AUTOMATED IMAGE GEOREFERENCE AND TACTICAL SUPPORT TO CANADIAN COAST GUARD USING DOWNLINK - ICEVU SYSTEMS

Z. Ou*, M. McGregor, A. Koonar, B. Zacharuk

Canadian Ice Service, Environment Canada, 373 Sussex Drive, E-3, Ottawa, Ontario, Canada K1A 0H3
(Ziqiang.Ou, Awtar.Koonar, Bob.Zacharuk)@ec.gc.ca, Mac.McGregor@sympatico.ca

Commission II, WG II/5

KEY WORDS: SAR/SLAR, Downlink, Remote Sensing, GPS, Image Georeference, Navigation, Wavelet Compression

ABSTRACT:

The annual variation of Canada's sea ice extent equals roughly half of Canada’s entire landmass. Each year, ships face many challenges traveling the Canadian waters of Labrador Sea, Gulf of St. Lawrence, and Arctic Ocean. There are more than 10,000 icebergs encountered in Canadian waters annually and about 90% of all icebergs are calved from the glaciers of Western Greenland. These environment conditions have caused some of history's more famous maritime disasters - most notably the Titanic, which sank off the coast of Newfoundland in April 1912. Timely ice information becomes especially important to all Canadian and international marine operations on Canadian waters. The mandate and mission of the Canadian Ice Service is to provide timely information on ice conditions for navigational purposes, to warn marine operators of hazardous ice conditions in Canadian waters, and to maintain a general historic knowledge of ice conditions and ice climatology. This paper discusses the Downlink - ICEVU system, an image-based spatial decision support system developed by the Canadian Ice Service, Environment Canada. It provides real time tactical support to the Canadian Coast Guard and commercial shipping in Canadian waters.

1. SYSTEM OVERVIEW

The Downlink - ICE-VU system is an image-based real-time decision support system. The system consists of two basic systems, namely, data acquisition and decision support, plus the communication infrastructure.

The DASH-7 Ice reconnaissance aircraft, which is equipped with a SLAR (soon will be upgraded to a new SAR), acquires Radar images. The aircraft navigation system provides image annotation data. Both Radar image and navigational annotation data streams are combined and compressed by the onboard Downlink system. The combined data can then be sent to Canadian Coast Guard icebreakers, commercial ships and ground receiving stations in real-time or near real-time by an S-Band transmitter.

At the same time, the image data is processed and geocoded onboard the aircraft by the onboard ICE-VU system. The Ice Service Specialists onboard the aircraft use the processed images to ensure the image quality and verify the accuracy of the georeference. They can also use the ice information from the georeferenced images along with their visual observation from the air to produce accurate ice charts. The generated ice charts can then be sent to the ships and ground stations by the S-Band transmitter, along with the georeferenced, annotated raw radar data.

The ICE-VU system, which is installed on the Canadian Coast Guard icebreakers, commercial ships, Canadian Ice Centre, and in Ice Operation Offices, receives the imagery and ice charts sent by the aircraft. The received raw Radar imagery is automatically geocoded by the ICE-VU system. The Canadian C[1]oast Guard icebreakers and commercial ships are equipped with a GPS receiver that is connected to the ICE-VU system.

When the georeferenced images and charts are loaded into a viewer, the ship’s position is automatically displayed as a layer on top of these products. As the ship traverses the waterway, the GPS updates the ship position on the viewer allowing the ship’s navigation officers to view the ships position relative to the surrounding ice and therefore safely navigate the ship through the ice covered waters. The ICE-VU system has plenty of image analysis and enhancement tools to make that task easier for the navigation officer. The officer can use the navigational aid tool to plan the routes based on ice conditions, to track the ship’s location, to generate navigational reports and even playback the ship’s tracks. The system operational scenario and its communication infrastructure are shown in Figure 1.

