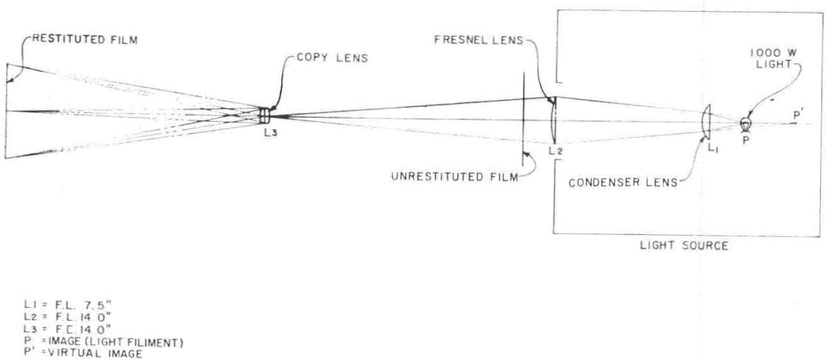

FIG. 12. Side looking radar restitutor projection system.

rewinds. The tape may also be advanced manually.

The digital logic performs all the logic manipulations required for operation of the system. It is composed of printed card circuits. Test points found along the base of the card file allow various signals to be monitored. The digital-to-analogue converter converts digital information to analogue servo voltages.

Although the equipment is designed to operate manually, the manual mode will not be used except for the initial set-up of the equipment. The semi-automatic mode of operation is also seldom used except for single flight lines or overlapping flights where the navigational input is absolutely accurate and no adjustment to the flight line is required. The automatic mode generally speaking will be the only method of restitution because theoretically, automation is the final end product for all advanced mapping systems.

Belock Instrument Corporation of College Point, New York, built the restitutor under contract to GIMRADA and delivered it for test in May of 1962.

The title of this paper, "Advanced Radar Map Compilation Equipment," is somewhat of a misnomer. Let us say that radar map compilation equipment has been advanced but that this is only the beginning of what the author hopes will someday be the Advanced Radar Map Compilation System.

Mapping from radar is still very much in its infancy. How long it will be before it can take that second significant step forward depends largely on the order of priority and the urgency for its need in defense mapping.

Photogrammetry as an aid to radar mapping research has proved to be invaluable. At the same time, radar has advanced the science of photogrammetry. Just as dividers are the tools of the draftsman, so should radar presentations be the tools for the cartographer. The author feels it is only a matter of time before radargrammetry will be as much of a common term in the mapping field as photogrammetry is today.

*Radar Network Adjustment**

JAMES E. STILWELL,
U. S. Army,
Engineer Geodesy, Intelligence and Mapping Research and Development Agency,
Fort Belvoir, Va.

THE Strategic Systems Division of the United States Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) is currently working on a task "Utilization of Radar Presentations for Topographic Mapping." The objective of this task is the development of a radar mapping system to provide the

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EDITOR'S NOTE: The Abstract for this paper is on page 484 of the 1963 YEARBOOK.

Army with an all-weather day or night mapping capability. Because of state-of-the-art limitations, a Planimetric Radar Mapping System will be developed initially to produce maps giving information of horizontal positions only, and as the state-of-the-art is advanced, a contouring capability will be added. The topographic or contour mapping system is the ultimate goal.

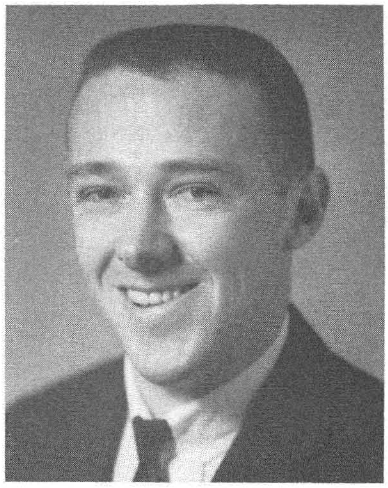
The inputs received at the data reduction center consist of the radar presentation, auxiliary data, and aircraft position data. The position data are necessary to reference the radar imagery to the earth's surface. At the data reduction center, the aircraft positions are adjusted, the radar record restituted, map compilation performed and maps printed. In the case of topographic maps, elevation data are added in the form of contours.

The Radar Network Adjustment is based on the premise that positioning systems employed under combat conditions will not be suitably accurate for mapping, and consequently positions given by these systems must be improved. It should be noted that when a positioning system of suitable accuracy is available, a network adjustment will not be necessary. The Radar Network Adjustment is predicated on the assumption that measurements on the radar record will yield more accurate distances than will the navigation system.

An explanation of the adjustment procedures can be seen from Figure 1. F_1, F_2 and F_3 represent flight lines with positional information available from the navigation system at the points denoted by circles. The first step in the adjustment is the establishment of a network of aircraft stations for which positional information is available. These aircraft stations represent points on the earth's surface which lie on the aircraft ground track (i.e., points directly over which the aircraft has flown).

