3D Simulation of robotic fish interactions with Physic-based underwater environment

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Abstract-**This paper presents the prototype of a realistic 3D simulation in order to study robotic fish's behaviors and its interactions with a physic-based underwater environment. Mainly, we focus the attention on the production of vortices and sudden generation of thrust forces produced by the fish. The robotic fish (based on the shape of a trout) is developed as a result of a project of the Telerobotics and Applications Department of Italian Institute of Technology. The system will be used to support experiments dedicated to the identification of behavioral patterns of fish and the understanding of how changes in the environment trigger them**

I. INTRODUCTION

In recent years, research on mechanical and control systems of underwater machines has been a grand challenge in the field of biomimetics, mechatronics and system modeling and design. The ideas and motivations emerge from observing how nature copes with its environment [1], [2]. For example, fish are able to survive by reacting to subtle changes in their hydrodynamic habitat while swimming, conserving energy, searching for food and dealing with predators. Research has shown that fish have a limited amount of behaviors that allows them to respond to specific stimuli [1], [2]. In parallel, to extend the knowledge concerning living beings behaviors, 3D environmental visualization and robotic simulations received a great attention and a lot of research efforts have been made in virtual reality, including computer graphics and physics engines[3], [4].

More specifically, a number of water simulators based on physics, dynamics and particles [3],[4] have been implemented. Although powerful and complex, most of these simulators have been created essentially for a specific purpose and considerably arduous to modify in order to make them general enough to be used in different contexts.

This work presents a procedure that enables the evaluation of vortices and forces generated by an underwater agent, in our case, a robotic fish. This procedure is aimed at recreating a virtual hydrodynamic habitat for the robotic fish based on, and supporting several underwater conditions. This has been made possible by the use of two powerful commercial tools: Autodesk Maya 2010 and RealFlow4.

Maya is a high-end 3D computer graphics modeling software, supporting animation, rendering and advanced match-moving capabilities. This widely used software package offers users an end-to-end creative workflow [5].

RealFlow is used in order to run simulation of fluids, water surfaces, rigid and soft bodies, fibers, and meshes. The groundbreaking advantage of using such software comes from the fact that it is particle based. The simulation controls the behavior of the involved elements using their physical properties. Each element can interact with each other, obeying to collision forces and accelerations. Through its Computational Fluid Dynamic engine (CFD) and the rigid body solver; it is possible to reproduce any type of effect from a tornado that devastates a city to a rainstorm [6]. By merging these two powerful platforms, we are able to design an extremely realistic, physically based continuous-particle model in conjunction with a stacking rigid body solver.

II. METHODS

A. *Creation of 3D robotic fish model (MAYA)*

This section is divided into several parts. In particular the authors would like to emphasize the following three stages of production.

1) The design of the 3D model of the robotic fish: The model has been designed to reproduce as accurately as possible each of the structural aspects of the robotic fish. The model is composed of a fully textured, high resolution polygon mesh. It is composed of a detailed UV Map that permits the use of several textures applied to different features of the Phong Shader [7]. The first texture is dedicated to the diffuse color parameter: it is the combination of a texture of a trout's skin with an ambient occlusion texture generated directly on the shape of the 3D model (Figure 1).

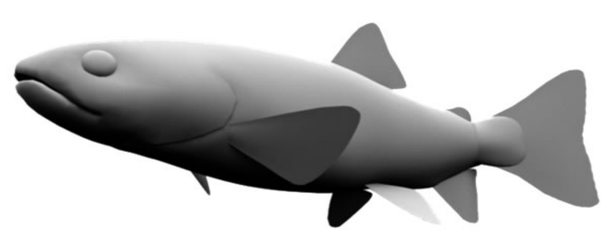

Figure 1. Ambient occlusion texture

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The ambient occlusion texture is a shading method which adds realism to local reflection models by taking into account the attenuation of light due to occlusion [8]. The second texture is dedicated to the Bump parameter: it is a technique where at each pixel; a perturbation to the surface normal of the object being rendered is looked up in a texture map and applied. The result is a richer, more detailed surface representation that resembles closely to the details inherent in the natural world, in this case the roughness of robot fish material.

