

学校编码: 10384

分类号 _____ 密级 _____

学号: 23320131153230

UDC _____

厦 门 大 学

硕 士 学 位 论 文

毫米波FMCW雷达信号处理关键技术研究

Study on Signal Processing Key Technology of Millimeter
FMCW Radar

陶明亮

指导教师姓名: 张贻雄 副教授

专 业 名 称: 通信与信息系统

论文提交日期: 2016年 月

论文答辩时间: 2016年 月

学位授予日期: 2016年 月

答辩委员会主席: _____

评 阅 人: _____

2016年 月

厦门大学博硕士学位论文摘要库

厦门大学学位论文原创性声明

本人呈交的学位论文是本人在导师指导下,独立完成的研究成果。本人在论文写作中参考其他个人或集体已经发表的研究成果,均在文中以适当方式明确标明,并符合法律规范和《厦门大学研究生学术活动规范(试行)》。

另外,该学位论文为()课题(组)的研究成果,获得()课题(组)经费或实验室的资助,在()实验室完成。(请在以上括号内填写课题或课题组负责人或实验室名称,未有此项声明内容的,可以不作特别声明。)

声明人(签名):

年 月 日

厦门大学博硕士学位论文摘要库

厦门大学学位论文著作权使用声明

本人同意厦门大学根据《中华人民共和国学位条例暂行实施办法》等规定保留和使用此学位论文，并向主管部门或其指定机构送交学位论文(包括纸质版和电子版)，允许学位论文进入厦门大学图书馆及其数据库被查阅、借阅。本人同意厦门大学将学位论文加入全国博士、硕士学位论文共建单位数据库进行检索，将学位论文的标题和摘要汇编出版，采用影印、缩印或者其它方式合理复制学位论文。

本学位论文属于：

()1.经厦门大学保密委员会审查核定的保密学位论文，于
年 月 日解密，解密后适用上述授权。

()2.不保密，适用上述授权。

(请在以上相应括号内打“√”或填上相应内容。保密学位论文应是已经厦门大学保密委员会审定过的学位论文，未经厦门大学保密委员会审定的学位论文均为公开学位论文。此声明栏不填写的，默认为公开学位论文，均适用上述授权。)

声明人(签名)：

年 月 日

厦门大学博硕士学位论文摘要库

摘要

毫米波调频连续波(FMCW)雷达质量轻, 体积较小, 易于高度工业集成, 工作频带较宽, 分辨率高, 具有较好的全天候工作能力, 并且抗干扰能力强, 从而使得毫米波FMCW雷达在汽车防撞、环境遥感、工业控制、战场监视、精确制导等民用和军用领域中有广泛的应用前景。因此, 本文以毫米波FMCW雷达信号处理为题, 展开了如下几个方面的工作:

(1) 介绍了毫米波FMCW雷达的系统结构; 对线性调频信号模型进行了分析, 并比较了匹配滤波方法与去斜方法, 给出了线性调频波形的模糊函数; 介绍了锯齿波与三角波的运动参数估计原理, 并分析了调频连续波在测量多目标时存在的问题。对现有的几种多目标分辨波形的参数估计原理进行分析, 包括单频连续波雷达原理, 变周期三角波多目标分辨方法, 以及基于线性调频信号二维FFT方法的多目标分辨, 对这三种方法分别进行仿真。

(2) 针对变周期三角波方法对硬件计算能力和调频斜率的要求较高的弊端。提出了一种基于组合波形的FMCW雷达波形, 该波形可以在运算能力较低、调频斜率较低的情况下, 进行快速多目标分辨, 以及目标的测距测速。

