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STUDY ON ADVANCED BEHAVIOR ANALYSIS FOR TOWFISH USING PARTICLE-BASED SIMULATION AND REAL-TIME RENDERING

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Abstract. *Recently, the needs for the detection of underwater targets are gradually increasing in military and civil maritime domains. In order to satisfy these needs, various sonars are developed and applied globally. Among small-sized sonars, the interferometric synthetic aperture sonar (InSAS) that obtains high resolution 3-D images using short multiple arrays is very useful. As the distortion and the false alarm occur in the images according to the behavior of a towfish with the InSAS, the optimization of the hull shape and mechanism of a towfish is important. Therefore, the behavior analysis of a towfish is necessary to develop the InSAS successfully. However, the conventional behavior analysis methods have drawbacks in terms of time, cost, difficulties and complexity. To study the advanced behavior analysis of a towfish, a behavior analysis method of a towfish using the particle-based simulation and the real-time rendering is considered. Study results show the overview of the behavior analysis of a towfish, the implementation of the behavior analysis of a towfish and the need for additional studies.*
Keywords: Interferometric synthetic aperture sonar, Towfish, Behavior analysis, Particle-based simulation, Real-time rendering

1. **Introduction.** Recently, the needs for the detection of underwater targets are gradually increasing in military and civil maritime domains [1,2]. In order to satisfy these needs, various sonars are developed and applied globally. Among small-sized sonars, the synthetic aperture sonar (SAS) [3] that obtains high resolution images using short arrays and the interferometric SAS (InSAS) [4] that obtains high resolution 3-D images using short multiple arrays are very useful because they have the same effects of the large-sized sonars using long arrays.

As the distortion and the false alarm occur in the images according to the behavior of a towfish [5] with the SAS or the InSAS, the optimization of the hull shape and mechanism of a towfish is important for obtaining better sonar images. Therefore, the behavior analysis of a towfish is necessary to develop the SAS or the InSAS successfully. However, as the conventional behavior analysis methods, an analytical approach [6,7] has drawbacks in terms of time and cost in identifying hydrodynamic coefficients and a mesh-based computational fluid dynamics (CFD) [8] has drawbacks in terms of difficulties and complexity in severe water situations.

To study the advanced behavior analysis of towfish, a behavior analysis method of a towfish using the particle-based simulation and the real-time rendering is considered. This method is good to overcome these time, cost, difficulties and complexity.

The overview of the behavior analysis of a towfish is described in Section 2 and the implementation of the behavior analysis of a towfish is described in Section 3. Finally, the conclusions are summarized in Section 4.

2. **Overview of Behavior Analysis of Towfish.** Related to the overview of the behavior analysis of a towfish, the studies of the necessity of the behavior analysis of a towfish and the representative methods for the behavior analysis of a towfish are explained as follows.

The necessity of the behavior analysis of a towfish is the optimization of the towfish hull shape and mechanism: in the cases of small-sized sonars, the SAS that obtains high resolution images using short arrays and the InSAS that obtains high resolution 3-D images using short multiple arrays. Upper and lower sides in Figure 1 respectively show the principles of the SAS and the InSAS.

