# Correcting Distortion of Views into Aquarium

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**Abstract.** In this paper, we discuss a way to correct light distortion of views into an aquarium. When we see fish in an aquarium, they appear closer also distorted due to light distortion. In order to correct the distortion, the light rays travelling in the aquarium directly towards an observer should hit him/her after emerging from the aquarium. A basic idea is to capture those light rays by a reference camera, then merge the rays as a single view, which is displayed to the observer. An experiment in a real world environment shows that light distortion of a view into an aquarium can be corrected using the multiple reference camera views.

**Keywords:** distortion correction, aquarium, light distortion.

## 1 Introduction

Aquariums provide extraordinary experience and opportunities for people to learn about sea creatures. Primary school students might learn what they look, what they eat, how they swim, how they work together to hunt their prey, etc. High school students might learn how food chain works, how sea creatures fight against the water pressure, how fish organize their schools, etc. Researchers might learn how water pollution affects sea environments, what kind of problems the global warming causes in the sea environments, etc. Thus aquariums play an important role in education for a wide range of people.

The structure of aquaria is quite simple. It is an acrylic box with empty space inside, which is filled with sea water. One of problems inevitably focused on is water pressure. Recently, the size of aquaria has become huge to exhibit migratory fish and large fish, also to reduce their stress levels, resulting in high water pressure. For example, the largest aquarium in Japan belongs to Okinawa Churaumi Aquarium. Its size is 35m high x 27m wide x 10m deep. So, the water pressure is tremendous. To resist the water pressure, the acrylic glass of the aquarium is made 60cm thick. The thickness of acrylic glass however causes another problem. That is light distortion.

Do you have any experience of seeing fish distorted while you watch them in an aquarium, especially in a diagonal direction to the acrylic glass? Those

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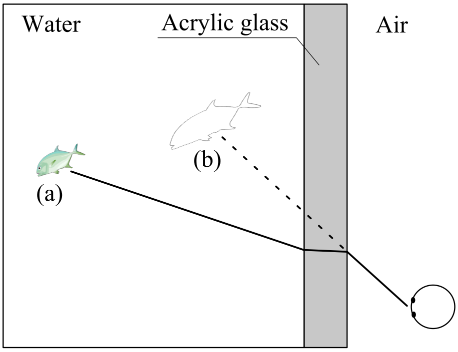



**Fig. 1.** Light distortion in an aquarium (top view)

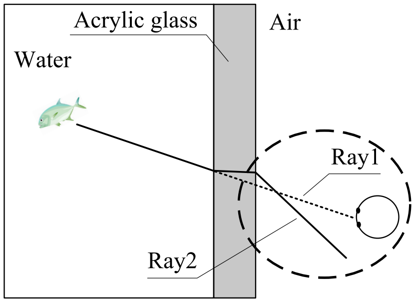
fish appear closer also distorted. This is due to light distortion. Technically, this phenomenon stems from light refraction where light rays bend passing through the surface of the acrylic glass. To deal with the light distortion, we use a set of photos taken at specific positions and the image based rendering technique [1].

There have been studies dealing with light distortion for measurement of underwater objects [2]. As mentioned above, photos taken by an underwater camera are affected by light distortion in the same way. It leads to inaccuracy of measurement on the photos. To deal with this problem, correspondence from each pixel on the photos to a single light ray, called ray-map, is created during the calibration process. The map enables accurate measurement of objects on the photos even though the objects appear distorted. In contrast, Sedlazeck et al. study on a way to create photo-realistic underwater images by modeling light refraction, light scattering and light attenuation [3]. So far, no studies are found attempting to construct distortion-free views. 3D structure estimation of underwater objects studied in [4] could construct those views using the extracted geometric information, but it seems inappropriate to create underwater atmosphere by including drifting dust, ascending air bubbles, tiny creatures and the like. Therefore, in this paper, we focus on the image based rendering for distortion-free views.

