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Solutions of Some Critical Problems for Preparation of Nation-wide Digital Enumeration Area Maps Based on Aerial Photographs

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***Abstract*—The gigantic task of preparation of digital Enumeration Area (EA) maps of whole Bangladesh was completed as a milestone initiative to move towards digital technology from conventional manual techniques. The nation-wide EA mapping based on aerial photographs and available conventional geo-information was initially constrained by a number of problems which were overcome and managed through innovative techniques. Mismatching of the administrative boundaries, digitized from the existing maps, with the aerial photo-mosaic appeared to be a critical problem. This mismatching caused relative geographical shifting of the locations of landmarks (surface features) on each EA map. Geographic feature based georeferencing backed by newly developed control point extension technique was employed to overcome this problem. The next problem was the requirement of time for composing thousands of EA maps. It was estimated that conventional technique based on composition of single map at a time required time that would override the project period significantly. A series map generation procedure was introduced to reduce the map composition time. Finally, monitoring of the progress of the mapping activities was an issue at management level that was addressed under the present work. A procedure to estimate time requirement for completing each task of EA map preparation was worked out. Based on the time requirement, a progress monitoring system was developed and introduced.**

***Keywords*—Enumeration area, Aerial photograph, Mismatching of boundary, Progress monitoring, Control point extension.**

I. INTRODUCTION

Bangladesh Space Research and Remote Sensing Organization (SPARRSO) carried out the task of preparation of digital EA map under the initiative of Bangladesh Bureau of Statistics (BBS) and funded by the United Nations Fund for Population Activities (UNFPA). The activity of the EA map preparation started in 2001 and ended in 2009. The idea behind the project was that the enumerators of BBS would use these EA maps during collection of census data to identify the enumeration area accurately allotted for them so that no over or under-shoot occurred in enumeration. Earlier BBS used hand-drawn sketch EA maps which included geographic over-shoot or under-shoot or both because the sketch maps were prepared by different people and frequently they did not consult with each other for area demarcation. Those EA maps contained sufficient landmarks to identify the EAs but did not contain geographic reference. Use of these sketch map rendered errors in census due to incomplete or multiple coverage. Similar problem was reported by researcher [1]. Coverage error due to inaccurate maps and subsequent errors in census due to omissions or duplications of persons or housing were mentioned in research works [2]. Updating of sketch maps/hardcopy maps is another critical problem to use them in census operation. In order to get rid of these problems a paradigm shift from the traditional mapping approach into GIS based digital mapping was proposed [1], [3], [4]. Reference [5] reported an early effort of Statistics Canada in this context. Most of the developed countries have population counted in geo-referenced census block for a long time and they start to optimize the geospatial infrastructure of census recently. Reference [6] gave a comprehensive review in this context. Some developing countries started to shift into GIS based digital mapping for census operation on the occasion of 2010 round census [1], [7], [8], [9] and Bangladesh was one of these countries.

Definition of EA and different procedures for preparation of EA maps were comprehensively given by [2]. An EA map is a map that contains demarcation of enumeration areas using EA lines, landmarks and administrative boundaries. Landmarks and administrative boundaries are used to identify the EA in the ground.

Preparation of EA maps of whole Bangladesh using aerial photographs was a huge job and sound technical and management steps were needed for successful carrying out the project. The main technical steps used for digital EA map preparation are given below:

i. Generation of base data layer.
ii. Generation of thematic data layers
iii. Generation of boundary data layers.
iv. Generation of enumeration areas.
v. Validation of the data layers
vi. Composition of EA maps