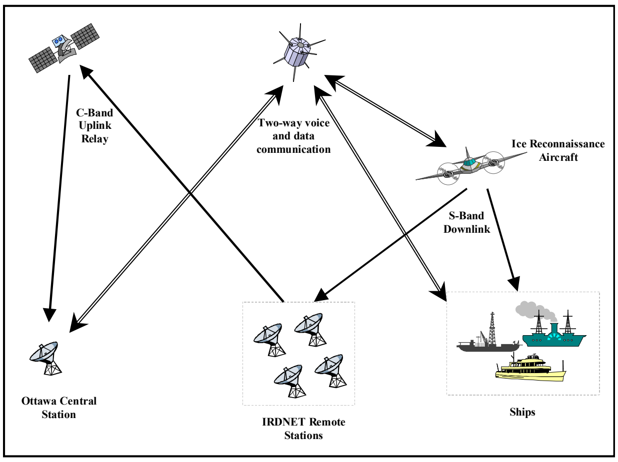

Figure 1. System Operational Scenario

* Corresponding author

All data collected during the flight is sent to the Canadian Ice Service located in Ottawa and to Canadian Coast Guard Ice Operation Offices through an Ice Reconnaissance Data NETwork (IRDNET) system. The IRDNET consists of a central command/control centre and a receiving station at Ottawa and five remote ground stations located in eastern Canada and at various spots in the Canadian arctic. The data is first sent to the IRDNET ground station that is in line of sight of the aircraft by S-Band**,** then it is uplinked to the satellite using C-Band for delivery to Canadian Ice Service in Ottawa and to various CCG Ice Operations Offices. The data received at Canadian Ice Service is processed and catalogued by another system called Ice Services Integrated System (ISIS) to generate daily image analysis, ice analysis and forecasting charts and image products. These products are then sent to our clients and partners and are made available on our geo-spatial web site to the general public.

2. AIRBORNE DATA ACQUISITION SYSTEM

The Figure 2 shows the high level configuration of the airborne system. The system consists of a Radar subsystem, Downlink subsystem, ICE-VU subsystem and S-Band transmitter. The detailed system hardware and software configurations were described in (Koonar and Ou, 1999).

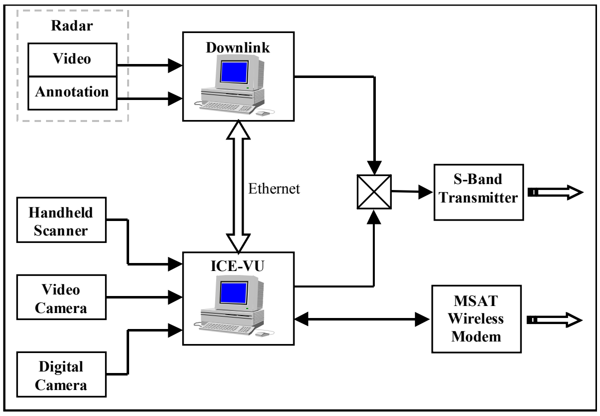

Figure 2. Airborne Ice Reconnaissance Systems

There is additional image and video capture equipment installed onboard the ice reconnaissance aircraft. These include a ZEISS mapping camera, digital camera and digital video camera to provide additional means of acquiring image data from the air. The digital camera and digital video camera images are downloaded into the ICE-VU system aboard the aircraft. The videos and still pictures of ice conditions can then be sent in real time or near real time to Canadian Coast Guard (CCG) Icebreakers and commercial ships by the Downlink system. All data are also sent to the Ice Forecast Centre at Ottawa through IRDNET.

An alternative MSAT voice and data communication link can be used to send the images and videos, ice charts and text messages to all Ice Operation Offices, CCG and commercial ships as well as the Ice Forecast Centre at Ottawa.

To assist the Ice Specialists on the aircraft, an Onboard Analysis Subsystem is currently in the concept stage (Canadian Ice Service, 2002). The system will be configured with a small network linking a server and one or more workstations. This allows the analysts to interpret newly processed SAR/SLAR imagery in near real-time, generate an analysis enhanced by visual and other sensor data. Visual data entry will be based on pen computers that will use GIS technology for attribute and feature inputs. Data integration and analysis will be performed on the server. The final products are then downlinked to coast guard ships, commercial ships or satellite broadcast stations for delivery to Ice Forecast Centre and to CCG Ice Operation Offices.

Beyond their standard ice duties, there will be opportunities in which aircraft equipped with the Onboard Analysis Subsystem could provide real-time decision support to all other time critical disaster assessments such as flooding, forest fire and pollution.

