Remote Sensing Brief

Small Area Population Estimates Using Aerial Photography

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INTRODUCTION

Remote sensing technology is slowly finding more wide-spread application within the social and planning sciences. One such area is the estimation of population data. This paper describes the results of an empirical study that combines aerial photo-derived housing unit counts with certain demographic multipliers to make small area population estimates. The findings suggest that the technique is well suited to calculating timely population data in the absence of conventional population or housing surveys, and that the accuracy of the overall methodology is most affected by the precision of the demographic multipliers derived from non-photographic sources rather than by errors in the photo-based counts.

METHODOLOGY

Housing unit methods for population estimation are commonly based on an estimated housing stock derived from school district surveys, utility files, plat maps, or census count updates using building permit data or certificates of occupancy (U.S. Bureau of the Census, 1966). This estimated housing stock is multiplied by an average household size to obtain an approximation of the population size. This basic format was used by Hsu (1971) in a photographic study near Atlanta, Georgia, although previous demographic work had questioned the accuracy of this relatively crude methodology (Starsinic and Zitter, 1968). Recent research has shown that accuracy can be greatly improved by adjusting the housing stock for levels of vacancy, and by making the vacancy levels and household sizes functions of the composition of the housing stock (Smith and Lewis, 1980; 1983).

This study tests the effectiveness of aerial photographs as an alternative source of the housing stock data for use with the more refined technique described above. Two housing types are used to describe the housing stock's composition: single-family and multi-family structures. Improved methods for enumerating these structure types have been reported (Watkins, 1984), and the use of these variables with type-specific vacancy rates and household size figures has been effective in increasing the technique's accuracy.

The following equation outlines the procedure used in this study to estimate total population:

$$P_T = [HC_S - (HC_S \times VR_S)]HS_S + [HC_M - (HC_M \times VR_M)]HS_M$$

where HC_S and HC_M are the photo-derived housing counts for single-family and multi-family units respectively, VR_S and VR_M are the associated vacancy rates used to adjust the housing counts, and HS_S and HS_M are the number of persons per household for each structure type. Housing counts were made for three census tracts in Boulder, Colorado, for two census dates. Counts for 1970 were made from black-and-white aerial photographs with a scale of 1:20,000, and 1980 counts were made from black-and-white photographs with a scale of 1:6000. The results of the photographic housing count are summarized in Table 1. The necessary vacancy rates and household sizes for 1970 were computed from city-wide 1970 census data on occupied housing units and populations, with the same structure-specific values being applied to all three census tracts. The 1980 values used in the study were taken from a 1978 intercensal survey and were assumed to have remained constant between 1978 and 1980. These same structure-specific 1980 counts were also applied to all three census tracts. These data are shown in Table 2. The populations computed for each census tract using this methodology were compared with census data as a test for accuracy. Even though the census results are not error free, they are a commonly used source of information and a reasonable standard for comparison.

RESULTS

The results of the study are shown in Table 3. The relative error by tract for both census dates is calculated as the ratio of the difference between the population estimated using housing counts and the

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TABLE 1. PHOTOGRAPHIC AND CENSUS HOUSING COUNT COMPARISON: 1970 AND 1980

Study[1] Area	Dwelling Units: Photo Count	Dwelling Units: Census Count	Relative Error (%)
1970			
1	857	871	−1.61
2	1305	1314	−0.68
3	1335	1340	−0.37
Total	3497	3525	−0.79
1980			
1	2112	2221	−4.91
2	2052	2117	−3.07
3	1624	1651	−1.64
Total	5788	5989	−3.36

[1] The study areas remained constant in terms of geographic size over the two test years.

TABLE 2. DEMOGRAPHIC AND HOUSING MEASURES USED IN THE 1970 AND 1980 STUDIES

Year	Vacancy Rates[1]: Single	Vacancy Rates[1]: Multiple	Household Sizes[2]: Single	Household Sizes[2]: Multiple
1970	1.4	4.3	3.4	2.1
1980	0.6	2.1	3.2	2.0

[1] Vacancy rates shown as percent of all units of the specified type that are vacant.
[2] Household sizes represent the number of persons per household of the specified type.

census population figures to the census population figure. The most noteworthy result is the relatively small size of the reported errors. This is true for both 1970 and 1980 and for all of the study areas except Area 1 in 1980 (a positive error, the estimated population exceeded the census count, of 16.57 percent).

A more detailed look at the results of each census date application reveals several important points. First, the magnitude and direction of error in the 1970 study parallels the expected results, that is, the housing unit counts from the aerial photographs were lower than the census figures, and the corresponding total population should therefore also be underestimated (i.e., negative relative error). Study Area 2, however, exhibited a positive relative error, which may be due to the complex housing composition of the area. As Table 3 shows, the majority of the dwelling units in this tract are in multiple-unit structures, unlike areas 1 and 3, and many of these structures are converted single-family dwellings, the most difficult type to correctly identify (Watkins, 1984).