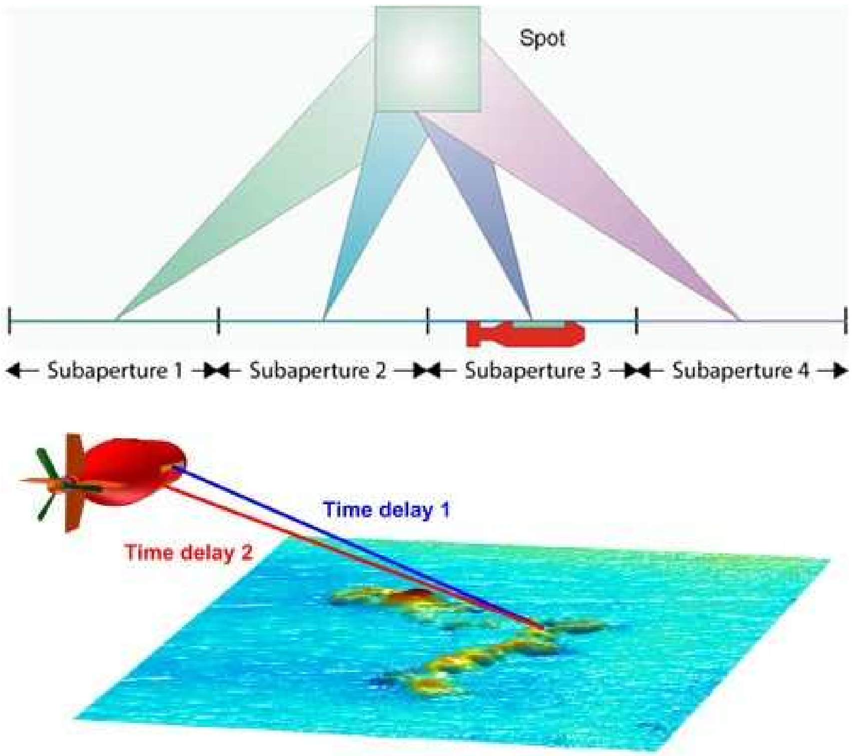

FIGURE 1. Principles of SAS and InSAS

As the distortion and the false alarm occur in the images according to the behavior of a towfish with the SAS or the InSAS, the optimization of the hull shape and mechanism of a towfish is important. The distortion and the false alarm may degrade images. Therefore, the behavior analysis of a towfish is necessary to develop the SAS or InSAS successfully.

The representative methods for the behavior analysis of a towfish are an analytic approach, a mesh-based CFD and a mesh-free CFD.

The analytical approach executes the modeling and simulation based on the motion equation [6,7] with the hydrodynamic coefficients which are identified according to the hull shape of a towfish and require much time and cost:

$$\boldsymbol{Ma} = -\begin{bmatrix} \boldsymbol{F}_I \\ \boldsymbol{G}_I \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_R \\ \boldsymbol{G}_R \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_H \\ \boldsymbol{G}_H \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_P \\ \boldsymbol{G}_P \end{bmatrix} \tag{1}$$

where $\boldsymbol{M}$ is a mass matrix, $\boldsymbol{a}$ is an acceleration vector, $\boldsymbol{F}_I$ and $\boldsymbol{G}_I$ are inertia force and moment vectors, $\boldsymbol{F}_R$ and $\boldsymbol{G}_R$ are restoring force and moment vectors, $\boldsymbol{F}_H$ and $\boldsymbol{G}_H$ are hull force and moment vectors, and $\boldsymbol{F}_P$ and $\boldsymbol{G}_P$ are propulsion force and moment vectors. However, it is not easy to predict the water behavior in severe water situations and it is very limited for this event because it is almost impossible to deal with the nonlinear free-surface flows, while the CFD has good ability to overcome these difficulties. Among CFDs, the mesh-based CFD has been well developed and evaluated so far but still has difficulties and complexity to precisely capture the free-surface with fragmentation and reconnection like splash and breaking waves.

As a mesh-free CFD, the particle-based method [9] has the advantage in dealing with complicated free-surface flows because the free-surface can be naturally captured without numerical diffusion. The simulation using graphic processing unit (GPU) is applied to the prediction of 6-DOF ship motions in severe water condition [10]. The governing equations dealing with compressible fluids are as follows and they are concerned with mass, weight function, tuning parameter, speed of sound, position vector, wave length, wave height:

$$\begin{aligned} &\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \boldsymbol{u}) = \boldsymbol{0} \\ &\frac{D\boldsymbol{u}}{Dt} = -\frac{1}{\rho}\nabla P + \boldsymbol{g} + \Theta \end{aligned} \tag{2}$$

where ρ is a density, $\boldsymbol{u}$ is a velocity vector, P is a pressure, $\boldsymbol{g}$ is a gravity vector, and Θ is a diffusion term.

While the conventional behavior analysis methods such as an analytical approach and a mesh-based CFD have drawbacks in terms of time, cost, difficulties and complexity, a mesh-free CFD is good to overcome these time, cost, difficulties and complexity.

3. **Implementation of Behavior Analysis of Towfish.** Related to the implementation of the behavior analysis of a towfish, the study of a behavior analysis method of a similar towfish using the particle-based simulation and the real-time rendering is performed as follows.

For this simulation and rendering as a performance estimation method [11], the Unreal Engine of Epic Games, Inc. [12], the PhysX FleX module and the compute unified device architecture (CUDA) of the NVIDIA Corp. [13] are used. The Unreal Engine as a real-time rendering tool enables to implement the 3-D rendering and the PhysX Flex module as a particle-based simulation technology enables to implement the interaction of rigid body and fluid using the same particle expression about all object types. The loop of the related algorithm [14] is shown in Table 1.

