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# 等离子高分子导电薄膜的微型机器鱼图像分析

聂林<sup>1</sup>, 陈伟<sup>1</sup>, 李德胜<sup>1</sup>, 郭书祥<sup>2</sup>

(1. 北京工业大学机械电子学院, 北京 100124;

2. 日本国立香川大学智能机械系统学院, 日本香川 761-0396)

**摘要:** ICPF 是能够被 1.5 V 低电压驱动的等离子高分子导电薄膜, 具有质量轻、响应速度快的特点。用长 21.6 mm、宽 4.6 mm、厚 0.2 mm 的 ICPF 薄膜驱动微型机器人能够以 3 mm/s 的速度在水中运动。为了对其运动姿态进行检测和控制, 设计了微型机器人的图像处理系统, 此系统由 CCD 摄像机、图像接口卡、计算机和波形发生器组成。通过 CCD 摄像机获取机器人的运动图像序列; 利用目标短时相似性, 对每一帧图像进行色调自动阈值分割和边缘提取得到目标二值图像; 采用改进的 Hough 圆变换计算出目标在图像中的位置和运动方向。最后, 根据目标的位置和运动方向, 通过波形发生器, 改变 ICPF 两端的电压和频率来实现对机器鱼姿态的控制。本系统在 Pentium 4 2.8 G 内存 1 G 的电脑上, 处理一张图片需 52 ms, 可以实现对机器人的实时检测、跟踪和控制。

**关键词:** 微型机器人; 等离子高分子导电薄膜; 图像处理; Hough 圆; 视觉伺服

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## Image analysis on ICPF actuated micro-robot

NIE Lin<sup>1</sup>, CHEN Wei<sup>1</sup>, LI De-sheng<sup>1</sup>, GUO Shu-xiang<sup>2</sup>

(1. *School of Mechanical Engineering and Applied Electronic Technology, Beijing University of Technology, Beijing 100124, China;*

2. *Department of Intelligent Mechanical Systems, Kagawa University, Kagawa 761-0396, Japan*)

**Abstract:** The Ionic Conducting Polymer gel Film (ICPF) can be driven by a low voltage (about 1.5 V) and has advantages in the less mass and fast response. A micro-robot moved at 3 mm/s velocity in the water can be actuated by the ICPF (21.6 mm × 4.6 mm × 0.2 mm). An image processing system is designed for detecting and controlling the movement and posture of the micro-robot, which consists of a CCD camera, an image interface card, a computer and a waveform generator. A movement and posture image sequence of the robot fish is captured by a CCD camera to obtain a binary image of each frame by the hue automatic threshold segmentation and boundary extraction based on the similarity target of in a short period. Then, the target location and movement direction are calculated by the circle detection using improved Hough transform. According to the target location and movement direction, the robot fish posture can be controlled by changing the voltage and frequency of ICPF and by using the waveform generator. Results show that system consumes 52 ms for processing a piece of pic-

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ture in a Pentium 4 2.8 G computer with 1 G memory and achieves the real-time detection, tracking and control for the micro-robot fish.

**Key words:** micro robot; Ionic Conducting Polymer gel Film (ICPF); image process; visual servo; Hough

## 1 Introduction

Many researchers have studied the miniature biomimetic robot. Micro-robot is designed by imitating various biological diversities, such as robot fish, robot crickets<sup>[1]</sup>. Based on the fish characteristics of swimming, sensitive sensory organ and mechanism, combined with modern science and technology, the research of robot fish aims to develop highly efficient, highly mobile and intelligent underwater robot and underwater delivery to help mankind solve the specific problems. For example, robot fish can be applied in the narrow space, such as pipeline for detection. Micro-robot fish can also be used for vascular disease diagnosis and treatment<sup>[2]</sup>. Since micro-robot fish has the characteristics of small size and light weight, the actuator materials can be classified into piezoelectric material(PZT), ferromagnetic rubber, shape memory alloys (SMA), micro-propeller and so on<sup>[3]</sup>. A micro-robot using ICPF actuators has several advantages. One of them is the great possibility to work in a very small and dangerous space, another is that the micro-robot can be actuated with low voltage. Moreover, it has many other advantages such as light weight, good input response, high security, high efficiency of power transition, littler noise, etc.

