Automatic Target Recognition (ATR) with Submarine Periscope Imagery
Areté Associates
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1. Objective

Demonstrate the feasibility of automatic target recognition (ATR) with periscope imagery by implementing a suite of ATR algorithms, applying them to simulated images, and quantifying classification performance as a function of target and environmental variation.

2. Statement of the Problem

Since Kollmorgen installed the first-ever periscope on a submarine in 1916, periscope technology has advanced considerably. Very fast optics and multiple imaging bands have greatly improved target detection while high-resolution digital imagery has facilitated increasingly sophisticated image processing. Despite these advancements in imaging technology, targets are still classified as before – by human observation and comparison with known target profiles.

With some 2900 warship classes worldwide, the target recognition task quickly becomes overwhelming for human observers. Time is lost making manual comparisons and range often closes without knowledge of the potential threat. Human observation is severely limited in hull-down conditions, when most of the target is below the horizon. Workload and fatigue become important considerations in the areas of heaviest maritime traffic – which often correspond to submarine operating areas.

Figure 1: A tactically useful ATR algorithm will be able to classify targets by extracting key features while much of the hull remains below the horizon.

Automatic Target Recognition (ATR) will offer several advantages to submarine effectiveness and safety. By providing more accurate classification at greater ranges, it will support faster decision-making. In regions of high target density, ATR can overcome degraded human performance and provide more consistent classification results.

Areté Associates proposes a RIPS project that demonstrates ATR feasibility with the Navy's current periscope imaging system.

The basic approach will be to implement a suite of ATR algorithms, apply these algorithms to images generated using Areté's Synthetic Ocean Scene Generator (SOSG) software, and quantify classification performance as a function of target and environmental variation.

3. ATR Algorithm

We propose a hierarchical approach to target classification. The proposed algorithm starts with coarse information, such as moments and angular dimensions, to eliminate incompatible classes before proceeding to more detailed and computationally intensive comparisons, e.g., correlation filters. In addition to being computationally efficient, this approach allows the operator to be presented with successively more detailed information as it is gleaned from the target while further comparisons are performed in the background.

For the RIPS program, we will restrict attention to initial coarse classification based on ship silhouettes. This work will build a solid foundation for future development of more detailed algorithms that account for variations in illumination.

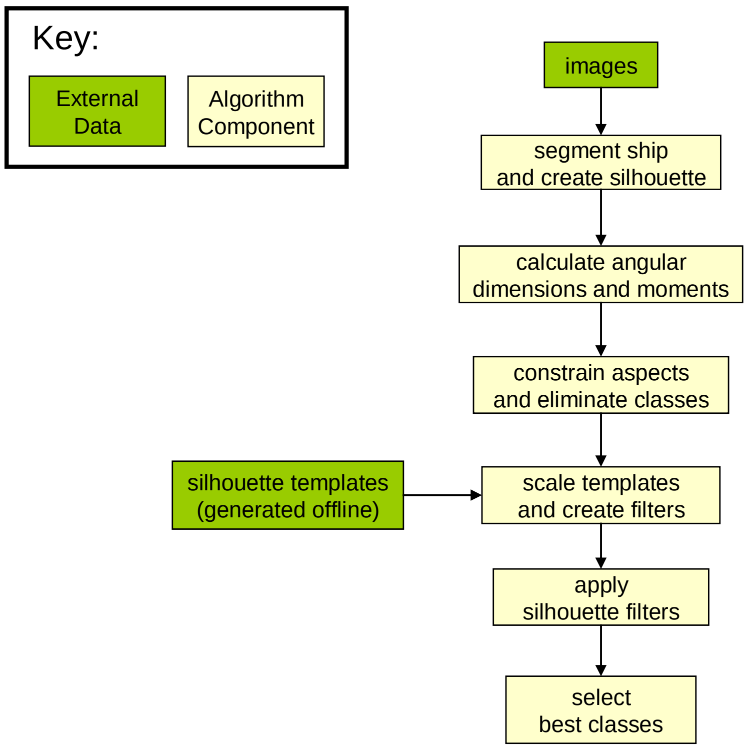

Figure 2: Flowchart for a possible RIPS periscope ATR algorithm.

Figure 2 illustrates one possible approach to the initial coarse classification. The first step involves segmenting targets from the background and generating silhouettes. Figure 3 shows examples of target segmentation and silhouette creation using real data.

The next step is to calculate the moments and angular dimensions of the silhouette. The angular dimensions constrain the number of aspects considered when generating the correlation filters. The moments provide a coarse measure of shape used to eliminate incompatible classes. Figure 4 shows two ship silhouettes with differing moment characteristics.

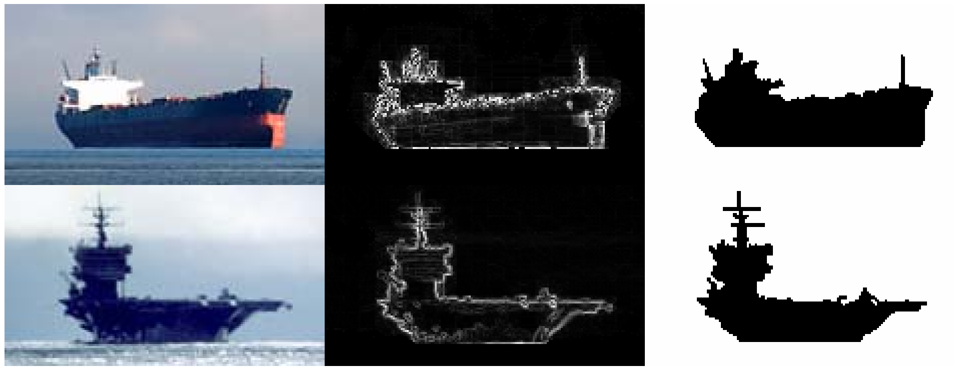

Figure 3: Examples of target segmentation and silhouette creation.