2) The rig process:

This process is essential for the preparation of a model for animation. This involves setting up an internal skeleton that affects where the model's joints are located and ultimately their degrees of freedom.

The skeleton of the simulated fish is composed of 5 joints, as showed in Figure 2. The joint number 1 (root-joint) and number 5 are fixed (without rotation), this technique is used in animation to define the area influenced by the hierarchy of the skeleton. The joints number 2, 3 and 4 are respectively: Head-joint, Body-joint and Tail-joint. The latter is the equivalent of the fish's servo. These joints are essential for the animation phase.

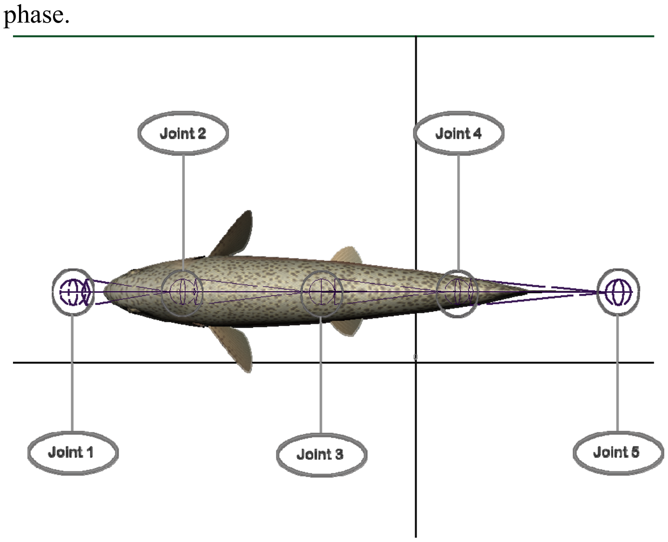

Figure 2. Example of joint skeleton of simulated fish

3) The data acquisition and animation:

The model has been constructed collecting data directly from the robotic fish in order to achieve an exact replication of the model and its movements.

This process starts by applying the data to the 3D model. As described above, the structure of the skeleton has been thought as recreation of the "servo" of the robot. At this stage, the data, collected during the physical robot simulation, have been applied to the "Tail-joint".

The next step is dedicated to adjust the animation flow: due to the visualization of the animation curves, provided by Maya, we are able to smooth the movement of the 3D fish and to add parameters improving the realism of the swimming behavior. For this reason we have included rotation of the Head-joint and Body-joint in order to simulate the flexuosity of a fish skeleton [1]. Further implementation will focus on including the movement and the forces generated by the fins (Dorsal, Pectoral, Pelvic, Adipose and Anal) [9].

The model is now able to be exported and imported in Realflow4.

III. Creation of underwater scenario (Realflow4)

The preliminary work stage of the project is primarily concerned on few aspects of the different underwater conditions. Future work will expand the model in order to integrate a large amount of conditions.

A. Static water

A container of particles completely deprived of flow, permitting the study of the movements of the model in a simple environment where the external forces are only defined by gravity and pressure.

B. Water flow

An emitter of particles recreates a realistic flow of water depending on different parameters such as speed, viscosity and finally internal and external pressure. Within the flow, the model of the robotic fish is recognized as a rigid body. The water flow therefore applies a chain of forces upon it (gravity and friction for instance) which can be visualized in the 3D model. To intensify the water feedback, we decided to simulate two different typology of flow in order to generate different underwater situations.

