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Certification Article

Close-Range Photogrammetric Assignment in a Submarine

BY SANDY WEISS

Retrofitting nuclear submarines is an endeavor that the U.S. Navy undertakes with regularity. When the Navy redecorates with new walls called bulkheads, the walls are made of three inch thick steel plate that must be cut to size and then fit into the appropriate locations within the ships. The locations that the bulkheads fit into can be very irregular in shape. There are a multitude of pipes and other surface mounted structures that must be accommodated. When the steel is cut too small, it is scrapped, costing a great deal in time and money and the process must start from scratch. When the steel is cut too large, crews of grinders must laboriously resize the piece until it fits into the opening. This operation can take a crew days to complete. The Navy, in an attempt to find a better way to cut the bulkheads to the right size the first time, hired our company to find the solution.

The particular submarine that we worked on was in dry dock in Charleston Naval Shipyards, South Carolina. The ship was not only receiving a new bulkhead but was also being outfitted with two 40 ton diesel generators which were intended to be backups to the nuclear reactor. Our project was to supply dimensional data for the new bulkhead that could then be fed into a computerized torch that would cut the steel plate to the perfect size to fit the opening, and also to supply a map of the bolt posts that had to be installed in the floor of the generator room to fit the holes in the bottoms of the generators.

There is an assortment of ways to accomplish the requirements that the Navy asked, but only one of the ways would work under the time constraints that were placed on us. We were allowed only one day to perform all of the required measurements. We could not be on the base before 800 hours and we had to be off the base by 2400 hours due to Naval regulations. The bulkhead location was down inside the ship below too many decks and through too many hatches to bring in any kind of man lift. The ceiling was too high to use a Faro-arm, portable coordinate measuring machine for data acquisition without building a scaffold. The bulkhead location was a very irregular shape and would require a great many sightings with a total station in order to have enough information to use the total station as the only means of data acquisition. We decided to solve the problem photogrammetrically.

Photogrammetry as defined by Dr. Paul Wolf in his book entitled, *Elements of Pbotogrammetry,* is "the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images." Included within the definition of photogrammetry are two distinct areas: "(1) metric photogrammetry, which involves precise measurements and computations to determine sizes and shapes of objects", as was used in this job, "and (2) interpretative photogrammetry, which deals with the recognition and identification of objects." In the area of metric, the primary application is the generation of planimetric and topographic maps, derived most often from aerial photographs taken from airborne vehicles. Terrestrial photos can also be used for this purpose and the technology is then classified as close-range.

For this project, we used our Wild-Heerbrugg P-32 terrestrial metric camera. The camera uses 120 roll film and flattens the film against a glass plate at the time of exposure. The glass plate has six feducial reference marks etched into it. These cameras were distributed in North America, until recently, by Leica. Leica has ceased distribution, but the cameras can still be rented from some large surveying companies if the need should arise. The only comparable camera currently being sold in this country is the Rolleiflex 6008. The Rolleiflex 6008 metric has a number of advantages over the Wild including, interchangeable lenses, through the lens metering, motor drive and an 11 X 11 built-in grid plate (r'eseau). The Rolleiflex is, however, a 6X6 cm. format, while the Wild is a 6X9 cm. format. For the ultimate in measuring precision, we stick with the older

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camera and the larger format. For more information about the Rolleiflex 6008, log onto the Rollei web site at www.rollei.com.

We used Kodak technical pan film for the ultimate in both sharpness and contrast. To shoot the intended bulkhead location, we first had to grind, stripe and target the entire circumference (figure 1). Then we brought in four 1200 watt photoflood reflectors so that we would have enough light to shoot at a small aperture with the camera. We had to shoot at a distance within the minimum focusing requirements of the camera and rely on depth of field to supply the required sharpness. We used a total station to record at least 12 reference control points, some of which would be contained in each of the photographic stereo pairs. We then shot enough overlapping stereo pairs to cover the whole opening that the bulkhead was to fit into. After shooting the required photos in the ship, we went to a hangar type building on shore nearby where the generators that were to be installed were stored. In order to shoot photos of the holes in the bottom of the generators, the Naval personnel had to hoist

