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廈門大學

博 士 学 位 论 文

深水网箱中鱼类声学散射特性和鱼群状态  
监测仪研究

Study on Acoustic Scattering Characteristics of Fish and  
Monitor System for Bred Fish in Offshore Fish Cage

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## 摘要

深水网箱养殖因其抗风浪、耐海流能力强、养殖容量大、高产高效、环保等优点成为目前国内外海洋水产养殖业可持续发展的必然趋势。然而，与传统网箱养殖比较，深水网箱养殖由于网箱所处水域深、鱼群活动空间大，肉眼不容易观察到网箱内鱼群的活动及网衣安全状态，一旦发生逃鱼，经济损失巨大。因此，如何对网衣安全、网箱内鱼群生长情况、鱼群量变化进行日常监测，当发现网衣破损、鱼群逃逸等异常状况时及时报警是深水网箱养殖推广过程中急需解决的一项关键技术。本文针对深水网箱养殖中急需解决的鱼群安全问题，开展了鱼类声学散射特性和鱼群量估计算法研究，设计并实现了一套深水网箱鱼群状态远程、实时声学监测系统。

论文主要内容：

1、在了解国内外鱼类声学探测研究的基础上，深入、系统地分析了影响鱼类声学散射强度的各种因素，引出可用于衡量这些因素影响作用大小的无量纲比率 $\mathfrak{R}$ ，介绍了研究鱼类声学散射强度的两种方法：模型估算法和直接测定法，并在实验室水池中采用受控实验法直接测定了相关鱼类的声学散射强度；

2、在深水网箱鱼群量估计算法研究中，创新性地提出了利用回波积分算法和脉冲宽度检测法来估算鱼群量，并通过深水网箱养殖现场实验比较了两种算法的性能；

3、研究了典型深水网箱养殖环境下噪声、混响的干扰特性和在干扰背景下利用匹配滤波、相关、时间变化增益控制等信号处理方法提取鱼群和网衣目标回波；

4、根据深水网箱养殖的特殊环境要求，设计了一套深水网箱水声鱼群状态远程监测系统，系统包含了位于网箱养殖现场的声探测系统、位于岸站中的用户监测系统以及用于连接这两个系统、实现海上和岸站之间通信的无线数据传送系统；

5、首次提出并实现了一种基于环形多波束换能器阵的网箱分区扫描方法，同时还研制了多路信号并行处理与采样装置，完成对各波束探测回波信号的调理

和采集，不仅简化了探测系统结构，而且提高了网箱探测速度、克服了游动鱼群重复探测的问题、有效减少了探测盲区，为实现较高的网箱鱼群量估计精度奠定了基础；

6、基于美国 NI 公司的实验室虚拟仪器集成环境 LabVIEW 进行监测系统平台的程序开发，利用 LabVIEW 软件中功能强大的数字信号和图像处理模块，提高回波信号处理性能，实现鱼群回波的高清晰度彩色显示，并设计了友好的人机操作界面。

通过实验室水池和福建泉州围头港深水网箱养殖现场的测试，表明该监测系统具有操作简单、易于安置、性能稳定的特性；实现了深水网箱网衣安全和鱼群状态的远程、实时监测；能够对养殖生产中出现的网衣破损、鱼群逃逸等异常情况及时示警；采用回波积分法对百余次的深水网箱实际探测结果进行鱼群量评估，平均估计偏差为 11.5%，达到了较好的估计效果；通过对网箱实施长时间的连续探测，还可以向用户提供网箱鱼群量大小、鱼类生长情况、投饵量等有效养殖信息。

**关键词：**深水网箱；鱼群监测；水声多波束；鱼类声学散射模型；鱼群量估计算法

## Abstract

For its advantages of strong resistance to wind waves and tidal current, large breeding capacity, high efficiency and environmental protection, fish culturing in offshore fish cage becomes the developing trend of sustainable marine aquaculture industry at home and abroad. However, compared with the traditional fish culturing, it is difficult to observe fish school activity and the status of net clothing by naked eye due to deeper water and wider fish culturing space in offshore fish cage. Therefore, we urgently need a way to observe cage security, fish growth and fish amount on a regular basis without having to visit the cages by fishers themselves and give an alarm in the time when net clothing was damaged or fish escaped. In order to solve the security problems of fish in cages, the paper carried out a series of experiments related to acoustic scattering intensity of fish and developed a real-time acoustic monitor system to monitor offshore fish cage remotely.

