Biological Inspiration in Human Centred Robotics

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Abstract: *Human Centred Robotics (HCR) concerns with the development of various kinds of intelligent systems and robots that will be used in environments coexisting with humans. These systems and robots will be interactive and useful assistants/companions for people in different ages, situations, activities and environments in order to improve our quality of life. This paper presents our current research work toward the development of advanced theory and technologies for HCR applications, based on inspiration from biological systems. More specifically, both bio-mimetic system modelling and robot learning by imitation are discussed respectively, and some preliminary results are demonstrated.*

Key words: Biological inspiration, Human centred robotics, Robotic Fish, Modelling, Learning by imitation.

1. INTRODUCTION

Traditionally, industrial robots have been mainly used in manufacturing, especially the car industry. These robots have very little sensory capability and intelligence. They can only work in well structured environments to achieve high speed and high accuracy operations. If the environment is changed, they would be unable to function well because they have no ability to adapt. Therefore, these systems have little use in an unstructured environment, especially unable to interact with human.

After the recent advancement of computing and robotics technology, intelligent systems and personal robots are soon ready to serve us in our home, hospital, office and everywhere. These systems and robots are mobile, autonomous, interactive and intelligent, which draws inspiration from behaviour demonstration of biological systems. Recently, a number of new application areas have received significant interests in the robotics community, including entertainment robots, medical robots, education robots, service robots, etc.

Human centred robotics poses a number of challenges. Firstly, it has to deal with uncertainty within the system, such as sensor noise, actuator inaccuracy, and components failure. Secondly, it has to handle huge uncertainty in the real world which is dynamically changing all the time. To catch up these changes in real time is very difficult since no sensor is able to work in all the situation and circumstances. Thirdly, human-robot interaction is a key for success, including communication with and navigation around humans. Finally, inspiration from biological systems is an important issue to be addressed in human centred robotics since it could provide some guidelines to solve the problems.

The rest of this paper is organized as follows. Section 2 describes the modelling of robotic fish and the realisation of basic swimming behaviours. Some preliminary experiment results are given to show the feasibility. Section 3 introduces robot learning by imitation from human operation. Finally, a brief conclusion and future work are given in section 4.

2. MODELLING A ROBOTIC FISH

Most of previous robotic fish researches focused on the hydrodynamics mechanism of fish-like swimming i.e. the steady straight swimming [12], the special skin material [4] and mechanical structure of robotic fish models. Some researchers focused on the animation of a real fish, such as Tu [13]. Their main aims are the fish-like behaviours of artificial fishes but not the motion control or the autonomous navigation. Our project aims to design and build an autonomous navigation robotic fish which would swim like real fish and realize autonomous navigation. Figure 1 presents a virtue robotic fish, and its 3D model with 4 joints for propulsion is presented in Figure 2.

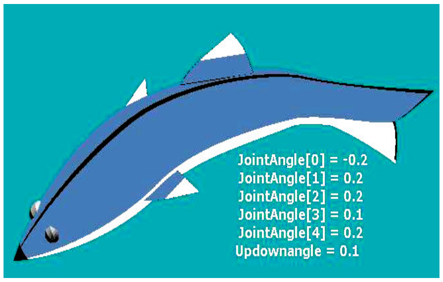

Figure 1 A virtue robotic fish

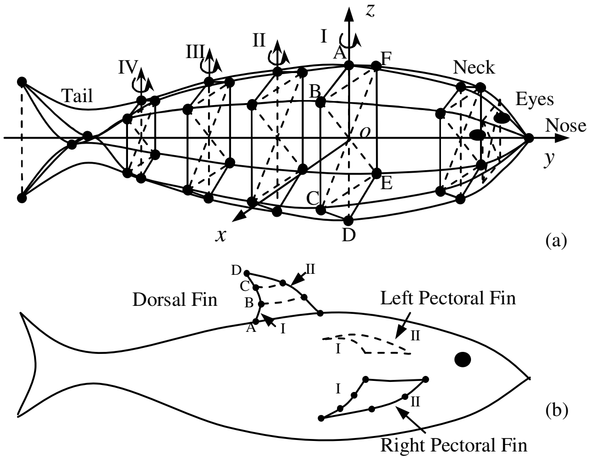

Figure 2 3D robotic fish model

2.1 Fish Swimming Mode

The nature evolvement gives fish a large variety of moving abilities, which can be characterised as swimming or non-swimming (jumping, burrowing, flying and gliding, jet propulsion). In our project, we focus on the swimming movement of carangiform fishes which generate thrust and manoeuvrable motions by the last half/third of their body. For example, the swimming motion of saithe, rainbow trout, cod and common carp belongs to this class. On the base of temporal features, swimming movements of carangiform fishes have been classified into two generic categories [10]:

- Periodic (steady or sustained) swimming: It is characterised by a cyclic repetition of the propulsive movement for a long distance at a random speed.
- Unsteady swimming: It includes fast starts, sharp turn, burst and brake. Transient movements last seconds and are typically used for catching prey or avoiding predator.