3. SHIPBORNE DECISION SUPPORT SYSTEM

ICE-VU system is designed specifically as marine decision support application. It is installed on the Canadian Coast Guard icebreakers, commercial ships and in Ice Operation Offices, onboard the aircraft, and at Ice Forecast Centre. It provides Coast Guard and Ice Operations staff with the capability to receive real-time Synthetic Aperture Radar (SAR) and Side Looking Airborne Radar (SLAR) data, digital camera images, live digital videos, ice charts and text messages or to download processed satellite images and ice charts from Ice Forecast Centre.

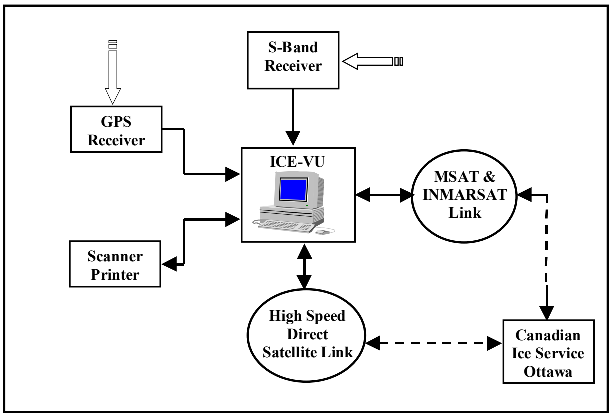

Figure 3. Shipborne Navigation Systems

The ICE-VU system monitors the incoming data ports. When new data arrives, it automatically opens a waterfall display and the received data is saved onto the local disk drive. A Watchdog is monitoring the file system. Once a raw SAR/SLAR radar image received by the system, it will be automatically processed and geocoded by the Watchdog.

The Canadian Coast Guard icebreakers and commercial ships are also equipped with a GPS receiver. The ship's positioning data is fed into the ICE-VU system. When the georeferenced images and charts are loaded into a viewer, the ship's position is automatically displayed as a layer on top of these products. As the ship traverses the waterway, the GPS updates the ships position on the viewer allowing the ship's navigation officers to view the ships position relative to the surrounding ice and therefore safely navigate the ship through the ice infested waters. The ICE-VU system has plenty of image analysis and enhancement tools to make that task easier for the navigation officer. The officer can use the navigational aid tool to plan the routes based on ice conditions, to track the ship's location, to generate navigational reports and even playback the ship's tracks.

All ship's positions are also reported to Ice Forecast Centre at Ottawa and stored in ship's location database. This information helps the Ice Specialists to provide better ice information coverage to those particular areas.

4. WAVELET IMAGE COMPRESSION

When real-time live data is required by the ships or ground stations, the radar image has to be compressed to reduce the data volume before transmission due to the bandwidth limitation of the S-Band transmitter.

Since the radar data is collected line by line and the data has to be transmitted out in the same fashion, we cannot wait until the whole leg is finished. Thus, the one-dimension discrete Daubechies wavelet transformation (Press, Teukolsky, Vetterling and Flannery 1992) is used to compress the radar image line by line.

The advantages of the line by line, one-dimensional compression include:

- Compression and decompression can both be done in real time as the data comes in.
- When there is data loss during the transmission, it will not affect any other lines of data.
- Easy implementation and fast calculation.

The forward Daubechies wavelet filter coefficient matrix is give by:

$$C = \begin{pmatrix} C_0 & C_1 & C_2 & C_3 & & & & & & \\ C_3 & -C_2 & C_1 & -C_0 & & & & & & \\ & & C_0 & C_1 & C_2 & C_3 & & & & \\ & & C_3 & -C_2 & C_1 & -C_0 & & & & \\ & & & & \cdots & \cdots & & & & \\ & & & & & & C_0 & C_1 & C_2 & C_3 \\ & & & & & & C_3 & -C_2 & C_1 & -C_0 \\ C_2 & C_3 & & & & & & & C_0 & C_1 \\ C_1 & -C_0 & & & & & & & C_3 & -C_2 \end{pmatrix}$$

Where blank entries signify zeros.