In the first visualization, the static 3D model of the fish is completely submerged into a water flow identified as a Realflow emitter. As previously described, the emitter offers several parameters, essential to define a realistic aspect of the liquid. In this particular case the density is set at 1000 kg/m³. Other modified parameters are: "Viscosity", critical in order to measure the resistance of the fluid, the "Speed" attribute, which controls the rate of the particle emission, (increasing the

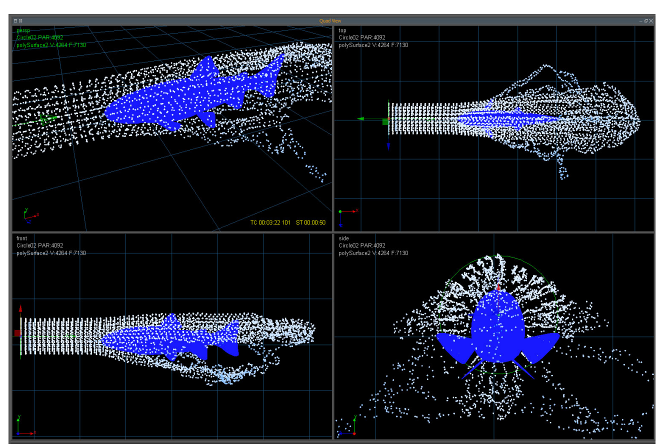

Figure 3. Screen capture of a water flow over the fish body (static)

speed will create more particles per second) and the “Max particles” that define the maximum amount of produced particles.

Figure 3 clearly demonstrates the influence that the shape of the model has on the flow.

At this stage of visualization, the animation of the fish has been inserted. In Figure 4 we can notice the different reaction of the water flow.

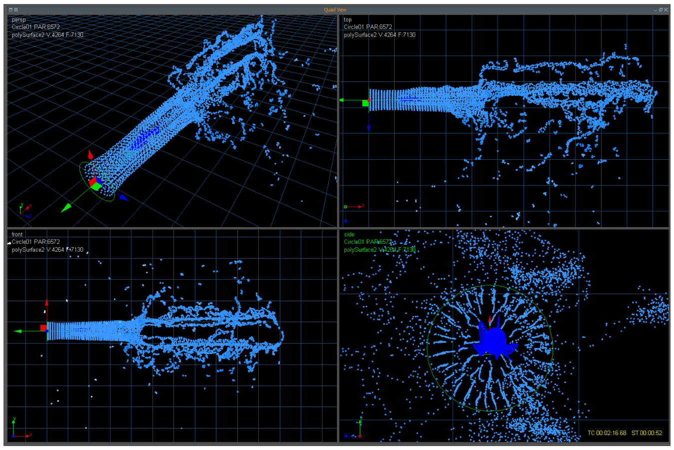

Figure 4. Screen capture of a water flow over the fish body (animated)

The second typology of flow is generated by a linear emitter, to simulate a water surface; in this case only half of the 3D model is immerse into the flow (Figure 5). The features of this fluid are the same as previously described.

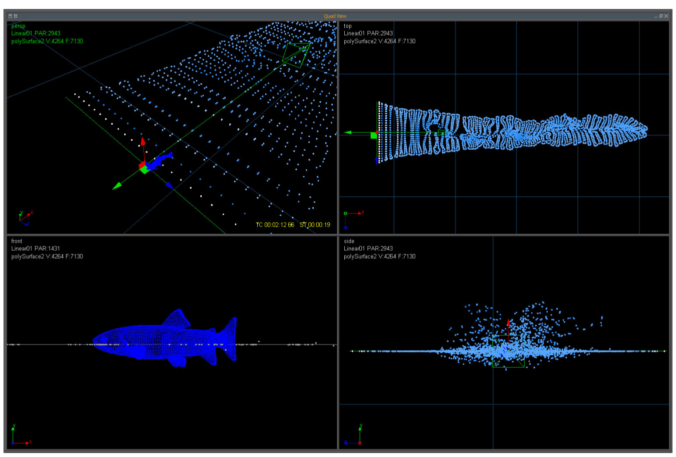

Figure 5. Screen capture of a water linear flow over the fish body (animated)

This visualization emphasizes the representation of vortex generated by the fish.

IV. MENTAL RAY RENDER OF UNDERWATER ENVIRONMENT (MAYA)

This phase is essential in order to provide a realistic representation of the underwater scene.