Periodic swimming has traditionally been the centre of scientific attention among biologists, mathematicians and roboticists. In fact, swimming at uniform velocities along a straight path is rather exceptional among fishes. The unsteady motions play an important role in fish life. Some biologists have recently cast light on the kinematics of fish. Therefore, we are realizing it in our robotic fish and study its advantage in the engineering field.

For research convenience, we divide the carangiform fish swimming motion into several basic behaviours based on the observation from biologists and ourselves.

- *Straight cruise*: The fish swims along a straight line at a constant speed, possibly with small acceleration / deceleration ($|a|<0.3L/s^2$, L is the length of fish body).
- *Cruise in turning*: Fish is turning in a small angular speed ($|\omega| < 0.5 rad/s$) but at a constant linear speed.
- *Burst*: the fish shows sudden straight acceleration which consists of cyclic fast undulation. The burst-and-coast swimming behaviour is commonly used in fish life for energy saving expected up to 50% [14].
- *Sharp turn*: It generates a sudden angular acceleration for avoiding predators or obstacles. There are two main types of sharp turn, namely C-shape and S-shape.
- *Brake*: The fish generates a sudden straight deceleration by its special tail motion, usually in combination with pectoral and pelvic fins. In the process, the fin rays of the tail fin are actively bent forwards [12].
- *Coast*: It is a motion in which the fish body is kept motionless and straight.

2.2 Realization of Basic behaviours

To realize the fish-like motion, four tail joints of a robotic fish must approximate the kinematical swimming function of a real fish. As shown in Figure 3, the ideal wave is a swimming function and the approximation result shows that four tail joints $\theta_1 ... \theta_4$ turning respectively. The added-mass hydrodynamic theory [5] is adopted here to achieve three fish-like swimming behaviours, namely straight cruise, cruise in turn and sharp turn (C-shape). The coast is only a status for motion planning and it could be realized directly by keeping the tail straight without movement. The brake and the burst will be investigated in future.

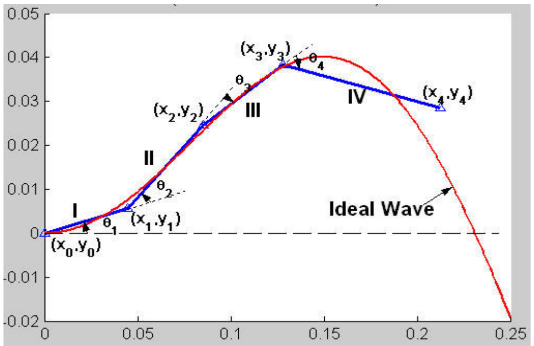

Figure 3: An example of swimming function approximation

Straight cruise

The motion of the fish tail in straight cruise could be described by a travelling wave (1) which was originally suggested by Lighthill [6]. The original point of (1) is set at the conjunction point between the fish head and its tail. The parameter vector $E = \{c_1, c_2, k, \omega\}$ is the key element to determine the kinematics of the fish tail.

$$y_{body}(x,t) = (c_1 x + c_2 x^2)\sin(kx + \omega t) \qquad (1)$$

where y_{body} is transverse displacement of a tail unit; x is displacement along the main axis; $k = \frac{2\pi}{\lambda}$ is the wave number; λ is wave length; c_1 is linear wave amplitude envelope; c_2 is quadratic wave amplitude envelope; $\omega = 2\pi f$ is wave frequency; f is oscillating frequency of tail; t is time. Figure 4 shows a discrete travelling wave in one cycle by 18 divisions. Figure 5 is the final joint angle data for one straight cruise.