Note the structure of this matrix. The first row generates one component of the data convolved with the filter coefficients $C_0, \ldots C_3$. Likewise the third, fifth, and other odd rows. These components are called the "smooth". The even rows perform a different convolution, with coefficients C_3, $-C_2$, C_1, $-C_0$. They are called the "details". Therefore, The overall action of the matrix, overall, is thus to perform two related convolutions, then to decimate each of them by half, throw away half the values and interleave the remaining halves.

The non-zero coefficients are determined by the orthogonal condition of the matrix C with the second order of vanishing moments. The closed form solution for the coefficients $C_0, \ldots C_3$ are given below:

$$C_0 = (1 + \sqrt{3}) / 4\sqrt{2}$$
$$C_1 = (3 + \sqrt{3}) / 4\sqrt{2}$$
$$C_2 = (3 - \sqrt{3}) / 4\sqrt{2}$$
$$C_3 = (1 - \sqrt{3}) / 4\sqrt{2}$$

The inverse Daubechies wavelet filter coefficient matrix is the transpose of C.

The Discrete Wavelet Transform (DWT) consists of applying a wavelet coefficient matrix like C hierarchically, first to the full data vector of length N, then to the smooth vector of length N/2, then to the smooth-smooth vector of length N/4, and so on.

To invert the DWT, one simply reverses the procedure, starting with the smallest level of the hierarchy. The inverse matrix of $C^{-1} = C^T$ is of course used instead of the forward matrix C.

Our experience tells us that the one-dimension discrete wavelet transformation can easily achieve 8:1 compression ratio without visually noticeable loss of information.

5. AUTOMATIC RADAR IMAGE GEOREFERENCE

The SAR/SLAR images are geocoded automatically by the system. The Ground Control Points (GCP) are obtained from the radar configuration geometry and the navigational parameters provided by the aircraft navigation system.

As shown in figure below, for each side of each scan line, we calculate the latitudes and longitudes of the first and last pixel. From Radar Configuration Geometry, we know the Standoff Range and Swath Width. We also know the latitude and longitude of the aircraft position and the adjusted flight direction from aircraft navigation system. Thus, the scanning direction is known too, which is perpendicular to the adjusted flight direction.

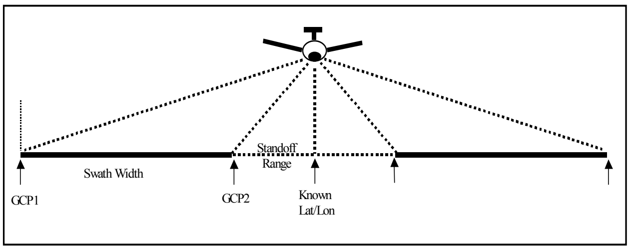

Figure 4. Airborne Radar Configuration Geometry

Starting from a known point (Latitude and Longitude), to determine the Latitude and Longitude of a new point with a specified distance in specified direction is well known as a traditional Geodetic Direct Problem. There are many algorithms available for this calculation. The image distortion caused by the earth curvature can be calibrated too, but this distortion is insignificant for our purposes.

6. CONCLUSIONS

With years of operational experience, the system has proved to be a reliable, real time tactical decision support system. It conducts over 20 million square kilometers of airborne reconnaissance annually and delivers ice information to support marine operations in Canada's ice-infested waters.

Further development will include a new SAR, an Onboard analysis system to allow the analyst to interpret newly acquired radar image in near real time, a pen computer based visual data entry system, and a mounted high resolution digital camera to provide three dimensional photographs.

Beyond its standard ice duties, there is enormous potential to use this system and technology in other disciplines where timely and accurate information is critical, such as in flood, forest fire, and pollution assessment and control.

REFERENCES

Canadian Ice Service (CIS), 2002, Navigating Icy Waterways Using GIS, *ARC North News*, ERSI Canada, Vol.5, No. 2, pp.10-11.

Koonar, A and Ou, Ziqiang 1999, Real Time and Near Real Time Tactical Support Using Ice Reconnaissance Aircraft Systems, *Fourth International Airborne Remote Sensing Conference and Exhibition*, June, Ottawa.

Press, William H., Teukolsky, Saul A., Vetterling, William T. and Flannery, Brain P. 1992, *Numerical Recipes In C*, Cambridge University Press, pp.591-606.