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Comparative Evaluation of Potential of Optical and SAR Data for the Detection of Human Settlements using Digital Classification

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Abstract

Detection of human settlements on satellite imagery is an important activity as it is the first step in population estimation and analysis of settlement patterns using satellite data. Radar data is particularly suited for this purpose as settlements are generally well accentuated due to the presence and effects of horizontal and vertical structures (dihedral and trihedral reflectors). Optical and IR sensors data is also useful for this purpose since settlements tone, shape and association/connectivity with rail/road network allows a settlement to be clearly seen on the false color composite (FCC). However, in case of optical and IR data, the detection is mostly based upon the visual interpretation due to the mixing of the spectral signatures of settlements with fallow land and few wasteland categories including gullied/ ravenous land. Hence use of digital classification of optical and IR data for the detection of human settlements leads to relatively poor classification accuracies in terms of omission and commission errors. In contrast to the dependence of optical sensors on spectral signatures, backscattered energy sensed by SAR is strongly dependent on the physical properties of an object like roughness, orientation and its dielectric properties. Hence, SAR can play an important role in the detection of human settlements. However, so far use of SAR data in detection and detailed urban mapping has received less attention as compared to the use of SAR data in agricultural, forestry, geology, geomorphology and hydrological studies. This paper attempts to demonstrate the potential of higher incidence angle SAR data in detecting human settlements using digital classification technique. Study indicated that human settlement could be digitally classified with classification accuracy as high as 98.23% using SAR data alone. However due to mixing of few categories of wasteland with fallow land, overall classification accuracy as low as 75.59% is achieved when SAR data alone is used. It is observed that synergic use of SAR and optical data acquired in the month of February proved to be the best showing highest overall classification accuracy of 89.33% with classification accuracy of human settlement to be 93.10%.

1. Introduction

Along with alarming population explosion, there is a universal trend towards urbanization. In order to establish and maintain an efficient system of human settlement function, such as housing, transportation, health and other human services, timely and accurate information on size of human settlements, its spatial distribution and dynamics is needed. This information is among the most critical information needed for future economic development planning, natural resources allocation and environmental management. Remote sensing has a promising role to play in the field of human settlement mapping. Potential of remote sensing technique for human settlement detection, population estimation and urban analysis has been demonstrated by several researchers way back in mid fifties (Green, 1956, 1957 and Porter, 1956). Optical remote sensing has long proven to be an efficient tool for human settlement mapping (Henderson, 1979, Hofman, 2001, Lo, 1986 and Ridd and Liu., 1998). Lot of work has already been done in this field using optical sensors like Landsat and IRS series of satellites as human settlements are clearly seen on the standard false color composite (FCC) of IRS or Landsat. As far as visual interpretation is concerned optical data serves the purpose. However, mapping of human settlements by means of digital classification techniques is still very difficult. Since reflectance measurements in the visible and IR regions are primarily related to molecular resonance of surface materials, objects with different physical dimensions may give similar signatures on optical imagery (Henderson and Lewis, 1998). Due to this reason, on a FCC, signature of habitation, fallow land and gullied land are mixed with each other and therefore in case of digital classification of human settlements there is lot of commission / omission error from fallow fields and wasteland categories like gullied / ravenous land. In contrast to this, the RADAR backscatter is largely determined by the physical properties of surface objects such as surface roughness, orientation and dielectric behavior. Due to these reasons, objects that appear identical on a standard FCC appear quite different on SAR imagery. In general, the habitation structure mostly exhibits corner reflector effect. Due to this reason, backscattering coefficient of habitation is very high as compared to that of agricultural land (both crop covered fields and fallow fields) and gullied land, for that values of backscattering coefficients are mostly negative. Moreover, in case of high incidence angle SAR data it is likely that the incidence angle falls within ±10° of the bore-sight, giving rise to very strong backscatter (+2dB to +6dB in the present case). Radar applications in urban analysis, settlement detection and population estimation has been successfully demonstrated by many researchers world over (Henderson, et al., 1995, 1997, 1998).

Sensitivity of Radar towards human settlements when coupled with its all weather capability and its potential to acquire the data irrespective of sunlight conditions, make Radar a unique choice for detection and detailed urban mapping. It is particularly useful for those areas of the world, where cloudy and inclement weather prevails for a longer duration. For example Brazil, Costa Rica, Venezuela, Panama, Guatemala, Nigeria and Togo along with number of other countries had already imaged their entire countries by commercial Radar systems. However, in India use of Radar data for urban studies have received very little attention and only few studies have been carried out using SAR data from airborne and space borne sensors (Mohan, et. al., 1992, 1993 and Srivastava et. al., 2003).