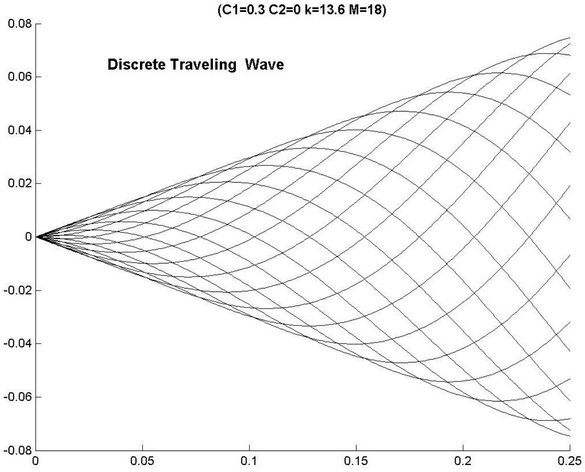

Figure 4: A discrete travelling wave

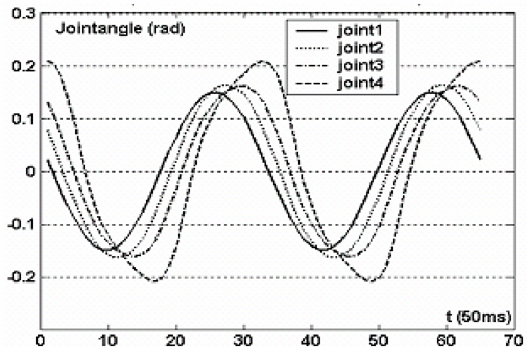

Figure 5 Joint angle curves in 2 cycles of a straight line motion

Cruise in turning

When a fish is at cruise in turning, the motion of its tail is similar to that in straight cruise except for adding a deflected angle to control the angular speed (Figure 6).

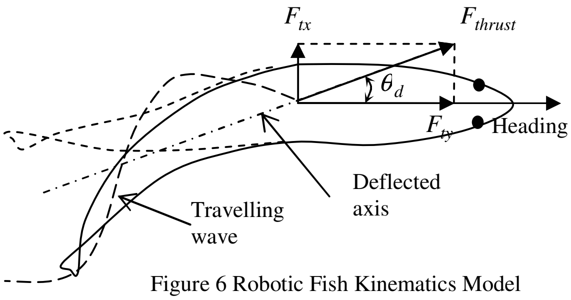

Figure 6 Robotic Fish Kinematics Model

The deflected angle θ_d only affects the turning value of the first joint by adding itself as an offset (Figure 7).

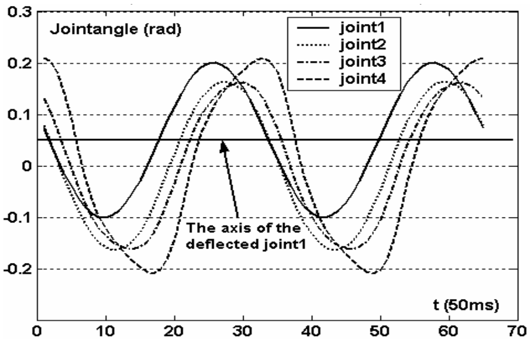

Figure7 the joint angle curve in two cycles in a turning cruise

Sharp turn

Although many biologists made research on sharp turn or fast-start behaviours, they mainly focused on the kinematics of whole fish body in the earth coordination and even now there is no equation to describe it due to its complexity. To realize the sharp turn motion in the robotic fish, we proposed a novel method to describe the approximate joint-end trajectory in the relative coordination in which the fish tail moves relative to the fish head.

Figure 8 is a C-shape sharp turn sequence recorded from an adult carp [11]. We divide it into two stages: *shrink stage* and *release stage*. In the shrink stage (about from 0ms to 50 ms in Figure 8), the tail bends to one side very quickly. The quicker is the sharp turn, the bigger is the tail bending angle.

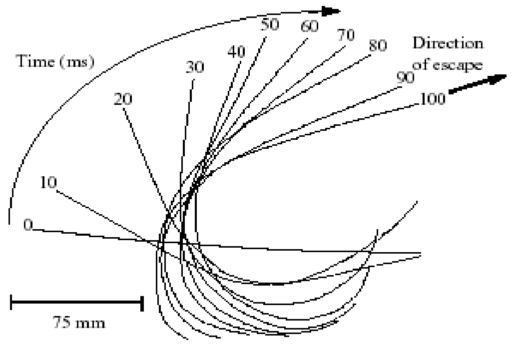

Figure 8 A C-shape sharp turn sequence [11]

In the release stage (from 60ms to and beyond 100ms), the tail unbends in a relatively slow speed from the middle section of the body to the tail tip. A circle function (2) which is tangent to x-axis is used to describe the joint-end trajectory. The centre of the circle changes respect to time.