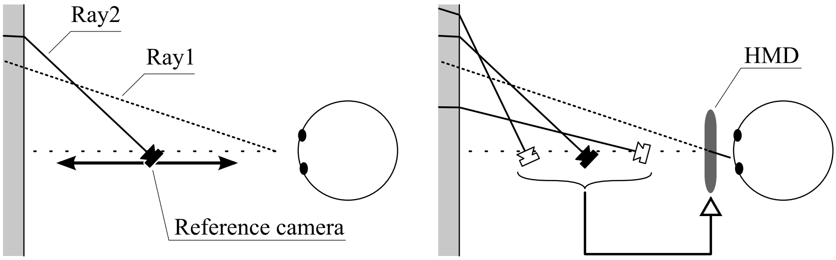
The rest of the paper is organized as follows. In Section 2 it is explained how light distortion occurs in an aquarium and how different the fish would look. Then a basic idea to correct the distortion is explained in Section 3. In Section 4 it is shown that the idea could correct the distortion in real world environments. Finally we give concluding remarks in Section 5.

## 2 Light Distortion in Aquarium

Figure 1 illustrates how light distortion occurs in an aquarium. An observer stands in front of the acrylic glass of the aquarium. The observer sees an imaginary fish (b) in the direction represented by the dotted line, which is visually




(a) Two key light rays. Ray1 travels without consideration of light refraction while Ray2 is refracted on the two boundaries: water to glass, glass to air.




(b) Close-up in the dashed circle in (a). Ray2 is captured by a reference camera.

(c) Images captured by the reference camera is displayed on the HMD. Thus, Ray2 is seen in the direction of Ray1.

**Fig. 2.** Our approach to correct light distortion (top view)

created from the real fish (a). The solid line represents the light ray passing through the acrylic glass. The light ray emerging from the fish (a) takes the first contact with a boundary between water and the acrylic glass then the light ray is refracted. It continues to travel inside the acrylic glass and takes the second contact with a boundary between the acrylic glass and air then the light ray is refracted again. After that it travels in the air to the observer's eye. Thus, the observer will be misled into perceiving the fish (b) as the real. The light distortion becomes more significant when the observer stands diagonal to the acrylic glass and sees fish. The light distortion leads to misperceiving of not only the position of the fish but also the size. The next section describes a way to correct the light distortion.

## 3 Correction of Light Distortion

Figure 2 illustrates how the light distortion is corrected. (a) shows an observer being right in front of the straight line coming from a fish. Ray2 represents the

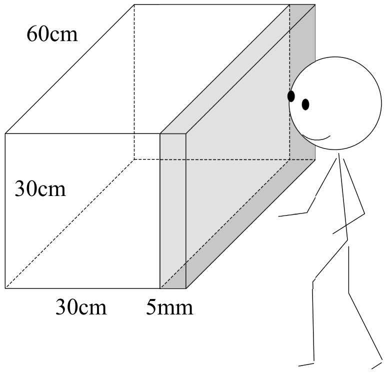



**Fig. 3.** A simulated glass aquarium

actual light path. Thus, in this case, the observer does not see the fish in that direction represented by Ray1. The point is how Ray2 could be seen by him/her at their position. In this research, we take following two steps to expose Ray2 to the observer. As shown in Figure 2(b), the first step is to gather all light rays which should go straight to the observer from the fish. To gather the light rays, a camera (hereinafter referred to as the reference camera) is placed at a series of positions and captures the rays. Each of the images taken by the reference camera includes a part of color information, all of which is necessary to construct the light distortion-free observer view. That is, in the second step, these images need to be merged as a single view before it is finally displayed on the HMD as shown in Figure 2(c). Consequently, the observer sees the fish in the right direction.

In the next section, we simulate a small-sized aquarium on a computer and show that the light distortion can be corrected.

## 4 Experiment on Correction of Light Distortion

First of all, the positions and orientations of the reference camera need to be obtained in order to capture the light rays of interest as shown in Figure 2(c). To obtain those, we simulated a small-sized glass aquarium on a computer and traced light rays between the observer and aquarium. Note that in the simulation and following experiment the aquarium used is made of glass instead of acrylic glass. Refractive indices were set to 1.52 for the glass, 1.33 for the water inside. The observer's position was set to 5cm to the aquarium. Figure 3 shows the simulated glass aquarium of 5mm thickness. Figure 4 shows some of the simulated light rays. The dotted and solid lines correspond to Ray1 and Ray2 in Figure 2, respectively. As seen in the figure, becoming closer to the aquarium, more angled light rays need to be captured. To be general, when the observer is at $D$ mm to the aquarium then a ray (or the dotted line which should come to the observer from the direction of $\theta_o$ off-center) can be captured at $x$ in the direction of $\theta_c$, which are given by