## 2 Micro-robot fish

### 2.1 Structure of robot fish

ICPF actuator uses the film of perfluorosulfonic acid polymer (Nafion 117, du Pont and company) as substrate which is chemically penetrated on it's both sides with platinum. ICPF contains the sodium ions and the sulfonic groups<sup>[4]</sup>. In

water, the sodium ions are ionized from the sulfonic groups. Voltage applied on ICPF yields an electric field through the membrane. Sodium ions migrate from the anode to the cathode by electrostatic force and balance against negative charge. On the other side, the sulfonic acid groups are fixed to the high polymer chain and cannot migrate in the membrane. So, this makes the membrane bend by the electrostatic force, and generates internal stress that expands the gel near the anode. Voltage changed alternatively is put at ICPF ends. In this way, ICPF would have curved changes, and thus produce a forward thrust<sup>[5]</sup>. In this paper, a double-tail robot fish is studied as shown in Fig. 1. The fish body is

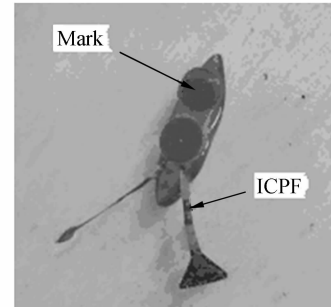


Fig. 1 Double-tail ICPF actuated robot fish

made of wood, and has streamlined design with a double actuator installed symmetrically at the rear part of the body. Parameters of the robot fish are shown in Tab. 1.

Tab. 1 Parameters of micro-robot fish

| Parameters   |   |
|--------------|---|
| Size         | 65.6 mm×20.8 mm×6.2 mm                  |
| Weight       | 25.6 g                                  |
| Material     | wood, plastic                           |
| Actuator     | ICPF<br>Actuator(0.2 mm×4.6 mm×21.6 mm) |
| Power supply | Electricity(3 V)                        |

## 2.2 Control system

AT89S52 SCM and OPA551 amplifier are adopted for the robot fish control system. This system can produce two-way waveform signals which can be controlled independently. Signals are sent to those two ICPFs respectively to produce driving force through the copper wire with diameter of 0.3 mm. This control system adopts asynchronous serial communication module, which can accept the information of upper PC feedback voltage and frequency. The driving force of robot fish in this paper comes from fish-tail, and speed control of robot fish can be achieved by changing the swing frequency of fish-tail. However, going up to a certain frequency, speed reduces, fish-tail swings severely, and the driving force greatly reduces. The swing rate differs with different voltage of ICPF, so the movement of robot fish can be controlled by changing the voltage value.

## 2.3 Vision systems of robot fish

This paper adopted image-based visual servo control system which means characteristic information observed by camera and used for the feedback directly and three-dimensional posture do not need to be estimated. The error from robot kinematics and calibration can be reduced using image-based methods, bypassing 3D reconstruction and using image feature to control the movement of robot fish directly.

Fig. 2 is the workflow of robot fish vision system. CCD camera above the fish tank can get the color image signal of real-time simulation of the whole tank. Images are transmitted to the video acquisition card installed in the PCI slot through a data line. Simulated color image is transformed to digital color image and deposited into host memory. Robot fish posture can be calculated through image processing software. According to the strategy, control signals can be transmitted to the control system of robot fish through serial communication. In this paper, the size of the fish tank is  $56.5 \text{ mm} \times 27 \text{ mm}$ , CCD

camera resolution is  $800 \times 600$ , frame rate is 15 per second, and ordinary fluorescent light is adopted.

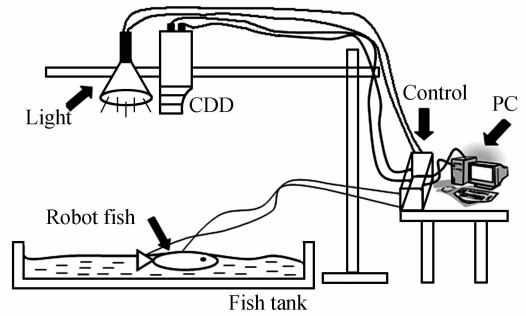


Fig. 2 Workflow of robot fish vision system

## 3 Research on visual identification of robot fish

In this paper, image-based recognition system of static scenes is studied. Its major task is to track fish movement, and convert it into the information that robot fish could identify. Processing speed of recognition system determines the efficiency of the implementation of the system. In order to identify the movement and posture of fish rapidly and accurately, a red circle is marked on the fish's head and a blue circle on the fish's tail, so that the fish can be identified and located through the image characteristics.