$$[x-Cx(t)]^2+[y-Cy(t)]^2=Cy^2(t) \tag{2}$$

where

$$Cx(t)=\begin{cases}(cx_1-cx_0)(t-t_0)/(t_1-t_0)+cx_0 & t\in[t_0,t_1) \\ cx_2\left(t-t_1/t_2-t_1\right)^2 & t\in[t_1,t_2]\end{cases}$$

and

$$Cy(t)=\begin{cases}\min(cy_0,cy_1\cdot e^{-k(t-t_1)}) & t\in[t_0,t_1) \\ (cy_1-cy_2)(t-t_2)/(t_1-t_2)+cy_2 & t\in[t_1,t_2]\end{cases}$$

where $cx_i, cy_i, t_i, (i=1,2,3), k$ are parameters to decide the feature of the sharp turn such as shape, bending speed and maximum bending angle, etc.

Figure 9 shows the computation of joint angles $\theta_i (i=1...4)$ and we skip it here due to easy deduction. The curve A-B-C is the trajectory of the centre of the circle in which the sub-curve A-B is the shrink stage ($t\in[t_0,t_1)$) and the sub-curve B-C is the release stage ($t\in[t_1,t_2]$). Figure 10 shows a bending sequence of the fish tail in a sharp turn.

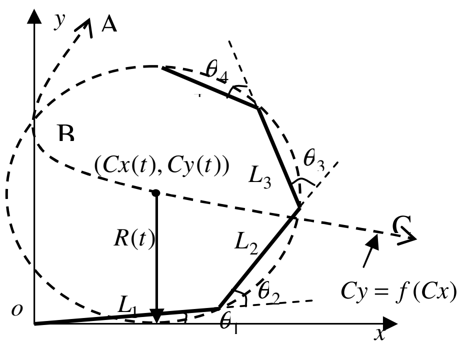

Figure 9 The joint-end trajectory of C-shape sharp turn

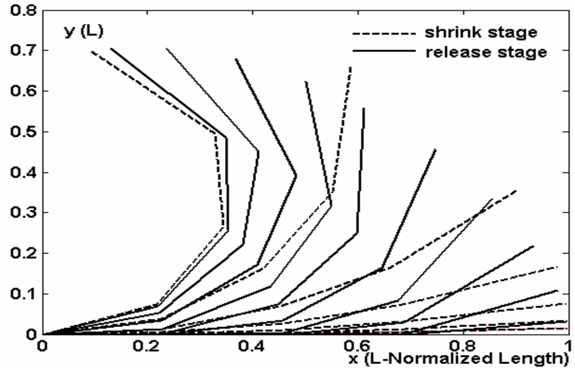

Figure 10 The tail bending sequence in a sharp turn

2.3. Experimental Results

There are two platforms for our experiments: the 3D simulator [7] and the real robotic fish. Firstly, the basic motion behaviours are tested in the simulator in order to find proper parameters or narrow their scope. Then the real robotic fish is used for test and optimise these parameters. Figure 11 shows a diagram describing how to implement optimisation.

For the straight cruise, the 3D simulator is able to show the undulation details of the fish body and output the kinematical information of swimming such as position, speed and acceleration. Figure 12 shows a result of a simulator experiment which is used to get the kinematics performance of the straight cruise. The dash straight line is the desired target speed while the bottom solid wave and the top wave are the speed and acceleration output respectively. The initial speed of the robotic fish is 0.6 (L/s) and then reaches its target speed (0.75L/s) after about 20s. At the same time, the average acceleration of the robotic fish changes from 0.05 to 0 (L/s^2).

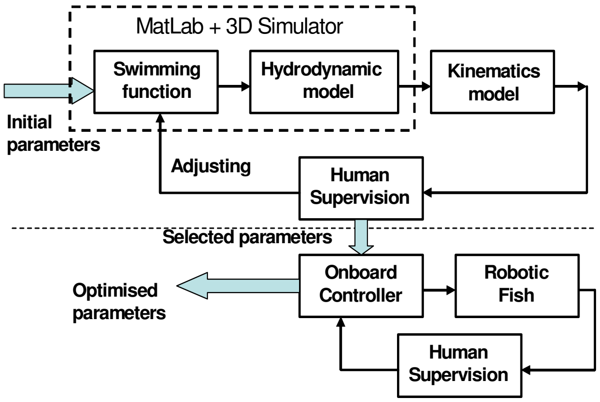

Figure 11 An Optimisation Method for Swimming Functions

The experiment results show that the realization of straight cruise and cruise in turning could generate constant smooth motions and the respect linear speed or angular speed is controllable. For realising the sharp turn, the outline of the robotic fish motion is already like a real fish but the turning angle control method is not exact.