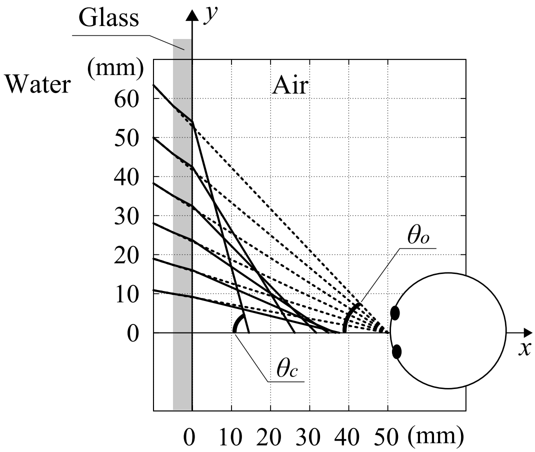



**Fig. 4.** Simulated light rays between the observer and aquarium (top view)

$$\theta_c = \arcsin\left(\frac{n_3}{n_1}\sin\theta_o\right), \tag{1}$$

$$x = \frac{(G + D)\tan\theta_o - G\tan\theta'}{\tan\theta_c}, \qquad \theta' = \arcsin\left(\frac{n_3}{n_2}\sin\theta_o\right) \tag{2}$$

where $n_1$, $n_2$ and $n_3$ are refractive indices for air, glass and water, respectively. $G$ is the thickness of the glass aquarium.

We have now obtained where and which orientations the reference camera should be placed in to capture the light rays of interest. Next we make sure that a set of the images captured by the reference camera is sufficient to create the light distortion-free observer view. Figure 5 shows a glass aquarium in a real world environment. The aquarium is the same size as the simulated. Water plants and rocks were placed in a way as shown in the figure. Figure 6 shows an experimental setup. The reference camera was placed at 25 to 50mm to the aquarium along the line, also was angled at $50^o$ off-center for 25 to 31mm and by $20^o$ for 32 to 50mm. At each position one reference view was taken, therefore 26 reference views in all were obtained. Another camera representing the observer was placed at 50mm to the aquarium and was angled at $25^o$ off-center. To map pixels on the observer view to those on the reference views, light rays were traced from the observer to the reference camera. This mapping allows the creation of the light distortion-free observer view from the reference views.

Figure 7(a) shows a view into the empty aquarium, which was taken at the observer's position. Figure 7(b) shows a view at the same position but the aquarium is filled with water. As expected, the view is distorted compared to (a). Specifically the objects in (b) appear larger towards the right. Figure 7(d) to (f) represent the reference views. Note that these views are all affected by light distortion. Finally as shown in Figure 7(c), the desired view from the observer

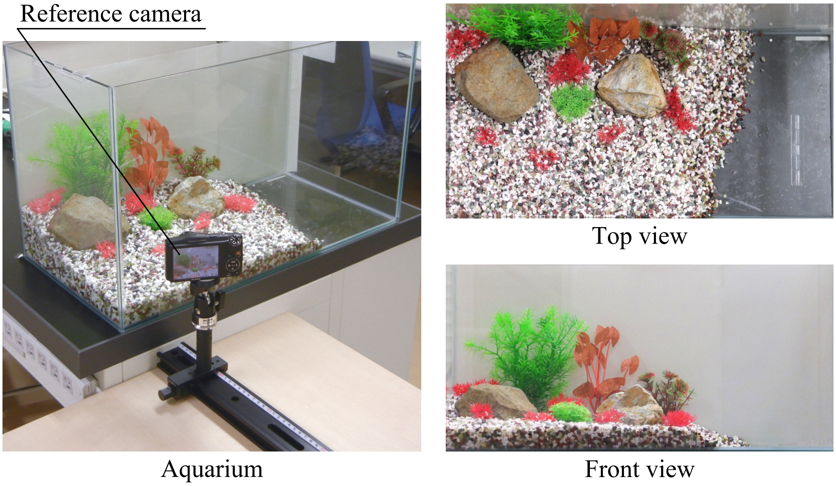



**Fig. 5.** A glass aquarium in a real world environment. Note that no water in the aquarium to see the right positions of the water plants and rocks inside.

