份有限公司湖北传输局

授权公告日：2013年01月02日

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局长 田力普

中华人民共和国国家知识产权局
2013年01月02日

第 1 页（共 1 页）

证书号第3258964号

发明专利证书

发 明 名 称：一种管道检测方法、装置以及存储介质

发 明 人：李清泉；朱家松；汪驰升；陈智鹏

专 利 号：ZL 2017 1 0841141.X

专利申请日：2017年09月18日

专 利 权 人：深圳大学

地 址：518060 广东省深圳市南山区南海大道3688号深圳大学

授权公告日：2019年02月19日　　　授权公告号：CN 107795854 B

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局长
申长雨

2019年02月19日

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其他事项参见背面

163856

证书号第3376228号

发明专利证书

发 明 名 称：基于测深激光全波形数据的漫衰减系数提取方法及系统

发 明 人：李清泉；丁凯；朱家松；汪驰升；王丹；崔扬

专 利 号：ZL 2017 1 0041595.9

专利申请日：2017年01月20日

专 利 权 人：深圳大学

地 址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2019年05月14日 授权公告号：CN 106802289 B

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局长
申长雨

国家知识产权局
2019年05月14日

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其他事项参见背面

160114

证书号第3357351号

发明专利证书

发 明 名 称：一种基于自适应选择节点的多波束测深估计方法及系统

发　明　人：李清泉;汪驰升;朱家松

专　利　号：ZL 2016 1 0154703.9

专利申请日：2016年03月17日

专 利 权 人：深圳大学

地　　　址：518060 广东省深圳市南山区南海大道3688号

授权公告日：2019年04月30日　　　授权公告号：CN 105841777 B

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局长
申长雨

国家知识产权局
2019年04月30日

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其他事项参见背面

160139

证书号第3212162号

发明专利证书

发明名称：隧道影像拼接方法及系统

发明人：李清泉;曹民

专利号：ZL 2016 1 0056749.7

专利申请日：2016年01月27日

专利权人：武汉武大卓越科技有限责任公司

地址：430223 湖北省武汉市东湖高新区武大科技园4路6号

授权公告日：2019年01月11日　　　授权公告号：CN 105550995 B

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国家知识产权局

2019年01月11日

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其他事项参见背面

161864

证书号第3174740号

发明专利证书

发 明 名 称：一种基于线结构光三维测量的公路标线检测方法

发　明　人：李清泉;张德津;曹民;林红

专　利　号：ZL 2016 1 0827906.X

专利申请日：2016年09月18日

专 利 权 人：武汉武大卓越科技有限责任公司

地　　　址：430223 湖北省武汉市东湖高新区武大科技园4路6号

授权公告日：2018年12月07日　　　授权公告号：CN 106373134 B

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局长
申长雨

国家知识产权局
2018年12月07日

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其他事项参见背面

证书号第2498279号

发明专利证书

发 明 名 称：基于机器视觉的轨道刚度测量方法

发　明　人：李清泉；曹民；张德津；林红；谢和礼；李辉；张志刚；文艺

专　利　号：ZL 2014 1 0400026.5

专利申请日：2014年08月14日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2017年05月31日

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局长
申长雨

中华人民共和国国家知识产权局
2017年05月31日

第 1 页（共 1 页）

证书号第2285632号

发明专利证书

发明名称：基于钢轨变形速度的轨道刚度快速测量方法

发 明 人：李清泉；张德津；曹民；林红；曲旋；王新林；孙小进；马斌

专 利 号：ZL 2014 1 0353102.1

专利申请日：2014年07月23日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2016年11月02日

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局长
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中华人民共和国国家知识产权局
2016年11月02日

第 1 页 (共 1 页)

证书号第1627899号

发明专利证书

发 明 名 称：基于汽车载体进行大型露天料场体积的自动测量方法

发　明　人：李清泉；张德津；曹民；张志刚；马斌；曲旋；李庆坤；章丽萍
李辉；文艺

专　利　号：ZL 2012 1 0347087.0

专利申请日：2012年09月18日

专 利 权 人：武汉武大卓越科技有限责任公司

授权公告日：2015年04月08日

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2015年04月08日

第 1 页 (共 1 页)

证书号第3394693号

发明专利证书

发明名称：一种三维路面标准轮廓提取方法及系统

发 明 人：李清泉;张德津;曹民;林红;桂容

专 利 号：ZL 2017 1 0861319.7

专利申请日：2017年09月21日

专 利 权 人：武汉武大卓越科技有限责任公司

地 址：430223 湖北省武汉市东湖高新区武大科技园4路6号

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Notice of acceptance for patent application

Davies Collison Cave Pty Ltd
Level 15
1 Nicholson Street
MELBOURNE VIC 3000
Australia

Your reference	35274945/RAB
Application number	2015392660
Applicant name	Wuhan Wuda Zoyon Science and Technology Co., Ltd

Dear Davies Collison Cave Pty Ltd,

This patent application was accepted on 29 April 2019. The accepted specification incorporates the following amendments:

S104 amendments up to and including item number: 2

The total number of claims at acceptance has been reported as: 7

Notice of the acceptance will appear in the Australian Official Journal of Patents on 16 May 2019.

Please review the acceptance details attached to this letter to ensure that they are correct. If you wish to amend any details prior to the grant please do so within 3 months of the advertisement of acceptance.

An Invitation to Pay (ITP) the acceptance fee will be issued to you. This fee will include an additional component if the number of claims exceeds 20.

Details of this patent application can be viewed on AusPat, our Australian patent search database.

Yours sincerely,

IP Australia

Acceptance summary

Standard patent details

Patent number:	2015392660
Title:	Stepwise-refinement pavement crack detection method
Your reference:	35274945/RAB
Number of claims at acceptance:	7

Applicant and inventor details

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Prior art details

Prior art documents:
US 20060276985 A1
CN 103870833 A

Priority details

Priority details:	None

International classification

G06T 7/00 (2006.01)

代表性论文及著作

目录

Computers & Geosciences 35 (2009) 2185–2190

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Variable-scale representation of road networks on small mobile devices

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ARTICLE INFO

Article history:
Received 22 January 2008
Received in revised form
28 November 2008
Accepted 3 December 2008

Keywords:
Adaptive visualization
Multi-resolution
LBS

ABSTRACT

A method is proposed for the adaptive multi-scale representation of road networks for location-based service applications. The method is able to automatically set a feasible scale according to geographic scope, the complexity of the road network, and the distance to the viewer. Moreover, the method achieves multi-scale representations of road networks on a display screen. The key steps of the method and the initial experimental studies undertaken to evaluate its feasibility are described.

1. Introduction

Visualization of spatial data (e.g., images, vector data) is of vital importance for spatial recognition, augmented reality, and many other different fields of application. Among these are location-based services (LBS) and car navigation systems, the typical characteristics of which are that the representation medium of the spatial data relies on mobile devices with small screens. As a consequence and because of the nature of mobile devices, display, particularly on small mobile devices, cannot simply rely on the techniques designed for traditional web or desktop applications.

The key factors affecting the display on small mobile devices can be summarized as follows:

- Data presentation and exploration on mobile devices are strongly affected by the small size and resolution of the displays.
- The computing capability is weak and the limited storage space implies that large datasets cannot be loaded on the device.
- Frequent zoom in/out and pan operations are tedious and cognitively complicated due to global context loss.