The contents in the paper are as follows:

1. Deeply analyses the role of various factors on the acoustic scattering intensity of fish, and introduces a non-dimensional ratio which can be used to measure the impact of those factors with different dimensions. Compares of two popular methods of model and direct measurement used to describe acoustic scattering intensity of fish, and directly measured acoustic scattering intensity of fish with controlled experiment in the pool of lab.
2. Proposed the echo integration algorithm and pulsewidth detection algorithm to estimate the fish amount in offshore fish cage, both of which were tested in the field of offshore fish cage.
3. Studied the characteristics of noise and reverberation interference in the offshore fish cage and the signal processing methods, such as correlation, matched filter, time-varied gain to extract effective target echo under the condition of strong ocean noise and reverberation disturbance.

4. According to the special environmental requirements for monitoring offshore fish cage, designed a remote monitor system including acoustic detecting system which is placed in the field of offshore fish cage, user monitoring system which is placed in the shore station and wireless data transmission system to connect the other two systems to realize remote monitoring.

5. Improving the scanning mode of cage monitoring, replaced the traditional single-beam rotating scanning mode with cage-division scanning mode which was first proposed and based on the technique of acoustic multi-beam. The new scanning mode integrating with a multi-path signal parallel processing and acquiring device not only simplifies the system structure, but also speeds up the cage scanning, reduces the blind zone and achieves a higher accuracy of fish amount estimation.

6. Based on Laboratory Virtual Instrument Engineering Workbench (LabVIEW), we developed the user monitoring system which takes advantage of powerful digital signal and image processing modules of LabVIEW to strengthen the capability of echo processing and image display, achieve friendly man-machine interface.

Tests in the pools of lab and in the field of offshore fish cage in Weitou harbor, Quanzhou of Fujian show that the monitor system for bred fish in offshore fish cage is simple, easy placement, and robust under different environmental conditions. It can real-time monitor fish activity and net clothing remotely, give an alarm in the time when net clothing damage or fish escape, estimate fish amount by echo integration algorithm with the average estimation error 11.5% and successfully provide users with a variety of information such as fish amount, fish growth and feeding volume in the offshore fish cage.

**Key words:** offshore fish cage; fish monitor; acoustic multi-beam; acoustic scattering model of fish; fish amount estimation algorithm

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## 第一章 绪论

### 1.1 引言

由于海洋天然渔业资源持续衰退，国家实行了“减船减产”的海洋捕捞管理政策，使海洋捕捞量不断萎缩，海水产品特别是优质、鲜活的中高档海水鱼类产品供应越来越多地依赖于海洋养殖。如表 1.1 所示，在 1998~2008 年间，海水鱼类捕捞产量整体下降了 20%左右，而海水鱼类养殖产量增加了 140%。

表 1.1 海水鱼类捕捞和养殖产量及年增长率<sup>[1]</sup>

**Table 1.1 Annual production and growth rate of catching and aquaculture**

年份	海洋捕捞		海水养殖	
	产量 (万吨)	年增长率 (%)	产量 (万吨)	年增长率 (%)
1998	1025.3		30.7	
1999	1024.2	-0.1	33.9	10.4
2000	990.0	-3.3	46.3	36.6
2001	963.2	-2.7	49.5	6.9
2002	964.5	0.1	56.1	13.3
2003	973.1	0.9	51.9	-7.5
2004	959.0	-1.4	58.3	12.3
2005	986.1	2.8	65.9	13.0
2006	965.8	-2.1	71.5	8.5
2007	822.4	-14.8	*	
2008	789.6**	-4.0	74.8	

\*: 没有搜集到该年的确切数据; \*\*: 该数值没有包括远洋捕捞量。

我国海水鱼类养殖包括浅海传统网箱养殖和大型抗风浪深水网箱养殖。目前仍然以浅海传统网箱养殖为主。但是，这种养殖方式存在许多问题。一是生产存在极大的安全隐患，传统网箱结构简单，木质结构抗风浪能力差，在台风袭击中可能产生重大经济损失和人员伤亡，如 2001 年“飞燕”台风摧毁或损坏的海水网箱达 21 万只，造成直接经济损失 11.8 亿元；二是这些网箱主要分布在半封闭内湾和有天然屏障的近岸浅海区，局部海域养殖密度过大，破坏了海区自然环境；三是由于网箱连片开发，布局不科学，水体交换差，鱼饵及鱼类排泄物在海底淤积，养殖病害日益频繁，养殖鱼类品质下降，每年因病害遭受的损失就有



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