### 3.1 Image segmentation

A suitable color space should be chosen for the color image segmentation. HSI color model is adopted to reduce the effect of illumination system on the color segmentation. HSI color model is a model that naked eye can tell and it can match the visual characteristics of human being much better. The color signals can be cataloged into three kinds of attributes: hue (H), color saturation (S) and brightness (I). The conversion formula used for the RGB color space to the HSI color space are showed as follows:

$$\begin{cases} \theta = \arccos \left\{ \frac{[(R-G) + (R-B)]}{2\sqrt{(R-G) + (R-B)(G-B)}} \right\} \\ H = \begin{cases} \theta & B \leq G \\ 2\pi - \theta & B > G \end{cases} \\ S = 1 - \frac{3}{R+G+B} [\min(R, G, B)] \\ I = \frac{R+G+B}{3} \end{cases} \quad (1)$$

Because of small changes of the static background scene, a larger threshold can be selected artificially in component  $I$  and the value greater than threshold can be determined as background point. Then threshold segmentation of non-point background colors can be conducted automatically. The threshold is set automatically. The iterative steps described by Gonzalez and Woods [2002] are<sup>[6]</sup>:

(1) Select an initial estimated value of  $T$ ;

(2) Segment the image using  $T$ . This will produce two groups of pixels:  $G_1$  consisting of the pixels with hue level values is greater than  $T$  and  $G_2$  consisting of the pixels with hue value is less than  $T$ ;

(3) Calculate the average pixel color values  $u_1$  and  $u_2$  within the scope of  $G_1$  and  $G_2$ ;

(4) Compute a new threshold value:  $T = \frac{1}{2}(u_1 + u_2)$ ;

(5) Repeat step (2) to (4) until the  $T$  value of successive iterations is less than the predefined parameter  $T_0$ .

The red and blue circle can be obtained more accurately by this method. Each picture should go through iteration, which will affect the image processing speed. Since brightness changes little in static scene in this study,  $T_0$  should be set close to the value, which can be obtained through a relatively large number of experiments to reduce the number of iteration.

### 3.2 Circle detection using improved Hough transform

Since Hough transform was proposed in 1962, many improved algorithm have emerged. Hough transform can be applied to detect straight line,

circle and parameter curve. It has characteristics of the overall situation, anti-jamming and other advantages. Circle detection usually detected the center, and other parameters, such as radius of the circle. In this study, the center of goal needs to be detected, for the radius of circle can be obtained in advance.

The circle with the center of  $(a, b)$  and the radius of  $r$  can be described as  $(x-a)^2 + (y-b)^2 = r^2$  in parameter space. At this time, parameter space belongs to the three-dimensional space, and has three components including  $a$ ,  $b$ , and  $r$ . The radius is known in advance in this study, so it becomes a two-dimensional issue. Because the radius is fixed for a circle, the collection of the points on the circumference has the characteristics of the same radius and different  $a, b$  values in parameter space, as Fig. 3 shown.

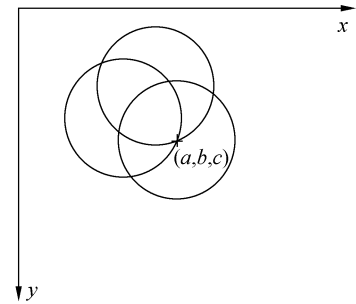


Fig. 3 Description of points on circles in parameter space

The points on the circle of the image space are mapped to the parameters space, and the intersection in the parameters space would be the center apparently.

An accumulator unit is built in the plan of  $x$ ,  $y$ , and each point corresponds to a unit. The binary image containing the edge of the circle can be gotten after pretreatment. Draw a circle whose center is the point of the edge and radius is  $r$ . Thus, the value corresponding to the point on the circle would plus one. After a calculation, the largest value of the accumulator unit is the coordinate value of center.

### 3.3 Scanning and recognition of small region

The initial centers of red and blue circle can be obtained through hue threshold segmentation and circle detection using improved Hough transform. Because the velocity of robot fish is about 3 mm/s, the instantaneous mobile scope is so small that the scope of scanning and recognition is reduced. The current frame central location would be gotten, only if the small area near the center of the last image is scanned.