(3) 基于硬件平台进行算法实现, 并在真实实验场景下进行算法验证。

关键词: 毫米波雷达; 调频连续波; 多目标分辨; 波形设计; 快速匹配算法; 测距测速

厦门大学博硕士学位论文摘要库

Abstract

Millimeter FMCW radar is a new kind of high range resolution radar with advantages such as light weight, small volume, ease of industrial integration, large bandwidth, capable of working around the clock, undesirable to interact with other electronic systems. And make it a good choice to be used for fine-resolution compact radar operation and are becoming increasingly popular. Some typical and emerging civil and military applications include collision avoidance of automobile, meteorological, industrial production, ordnance guidance, battlefield surveillance etc. Therefore, we focus on the signal processing of millimeter frequency modulation continuous wave (FMCW) in this article. And the main objectives of our research work can be summarized as follows:

(1) The system structure of millimeter wave FMCW radar is discussed in detail. Signal model of linear frequency modulation is analyzed. And compared matched filter means with de-chirp method. The ambiguity function of linear frequency modulated waveform was deduced. The theory of triangle linear frequency modulated waveform in measuring the motion parameters of targets was analyzed. And the problem when measuring the motion parameters in multi-targets situation was proposed. The theory of multi-targets distinction and motion parameters estimation based on existing several waveforms was analyzed. First, the theory of single frequency continuous waveform radar was explained in detail. Then a waveform using two or more triangle linear frequency modulated waveform with different frequency modulated slope was set out to solve problem in multi-targets situation. Besides, the method of 2D-FFT based on linear frequency modulated waveform was analyzed to solve multi-targets distinction, and simulation was deployed on three methods above.

(2) Aiming at the drawback of waveform using two or more triangle linear frequency modulated waveform with different frequency modulated slope which need high calculation ability of hardware and big frequency modulated slope, a frequency modulated continuous waveform base on combined waveform was proposed in this

article. It could deploy fast multi-targets distinction under the condition of low computation ability and small frequency modulated slope and measure the range and velocity information of targets.

(3) Implementing algorithm based on hardware platform, and validating algorithm in real-world experimental scene.

Key Words: Millimeter wave radar; Frequency modulated waveform (FMCW); Multi-targets distinction; Waveform design; Fast paring algorithm; High precision velocity detection; Measuring range and velocity

厦门大学博硕士学位论文摘要

目录

摘要.....	I
Abstract.....	III
目录.....	V
Contents	IX
第 1 章 绪论	1
1.1 研究背景.....	1
1.2 国内外发展现状.....	3
1.3 课题研究意义.....	6
1.4 本文结构安排.....	7
第 2 章 雷达结构和波形及测速测距原理.....	9
2.1 调频连续波雷达系统的结构.....	9
2.2 线性调频波形分析.....	10
2.2.1 线性调频信号模型.....	10
2.2.2 匹配滤波方法与去斜方法.....	15
2.2.3 LFM 波形的模糊函数	18
2.3 锯齿波调频连续波运动参数估计原理.....	24
2.4 三角波调频连续波运动参数估计.....	28
2.5 三角波调频连续波在测量运动多目标时存在的问题.....	30
2.6 本章小结.....	32
第 3 章 多目标运动参数估计波形.....	34
3.1 单频连续波测速原理.....	34
3.1.1 多普勒效应.....	34
3.1.2 多普勒测速原理.....	35
3.1.3 连续波多普勒雷达.....	36
3.1.4 仿真实验.....	40

3.1.5	连续波多普勒方法总结.....	41
3.2	变周期三角波多目标分辨方法.....	42
3.2.1	变周期三角波多目标分辨方法原理.....	42
3.2.2	变周期三角波多目标分辨算法流程.....	43
3.2.3	仿真实验.....	45
3.2.4	变周期三角波多目标分辨方法总结.....	47
3.3	线性调频信号二维 FFT 方法.....	47
3.3.1	线性调频信号二维 FFT 方法介绍.....	47
3.3.2	线性调频信号二维 FFT 方法原理.....	49
3.3.3	仿真实验.....	51
3.3.4	线性调频信号二维 FFT 方法总结.....	54
3.4	本章小结.....	54
第 4 章	基于组合波形的 FMCW 雷达信号处理算法.....	56
4.1	组合波形设计方法.....	56
4.2	快速多目标分辨算法.....	57
4.3	多目标测角方法.....	60
4.4	仿真实验.....	66
4.5	本章小结.....	72
第 5 章	实验结果.....	73
5.1	实验平台.....	73
5.2	实验结果.....	76
5.2.1	静态径向测距精度实验.....	77
5.2.2	静态多目标分辨率实验(径向距离不同).....	78
5.2.3	静态目标(多目标)测距实验.....	79
5.2.4	静态目标方位角误差实验.....	81
5.2.5	动态目标实验.....	82
5.3	实验总结.....	86
第 6 章	总结与展望.....	87