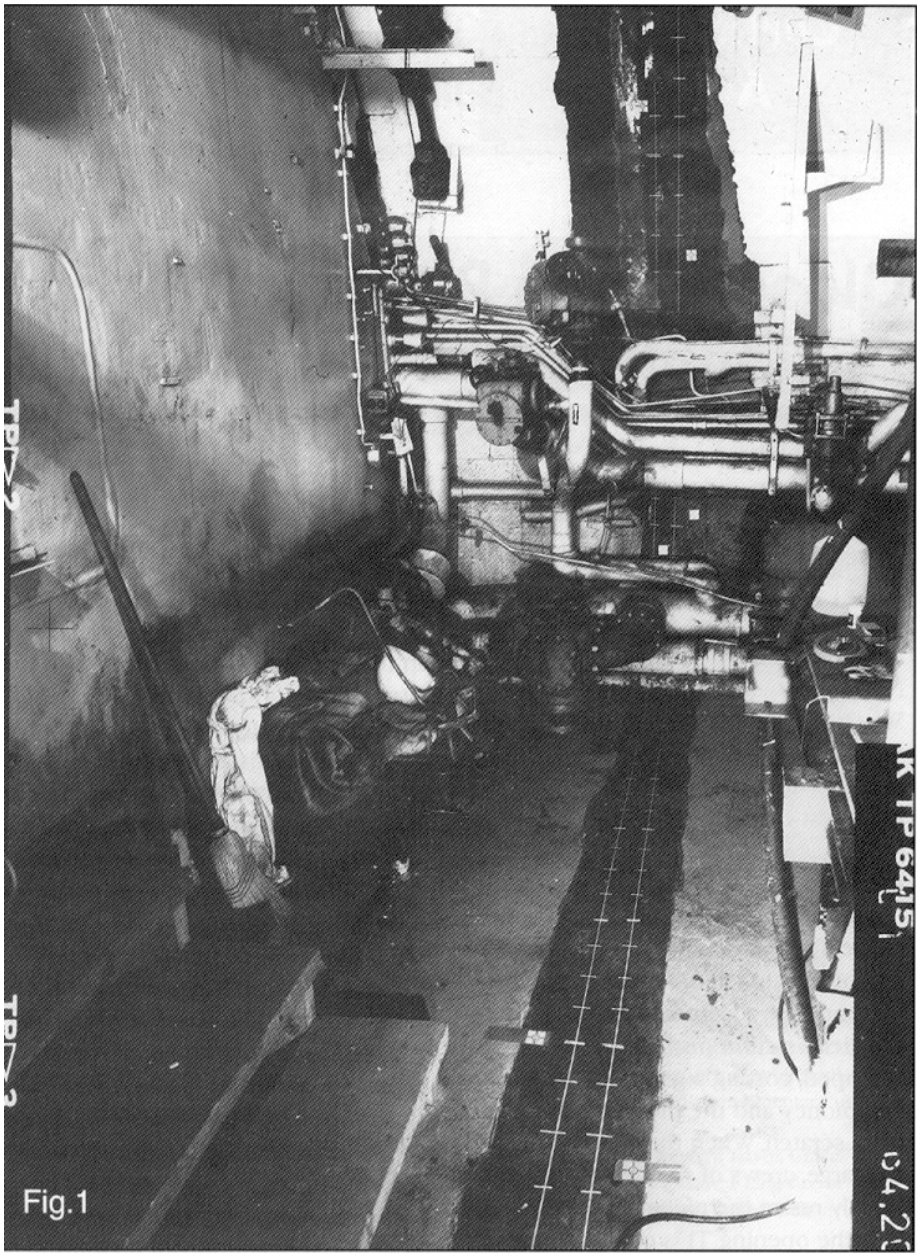
Fig.1

one of the generators up to the roof of the hangar and I had to lie on my back on the floor underneath and shoot straight up (figure 2). This would have been a scary undertaking under the best of conditions but was scarier yet when I found out that the crane that was lifting the generator was rated for only 30 tons. Luckily, the cables held and we only had to take photos of one unit, because the two generators were identical.

The Navy requires that all film shot at their classified installations be processed and inspected before it leaves the base. I was informed of this before we left our lab and brought a portable darkroom along and set up in the men's locker room. I had a changing bag, tank, developer, fixer and alcohol for drying the film. I developed the film in Kodak Technidol. The pressure to have the film developed successfully was very intense. There was a crew of eleven Naval personnel waiting for me, with the generator still hoisted in the air, awaiting the results. The film came out perfectly and the generator was lowered to the ground without mishap.

Back at our office, we turned the film over to our stereo compilation expert. This aspect of the data acquisition is only done by highly trained special-