Aircraft stations are selected from the radar records at a specified interval along each flight line. For every station on one flight line there is a corresponding station chosen on the adjacent flight line. In this manner the network of aircraft stations is established.

After the network has been formed, tie points must be selected from the radar record. The aircraft flight lines are so spaced that overlapping radar imagery is obtained, as indicated by the shaded areas. Within this overlapping area can be found images which are seen from both flight lines, and are easily identifiable on both flight line radar records. One of these images is selected for each pair of corresponding aircraft stations on adjacent flight lines. The images thus selected are called tie points.



James E. Stilwell

From the positioning system we have coordinates for each aircraft station, and can calculate the distances along and across the flight line, between each aircraft station and the adjacent station. With these distances established from the positioning system and radar measurements, the necessary redundant data to write equations for performing a least squares adjustment are available.

The along-line and across-line equations thus established have as the unknowns the coordinates of the aircraft stations. Before a solution of the equations is obtained, one or more control points, (i.e., points whose coordinates are known) are introduced into the equations. These points may be either aircraft stations (nadir control) or tie points (radar control) whose ground coordinates are known. After control points are introduced, the equations are solved by the method of least squares. The solution yields adjusted coordinates for each aircraft station. These coordinates will in general be more accurate than those given by the positioning system.

In practice, a digital computer is used to perform the network adjustment. Inputs to the computer include navigation positions of the aircraft stations, coordinates of control points, measurements made on the radar record and auxiliary information such as altitude above sea level. The computer then calculates distances between aircraft stations, forms the along and across flight line equations, solves them and prints out the adjusted aircraft station positions.

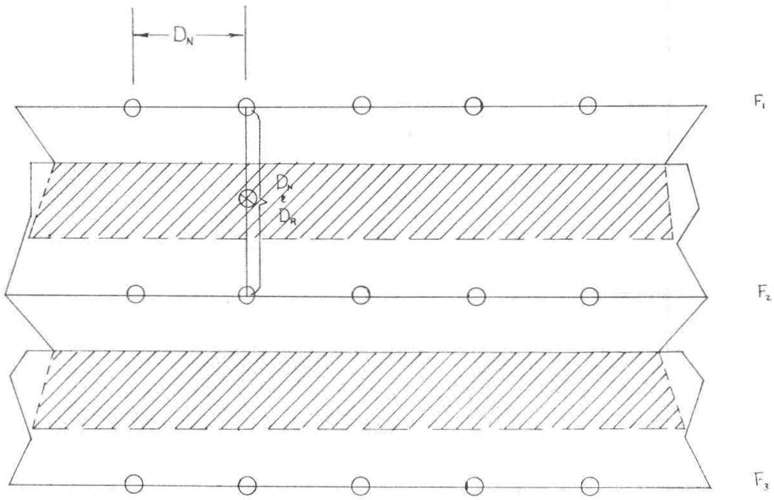


FIG. 1. General network configuration.

The Radar Network Adjustment technique was developed during an investigation to determine the concepts for a Planimetric Radar Mapping System. To prove the validity of the technique, navigation data, radar presentations, and KC-1 photography were obtained from U. S. Air Force Monticello flights over the Red River Test Area which covers parts of Oklahoma, Texas, Arkansas and Louisiana. An adjustment test was performed. Using data from three 200 mile flight lines, two types of networks were formed: one with aircraft stations selected every 20 miles, the other with stations selected every 10 miles. Selecting aircraft stations every 20 miles produced a 30 point net; selecting aircraft stations every 10 miles produced a 60 point net. These networks were adjusted using both radar control and nadir control. For each type of control the adjustment was performed using two, four, six and eight control points. The results of these adjusments are summarized in Table I.

Improvement in σ, the root mean square radial error, ranged from 6% to 49%. To improve these results weighting and scaling factors were applied to the network equations. Weighting factors allow the more accurate

TABLE I

TEST 1

RESULTS OF ADJUSTMENTS

	Radar Control				*Nadir Control*			
	No. of Control Points	*Meters* σ_1	*Meters* σ_2	*Per Cent Improvement in* σ	*No. of Control Points*	*Meters* σ_1	*Meters* σ_2	*Per Cent Improvement in* σ
30 Point Network	2	1,616	1,510	6	2	1,596	1,226	23
	4	1,616	1,343	16	4	1,422	767	46
	6	1,616	1,168	27	6	1,453	807	44
	8	1,616	1,030	36	8	1,501	809	46
60 Point Network	2	1,654	1,496	9	2	1,645	1,197	27
	4	1,654	1,144	30	4	1,577	799	49
	6	1,654	1,108	33	6	1,597	859	46
	8	1,654	1,128	31	8	1,622	855	47

σ_1 is the root mean square radial error in assumed positions.
σ_2 is the root mean square radial error in adjusted positions.