### 3.4 System workflow

Real-time picture can be obtained by CCD, and target can be recognized through median filter, boundary extraction and circle detection using the improved Hough transform. Thus, the posture of robot fish can be determined and the strategy made previously can be corrected. Signal from computer is sent to actuators, and then the voltage and frequency of the ends of the ICPF are changed in order to change the posture of robot fish. The change of posture is captured by camera. Thus, a closed-loop control system is completed. Fig. 4 is the workflow of this system.

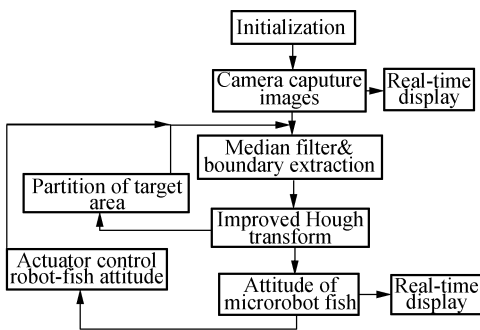


Fig. 4 System workflow

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The real-time image processing is the basic requirement of this system. The real-time processing procedure is programmed with the Microsoft Visual C++ 6.0 and the cost to process a picture is 52 ms using Pentium 4 2.8 G computer with 1 G memory, which fully meets the requirements of system. Detection and control of the moving target are realized in this system, which will be beneficial for the further study on the dynamic analysis and design of a micro-robot.

## 4 Conclusions

In this paper, the control part and image processing algorithms of double-tail ICPF actuated robot fish are introduced and the control platform are described. Robot fish can turn the corner and avoid the barrier, which proves the validity of this system. However, due to the lighting, ICPF actuator and near-wall effect of tank, some problems emerge. When the interference of lighting becomes large, robot fish can not be identified precisely and the accuracy of fish swimming control is lower, which all needs to be improved in the further study.

Since the object is underwater, various factors should be taken into account, such as hydrodynamic, the impact of fluctuations in the water and so on. So the research on the underwater bio-mimetic robot is more complicated than that on the traditional robot, and there are more works to do.

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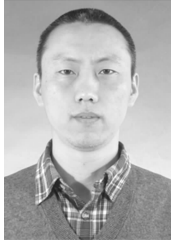
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#### Authors' biographies:



**NIE Lin** (1971—), male, Ph. D. candidate of the Beijing University of Technology, his research interests are MEMS, measurement and control technology, micro-robot and so on. **E-mail**: niechuanlin@emails.bjut.edu.cn



**LI Desheng** (1962—), male, Ph. D., professor of the Beijing University of Technology, his research interests are MEMS, measurement and control technology, micro-robot and so on. **E-mail**: dsli@bjut.edu.cn



**CHEN Wei** (1984—), male, M. S. candidate of the Beijing University of Technology, his research interests are micro-robot and image processing. **E-mail**: chenwei\_chenwei@bjut.edu.cn



**GUO Shuxiang** (1963—), male, Ph. D., professor of the Kagawa University, Japan, his research interests are MEMS, measurement and control technology, micro-robot and so on. **E-mail**: guosx@bjut.edu.cn

#### ● 下期预告

## 飞行姿态模拟器建模及输入受限混杂控制

张 刘, 金 光, 郑亮亮

(中国科学院 长春光学精密机械与物理研究所, 吉林 长春 130033)

为进行飞行姿态仿真研究, 基于 dSPACE 建立了地面飞行姿态半物理仿真模拟系统, 对有界高阶耦合非线性系统运用混杂不变集原理和无源控制器设计方法进行鲁棒控制器设计研究。首先, 使用 Lagrange 法建立了具有控制约束的非线性 Euler-Lagrange (EL) 动力学模型。然后, 利用 EL 系统内在特性, 基于非线性状态依赖动态脉冲系统的不变集原理的有关结果, 运用混杂能量控制方法, 设计了输入受限的非线性混杂控制器, 并进行了数学仿真。最后, 将所设计的混杂控制器应用于地面飞行姿态模拟器中, 进行了半物理仿真实验。仿真结果表明, 动态响应时间为 20 s, 稳态精度优于 5%, 超调量约为 25%, 在外加扰动作用时仍能实现稳定调节能力。结果表明所给的饱和控制算法具有较强的可靠性, 对系统参数误差和外干扰具有一定的鲁棒性。