The base data layer was one from which thematic data layers (landmarks) needed for identification of the EA lines were extracted. It also provided referencing for all the other data layers mentioned above. In Bangladesh context, each EA contains 100 to 130 households [10]. Bangladesh is a highly populated country (population density was 1015 as of 2011 census) and the geographic area of an EA is very small. Therefore, for identification of EA, landmark having high spatial resolution was one of the main requirements. To fulfill this requirement, landmark features were extracted from the base data layer generated from aerial photographs. The aerial photographs were taken at 1:25,000 scale and were processed using standard digital photogrammetric techniques including ortho-rectification to generate aerial photo-mosaic. Thematic data layers containing landmarks were generated from the aerial photo-mosaic using on-screen digitizing techniques. The boundary data layer was generated by digitizing the upazila map of the Directorate of Land Records & Survey (DLRS). Digital EAs were generated by transferring EA lines from the hand-drawn sketch EA maps of BBS to the digital EA data layer by digitization. The validity of the boundary and thematic data layers were checked in the field. The data layers were edited based on the information collected from field. Finally, EA maps were composed using all the data layers mentioned above. Nation-wide digital EA mapping was not straight forward and a number of difficulties arose during mapping activities. This paper presents the main encountered problems and the solution to overcome the problems.

II. Problems Encountered

The main problems encountered during the EA mapping activities were (i) mismatching of administrative boundaries with aerial photo-mosaic, (ii) long map composition time and (iii) difficulties in monitoring progress of the mapping activities. Details of the problems are given in the following sections.

A. Mismatching of Administrative Boundaries with Aerial Photo-mosaic

Being a highly populated country, each EA covers very small geographic area in Bangladesh. Therefore, the boundary concerned for EA was mouza (the lowest revenue collection unit in Bangladesh, corresponds to specific land area within which there may be one or more settlements) which itself covers small geographic area (a moderate mouza may covers approximately 1.4 Sq. km area). Authoritative mouza boundary was obtained from the Upazila (smallest administrative unit in Bangladesh) based mouza maps of the Directorate of Land Records & Survey (DLRS) in hardcopy form. These maps were initially geo-referenced based on the geographic coordinate values provided with the maps and the mouza boundaries were digitized from them. When these boundaries were superimposed on the aerial photo-mosaic, they were found to shift from the true locations confirmed by GPS based information collected from field. It was found that this shifting of the boundaries, in many cases, partly altered the mouza based geographic feature identity of EA maps which would create serious problem for the field enumerators to identify the EAs during census data collection if they use these maps.

B. Long Map Composition Time

The EA map designed for BBS contained a map frame and two index frames. The map frame presented the EA along with the thematic data layers (landmarks). The district index frame showed the particular upazila of a district under mapping. The upazila index frame showed the particular mouza of the upazila under mapping. EA maps were based on mouza. To make an EA map comprehensive to the enumerator it must show only the landmarks and the EA lines of the particular mouza under mapping and at the same time the full part of the mouza based upazila boundary in the map frame. In digital map composition, this can conventionally be done by generating thematic data layers for each mouza. Generation of data layers for each mouza and then using them in independent map composition for each mouza are very time consuming. On the other hand, this creates huge problem for database management and archive of EA maps. Composition of upazila index frame also consumes extra time since for each EA map a particular mouza is to be shown. Total number of EA maps composed to cover the whole country was 56,757. It was calculated that conventional independent map composition would take huge time which would override the project period. This was another critical problem to solve.

C. Difficulties in Monitoring Progress of the Mapping Activities

The project was carried out in three phases each having duration of three years. Total area of the country was divided under the three phases for the EA mapping. To carry out the tasks of preparation of EA maps, four mapping groups were formed each having ten working manpower on average. The mapping area under each phase was more or less equally distributed among the mapping groups. This arrangement established four independent mapping chains to carry out all the tasks of preparation of the EA maps. The nation-wide EA mapping based on aerial photographs was a very time critical project. It was, therefore, very important to monitor the progress of the work on regular basis so that management action could be under taken timely to recover a mapping group under running significantly. However, progress monitoring of such a project was difficult since it involved generation of a number of different data layers most of them manually and, thus, progress depended on the skill, speed and performance of operators which were highly variable.

III. SOLUTION OF THE PROBLEMS

A. Mismatching of Administrative Boundaries with Aerial Photo-mosaic

The causes of the mismatching mentioned earlier was investigated and the following causes were found, (a) geographic coordinates provided with the DRLS boundary maps were not always correct, (b) Aging of the paper on which DLRS maps were printed rendered shrinking and expansion effects on the map scale. These problems were discussed in details by researcher [11]. Because of these problems, geographic coordinate based matching alone was found not possible in majority of the cases. In order to solve this problem a feature based matching technique was used. The DLRS boundary maps had few landmark features (ponds, cross-section of roads, etc.) which were used to register the scanned DLRS map with the aerial photo-mosaic. Some of the DLRS maps had inadequate landmarks to generate the required number of GCP for calculating transformation matrix appropriate for the maps to register. A Control Point Extension (CPE) technique was developed and used to generate additional GCPs in cases where the landmark based GCPs were not adequate. The steps for register the DLRS maps are given in figure 1.