The 1980 results show rather startling differences from the 1970 application. The lowest error was recorded for Study Area 2 which, as noted above, has the most diverse housing composition. Furthermore, all of the other errors of estimate exhibit a positive trend with an overall error much larger than the 1970 study. What makes these results even more intriguing is that the overall housing count error, −3.36 percent, was much greater in 1980, and opposite in sign to the total relative error of the population count.

These results lead to one of the most important findings of this study: the accuracy of a photo-based population estimation procedure is highly dependent upon the accuracy of the household size and vacancy rate figures. Support for this statement appears in two ways. First, the housing counts are quite accurate as compared to the census and they also exhibit a consistent direction of error (see Table 1). Second, the population errors of estimate are not clearly related to the housing count errors. Taking the 1980 results for Area 1 as an example, both the housing count and population estimates showed the greatest deviation of any tract from the census figures, but these deviations were in opposite directions. The primary causes of this difference are the

TABLE 3. ESTIMATED AND CENSUS POPULATION COMPARISON: 1970 AND 1980

Area	Photo Household Count: Single	Photo Household Count: Multiple	Population: Estimated	Population: Census	Relative Error (%)
1970					
1	797	60	2839.4	3001	−5.39
2	515	790	3319.5	3057	+7.91
3	1300	35	4429.8	4745	−6.64
Total	2612	885	10588.7	10803	−1.98
1980					
1	1662	450	6167.9	5291	+16.57
2	269	1783	4346.6	4288	+1.37
3	1332	292	4807.5	4538	+5.94
Total	3263	2525	15322.0	14117	+8.54

use of demographic measures that were not representative of the housing composition of that particular census tract.

The city-wide vacancy rate and household size values no doubt vary from those of each separate census tract. Individual tract computations would improve the results, but there would be an added cost of having to conduct more detailed ground surveys to isolate the necessary information for all the census units under study. If the total population for a large number of tracts within a city is to be studied, then the application of city-wide rates will better represent the aggregate characteristics of all the tracts. Smaller areas of study, or areas comprised primarily of a specific housing type, may warrant detailed surveys to derive the vacancy rates and household sizes at a sub-city scale. Such detailed surveys would also have the added advantage of being made independently of the Census Bureau studies. Furthermore, it may be necessary to focus on alternative dwelling unit types when they appear either to dominate an area, or possess occupancy characteristics that differ greatly from standard single-unit or multiple-unit structures. Mixed-use structures in a commercial area may fall into this category. It is clearly not enough to assume that the housing composition variables are uniform throughout a city. Area 1, for example, experienced the addition of nearly 700 mobile homes between 1970 and 1980, and the vacancy patterns and family composition of these structures probably vary considerably from the city average for single-family units.

CONCLUSIONS

This study applied demographic measures to photographically-derived household counts as a means of estimating populations at a sub-city level. Tract figures were used to provide an explicit test for accuracy against decennial census data, and the method provided fairly useful results. The evidence indicates that housing unit counts from photos are quite accurate. Therefore, the key to the overall accuracy of the population estimate is in determining the values of the demographic measures—vacancy rates and household sizes in this study—that most effectively convert the housing unit enumeration into a population figure. Unfortunately, these measures are "invisible" to the photointerpreter, and must therefore be acquired from nonphotographic sources, either by detailed survey or by extrapolation from known data. The methods used to obtain these measures will, of course, be determined by time or monetary constraints and the level of accuracy required in a particular study.

The value of this method lies not in its ability to replicate census data, but in its ability to produce timely and representative results in the absence of standard surveys for user-specified study areas. Data restrictions such as political boundaries, misfiling of records, or misreporting of building permits and demolitions can be overcome with the use of aerial photographs which, in the case of many municipalities, are easily obtained from planning departments, utility companies, or engineering firms. The only requirement of the photographs is that they be of sufficient quality to allow accurate dwelling-unit enumeration. Scales ranging from 1:20,000 to 1:40,000, for example, should be adequate for areas with predominantly single-family dwellings, while larger scales, of approximately 1:6,000 to 1:10,000, may be needed for neighborhoods comprised of multiple-unit or multiple-use structures.

Finally, as with other applications of remote sensing, care must be taken in selecting the ancillary data to use in conjunction with the image interpretation. As social science and planning uses of remotely sensed data become more widespread and better understood, these outside data should improve. The quality of the photo-derived housing counts is one indicator of the great potential for remote sensing in the these areas; the errors introduced by the demographic estimates indicate how much is not yet known.

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