A. *Importing the Realflow scene into Maya*

Due to the compatibility of the software used, the integration of the scene generated in RealFlow directly into the interface of Maya has been implemented. This permits the adjustments and improvements on the environment with material and high quality textures. One of most important aspect is the material applied to the water. For this simulation we have used the mental ray mia_material [9]. The mia_material is a monolithic material shader that is designed to support most materials used by architectural and product design renderings. It supports most hard-surface materials such as metal, wood and glass. It is especially tuned for fast glossy reflections and refractions.

B. *Lighting and rendering with Mental Ray*

Mental ray is a photorealistic rendering engine which generates images of outstanding quality and realism. It combines the behavior of light with full programmability for the creation of visual phenomena.

We are therefore able to recreate an underwater environment complete with light distortion, reflection and refraction. One of the most common techniques in Computer Graphic, Global illumination [10] has been integrated. This is a general name for a group of algorithms that are meant to add more realistic lighting to 3D scenes. Such algorithms take into account not only the light which comes directly from a light source (*direct illumination*), but also subsequent cases in which light rays from the same source are reflected by other surfaces in the scene, whether reflective or not (*indirect illumination*). To emphasize the realism of the

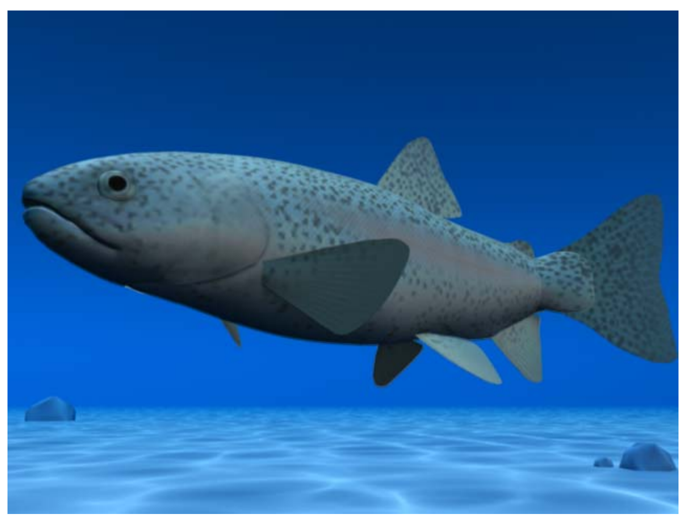

Figure 6 Screen capture of the final rendering.

underwater environment, we have improved the lighting setup and have added two ambient light; the first was to produce a diffuse blue light as in deep sea, the second was an Environment Fog, that gives the fuzzy appearance of the underwater vision. Another important element was a Directional light, useful to simulate the sun light through the waves: at the light color parameter we applied an animated fractal texture, able to recreate a wave motion.

V. Results and Conclusion

This paper presents a complete simulation chain. The work includes three major steps: (1) a 3D fish modeling based on the shape of a trout and its data acquisition; (2) the study of several water flow examples; (3) visualization and understanding of the behavior of the fish while interacting in its environment.

The 3D model was imported from a commercial library and was subjected to three different water flow conditions: one static and two dynamic. After a light-processing step, the data derived are then used to create realistic videos; the outputs of the simulator are frame sequences and vortex data files generated off-line.

Through the presented examples, we have demonstrated the diverse tools used in order to build a realistic 3D model of a trout and its underwater habitat. Furthermore the system supports online parametric adjustments that act directly on the water dynamics in order to observe and study the diverse fish behaviors. In addition, the developed environment can support multiple fish models and water conditions allowing complex and realistic environments.

Future work aim to achieve flexible approaches in order to define several scenarios: firstly, by extending the system and generic situations and secondly, by targeting the footbridge with sophisticated hardware-based tools such as 3D laser scanners. The potential impact of this system can be helpful for robot designers, biologists, researchers or hobbyists dealing with underwater locomotion.

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