To communicate spatial data in both overview and detail, the system has to allow the user to flexibly zoom in and out (Brenner and Sester, 2005). Map data, particularly, road networks, are critical to routing, positioning, and guided navigation in car navigation systems. Extensive research has been done regarding the visualization of spatial data on small mobile devices (e.g., Harrie et al., 2002; Alan et al., 1996). Brenner and Sester (2005) implemented a method in which generalization operators were used for displaying building polygons on small mobile devices. Reichenbacher (2003) proposed a framework for mobile visualizations. Agrawala and Stolte (2001) developed techniques for the generalization of cartographic data that improved the usability of maps for road navigation on mobile devices. Their techniques are based on cognitive psychology research and are meaningful for personal navigation, as all turning points along the route are shown and less attention is paid to the length and direction of each road. Dong et al. (2007) also proposed a method to generate semantic road maps for mobile navigation. In their approach, semantic road maps are generated by distorting road lengths and angles and by simplifying road shapes. However, the maps may be too large to be displayed on the small screens of mobile devices. Several studies have explored the generation of variable-scale maps based on the principles of the Fisheye view (Sarkar and Brown, 1992), which shows a detailed representation of a circular area surrounding a point of interest (POI), e.g., a mouse point, whilst using a small scale and applying generalization and distortion operations to fit the remaining map area in the available space. However, with this technique road maps cannot be displayed on the screens of car navigation systems.

Fig. 1 shows a planned route consisting of a long and straight road. Suppose that a set of generalization operators are applied to generalize the road network. The generalized road map may still be too large to be displayed on a small screen, and the user might lose the context based on such a map. Thus, neither a generalized

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0098-3004/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cageo.2008.12.009

A Sensor-Fusion Drivable-Region and Lane-Detection System for Autonomous Vehicle Navigation in Challenging Road Scenarios

Qingquan Li, Long Chen, Ming Li, Shih-Lung Shaw, and Andreas Nüchter, *Member, IEEE*

***Abstract*—Autonomous vehicle navigation is challenging since various types of road scenarios in real urban environments have to be considered, particularly when only perception sensors are used, without position information. This paper presents a novel real-time optimal-drivable-region and lane detection system for autonomous driving based on the fusion of light detection and ranging (LIDAR) and vision data. Our system uses a multisensory scheme to cover the most drivable areas in front of a vehicle. We propose a feature-level fusion method for the LIDAR and vision data and an optimal selection strategy for detecting the best drivable region. Then, a conditional lane detection algorithm is selectively executed depending on the automatic classification of the optimal drivable region. Our system successfully handles both structured and unstructured roads. The results of several experiments are provided to demonstrate the reliability, effectiveness, and robustness of the system.**

***Index Terms*—Autonomous vehicles, drivable-region detection, lane detection, light detection and ranging (LIDAR), multilevel feature fusion, vision.**

I. Introduction

ROAD/LANE detection is a challenging task and a critical issue in autonomous vehicle navigation. Particularly in situations where no position information is available, a navigation system must be aware of the different kinds of terrain and road situations without the need for user input. This paper presents a real-time-capable road and lane detection system that deals with various kinds of challenging situations in real-world urban scenarios.

The complexity of urban environments is mainly due to the following factors.

1) Structured and unstructured roads occur alternately. Fig. 1(b) and (c) shows structured roads, and the other subfigures show examples of roads without lane markings.
2) Pavement uniformity cannot be always taken as given. There is interference from many causes, such as heavy shadow [cf. Fig. 1(d) and (h)], pavement distress, dirt, and puddles. Fig. 1(e) shows a road where oval stones and concrete are present, and Fig. 1(b) shows a road that has different colors and some dirt on it.
3) The appearance of a road may frequently change because of weather conditions, e.g., due to rain or snow [see Fig. 1(g)], and it also changes depending on the time of the day [see Fig. 1(c)].
4) The curvature of a road is not always as low as it is in highway scenarios. Here, we use "highway" in the sense of a paved main direct road, in contrast to a minor road. Fig. 1(a) shows a sharp turn where the camera at the front does not cover the whole turn.

Focusing on these challenging situations, we propose a multicue fusion-based system. By efficiently using several laser scanners and cameras, our perception system figures out the optimal drivable region and detects lane markings if necessary. Our real-time road and lane detection system is distinguished from related approaches in the following ways.

- Our system reliably deals with challenging urban environments, including both structured and unstructured roads, in real time. We estimate whether we need to do lane detection based on the proposed fusion method, without manual switching, or use information from a GPS and a geographic information system (GIS). In the case of structured roads, the lanes and the road edges are located. For unstructured roads, the system detects the drivable region and the boundaries of the road.
- A fusion-based method is proposed. Feature-level fusion is used for drivable-region detection. The lane detection method is restricted to the optimal drivable region and is only applied when the road is estimated to be wide enough.
- The proposed strategy extracts the optimal drivable region in front of the vehicle instead of recognizing every pixel of

Manuscript received January 6, 2013; revised May 11, 2013 and July 9, 2013; accepted August 28, 2013. Date of publication September 9, 2013; date of current version February 12, 2014. This work was supported in part by the Fundamental Research Funds for the Central Universities, by the National Natural Science Foundation of China under Grant 91120002 and Grant 41001306, by the Shenzhen Dedicated Funding of Strategic Emerging Industry Development Program under Grant JCYJ20121019111128765, by the German Academic Exchange Service under Grant PPP VR China 54368573, and by the Sino–German Center for Research Promotion under Grant GZ 692. The review of this paper was coordinated by Dr. M. S. Ahmed.

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TVT.2013.2281199

Remote Sens. **2015**, *7*, 11501-11524; doi:10.3390/rs70911501

OPEN ACCESS

remote sensing

ISSN 2072-4292

www.mdpi.com/journal/remotesensing

Technical Note

A Model-Driven Approach for 3D Modeling of Pylon from Airborne LiDAR Data

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Academic Editors: Juha Hyyppä, Wolfgang Wagner and Prasad S. Thenkabail

Received: 11 May 2015 / Accepted: 27 August 2015 / Published: 9 September 2015

Abstract: Reconstructing three-dimensional model of the pylon from **LiDAR** (**L**ight **D**etection **A**nd **R**anging) point clouds automatically is one of the key techniques for facilities management GIS system of high-voltage nationwide transmission smart grid. This paper presents a model-driven three-dimensional pylon modeling (MD3DM) method using airborne LiDAR data. We start with constructing a parametric model of pylon, based on its actual structure and the characteristics of point clouds data. In this model, a pylon is divided into three parts: pylon legs, pylon body and pylon head. The modeling approach mainly consists of four steps. Firstly, point clouds of individual pylon are detected and segmented from massive high-voltage transmission corridor point clouds automatically. Secondly, an individual pylon is divided into three relatively simple parts in order to reconstruct different parts with different strategies. Its position and direction are extracted by contour analysis of the pylon body in this stage. Thirdly, the geometric features of the pylon head are extracted, from which the head type is derived with a SVM (Support Vector Machine) classifier. After that, the head is constructed by seeking corresponding model

Novel Approach to Pavement Image Segmentation Based on Neighboring Difference Histogram Method

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Abstract

Conventional human visual pavement distress detection method is very costly, time-consuming, labor-intensive, and is often dangerous due to exposure to traffic. It possesses various drawbacks such as being unable to provide meaningful quantitative information and with a long periodic measurement. In this paper, a novel pavement image-thresholding algorithm based on neighboring difference histogram method (NDHM) is proposed. The main idea of the proposed method is based on the facts that: (1) the distressed pixels in pavement images are darker than their surroundings and continuous; (2) the thresholding value is strongly related with the image standard deviation. In this method an objective function for maximizing the divergence between the two classes is constructed. The paper compares the new method with the classical discriminant analysis method of Otsu and the entropic method of Kapur et al. The experimental results have demonstrated that the distresses are segmented from the background correctly and effectively.

1. Introduction

Pavement condition data collection style has transformed from manually to automatically because of the development of computer technologies, digital image acquisition, and multi-sensors technologies, but the complexity of the digital image processing always made the data processing come to the bottle-neck of the application system. Many researchers have paid a great deal of attention to automated pavement cracking detection through image processing.