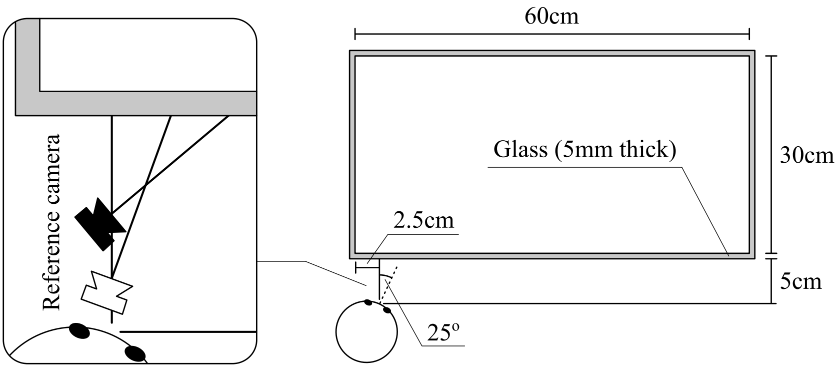



**Fig. 6.** An experimental setup (top view)

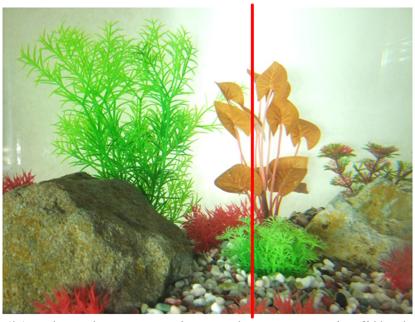
was constructed of the reference views. Pixels surrounded by a line in (d) and (e) contributed to the corresponding part of the view (c). Thus (c) is comprised of a part of each of the reference views. Although 26 reference views were taken, any views at 39 to 50mm positions were not used for (c). Here we calculated the limiting values of $\theta_c$ and $x$ when $\theta_o$ approaches zero, which are given by

$$\lim_{\theta_o \to 0} \theta_c = 0, \tag{3}$$

$$\lim_{\theta_o \to 0} x = \frac{n_1 n_2 (G + D) - n_1 n_3 G}{n_2 n_3} \approx 38.02. \tag{4}$$

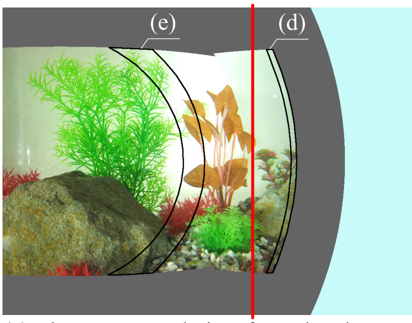
(a) The observer view when no light distortion affects it or no water is filled with.

(d) The view from the reference camera placed at 25mm to the aquarium and angled at 50° off-center.



(b) The observer view when water is filled with, in which the objects appear larger towards the right compared to (a).

(e) The view from the reference camera at 35mm and 20°.




(c) The constructed view from the observer, which is comprised of the reference views represented by (d) to (f).

(f) The view from the reference camera at 45mm and 20°.

**Fig. 7.** Views from the observer and reference camera in a real world environment. The vertical lines help understand to what extent the view is distorted, also corrected.

Therefore reference views up to 38mm position are sufficient to construct the light distortion-free observer view in this experimental setup. Finally it is obviously shown that the light distortion found in (b) was successfully corrected in (c), but not totally. Some peripheral part was left gray background. The gray background could be drawn if reference views at 1 to 24mm positions were available as well as upward/downward ones. In this experiment, only rightward reference views were used for simplicity. In addition, reference views up to 24mm position were unable to be obtained because of no room to place the reference camera even closer to the aquarium.

## 5 Conclusions

In this paper, we discussed a way to correct light distortion of views into an aquarium. When we see underwater objects, they appear closer also distorted due to light distortion. In order to correct the distortion, the light rays travelling in the aquarium directly towards an observer should hit him/her after emerging from the aquarium. First we found out where those light rays were heading by a computer simulation. Next those light rays were captured by a reference camera placed at the obtained positions. Finally the reference views were merged as a single view. This experiment in a real world environment confirmed that the light distortion-free observer view was successful constructed of the multiple reference views.

In the future work, we plan to expand the observer view by using not only rightward reference views but leftward/upward/downward ones. Also we seek another way to capture reference views so that it takes less time to complete the observer view. As a result, it will allow moving objects in the aquarium such as swimming fish and swaying water plants.

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