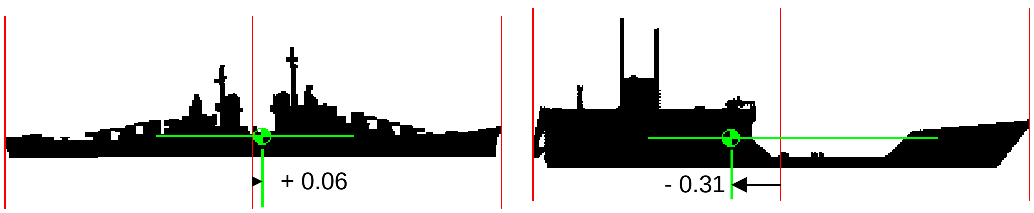

Figure 4: Two ship silhouettes with differing moments

For each surviving class, templates consistent with the estimated aspect would then be used to create a Maximum Average Correlation Height (MACH) filter. The MACH filter is defined as

$$HMach = \frac{M}{\alpha D + \beta S + \gamma U}, \quad (1)$$

where
M = FFT([mean of a set of template images])
D = The output noise variance (ONV), adjusting alpha contributes to noise tolerance.
S = The average similarity measure (ASM), adjusting beta contributes to distortion tolerance.
U = The average correlation energy (ACE), adjusting gamma contributes to peak sharpness.
[α, β, γ] = Scalars, known as the optimal trade-off parameters, which are useful in balancing the performance of the filter under a variety of conditions.

Each filter is designed to maximize the response to the class in question while remaining robust to variations in appearance and noise. For each class, a MACH filter would be created from the appropriate set of template images created offline using Areté's Synthetic Ocean Scene Generator (SOSG) software. Classification would be determined by which filter produces the strongest output.

This is one of several possible approaches. Alternatively, one could implement statistical methods such as Principal Component Analysis (PCA), or other correlation filters. We encourage the RIPS team to research several approaches and quantify the trade-offs.

4. Synthetic Ocean Scene Generator (SOSG)

"I'm king of the world!"
-Leonardo DiCaprio in Titanic, looking out over Areté-generated ocean.

Areté has been at the forefront of high fidelity simulation, particularly of the ocean environment. Our initial infrared-band ocean simulations eventually evolved into visible-band simulations used to generate photorealistic ocean imagery for Hollywood films such as *Titanic*. Recently, Areté has merged and expanded these capabilities into a single comprehensive application called the Synthetic Ocean Scene Generator (SOSG). For the RIPS program, SOSG would be used to generate any template images for MACH filters. To avoid the complications of real-world data, SOSG will also be used to generate the imagery used to test classification performance. Figure 5 shows example images generated by SOSG.

Figure 5: On-hand target models in SOSG-generated ocean scenes (left). Comparison of research vessel in SOSG imagery (upper right) with actual imagery (lower right).

5. Statement of Work

The RIPS team will be asked to perform the following activities to demonstrate the feasibility of ATR in periscope imagery:

1. Develop a target segmentation algorithm that creates a silhouette from SOSG-generated images.
2. Develop algorithms to calculate angular dimensions and moments of silhouettes and find moments that perform well in separating classes from one another. Quantify discrimination performance as a function of aspect and range. Develop logic to constrain target aspect for each class.
3. Develop more detailed classification algorithms to further eliminate candidate classes. These could be based on correlation filters, statistical techniques, or other methods. Ideally, you would conduct an exploratory study quantifying the performance of several potential algorithms.
4. Generate test images for each class using SOSG, varying parameters such as range, aspect, and sea state.
5. Apply the full suite of algorithms to the test images. Quantify classification performance as a function of class, range, aspect, and sea state. Measure algorithm execution time and make projections for larger databases and alternative computing platforms as a means of judging the feasibility of real time classification.

Existing algorithms, written in IDL or Matlab, for target segmentation, silhouette mensuration, and MACH filtering may be used as starting points for the RIPS effort.

6. Program Details

Kick-off Meeting: Areté staff will meet with the RIPS team to give an overview of the problem and expected program outputs. This meeting will prepare the RIPS team to write a detailed statement of work. This is a key document that will guide research throughout the program and ensure that reasonable goals are set and met in the limited time available. Additionally, we will schedule a time for weekly meetings to review progress.

Weekly meetings: One or more Areté staff will meet with the RIPS team each week to answer questions and review progress. Students are expected to give a 5-10 minute PowerPoint briefing reviewing recent results and plans for the following week. While these presentations require some extra work, they help clarify the significance of the past week's efforts and provide a great foundation for the mid-term and final presentations.

Documentation: Students will deliver mid-term and final reports and presentations documenting their research. Your research efforts will serve as the foundation of future work at Areté, so **documentation is crucial**. Someone two years later should be able to review the documentation produced during this program and piece together what you did, how you did it, and why it was significant. Thus, code should be well commented and the reports clearly written.

Finally, congratulations on being selected from a highly talented pool of students. We look forward to working with you. Good luck!

References

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