Over the past several decades, a number of approaches for automatic pavement cracking detection have been proposed which can be divided into two kinds of method classes: the image edge detection based class and the image area segmentation based ones. At the early stage of the image-based pavement cracking detection, several kinds of edge detection methods were proposed such as soble-based algorithm (Li. 2003), Wavelet-based canny algorithm (Bahram Javidi, el al. 2003), snake-based algorithm (Liang-Chien Chen, et al. 2001), and Dijkstra-based algorithm (Seung-Nam Yu, et al. 2006), they have been shown successful under limited condition according to their experimental results. However, due to the highly textured nature of road surface, which resulted in highly noisy pavement images, the edge detection based approaches can not get reliable results. In recent years, researchers pay more attention to image area segmentation based automatic pavement cracking detection, and especially pavement image thresholding. Image thresholding is the process of classifying image gray values into two or more classes. The gray level histogram is usually the starting point for image classification, however, the thresholding methods that use the shape of gray-level histogram suffer many difficulties. Entropy may be used as a criteria function of thresholding (J.N. Kapur, et al., 1985). Thresholding methods based on the entropy function do not always give a good solution. Sometimes, results obtained by the entropic thresholding methods are found to be biased. And other criteria can be found to be useful for

978-0-7695-3119-9/08 $25.00 © 2008 IEEE
DOI 10.1109/CISP.2008.13

ISPRS Journal of Photogrammetry and Remote Sensing 84 (2013) 100–113

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Review Article

Geometric structure simplification of 3D building models

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ARTICLE INFO

Article history:
Received 25 August 2012
Received in revised form 29 June 2013
Accepted 8 July 2013
Available online 13 August 2013

Keywords:
3D building model
Levels of detail
Simplification
Structure recognition

ABSTRACT

The complexity of building models directly affects the application efficiencies of 3D urban maps. To address the challenges of building models with various structures, we propose a structural simplification method in this paper. The geometric structures of building models are classified into three categories: embedded structures, compositional structures, and connecting structures, which can be extracted separately through convex/concave analysis. Some specific rules are proposed for the simplification of geometric structures, and the building models are suggested to be simplified progressively. The robustness and efficiency of the method are demonstrated by experiments, and the applications of the Levels of detail of the building models are illustrated.

1. Introduction

Due to technological advances in the fields of surveying and computer graphics, 3D maps have become very popular in various navigation applications, especially in urban environments (Grabler et al., 2008). Building models are the most important elements of 3D urban maps, and their complexity directly affects the application efficiency. Multi-resolution building simplification is recognized as a common solution that satisfies the demands of different application (Krüger and Stahl, 1998). Many simplification methods have been proposed out for specific types of building models or specific applications (Meng and Forberg, 2006; Sester, 2007), but the simplification of 3D building models still remains a challenge, particularly considering their variable structures (see Fig. 1 for some examples). Researchers have tried to avoid this problem by focusing on the preservation of features during model simplification (Coors, 2001; Jiang et al., 2011), whereas we focus directly on the structure in building models in this paper.

Compared with terrain and natural objects, the structures of building models are much more complicated, especially those of landmarks. For examples, a modern building model usually has countless windows on its walls, the balconies and chimneys of country houses can differ from each other in thousands of ways, columns are very common in Roman architectures, and artistic architectures are always composed of the parts with unique shapes, such as pyramidal or gabled roofs. Some structures represent the detailed features of the building models, which are trivial in representation, but other structures show the global shapes of the models, which are important for recognition.

Given the integrity and consistency of structures in the building model, we could not split each structure apart during simplification and need to simplify similar structures simultaneously. Extracting and grouping detailed structures for simplification and maintaining the global shape of 3D building model in the process of simplification are difficult problems. In this paper, we extracted three types of geometric structures depending on the topological relationships among components and we propose a structural simplification method for 3D building models.

The remaining parts of this paper are organized as follows. We review related work in Section 2. In Section 3, surface patch extraction algorithm is introduced as a preprocessing step to convert the triangular model into the polygonal model. In Section 4, we discuss the classification of the geometric structures of building models and describe a robust geometric structure extraction method in detail. Section 5 elaborates the structural simplification rules and proposes a progressive simplification method for building models. The experimental results are presented and discussed in Section 6. Finally, Section 7 briefly concludes the paper.

2. Related work

3D building models have special mesh construction patterns and application demands, but most simplification approaches for

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0924-2716/$ - see front matter
http://dx.doi.org/10.1016/j.isprsjprs.2013.07.006

Decision fusion of very high resolution images for urban land-cover mapping based on Bayesian network

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Abstract. Traditional image processing techniques have been proven to be inadequate for urban land-cover mapping using very high resolution (VHR) remotely sensed imagery. Abundant features such as texture, shape, and structural information can be extracted from high-resolution images, which make it possible to distinguish land covers more effectively. However, the multisource characteristics of VHR images place significant demands on the classification method in terms of both efficiency and effectiveness. The most often used method is vector stacking fusion, in which a single classifier is trained over the whole feature space; statistical differences and separability complementarities among different features are rarely considered. Hence, appropriate feature fusion and classification of multisource features become the key issues in the field of urban land-cover mapping. A novel decision fusion method based on a Bayesian network is proposed to handle the multisource features of VHR images which provide redundant or complementary results. Subclassifiers are constructed separately based on multiple feature sets and then embedded into the naive Bayesian network classifier (NBC). The final results are obtained by fusing all the subclassifiers into the NBC framework. Experiments on aerial and QuickBird images demonstrated that the performance of the proposed method is greatly improved compared with vector stacking methods, and significantly improved compared with the multiple-classifier systems and multiple kernels learning support vector machine. Moreover, the proposed method has advantages in feature fusion of VHR images in urban land-cover mapping. © *2013 Society of Photo-Optical Instrumentation Engineers (SPIE)* [DOI: 10.1117/1.JRS.7.073551]

Keywords: multisource features; decision fusion; Bayesian network; urban land-cover mapping.

Paper 12457 received Dec. 11, 2012; revised manuscript received Mar. 31, 2013; accepted for publication Apr. 15, 2013; published online Jun. 3, 2013.

1 Introduction

Very high resolution (VHR) commercial satellite images have facilitated research into land-cover mapping of urban areas. The maps generated from VHR images are important reference data for urban development planning, emergency response, and disaster assessment etc. Improvements in spatial resolution have made it possible to identify small structures such as houses or roundabouts in dense urban areas.[1] When analyzing VHR images, in addition to spectral characteristics, spatial information, including image texture, shape, structure, and context information, plays an increasingly important role in the classification process. As a matter of fact, it has been demonstrated that both spatial and spectral information are required simultaneously to achieve good classification performance.[2–5] These different types of features, such as spectral, textural and structural features, are usually combined to improve classification accuracy because they provide complementary information.

In recent years, significant attention has been focused on multisource features fusion of VHR images for urban land-cover mapping. Numerous algorithms have been proposed in the literature

0091-3286/2013/$25.00 © 2013 SPIE

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Multi-resolution representation of digital terrain models with terrain features preservation

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Abstract multi-resolution TIN model is an important issue in the contexts of visualization, virtual reality (VR), and geographic information systems (GIS). This paper proposes a new method for constructing multi-resolution TIN models with multi-scale topographic features preservation. The proposed method is driven by a half-edge collapse operation in a greedy framework and employs a new quadric error metric to efficiently measure geometric errors. We define topographic features in a multi-scale manner using a center-surround operator on Gaussian-weighted mean curvatures. Experimental results demonstrate that the proposed method performs better than previous methods in terms of topographic features preservation, and is able to achieve multi-resolution TIN models with a higher accuracy.

digital terrain models, level of detail, differential-geometry, quadric error metrics, topographic feature