6.1 论文工作总结	87
6.2 不足与展望	88
参考文献	89
致谢	94
硕士期间参与的科研项目和发表的论文	95

厦门大学博硕士论文摘要库

厦门大学博硕士学位论文摘要库

Contents

Abstract in Chinese..... V

Abstract in EnglishIII

Contents in Chinese V

Contents in English.....IX

Chapter 1 Introduction 1

1.1 Research Background 1

1.2 Development Status at Home and Abroad..... 3

1.3 Research Significance..... 6

1.4 Organization of the Paper 7

**Chapter 2 Radar’s Structure and Waveform and Motion
Parameter Estimation Basis..... 9**

2.1 The Structure of LFM Radar System..... 9

2.2 The Analysis of LFM Waveform 10

 2.2.1 The Model of LFM Signal 10

 2.2.2 Matched Filter Method and De-chirp Method 15

 2.2.3 The Ambiguity Function of LFM Waveform 18

2.3 Motion Parameter Estimation Theory of Sawtooth Waveform..... 24

2.4 Motion Parameter Estimation Theory of Triangle Waveform 28

2.5 The Problem of Triangle Waveform Multi-targets Detection..... 30

2.6 Summary 32

Chapter 3 Multi-targets parameter estimation Waveform 34

3.1 Single Frequency Continuous Wave velocity Detection Theory 34

 3.1.1 Doppler Effects 34

 3.1.2 The Theory of Velocity Measurement using Doppler 35

3.1.3	Continuous Wave Doppler Radar	36
3.1.4	Simulation Results	40
3.1.5	Summary of Doppler Method	41
3.2	Multi-targets Distinction using Waveform With Different Frequency Modulated Slope	42
3.2.1	Theory of Multi-targets Distinction	42
3.2.2	Algorithm Flow Chart.....	43
3.2.3	Simulation Results	45
3.2.4	Summary	47
3.3	2D-FFT Method Based on LFM Waveform	47
3.3.1	Introduction of 2D-FFT Method.....	47
3.3.2	Theory of 2D-FFT Based on LFM.....	49
3.3.3	Simulation Results	51
3.3.4	Summary	54
3.4	Summary	54
Chapter 4 FMCW Radar Signal Processing Algorithm Based on Combined Waveform		56
4.1	Introduction to Combined Waveform.....	56
4.2	Algorithm of Fast Multi-targets Distinction	57
4.3	Algorithm of Multi-targets Angle Detection	60
4.4	Simulation Results.....	66
4.5	Summary	72
Chapter 5 Experimental Results		73
5.1	Experimental Platform	73
5.2	Experimental Results	76
5.2.1	Static Radial Range Measurement precision Experiments	77
5.2.2	Static Multi-targets Distinguishability Experiments.....	78
5.2.3	Static Targets Range Experiments	79
5.2.4	Static Target azimuthal error Experiments	81

Degree papers are in the “[Xiamen University Electronic Theses and Dissertations Database](#)”.

Fulltexts are available in the following ways:

1. If your library is a CALIS member libraries, please log on <http://etd.calis.edu.cn/> and submit requests online, or consult the interlibrary loan department in your library.
2. For users of non-CALIS member libraries, please mail to etd@xmu.edu.cn for delivery details.