The registration process involved two work chains: coordinate based transformation based on the coordinate values available on the maps and the feature based transformation using GCPs based on the landmarks present on the DLRS maps. Where the coordinate based transformation did not give acceptable accuracy, the feature based transformation invoked. The feature based transformation was an iterative adjustment procedure that increases the number of GCPs and, if needed, the order of transformation to attain the acceptable accuracy of registration. Except for a few cases, transformation up to 2nd order was found sufficient to achieve required registration accuracy. The CPE technique itself is an iterative adjustment procedure that firstly uses bidirectional bearing restoration to locate a primary point (to be used for registration) on the DLRS map and then adjust the location of the point based on the shift of the boundary in the previous iteration. The steps of the CPE techniques are given below:

i. Bidirectional bearing of reference GCP was measured on the photo-mosaic. The bearing was measured with respect to two points that were identified on both the photo-mosaic and the DLRS map. The measurement procedure gave a triangle whose base was the line obtained connecting the two identified points.

ii. The bidirectional bearing was restored on the DLRS map based on the two identified points as mentioned above and the potential input GCP was located at the vertex of the triangle opposite to the triangle base. The actual input GCP was on or around this potential point.

iii. The potential GCP was used in the transformation and the shift of the resulting boundary in the direction of the triangle vertex was measured. The measurement of the shift was a critical aspect of the method. In Bangladesh context, the upazila boundaries normally follow spatial features like rivers, canals, roads etc. These features were identified on the aerial photo-mosaic through visual interpretation by superimposing the approximate boundaries obtained using coordinate based transformation. The shift in the boundary was measured with respect to these identified features. Accurate measurement of the shift was not possible because the measurement points cannot be identified accurately. Thus, step ‘v’ mentioned next needed to be repeated to obtain acceptable matching. In a few cases, the shift was estimated based on GPS survey when the relevance mentioned above was not found.

iv. The potential input GCP was adjusted according to the shift of the boundary and the transformation was repeated.

v. Steps ‘iii’ and ‘iv’ were repeated until desired matching of the boundary was obtained.

The feature based matching backed by the CPE technique was found accurate enough (positional error of

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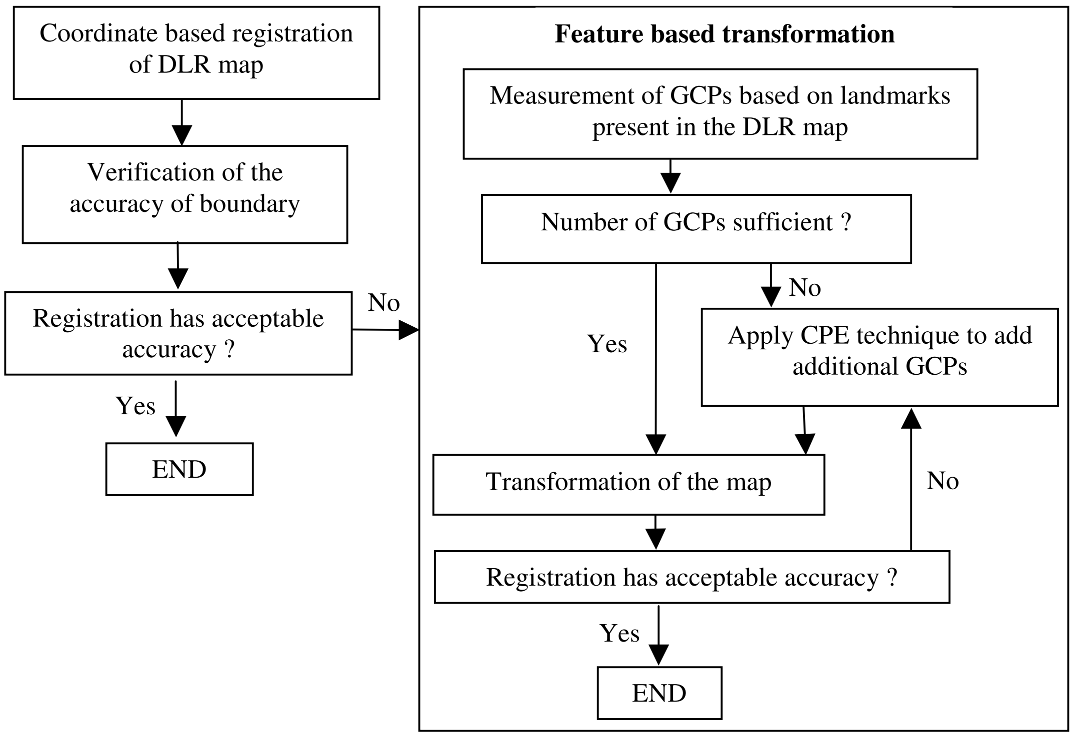