1 Introduction

The representation of digital terrain models at different levels of accuracy and resolution has an impact on applications such as geographic information systems (GISs)[1], virtual reality (VR), progressive transmission of spatial data[2], mobile visualizations, and Web-GIS[3]. Multi-resolution terrain models allow for representation, analysis and manipulation of terrain data at variable resolutions, and provide a promising solution for the progressive transmission of spatial data, spatial data compression, mobile visualizations, and so on. However, the existing methods and algorithms mainly focus on the accuracy and running times of generating the levels-of-details (LoDs) of terrains. Less attention has been paid to features preservation of terrains, particularly at a low resolution model. Suppose that the original terrain features are lost at a low resolution terrain

Received December 12, 2007; accepted January 14, 2008
doi: 10.1007/s11431-008-5015-4
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Supported by the National Basic Research Program of China ("973") (Grant No. 2006CB705500), the National Natural Science Foundation of China (Grant No. 40571134), the National Hi-Tech Research and Development Program of China (Grant Nos. 2007AA12Z241, 2007AA12Z212) and Outstanding Scholar of Ministry of Education of China (Grant No. NCET-07-0643)

An approach for traffic prohibition sign detection

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ABSTRACT

This paper presents an off-line traffic prohibition sign detection approach, whose core is based on combination with the color feature of traffic prohibition signs, shape feature and degree of circularity. Matlab-Image-processing toolbox is used for this purpose. In order to reduce the computational cost, a pre-processing of the image is applied before the core. Then, we employ the obvious redness attribute of prohibition signs to coarsely eliminate the non-redness image in the input data. Again, a edge-detection operator, Canny edge detector, is applied to extract the potential edge. Finally, Degree of circularity is used to verdict the traffic prohibition sign. Experimental results show that our systems offer satisfactory performance.

Keywords: traffic sign detection, color feature, shape feature, degree of circularity, Canny edge detector

1. INTRODUCTION

With the development of economic and society, the vehicle numbers and the incidents greatly increase years and years in China. For car drivers, correctly identifying traffic signs at right time and right place plays a crucial part in insuring themselves and their passengers' safe journey. Sometimes, due to changing weather conditions or viewing angles, traffic signs are not easily to be seen until it is too late. Development of automatic systems for recognition of traffic signs is therefore an important approach to improve driving safety [1]. Although the detection and recognition of traffic signs has been a problem studied by an important number of researchers in the world, it is necessary to research a special algorithm to detect the Chinese traffic signs because of the difference of traffic signs in every country.

Any road signs use particular colors and geometric shapes to attract drivers' attention. However, the difficulty of developing traffic sign detection and recognition systems largely comes from several aspects. First, colors may fade after long exposure to the sun, air pollution and weather condition. Moreover, paint may even flake or peel off, and signs may get damaged. Second, surrounding environments widely vary, such as varying lighting conditions from day to night, presence of shadows and occlusion and so on. Third, the signs may be slightly tilted, partially blocked by tree branches, dirt, or posts, or incomplete due to corrosion, all of which provide severe challenges.

Recently, many techniques have been developed to detect road signs [2,3]. Pacheco *et al* [4] used to add special color barcodes under road signs to help road sign recognition for vision-based systems. However, much time and resources would be consumed to replace road signs, making this solution uneconomical. Escalera and Moreno [5] combined colors and shapes to detect road signs. Aoyagi and Asakura [6] presented genetic algorithms to detect road signs from gray-level video imagery. Unfortunately, due to the discrete nature of crossover and mutation operators, optimal solutions are not guaranteed. Chiung-Yao Fang *et al*[7] employed the color video sequences to detect the road signs in complex traffic scenes and the Kalman filter, as the tracking technique, to reduce the search time for road sign detection. Miura *et al*[8] installed two cameras, one for wide-angle vision and the other for telephoto in the vehicle and developed a real time traffic sign recognition system based on active vision and color and shape information. Its disadvantages included

Geoinformatics 2006: GNSS and Integrated Geospatial Applications, edited by Deren Li, Linyuan Xia,
Proc. of SPIE Vol. 6418, 641819, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.712921

Proceedings of the 11th International IEEE
Conference on Intelligent Transportation Systems
Beijing, China, October 12-15, 2008

A Voronoi-based Hierarchical Graph Model of Road Network for Route Planning

Qingquan Li and Zhe Zeng

***Abstract*— The road network is a key part of route planning, the core function module of GIS-T. The better organization of the road network is used, the higher performance of route planning can be achieved. This paper proposes a Voronoi-based hierarchical graph model of road network for route planning. It constructs the hierarchical graph based on hierarchical spatial reasoning and utilizes graph Voronoi diagram to associate adjacent levels in hierarchical graph of road network. Because of using graph Voronoi diagram, the hierarchical graph model can make the hierarchical searching process simpler and more efficient. The searching range is shrinked and the consume time is decreased in the hierarchical route planning.**

I. INTRODUCTION

At the core of any GIS-T(Geographic Information Systems for Transportation) software are procedures or algorithms for conducting analyse and solving routing problems within a network [1]. The road network is a key component in ITS navigation system, location based services which are considered as applications of GIS-T software. The better organization of the road network is designed, the higher performance of route planning can be achieved. The hierarchy structure of road network is extensively applied to route planning algorithm.

The approaches of constructing the hierarchy are based on the following idea: The road network is primarily considered as an original graph. The graph is divided into several partitions. Then, the higher level subgraph is formed by all border nodes and shortest paths between these partitions. The two steps are recursively performed not until that the hierarchy of road network can be completely formed. For example, this idea can be found in [2], [3]. The HEPV model [2] was proposed by Ning Jing and Yun-Wu Huang. To achieve an effective fragmentation, they developed a partitioning algorithm called spatial partitioning which clusters graph links into partitions based on spatial proximity [4]. Spatial partitioning takes advantage of ITS map characteristics such as the grid-like (nearplanar) patterns, and the relatively short distance for the majority of links. In HiTi graph model [3], arbitrary shaped boundaries (e.g., political regional boundaries) partition a road map into a set of Component ROad Maps (CROM). The CROM can be defined to contain a set of CROMs, thus creating a multilevel hierarchy. The HiTi graph is a graph whose nodes are the boundary nodes of the CROMs and edges are the path view and cut connections of CROMs. The graph partition theory is mainly applied into these approaches, however the hierarchical attribute of road classes is rarely taken as a fundamental principle of constructing hierarchy.

A hierarchical structure based on an abstraction from the hierarchy of road classes and an algorithm which searches for an optimal path in the sub-graph of the highest possible level had been proposed by Adrijana Car and Andrew Frank [5]. This led to an efficient way-finding algorithm, even where standard simple graph search algorithms for the shortest path become inadequate. This hierarchical structure of the road network is also extensively supported by the two main vehicle navigation data formats, such as Kiwi and SDAL. However, there are two factors ignored by this hierarchical model. First, there is no criterion that the node, through which we can start to search the higher neighboring level sub-graph, can be decided at the beginning of the current level searching. And this node is also the target node in the current level searching. Second, because it is non-determinate, the range of the searching will be uncertainty in current level. In the worst case, the search range could be extended to much larger. The Voronoi-based hierarchical graph is put forward in this paper in order to solve this problems.

In this hierarchical model, the road network is divided into multi-level sub-graphs by road classes. The higher the level is, the smaller the sub-graph is. The graph Voronoi diagram [6] is used to construct hierarchical graph of road network because the shortest path distance between the nodes of the graph Voronoi region and its Voronoi node is smaller than between these nodes and other Voronoi nodes in the current level sub-graph. The current level sub-graph is partitioned by the graph Voronoi diagram of which Voronoi nodes are included by the higher-level neighboring sub-graph. Therefore, the Voronoi node of the graph Voronoi region, which exists in the current level sub-graph, should be the one that we can start to search the higher level. At the same time, the Voronoi node is also considered as target node in current level route planning, so the route search range can be limited by the heuristic strategy.

II. VORONOI-BASED HIERARCHICAL GRAPH STRUCTURE

The Voronoi-based hierarchical graph is mainly based on hierarchical spatial reasoning of road network and graph

This work is supported by the National Natural Science Foundation of China (No.40571134) and the National Basic Research Program of China (973 program, No.2006CB705500).