TABLE II
TEST 1
RESULTS OF ADJUSTMENTS
30 POINT NETWORK

Number of Control Points	*Radar Control*					*Nadir Control*				
	σ-Meters					*σ-Meters*				
	Before Adjustment	*Weighting Factors Radar—2 Navigation—1*				*Before Adjustment*	*Weighting Factors Radar—2 Navigation—1*			
			% Improvement	*Scaling Factor*	*% Improvement*			*% Improvement*	*Scaling Factor*	*% Improvement*
2	1,616	758	53	1,556	3	1,474	789	46	709	51
4	1,616	943	41	1,556	3	1,422	698	50	651	54
6	1,616	963	40	1,887	−16	1,439	881	38	818	43
8	1,616	897	44	1,839	−13	1,501	781	47	726	51

σ is the root mean square radial error.

information to have a stronger influence on the adjusted positions and are normally obtained by determining the probable errors for each subsystem. Since sufficient information for an error analysis of the system components was not available, weighting factors were assumed.

Scaling factors tend to reduce the effect of constant errors in the navigation system and radar measurements. These factors were obtained by comparing the true distances between control points with distances determined from the navigation data and the radar data. The scaling factors were then applied to radar and navigation distances between aircraft stations in the network equations.

The results of the adjustments of the 30 point network using control points, weighting factors, and scaling factors in various combinations are summarized in Table II. The application of weighting and scaling factors to the network equations improved the root mean square radial error when nadir control was used. When adjusting with radar control, the application of weighting factors improved the root mean square radial error; however when both weighting and scaling factors were applied, the root mean square radial error became worse.

The results of this initial test showed that aircraft positions were improved by applying the adjustment technique, and indicated that further tests would be desirable to determine the type, location, and number of control points necessary for optimum results. Additional tests of the adjustment technique were performed with data obtained from a joint Corps of Engineers-Signal Corps Airborne Target Location Test, flown over the Arizona Test Area.

The data used in the adjustments consisted of AN/APQ-55 Side-Looking Radar presentations, KC-1 photography, and auxiliary flight information from four parallel flight lines Since the aircraft did not carry a navigation system, it was necessary to simulate navigational positions. This was performed by letting a set of random numbers determine the magnitude of error for each aircraft station. The magnitude of error ranged between −150 meters and +150 meters in both Northing and Easting.

Three types of networks were formed, one with aircraft stations selected every two miles along a flight line, one with stations selected every four miles, and the third with stations selected every eight miles.

All adjustments of these networks were made using a navigation weighting factor of three and a radar weighting factor of two. Scaling factors were also utilized when the networks were adjusted with nadir control. Two, four and six control points were used in the adjustments. The results are summarized in Table III.

In general, only slight improvements in position were obtained by applying the adjustment technique, and the results of the various adjustments do not differ sufficiently to conclude that one adjustment is significantly better than another.

The weighting factors for these adjust-

TABLE III
TEST 2
RESULTS OF ADJUSTMENTS

	Nadir Control				Radar Control		
	No. of Control Points	σ_1 *Meters*	σ_2 *Meters*	*Per Cent Improvement in* σ	σ_1 *Meters*	σ_2 *Meters*	*Per Cent Improvement in* σ
68 Point Network	2	129	111	14	129	119	8
	4	131	114	13	129	115	11
	6	133	114	15	129	118	9
	4	131	111	16	129	112	13
34 Point Network	2	136	109	20	136	118	13
	4	140	110	21	136	116	15
	6	145	111	24	136	113	17
	4	140	111	21	136	115	15
17 Point Network	2	130	104	19	130	115	12
	4	138	112	18	130	118	9
	6	147	113	23	130	122	6
	4	138	112	19	130	119	8

σ^1 is the root mean square radial error in the assumed positions.
σ^2 is the root mean square radial error in the adjusted positions.

ments were obtained by performing trial adjustments using different factors and selecting those factors which gave the best results. A navigation weight of three and radar weight of two resulted from the trial adjustments; this indicates that the radar data gave less accurate distances than did the assumed navigational data. This is attributed to the inaccurate aircraft heading information which affects the determination of distances from radar measurements, particularly in the direction parallel to the line of flight.

In summary it can be stated that the adjustment technique is valid and will decrease position errors on the order of 150 meters; however its adequacy is dependent on the accuracy of the auxiliary equipment furnishing direction and attitude information to the radar sensor. It should be understood that radar is only a distance measuring device, and is dependent on other equipment for direction information. Based on present advances in the state-of-the-art of stable platforms it would not be optimistic to estimate that the adjustment technique will improve flight line positions to permit radar mapping at 1:250,000 scale.