Fig. 1 Steps for registering the DLRS boundary maps.

approximately 14 m Circular Error at 90% confidence level [12] was obtained based on independent check points [13]) to generate boundary layers from the DLRS hardcopy map for the EA map preparation. With the progress of the project work, higher number of upazila boundaries was prepared and requirement of the application of the CPE technique was decreased since additional GCPs were identified from the neighboring boundaries. However, at the initial stage of the project the CPE technique was found very useful.

B. Reduction of Time for Composition of EA Maps

Map composition time was reduced by introducing a series map generation procedure. The series map generation procedure reduced map composition time noticeably by composing the map frames of each EA map in series over a spatial database of upazila (an upazila is composed of a number of mouza). A boundary based shading technique was used to display only the spatial features (landmarks) and EA lines of a particular EA map in the map frame. The shading link was incorporated in the boundary data layer of the index frame for automatic display of the location of mapping area (mouza) in the upazila boundary. This also reduced the time for composition of the upazila index frame dramatically. A well designed map frame template was used to reduce the task of annotation of the maps. Figure 2 shows the technique of the series map generation procedure.

Pre-management of the thematic data layers gave three data layer composites (polygon, line and

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point) which were called only once during the composition of the master map. Each thematic data layer under a composite was attributed by unique identification number. Based on the identification number of all the thematic data layers, a master symbology file for each composite data layer was created. Three master symbology files were created

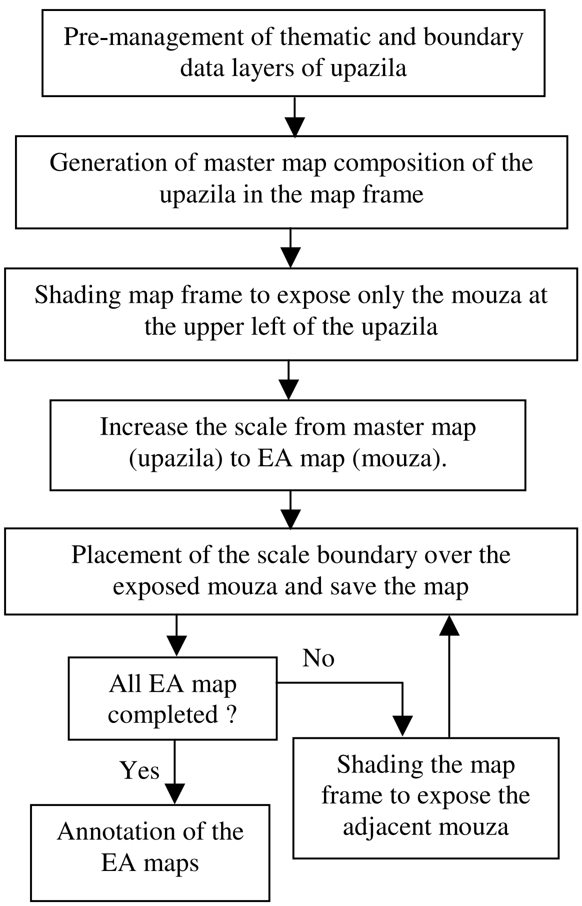

Fig. 2 Series map generation procedure.