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Hierarchical Model of Road Network for Route Planning in Vehicle Navigation Systems

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Abstract — Road network is a fundamental part of route planning in vehicle navigation systems. In this paper two aspects are considered for hierarchical model of road networks, which are data model and graph model. The former aims to present a hierarchical road network in vehicle navigation systems. The latter model constructs a multi-level graph according to the hierarchy traits of road network. Based on these two aspects, a road network can be better organized for route planning of vehicle navigation systems.

I. Introduction

Over two decades, GPS-assisted equipments have come to pervade many aspects of ITS. As an application among them, vehicle navigation technique is facilitating our daily lives. When driving to a place you wanted to go, it can accurately locate your position, rapidly calculate an optimal route, and then give your correct guidance through voice broadcast. The optimal route computation plays a key role in the above process. The conventional planar routing algorithms are time-consuming and inefficient when applied to large road networks. And they neglect hierarchy, which is a distinguishing feature of road network. The natural hierarchy can 'divide and conquest' large road network while route planning algorithms employ it. Most hierarchical approaches

Digital Object Identifier 10.1109/MITS.2009.933860

1939-1390/09/$26.00©2009IEEE

International Journal of Applied Earth Observation and Geoinformation 13 (2011) 110–119

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Path-finding through flexible hierarchical road networks: An experiential approach using taxi trajectory data

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ARTICLE INFO

Article history:
Received 11 December 2009
Accepted 20 July 2010

Keywords:
Path-finding
Road network
Hierarchy
Taxi trajectory
Navigation system

ABSTRACT

Optimal paths computed by conventional path-planning algorithms are usually not "optimal" since realistic traffic information and local road network characteristics are not considered. We present a new experiential approach that computes optimal paths based on the experience of taxi drivers by mining a huge number of floating car trajectories. The approach consists of three steps. First, routes are recovered from original taxi trajectories. Second, an experiential road hierarchy is constructed using travel frequency and speed information for road segments. Third, experiential optimal paths are planned based on the experiential road hierarchy. Compared with conventional path-planning methods, the proposed method provides better experiential optimal path identification. Experiments demonstrate that the travel time is less for these experiential paths than for paths planned by conventional methods. Results obtained for a case study in the city of Wuhan, China, demonstrate that experiential optimal paths can be flexibly obtained in different time intervals, particularly during peak hours.

1. Introduction

Navigation systems are an important component of intelligent transportation systems and have become a standard device in vehicles, cell phones and other mobile devices. Many web-based mapping services also provide navigation tools for regular users. Path planning, a core component of various navigation applications, involves identification of the shortest path for any given origin–destination pair in a directed graph in which a non-negative weight is applied to the length or travel time for road segments. The Dijkstra (1959) algorithm and label correcting (LC) algorithm (Bellman, 1958) routing are two classical methods used to solve the shortest path problem. Variants of these algorithms have been extensively studied (Cherkassky et al., 1996; Thorup, 2004). Depending on whether the edge weights are static or dynamic, we can classify theoretical computation schemes for the shortest path into two categories. In recent years, researchers realized that preprocessing of road networks can significantly improve the performance of the Dijkstra (LS) algorithm (Gutman, 2004; Goldberg and Harrelson, 2005; Kohler et al., 2006; Sanders and Schultes, 2006). Preprocessing is usually performed for road networks with static hierarchies. Computation for static networks can yield the exact shortest paths using Euclidean distance-based measurements. Computation for dynamic traffic conditions is a theoretically complicated operations research problem (Ahuja et al., 1993). The uncertainty of real traffic situations means that the best search results are not necessarily computed in reality. Finding the exact shortest path in road networks with dynamic traffic conditions (dynamic road networks) is a non-deterministic polynomial-time hard (NP-hard) problem (Ahuja et al.,2003). A few simplifying assumptions can be made, such as transformation of dynamic networks to time-dependent networks using the first in, first out (FIFO) condition. The shortest path in a FIFO network can be computed using the label algorithm (Kaufman and Smith, 1993). However, the theoretical assumptions do not completely hold in a real road network. Thus, there is a gap between theoretical algorithm research and real-world applications.

Taxi drivers usually disregard the planned routes computed by navigation systems. They tend to adopt their own "best" routes according to their driving experience. Very often, their solutions are more cost-effective (less travel time and lower costs) than the shortest paths identified by traditional path-planning algorithms. Their experience implicitly comprises their familiarity with local

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0303-2434/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jag.2010.07.003

Hindawi Publishing Corporation
EURASIP Journal on Advances in Signal Processing
Volume 2011, Article ID 649675, 12 pages
doi:10.1155/2011/649675

Research Article

Pavement Crack Classification via Spatial Distribution Features

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Received 18 December 2010; Revised 26 February 2011; Accepted 8 March 2011

Academic Editor: Mark Liao

Pavement crack types provide important information for making pavement maintenance strategies. This paper proposes an automatic pavement crack classification approach, exploiting the spatial distribution features (i.e., direction feature and density feature) of the cracks under a neural network model. In this approach, a direction coding (D-Coding) algorithm is presented to encode the crack subsections and extract the direction features, and a Delaunay Triangulation technique is employed to analyze the crack region structure and extract the density features. As regarding skeletonized crack sections rather than crack pixels, the spatial distribution features hold considerable feature significance for each type of cracks. Empirical study indicates a classification precision of over 98% of the proposed approach.

1. Introduction

Pavement crack types are important for pavement dilapidation analysis and pavement maintenance decision-making. For asphalt pavements, the pavement cracks can generally be classified into four types—the transverse crack, the longitudinal crack, the block crack, and the alligator crack [1] (see Figure 1). Each type of crack holds its own weight in the pavement maintenance evaluation. Therefore, the exploration of a robust and reliable approach for pavement crack classification has great significance.

Over the past several decades, with the development of high-speed cameras and large storage hardware, a real-time collection of pavement images has been realized. While along with the progress of image processing and pattern recognition techniques, the image-based crack recognition method gradually replaces the traditional manual method and becomes a common way for pavement crack detection [2–7]. Pavement crack recognition includes two stages—the crack detection and the crack classification. This paper mostly focuses on the later.

Though a variety of approaches for pavement crack classification have been proposed in the last two decades, most of them cannot meet the requirements in practice due to their inadequate consideration on spatial distribution features of the cracks. For example, the projection histogram methods [8–10] can be qualified to identify the directional difference between cracks, but it may not be capable of distinguishing the density difference. In a pavement image, typically, a crack has a linear or curvilinear structure, the spatial distribution of the crack points determines which type of crack it is. Therefore, analyzing the crack's spatial distribution features, that is, the direction feature and density feature, is the key point to crack classification. In this study, a novel pavement crack classification approach is proposed by using spatial distribution features in a neural network. Under this approach, the problem of crack feature extraction is formulated as the problem of direction and density feature extraction on a binary skeletonized crack section. Generally, the transverse and longitudinal cracks hold much more direction features than the block and alligator cracks, while the block and alligator cracks have more density features. Moreover, the block cracks own less density features than the alligator cracks. According to these characteristics of the different crack types, we present a direction coding algorithm (D-Coding) stemming from Freeman coding [11] to acquire the direction features from skeletonized crack sections, meanwhile we adopt the Delaunay Triangulation