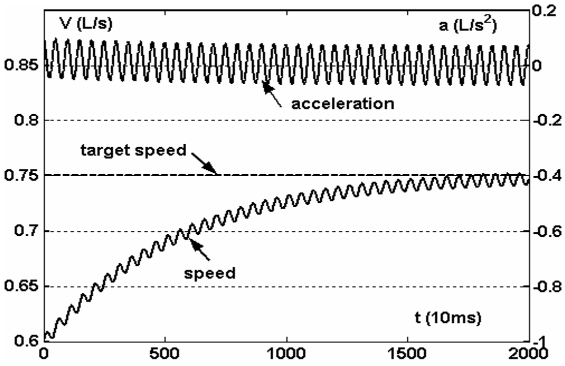

Figure 12 A test result of straight cruise in a 3D simulator

3 ROBOT LEARNING BY IMITATION

The robots of tomorrow will be able to work in the real world that is highly dynamic and unpredictable. Those robots will be identified as service robots and their application will depend on their owner's needs. Service robots are understood as helpful machines in the service of humans. Hence, the introduction of robots in places where humans live or work requires safety, functionality, and effective human-robot interaction [15].

We presented a new learning approach to the application of service robots, which is based on learning by imitation. Service robots need to increase their set of actions, which would lead to the ability of adapting their behaviours. In contrast with traditional learning approaches learning by imitation presents considerable advantages; equip robots with the abilities to be efficient in applications requiring human interaction.

3.1 Our approach

Physiologists have revised imitation of behaviour. One attempt to explain the development of imitation is given by Meltzoff [9], who had introduced a four-stage progression of the imitative abilities, which consists of:

- Body babbling.
- Imitation of body movements.
- Imitation of actions on objects.
- Imitation based on inferring intentions of actions.

Our approach for learning by imitation is based on the principles of these four stages, guiding our attempt to reach imitation in robotic systems. Currently, we focus on the first two of these fundamental issues:

(i) to build a map of proprioception and end-states of the body part; and
(ii) to identify body parts as well as the relation between the observed body part and the own body part is necessary.

We had proposed an approach to merge both of them in a model called matching process that we had implemented in a robotic system. This process can relate the perception and the execution, taking advantage of the physical internal model as well as the identification of body parts and their movements.

3.2 Body Configuration

The restriction of what the robot is able to learn is outlined by the actions that the robot can perform and perceive. Hence, body babbling has been simplified by equipping the robots with a limited task domain set of actions. The consequence of such a compact set of actions is that the robot would be unable to learn new tasks involving either actions that are not part of the repertory, or unfeasible actions to be generated with the current primitives in the repertory.

Although, body babbling is a big issue, should we not try to follow the developmental complexity of nature for our robotic systems? We use nature as inspiration for our designs taking only the best characteristics and not trying to follow in detail the natural model. This is due to the limitations of the current technology and in some cases our lack of deep comprehension of the biological system. Therefore, it is an enormous challenge to develop a body babbling model as it is presented in human beings.

We might not be able to design a body babbling model close enough to the natural model. Instead, we can use scientific means such as control algorithms, which permit our robots to learn how to control their actuators as they map their movements to end-states. Using control algorithms is a way to endow robots with a model to describe their body configuration. Therefore, these models give a completed body configuration, where it is not necessary to recur the random trial-and-error learning, which would take a long time to converge into a well defined body configuration.

Robots are situated machines, which interact in the real world by changing of the values of their effectors. Changing the value of such variables will produce a movement in the space and therefore a new position. When the position control is required, the application must have a mechanism, which allows it to know its position in time. More details can be found in [1].

3.3 Identification of Body Parts

Neurophysicological experiments in humans described in [3] have revealed brain regions that present similar activity to the one presented by mirror neurons, for both perception and execution of action.

Mirror neurons have been discovered for a diversity of movements: grasping, tearing, manipulating, and placing objects, among others. Besides, some mirror neurons not only fire with a particular movement but also with a particular way to perform that action.

Mirror neurons give a good insight into understanding the innate observation-execution pathway in humans. Therefore, we can use the same idea of mirror neurons to approach imitation of body movements. The characteristics that we can use from mirror neurons are:

- Response only with a particular body part.
- Response to particular movements of those body parts.
- Response to the execution of those particular movements.