for the three composite data layers which were also called only once for composition of EA maps of an upazila. Along with the three composite thematic data layers, the master map contained another composite layer for the boundaries which essentially contained the outer limit of mouza, union and upazila. However, in some cases the part of the upazila boundary belonged to district, division or international boundary. A master symbology file was also created for the composite boundary data layer. The series generation procedure was initiated by composing a master map in the map frame by calling all the above mentioned thematic and boundary data layers in composite form. In the master map, data layers remained exposed for all the mouzas. In order to expose only a single mouza, the master map frame was shaded applying logical expression in the attribute table of the shade layer. The shade layer was a copy of the upazila boundary layer that contained polygons for all the mouza under the upazila. It was placed in the map frame (figure 3) below the boundary composite and above the thematic data layer composites so that when shading was applied for a particular mouza, the thematic data layers of only that mouza was exposed but the boundaries were exposed within the whole map frame. When the data layer for mouza was exposed for the first time, the scale of the data frame was increased from the master map to the EA map (1:10,000) and the reduced scale boundary was placed over the exposed mouza. As shown in figure 3, the same shade layer was used in the upazila index frame. Therefore, along with the mouza be exposed in the map frame, the same mouza was exposed automatically in the upazila index frame and the color assigned to the background boundary layer was shown indicating the mouza under mapping. Shading, placement of scale boundary and saving the map were continued until all the EA maps were framed. Annotation of the EA maps took small time since a well-designed map template was used.

The series generation technique of map composition was tested against the conventional independent map frame composition technique for three upazilas of Bangladesh. The series generation technique was found to perform by less than one tenth of the time taken by the conventional technique.

C. Progress Monitoring Procedures for EA Mapping

A 'Microsoft Excel' based progress monitoring scheme was developed to monitor the progress made by each mapping group and the total progress of the mapping activity on monthly basis. The progress monitoring involved the following steps,

i. Fixation of monthly targets of the mapping groups.
ii. Assessment of the monthly progress made by the mapping groups.
iii. Comparison of the target and actual progress.

Monthly target of the mapping groups was fixed dynamically in each month based on the following expression:

$$T_i = D_i * (100 - P_{i-1}) / (D_T - D_{i-1})$$

Where, T_i is the target of the month i (i = 1, 2 ….n; n is the total number of month of the project), D_i is the number of working day in the month i, P_{i-1} is the cumulative progress of a mapping group up to the previous month expressed as the percentage of the total work, D_T is the total number of working day of the project and D_{i-1} is the number of working day elapsed up to the last month.

The actual progress made by each mapping group was assessed based on a reference dataset of time for completion of the tasks of EA map preparation. The reference dataset was obtained based on expressions derived empirically. To derive the expressions, time required by ten operators to complete the tasks of EA map preparation of 16 upazilas were recorded at the initial stage of the project. The upazilas were selected as representative to reflect the area and feature density variations existed in the country. The expressions were given in table 1. Based on the reference dataset of time, an Excel data sheet was prepared for each mapping group to monitor the actual progress of the work. The excel data sheet was primarily configured for upazila based time domain progress of each task mentioned in table 1. The data sheet was then configured for integration of the progress of all the upazila under a mapping group to assess the cumulative progress of a group in percentage. The data sheet finally calculated the progress of a group in the last month and compared it with the target of the group for the month. An operator progress book was maintained where each operator entered the actual progress of the tasks assigned to him for each upazila at the last day of a month. The excel data sheet translated the operator's input into time and performed the subsequent calculation as mentioned above. A separate excel data sheet integrated the progress of all the groups to assess the total progress of the EA mapping activity. Management actions (increase of operating time and manpower, etc.) were undertaken to speed up the progress of a group when it under ran the monthly target for two successive months.