Efficient Calibration of a Laser Dynamic Deflectometer

Qingquan Li, Qin Zou, *Member, IEEE*, Qingzhou Mao, Xiaoyu Chen, and Bijun Li

***Abstract*—The bearing capacity of the road pavement is one of the most important indices that reflect the road condition. To collect such data, various deflectometers were developed in the past three decades. Note that the newly developed Traffic-Speed Deflectometer (TSD) declares to perform a nondestructive measuring at traffic speeds. However, TSD is limited as it needs more than 4 h to calibrate the system before a measuring task. This paper introduces a Laser Dynamic Deflectometer (LDD) developed at the Transportation Research Center of Wuhan University. LDD applies four laser Doppler sensors mounted on a measuring beam to capture the deflection velocity of the pavement surface. Unlike TSD using a servo to keep the beam static, LDD utilizes a gyroscope to measure and compensate the vibration of the beam. Moreover, in the procedure of calibration, LDD applies an efficient relative-motion method to calculate the relative angles between each two Doppler lasers, which reduces the time of system calibration to about 2 h.**

***Index Terms*—Bearing capacity, deflectometer, Euler-Bernoulli equation, laser doppler, laser sensor application.**

I. Introduction

THE bearing capacity is an important indicator for the structural condition of the road. In civil engineering, a road is required to be constructed with a bearing capacity complying with a certain standard. Therefore, all newly constructed roads should be undertaken a measurement of bearing capacity. Meanwhile, due to continuous vehicle loadings and environmental factors, the performance of the pavement structure would gradually be undermined, which may accelerate the damage of the road. Thus, to help make in-time and reasonable maintenance and rehabilitation decision, all longtime-used roads should be periodically diagnosed on their structural state, i.e., the bearing capacity.

In order to measure the bearing capacity of road pavements, various research efforts have been made in the past three decades, and several kinds of systems have been developed, e.g., Falling Weight Deflectometer (FWD) [1]–[4], Light Falling Weight Deflectometer (LWD) [5]–[7], Rolling Dynamic Deflectometer (RDD) [8]–[10], Rolling Wheel Deflectometer (RWD) [11], and Road Deflection Tester (RDT) [12], etc. However, most of them have limitations in the practice of road testing due to several reasons, e.g., high operation cost, low efficiency, low safety, traffic interruptions, etc. Given the successful applications of high-precision and high-speed laser Doppler sensors in measuring the velocity of moving objects [13]–[15], a traffic-speed measurement of the structural strength of the road has gradually been possible. Note that, the Traffic-Speed Deflectograph (TSD) [16]–[26] developed by Greenwood company is a continuous deflection measurement system, which uses high-speed laser Doppler sensors to measure the deflection velocity of the pavement and employs the Euler-Bernoulli equation to calculate the deflection range of the pavement. Since performing a fast and continuous measurement, and providing a safe environment for the operators, TSD is counted as the state of the art among the relative techniques.

However, TSD still has limitations in its geometric calibration. TSD applies four laser Doppler sensors to measure the deflection velocity of the road surface, where three of them, named L_1, L_2, and L_3, are used to capture the deflection velocity of three points in the deflection bowl, and one, named L_4, is taken as reference. In order to ensure the accuracy of the measurement, TSD should be calibrated before a measuring task, where some geometric parameters of the system should be found. In this calibration procedure, the most important part is to calculate the angles between each of the three measuring laser Doppler sensors, i.e., L_1, L_2, and L_3, and the reference laser Doppler sensor, i.e., L_4. To gain the values of these angles, back-calculation methods were used [18], [21], [23]. The initial calibration procedure was proposed by the Greenwood company, which involved removing the five tonne lead ballast and running the TSD over a stiff concrete pavement. Under the assumption that the stiff road deflects little under the reduced load, the calibration angles of the measurement lasers can be calculated in a back-calculation way. However, this calibration phase was delicate and may commonly take up to a half-day to finish [18]. Improved methods were exploited in [21], [23], where accelerometers were applied to calculate the deflection under the running load of TSD. This calibration procedure involved installing accelerometers under the pavement surface, which was also complex and time consuming.

In this paper, a new calibration method based on the idea of relative motion is proposed to efficiently calculate the geometric parameters. In this method, the relative angles between each two Doppler lasers are gained by moving a profile table under

Manuscript received June 26, 2012; revised September 8, 2012; accepted October 10, 2012. Date of publication February 7, 2013; date of current version March 8, 2013. This research is partially supported by the National Natural Science Foundation of China on Innovation Team Program under Grant 40721001, the National High Technology Research and Development Program of China (863 Program) under Grant 2012AA112503. The Associate Editor coordinating the review process for this paper was Dr. George Xiao. (*Corresponding author: Dr. Q. Zou*).

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TIM.2013.2240932

Image and Vision Computing 29 (2011) 861–872

Contents lists available at SciVerse ScienceDirect

Image and Vision Computing

journal homepage: www.elsevier.com/locate/imavis

FoSA: F* Seed-growing Approach for crack-line detection from pavement images☆

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ARTICLE INFO

Article history:
Received 28 July 2010
Received in revised form 29 March 2011
Accepted 10 October 2011

Keywords:
Line detection
Pavement crack
Seed-growing
Dynamic programming

ABSTRACT

Most existing approaches for pavement crack line detection implicitly assume that pavement cracks in images are with high contrast and good continuity. This assumption does not hold in pavement distress detection practice, where pavement cracks are often blurry and discontinuous due to particle materials of road surface, crack degradation, and unreliable crack shadows. To this end, we propose in this paper FoSA — F* Seed-growing Approach for automatic crack-line detection, which extends the F* algorithm in two aspects. It exploits a seed-growing strategy to remove the requirement that the start and end points should be set in advance. Moreover, it narrows the global searching space to the interested local space to improve its efficiency. Empirical study demonstrates the correctness, completeness and efficiency of FoSA.

1. Introduction

The detection of curvilinear structures, also referred to as lines, is a fundamental low-level operation, which has been adopted in various applications in computer vision and pattern recognition [1–3]. In general, line-detection algorithms can be classified into two types: local and global algorithms. The former exploits local features, such as intensity, gradient and local variance, to achieve goals of line enhancement and segmentation. It involves a series of edge detection operators [4, 5], morphological filter [6], steerable filter [7], and isotropic non-linear filter [2]. The later tracks and extracts lines in an overall view through dynamic programming to optimize target functions to a certain criterion. It consists of MAP statistic model [8], graphic model [9–11], snake model [12, 13], and decision tree model [3].

A pavement crack is typically with a curvilinear structure. A variety of approaches for pavement crack detection have been proposed in the last decade, but most of them cannot automatically detect cracks owing to grain-like characteristics of the road materials. They implicitly assume that speckle noises in image background are in low-level, and pavement cracks in images are with high contrast and good continuity. However, this assumption does not always hold in real world due to two reasons. One is that pavement images usually are mixed with the grain-like textured background, which acts as speckle noises that significantly affects the detection accuracy. The other is that cracks in pavement images are characterized by low Signal-to-Noise Ratio (SNR), low contrast, and bad spatial continuity.

Figure 1(a) shows a typical pavement image, Fig. 1(b) and (c) are the results from traditional local methods stemming from Canny edge detection [4] and wavelet transform [14]. As cracks are line-like structures on a large scale, these methods, that use small scale information, tend to extract only fragments of them.

In this paper, we propose FoSA — F* Seed-growing Approach for crack-line detection by extending the F* algorithm, which takes advantage of dynamic programming to track linear structures in a global view. It presents a seed-growing strategy to eliminate the requirement in the F* algorithm that the start and end points for tracking should be set beforehand. Thus, FoSA is capable of automatically identifying the start and end points. It also puts forward an interest-constrained technique which narrows the global searching space to the local space, and hence dramatically improves the efficiency of the F* algorithm. In fact, FoSA formulates the crack extraction problem as a seed-growing problem. It uses a filtering based on average path cost (i.e., APC-based filtering) over the crack element set to aggregate crack seeds with high credibility. With these seeds, FoSA presents an F* seed-growing algorithm (i.e., FoS) to collect crack strings. Finally, FoSA conducts pruning and linking operations to refine the crack strings and extract the whole identified cracks.