As the PhysX Flex module has the recommended specifications above GeForce 8 series, the GTX Titan X as a high performance graphic card is used. The GPU CUDA board used for this implementation is shown in Table 2.

The CUDA is a parallel computing platform and application programming interface (API) model. It is a general-purpose computing on GPU (GPGPU) technology that utilizes the GPU, which is only used for computer graphics, in computing application program. The processing flow on the CUDA is shown in Figure 2.

As the results of the particle-based simulation and the real-time rendering, the action results of the PhysX Flex module on hull shapes and towing forces are shown in Figure 3.

According to hull shapes and towing forces, the behaviors of a similar towfish are different. The upper cases of the vertically symmetric hull shape do not generate the vertically non-symmetric hull force while the lower cases of the vertically non-symmetric hull shape generate the vertically non-symmetric hull force. As the towing force is increased, the non-symmetric hull force is increased.

TABLE 1. Loop of algorithm

Algorithm 1 Simulation Loop

for all particles i **do**
  apply forces $\mathbf{v}_i \Leftarrow \mathbf{v}_i + \Delta t \mathbf{f}_{ext}(\mathbf{x}_i)$
  predict position $\mathbf{x}_i^* \Leftarrow \mathbf{x}_i + \Delta t \mathbf{v}_i$
  apply mass scaling $m_i^* = m_i e^{-kh(\mathbf{x}_i^*)}$
end for
for all particles i **do**
  find neighboring particles $N_i(\mathbf{x}_i^*)$
  find solid contacts
end for
while $iter < stabilizationIterations$ **do**
  $\Delta\mathbf{x} \Leftarrow \mathbf{0}$, $n \Leftarrow 0$
  solve contact constraints for $\Delta\mathbf{x}$, n
  update $\mathbf{x}_i \Leftarrow \mathbf{x}_i + \Delta\mathbf{x}/n$
  update $\mathbf{x}^* \Leftarrow \mathbf{x}^* + \Delta\mathbf{x}/n$
end while
while $iter < solverIterations$ **do**
  for each constraint group G **do**
    $\Delta\mathbf{x} \Leftarrow \mathbf{0}$, $n \Leftarrow 0$
    solve all constraints in G for $\Delta\mathbf{x}$, n
    update $\mathbf{x}^* \Leftarrow \mathbf{x}^* + \Delta\mathbf{x}/n$
  end for
end while
for all particles i **do**
  update velocity $\mathbf{v}_i \Leftarrow \frac{1}{\Delta t}(\mathbf{x}_i^* - \mathbf{x}_i)$
  advect diffuse particles
  apply internal forces $\mathbf{f}_{drag}$, $\mathbf{f}_{vort}$
  update positions $\mathbf{x}_i \Leftarrow \mathbf{x}_i^*$ or apply sleeping
end for

TABLE 2. GPU CUDA board

Category	Specification
CUDA Cores	3072
Base Clock	1000 Mhz
Boost Clock	1075 Mhz
Texure Fill Rate	192 Giga Texels/s
Memory Speed	7.0 Gbps
Memory Size	12 GB
Memory Maximum Bandwidth	336.5 GB/s
Media Port	HDMI, DP, Dual Link DVI-I
Power	Max 600 W

From these results, the behavior analysis method of a similar towfish is proven to have meaningful methodologies such as the Unreal Engine, the PhysX FleX module and the CUDA, and the GPU unit.

4. **Conclusions.** In this paper, a behavior analysis method of the towfish using the particle-based simulation and the real-time rendering has been well studied. The method is summarized as follows: it requires the particle-based simulation using the PhysX FleX