Those characteristics of the mirror neurons could be used to inspire our matching process. The solution could be in an insight of how human beings focus attention on body parts. Human beings do not focus their attention in every single body part, in order to identify it and its movements. Instead, we focus our attention in the final effectors, discarding the position of the other body parts [8]. Since the physical internal model of our bodies finds the necessary body configuration for the rest of our body parts satisfying the target position for the final effector.

3.3 Imitation of Body Movements

To achieve imitation of body movements, we propose a straightforward model. This model consists of three processes: perception, matching and execution process. The perception process receives the input from the camera. The aim of this process is to identify and extract the part of the body that would be imitated. In addition we would require converting from the observed body part’s coordinate system to the own-execution body’s coordinate system.

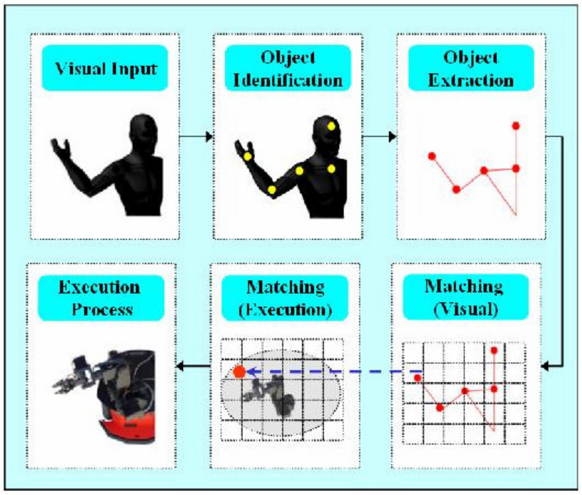

Figure 13 The Model for Imitation of Body Movements

Once the body part’s information is obtained this would be passed to the matching process, which consists of two same-sized "mapped-grids". One of them keeps the visual information about the final effector that will be imitated, and the second one keeps the information needed for the execution of that movement, as shown in Figure 13. Therefore, a new position in the visual part would trigger the execution part, then commands would be sent to the execution process and finally to the effectors.

3.4 Experimental Results

To investigate the abilities of the approach presented, we describe our experience with a Pioneer 2 mobile robot with an onboard 5 DOF arm. Our set-up consists of the Pioneer 2 mobile robot which is the imitator, and a human that is the model to be imitated and located in front of the robot. The robot observes the movements performed by the human and it is then able to perform them.

Figure 14 shows four images: The left two images show the model performing movements that describe a path. The right 2 images show the robot movements imitated by the model. The joints of the model are marked in different colours to simplify the feature extraction. The dark background permits the robot to focus only on the relevant features. We use the pseudo-inverse of the Jacobian matrix for the resolve motion rate control [2]. Figure 15 presents a 3D path (solid line) presented by the model/human, and the trajectory (dotted line) executed by the robot using the resolve motion rate control.

Figure 14 Movements performed by the human model

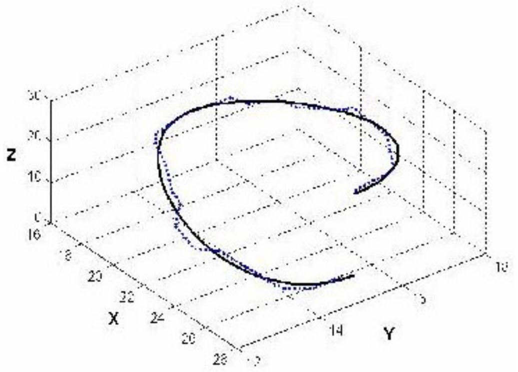

Figure 15 A 3D path presented by the human (solid line) and an actual path (dotted line) implemented by a robot arm

4 CONCLUSION AND FUTURE WORK

We believe that the challenge of future intelligent systems and robots lies in safe operation and flexible human-robot interaction, which implies a totally different set of requirements than for industrial robots that are operated in the structured environments. Instead of high speeds and position accuracy, these human centred robots should have necessary tenderness, compliance and adaptation, which is research inspiration to us.

This paper presents two examples of our current research that show how biological inspiration can be used to enhance robot modelling and learning. More specifically, one example is the modelling of a robotic fish, and another is robot learning by imitation.

Our future research will focus on the human-robot interaction which is a key issue to be addressed in HRC and requires the integration of natural languages, emotion and facial detection, gesture and body language, etc. This is an extremely challenge task.

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