The rest of this paper is organized as follows. Section 2 briefly overviews the related work on pavement crack detection. Section 3 introduces the F* seed-growing algorithm. Section 4 discusses FoSA in detail. Section 5 reports our empirical study and Section 6 concludes our work by pointing out future directions.

2. Related work

Intuitively, image-based techniques are fundamental in pavement crack detection, which have received intensive attention since the

☆ This paper has been recommended for acceptance by Paolo Remagnino.

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doi:10.1016/j.imavis.2011.10.003

DeepCrack: Learning Hierarchical Convolutional Features for Crack Detection

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***Abstract*—Cracks are typical line structures that are of interest in many computer-vision applications. In practice, many cracks, e.g., pavement cracks, show poor continuity and low contrast, which brings great challenges to image-based crack detection by using low-level features. In this paper, we propose DeepCrack - an end-to-end trainable deep convolutional neural network for automatic crack detection by learning high-level features for crack representation. In this method, multi-scale deep convolutional features learned at hierarchical convolutional stages are fused together to capture the line structures. More detailed representations are made in larger-scale feature maps and more holistic representations are made in smaller-scale feature maps. We build DeepCrack net on the encoder-decoder architecture of SegNet, and pairwisely fuse the convolutional features generated in the encoder network and in the decoder network at the same scale. We train DeepCrack net on one crack dataset and evaluate it on three others. The experimental results demonstrate that DeepCrack achieves F-Measure over 0.87 on the three challenging datasets in average and outperforms the current state-of-the-art methods.**

***Index Terms*—line detection, edge detection, contour grouping, crack detection, convolutional neural network.**

I. Introduction

Cracks are common defects that can be found on surfaces of various types of physical structures, e.g., the road pavement [1], [2], the wall of nuclear power plants [3], the ceiling of tunnels [4], etc. Repairing cracks is an important task for preventing the expansion of harms and keeping the safety of engineering infrastructures. For example, a crack on the highway pavement will easily become a hole in just one rainy night, which will then be hazardous for high-speed vehicles. For a country like China or US, there are over 100,000 Km highway to be tested and maintained periodically. Automatic testing methods are greatly desired to improve the testing efficiency and reduce the cost. Crack is one of the most common defects. Fixing a crack before its deterioration can greatly reduce the cost of maintenance. Up to date, fully automatic crack detection from noise background is still a challenge.

As a crack is visually a linear/curvilinear structure, crack detection can be formulated as line detection, which is a fundamental problem in computer vision [5]–[7]. In visual perception, a crack can be characterized from two perspectives. From a global perspective, it looks like a one-pixel wide edge in the image, as it is thin and often holds jumping intensity to the background. From a local perspective, it is a line object that has a certain width. Accordingly, the crack detection methods can be roughly divided into two categories: edge-detection based ones and image-segmentation based ones. In the ideal case, if a crack has good continuity and high contrast, then traditional edge detection and image segmentation methods could detect it with high accuracy.

However, in practice cracks may constantly suffer from noise in the background, leading to poor continuity and low contrast. For example, in the pavement image shown in Fig. 1(a), impulse noises brought by the grain-like pavement texture break the crack and undermine its continuity, while the shadow reduces the contrast between the crack and the background. In addition, the direction of exposure may also impact the imaging quality of the crack. These complications commonly lead to degraded performance of the traditional low-level feature based crack detection methods.

In recent years, deep convolutional neural network (DCNN) has demonstrated state-of-the-art, human-competitive, and sometimes better-than-human performance in solving many computer vision problems, e.g., image classification [8], object detection [9], image segmentation [10], [11], etc. For line detection, DCNN-based methods have also been proposed for tasks such as edge detection [12], [13], contour detection [14], [15], boundary segmentation [16], [17] and so on. These deep architectures build high-level features from low-level primitives by hierarchically convolving the sensory inputs.

In particular, when using deep learning for edge detection, it has been observed that, the convolutional features become coarser and coarser in the convolving-pooling pipeline, and the detailed features in larger-scale layers and the abstracted features in the smaller-scale layers can be fused together to improve the performance of edge detection [13], [18], [19]. When using deep learning for image segmentation, for example the SegNet [20], the convolutional features in the decoder network have been found to be useful to improve the performance of semantic image segmentation, and the

This research was supported by the National Natural Science Foundation of China under grant Nos. 61872277, 61301277 and 91546106, the National Key Research and Development Program of China under grant No. 2016YFB0502203, and the Hubei Provincial Natural Science Foundation under grant No. 2018CFB482. (*Corresponding author: Qingquan Li*)

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Laser-Aided INS and Odometer Navigation System for Subway Track Irregularity Measurement

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Abstract: Track irregularity is one of the most important factors in the regular maintenance and overhaul work needed to determine the state of a railway for safe operation. In this paper, a mobile approach to the measurement of subway track irregularity is proposed. A high-precision three-dimensional (3D) curve of railway track was surveyed by a track trolley equipped with a laser-aided inertial navigation system (INS) /odometer navigation system. Models for measuring the alignment, vertical, cant, and twist irregularities were established. These four types of irregularities were estimated using the 3D track curve. To solve the problem of inherent drift of the INS/odometer system, a laser scanner on the trolley was used to obtain observations of control points along the rail track for position updates. Measurements of real track irregularities were conducted to validate the proposed method. The experimental results indicate that this approach has good repeatability. The accuracy of track-irregularity measurements meets the technical requirements of the Shenzhen Metro in China. **DOI: 10.1061/(ASCE)SU.1943-5428.0000236.** *© 2017 American Society of Civil Engineers.*

Author keywords: Track irregularity; Mobile mapping; Laser scanning; Light detection and ranging (LiDAR); Inertial navigation.

Introduction

Track irregularity is a main source of ground-borne vibration and noise, and it can also lead to track deterioration and operational safety problems if it is not well monitored. It is one of the most important factors in regular maintenance and overhaul work for estimating the state of a railway (Liu et al. 2015; Luber 2009). Because subway mileage and the train speeds are increasing rapidly in China, the task of railway maintenance is becoming more and more difficult. An accurate and efficient measuring technique is necessary to confront this challenge.

The mobile measurement method is the preferred choice for rapid railway inspection. Currently, there are mainly two categories of methods of measuring mobile track geometry. Longer wavelengths track irregularities are measured by track-recording coaches (TRC) under wheel loading as a standard method, whereas shorter wavelength roughness is measured by accelerometer-based trolleys or mechanical displacement probes without wheel loading on for complementation (Nielsen et al. 2013). Either TRCs or trolleys can provide continues measurement. For these continuous measuring systems, the positioning and orientation of the platform are key technologies, since they help to build up a consistent reference frame that will determine the final accuracy of measurement. It is usual for TRCs to be equipped with GNSS (Global Navigation Satellite System) receivers for positioning and inertial sensors to detect track irregularities. The measured acceleration and angular rate are integrated into the relative displacement of the platform from which track irregularity is estimated. However, the GNSS signal is not always available in certain cases, such as in canyons or tunnels. Positioning accuracy will decrease dramatically in these cases. Hand-held trolleys, such as the widely used Amberg GRP series (Engstrand 2011), are positioned by observing the control network along the railway through a motorized total station. This method can reach a high level of precision; however, it is not efficient enough for long-distance operation, because the change of position of total station is time-consuming. To address this problem, a high-precision method of measuring mobile track irregularities that uses GNSS/INS integration has been proposed (Chen et al. 2015). However, it is not available in the subway environment. Because the time slots for rail maintenance of existing subway lines are limited as a result of high traffic volumes, traditional track geometry measurement methods cannot meet both the accuracy and efficiency requirements simultaneously.