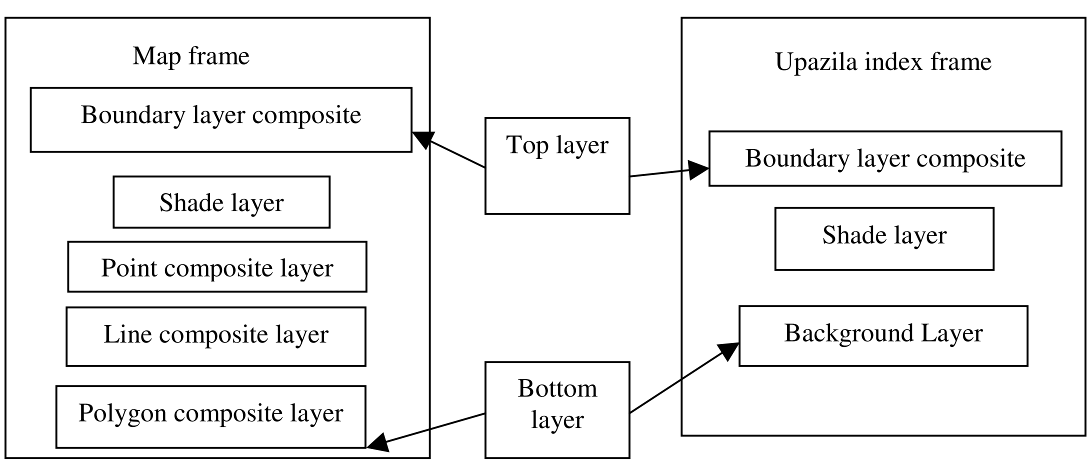

Fig. 3 Layer arrangement in data frame and upazila index frame.

Task		Expression	Remarks
Thematic layer generation by digitization	Settlement	$T_H = A_{u*}$ 0.0034	Based on average
	Building group	$T_H = A_u$* 0.0013	Based on average
	Pond group	$T_H = A_u$* 0.0012	Based on average
	River group	$T_H = A_u$* 0.0019	Based on average
	Road group	$T_H = A_u$* 0.0023	Based on average
	Forest	Estimated based on primary estimation of forest area.	
EA line data layer generation		$T_H = A_u$* 0.0046	Based on average
Boundary layer generation		$T_H = 0.13*N_m + 0.0001*A_u + 19.52$	Based on regression analysis
Field data collection		$T_H = U_t + 27.5$	Based on average
Field data incorporation		$T_H = U_t$* 11	Based on average
Vector layer management		$T_H = 11$	Based on average
Map series generation		$T_H = N_m$ * 0.17	Based on average
Annotation		$T_H = N_m$ * 0.33	Based on average
Note: T_H : Time in hour; A_u:Area of upazila; N_m: Number of mouza in a upazila; U_t: Upazila type (Urban upazila: 2, Rural upazila: 1);			

TABLE 1 :EXPRESSIONS TO CALCULATE THE TIME FOR COMPLETION OF EA MAPPING TASKS

IV. CONCLUSION

The activity of preparation of nation-wide digital EA map based on aerial photography presented in this paper was unique techniques in the last decade. The EA maps were used for population census in 2010 and are being used for other census activities by BBS. This paper particularly addressed three problems encountered during the EA mapping activities. Mismatching of administrative boundaries with aerial photo-mosaic was a critical problem and initially handicapped the whole mapping activity. However, this problem may be specific in the context of Bangladesh. The CPE technique was developed and applied to solve this problem. The CPE technique is a try and error based technique and found accurate enough for EA mapping. However, it is a time consuming technique. For applications requiring higher absolute accuracy of boundary layer the CPE technique may not be suitable. Long map composition time was another problem faced for preparation of the EA maps. Conventional independent map frame composition would take huge time which would override the total project period. Series map generation procedures backed by vector layer pre-management were used to solve this problem using ERDAS Imagine software. This solution can ideally be used for any nation-wide mapping activity. The same is also true for progress monitoring scheme developed for this gigantic mapping activity. However, the empirical expressions to calculate the time for completion of EA mapping tasks were derived based on the particular conditions of Bangladesh and may not be valid for other conditions. This is not a problem for using the progress monitoring scheme elsewhere as the empirical expressions can be derived for the particular conditions of a country/region based on the method used in this paper.

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