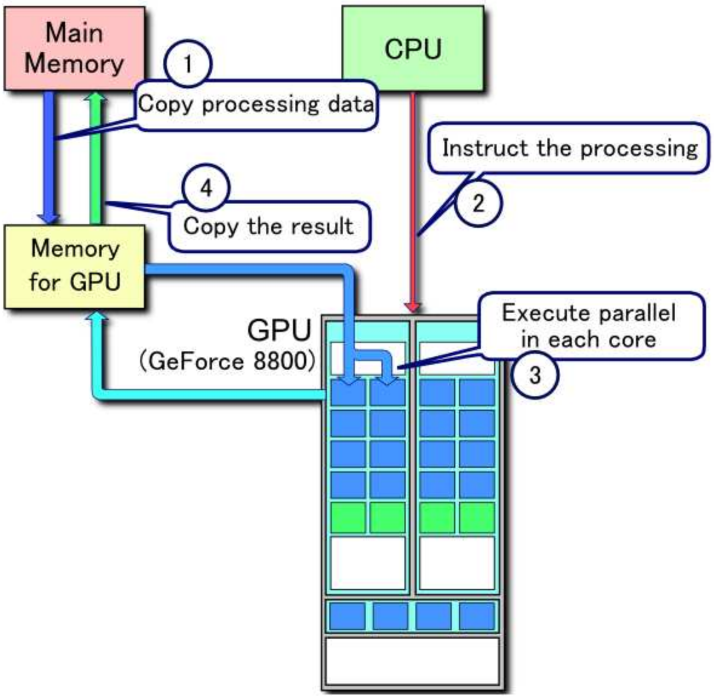

Figure 2. Processing flow on CUDA

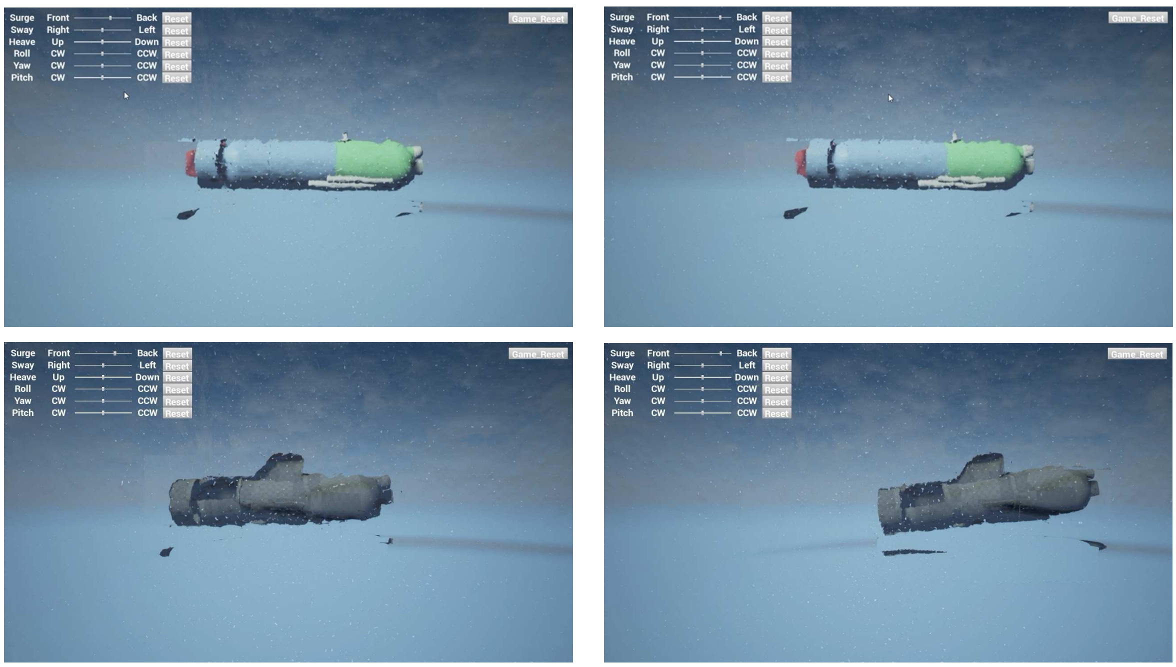

Figure 3. PhysX Flex action on shape and force

module to effectively analyze the behavior of a towfish in underwater; it requires the real-time rendering using the Unreal Engine to effectively visualize the behavior of the towfish. The CUDA and the GPU unit are necessary for both simulation and rendering. The study results showed the overview of the behavior analysis of a towfish, the implementation of the behavior analysis of a towfish and the need for additional studies. Through this, a basic behavior analysis method of a towfish for the underwater target detection has been established. In the future, additional studies such as a GPU parallel processing due to the increase of the particle numbers for more accurate behavior analysis of a towfish will be conducted.

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