The key issue in the mobile inspection of subway rails is how to accurately determine the position and attitude of the mobile platform in a GNSS-free environment. Mainly two categories of methods focus on this problem, namely, those that use global position information and those that do not. A simultaneous localization and mapping (SLAM)-based (Durrant-Whyte and Bailey 2006) local positioning method is a typical solution that does not require global position information. It realizes localization and mapping simultaneously in unknown environments. The mobile platform positions itself through matching current sensor data to the built map, which in turn helps to build the map of environment incrementally. There are many two-dimensional (2D) or three-dimensional (3D) applications indoors, in mines, or in any other GNSS-free environment, because of the self-contained property. Kohlbrecher et al. (2011) incorporated a robust scan-matching approach using a light detection and ranging (LiDAR) system with a 3D attitude-estimation system based on inertial sensing. The inertial sensor is aided by the measurement of scan matching

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Note. This manuscript was submitted on April 7, 2016; approved on March 9, 2017; published online on May 22, 2017. Discussion period open until October 22, 2017; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Surveying Engineering***, © ASCE, ISSN 0733-9453.

Automation in Construction 96 (2018) 350–365

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Automatic pavement defect detection using 3D laser profiling technology

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ARTICLE INFO

Keywords:
Pavement defect
Laser scanning
Sparse
Crack detection
Deformation defect detection

ABSTRACT

Asphalt pavement defects e.g. cracks, potholes, rutting, often cause significant safety and economic problems, thus, to automatic detect these defects is vital for pavement maintaining and management. The fact that 3D defect detection methods is superior to traditional 2D methods and manual survey methods in terms of accuracy and comprehensiveness has been widely recognized. Based on 3D laser scanning pavement data, an automatic defect detection method is proposed to detect pavement cracks and pavement deformation defects information simultaneously in this paper. Specifically, a sparse processing algorithm for 3D pavement profiles is first designed to extract crack candidate points and deformations support points, these processing is based on the assumption that the cracks are microscopic local defects while deformations are macroscopic defects in profiles. Then, the crack information can be detected by combining the extracted candidate points and an improved minimum cost spanning tree algorithm. On the other hand, the deformation depth information is acquired based on the profile standard contours which are constructed by profile envelopes and deformation support points, the accurate location and classification information of deformation defects can be obtained by the regional depth property. Experimental tests were conducted using real measured 3D pavement data containing two categories of defects. The experimental results showed that, based on the 3D laser scanning data, the proposed method can effectively detect typical cracks under different road conditions and environments, with the detection accuracy above 98%. Furthermore, different types of deformation defects including potholes, rutting, shoving, subsidence, can also be accurately detected with location error less than 8.7%.

1. Introduction

Pavement cracks, potholes, rutting, shoving and subsidence are the common forms of pavement defects [1], these typical pavement condition evaluation indicators are essential for pavement maintaining and management [2-5,7]. Some typical defects on the pavement reflect different depth and geometric features. For example, a crack often shows as an obvious linear structure [2,3,6], it generally holds a width greater than 1 mm and displays lower depth than the non-crack pavement background. A rutting is mostly resulted from the frequent traffic loads on pavement, which has certain width, depth and continuous length. Potholes [8-10] and subsidence are often featured with large area of deeper depth and deformation, and a shoving holds a certain higher elevation than normal pavement. These common pavement defects, often cause significant safety and economic problems, thus the automatic defect detection is a highly attractive problem.

In the past two decades, various of 2D imaging based systems and associated algorithms for pavement measurement have been developed for collecting in situ data to evaluate pavement conditions [2,3,11-15]. However, these traditional 2D image analysis-based pavement defect detection methods often suffer from their inability to discriminate dark areas not caused by pavement defects such as shadows and poor illumination [16–18,21]. Moreover, the 2D methods cannot detect some defects due to the lack of depth information [6]. The 3D laser scanning data has been proven its ability of obtaining the depth information and less vulnerable to lighting conditions [19,20], 3D laser technology has become the dominant approach to automatic pavement data collection in recent years [4,21,22].

Many studies were conducted to detect pavement defects based on 3D pavement data. Laurent et al. adopted an auto-synchronized laser

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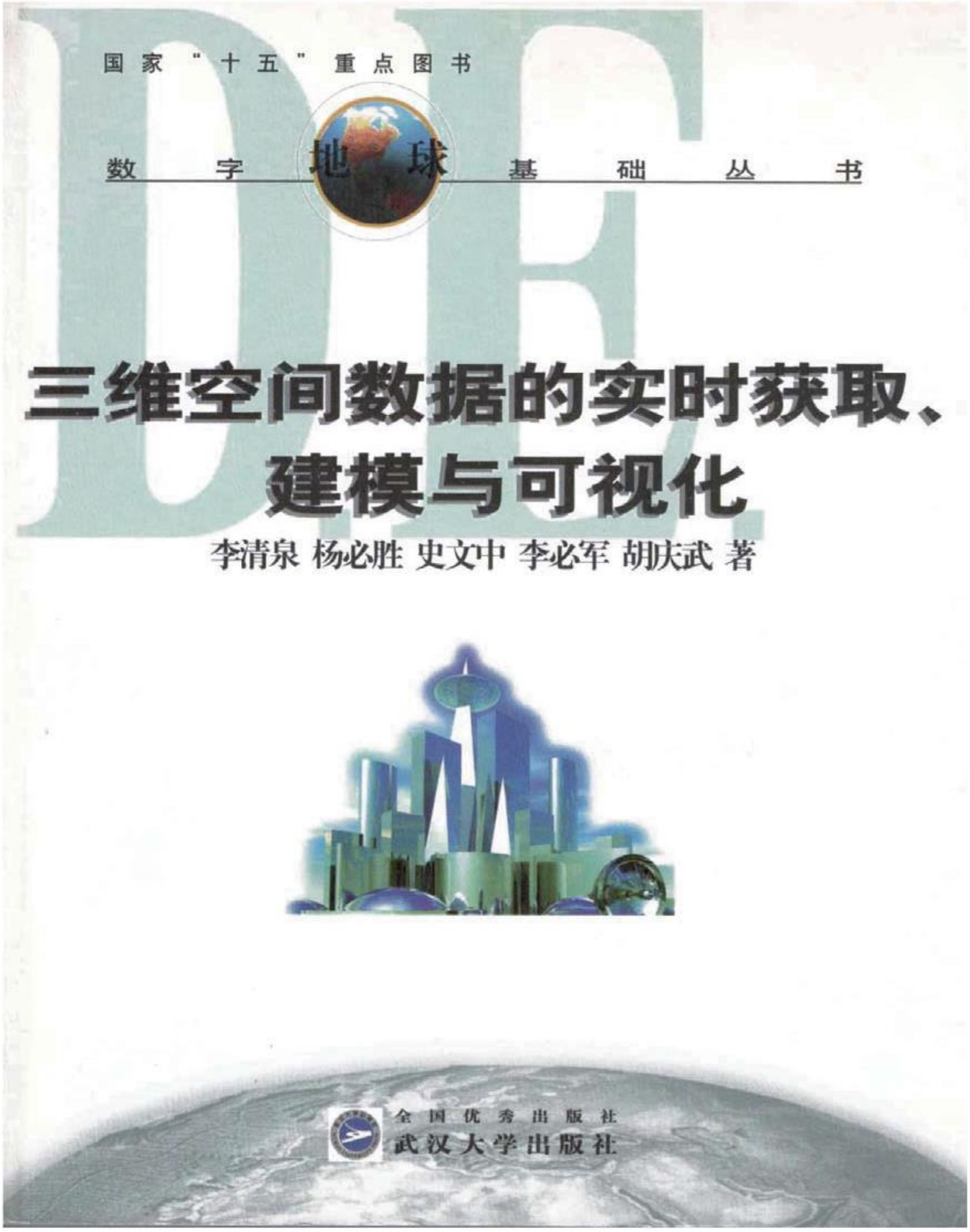
https://doi.org/10.1016/j.autcon.2018.09.019
Received 15 May 2018; Received in revised form 7 August 2018; Accepted 28 September 2018
Available online 10 October 2018
0926-5805/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