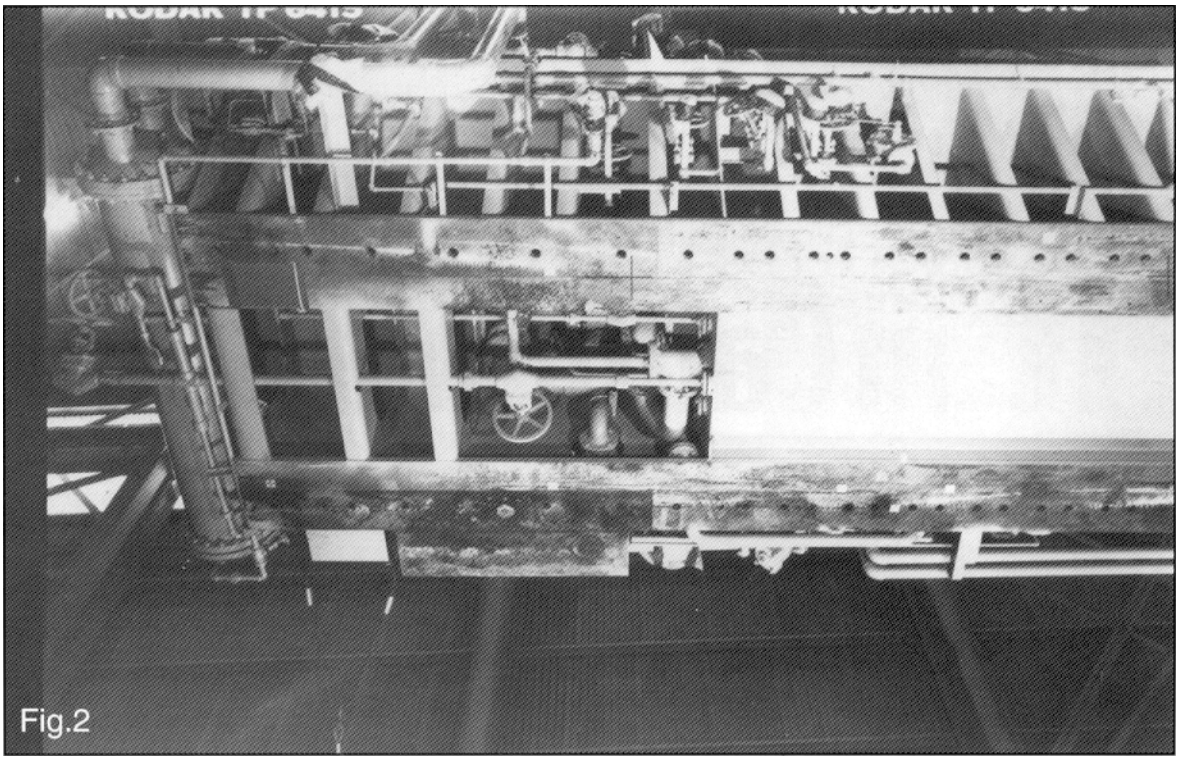
Fig.2

ists. He used an analytical stereo compiler to extract the necessary data directly from my negatives. (There is a representative compiler on the Rollei web site). He converted radial angle and distance measurements to the XYZ 3D Cartesian coordinates associated with each control point in the stereo model. He was able to successfully interpolate the unknown points that we didn't have time to physically measure and developed data from the internal geometry of the camera and the measured control points.

In the absence of the compilation equipment and personnel, there are software solutions to this aspect of the project. Two software packages that can be used for data acquisition from photogrammetric images are PhotoModeler and FotoG. I am more familiar with PhotoModeler, having used it myself, so I will concentrate on that package for this explanation. For more information on PhotoModeler, consult the web site at www.eossystems.com. A lite version of the software is downloadable for free from that location. PhotoModeler is able to utilize a wide variety of photographs, from any type of camera, and supply dimensions of the visualized subject. The accuracy of the measurements obtained are directly proportional to the type of camera used to take the photographs and the skill of the person doing the work. As with the compiler, the person doing this work on the computer should be highly skilled and well trained if the resultant measurements are to be relied upon. There is a very scholarly article on the Eossystems web site, written by Klaus Hanke, Associate Professor at the University of Innsbruck, Austria. The purpose of the article is to describe the accuracy obtainable with PhotoModeler when comparing the Wild P32 camera to a non-metric 35mm camera. The results of the study showed that the average accuracy obtainable with the 35mm camera was in the range of 1: 1700 of the object size and with the P32 was 1: 6500 of the object size. In the case of the submarine project, the required accuracy could have been achieved using either camera system.

Considering that the negatives from the P32 need to be digitized in order to be used by the software, using a digital camera for data acquisition is possible. Eossystems recognizes this as a viable option but warns that the resultant measurements might suffer in accuracy. Using a high end scanner will yield an 8K x 6K file from the P32 negative. The current, top-of-the-line digital camera, the Kodak 660, is only capable of a 3K x 2K file size. The use of proper targets on the subject will allow very similar accuracy in the ultimate measurements, but if the P32 is available, it makes the purchase of a $25,000 digital Camera seem unnecessary.

The finished product for both the bulkhead and the generator base was a mathematical model of 3D space with dimensions accurate to less than one eighth of an inch. This degree of error was within the parameters that were specified by the Navy: The mathematical model was then transferred to Pro-Engineer software by way of a DXF file. (For information about Pro/E solid modeling software, log onto the Parametric Technologies web site at www.ptc.com). Pro-Engineer has a handy option that talks directly to computerized cutting devices. The computerized torch was used for cutting out the bulkhead and a CAD generated map was used to generate the locations for threaded posts to fit into the holes in the bottom of the generator. The project was successful and the Navy now uses this protocol for similar applications.