2. Dataset and Study Area

For the present study one scene of higher incidence angle (43°), RADARSAT 1 SAR data along with three sets of optical (IRS-1D, LISS-III SAT scenes) data over parts of Agra, Mathura (U.P.) and Bharatpur (Rajasthan) districts, India were acquired. RADARSAT 1 operates at C-band, HH polarization, under a variety of viewing mode with varying spatial resolutions. Figure 1 (A) shows the higher incidence angle (43°) Standard-6 beam mode RADARSAT-1 SAR image acquired on 12-April-2000 whereas Table 1 shows the details of Standard-6 beam mode RADARSAT-1 SAR data. In addition to SAR scene, three SAT (Shift along track) scenes of IRS LISS-III with path/row 97/52, 53 (dated: 15-Dec-1999, 01-Feb-2000 and 20-March-2000) were also used. Spectral bands for IRS LISS-III are Green (0.52-0.59μ), Red (0.62-0.68μ), Infra red (0.77-0.86μ) and Short wave Infrared (1.55-1.70μ). Out of four bands, Infra red, red and green bands have been used for the digital analysis. As the objective of the study was to compare the potential of optical and SAR data for detection of human settlement, the optical and SAR data has been selected in such a way that their spatial resolutions are comparable with each other. IRS-LISS-III is having a resolution of 23.5 m for Infra red, red and green bands whereas the nominal resolution of RADARSAT 1 SAR data used in the study is 25.0 m. False color composite (FCC) of IRS LISS-III data for 15-Dec-1999 is shown in Figure 1 (B), whereas false color composite of IRS LISS-III data for 01-Feb-2000 and 20-Mar-2000 are shown in Figure 1(C) and Figure1 (D).

3. Data Analysis / Methodology

Following are the major steps involved in the data analysis :

3.1 DN to σ° conversion

For the RADARSAT-1 SAR data supplied from CCRS, output scaling in terms of gain and offset are applied to the data to ensure optimum utilization of the available dynamic range. DN image was converted to radar backscatter (σ°) image using the following equation.

$$\sigma^{\circ}\,dB = 10.0 \times \log_{10}\left[\{DN^{2} + offset\}/\,gain\right] + 10.0 \times \log_{10}(\sin(\alpha))$$

Table 1 : Details of RADARSAT-1 Standard-6 Beam Mode SAR Digital Data.

Specifications	Details
Beam mode	Standard
Beam position	6
Date of Pass	12-April-2000
Look Direction	Descending
Generating Agency	RSI
Incidence Angle (Central)	43°
Pixel Spacing	12.5 m
Nominal Spatial Resolution	25 m
Product Type	Path Image
Data Format	CEOS
Number of Image Lines	8493
Number of Image Pixel	8701
Number of bits per pixel	16 bits unsigned
Image size	148 MB

Where DN is the digital number of SAR image, which is in amplitude and α is the local incidence angle at that pixel position in the range direction. The header information was used for the calculation of α, the local incidence angle at each pixel (RSI, 1995).

3.2 Image Processing

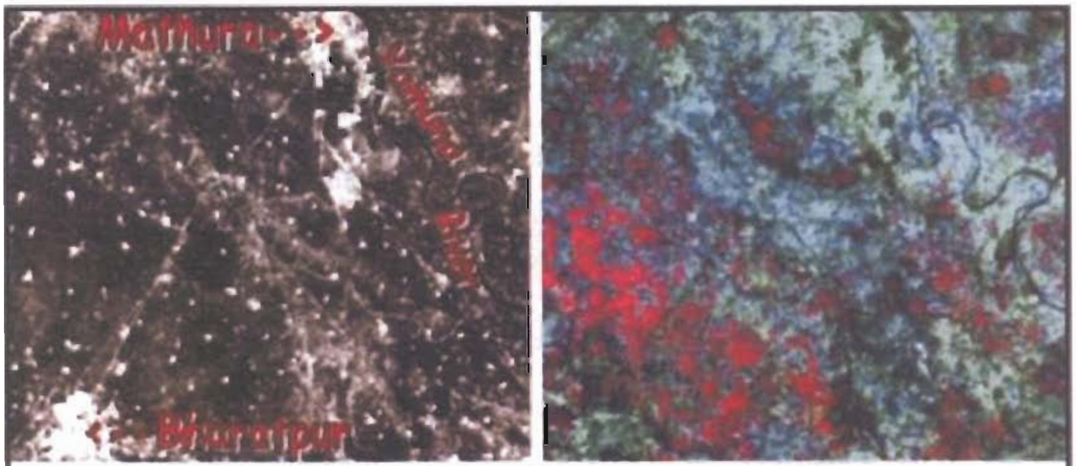
After conversion of DN to (σ^o), speckle suppression was carried out using Enhanced Lee-filtering algorithm (Lee, 1986 and Shi and Fung, 1994). Enhanced Lee Adaptive Filter divides the radar image into homogeneous, heterogeneous, and isolated point-target areas, and optimally filters each region. Due to this reason Enhanced Lee Adaptive Filter was used for detecting human settlement. Optical data from IRS LISS-III acquired on 15-Dec-1999 was geo-referenced using the Ground Control Points (GCPs) from 1:50,000 scale Survey of India (SOI) topographic maps. The registration accuracy for map to IRS LISS-III image (15-Dec-1999) was within a pixel. The other two IRS LISS-III images acquired on 01-Feb-2000 and 20-Mar-2000 and RADARSAT-1 SAR data acquired on 15-April-2000 were then co-registered with this geo-referenced image using nearest neighborhood method of resampling (Duggin and Robinore, 1990). Once, all the optical and SAR images were co-registered with each other, training windows were marked on the registered image for human settlements, fallow land and gullied/ravenous land, followed by signature extraction from SAR data and optical data. We use Bhattacharya distance to evaluate how well separated are data from different classes (Bhattacharya, 1943). Signature for all the land cover classes (Human Settlement, Fallow land and Gullied/Ravenous Land) were used to arrive at Bhattacharya Distance (BD) for reparability analysis between human settlement & fallow land and human settlements & gullied/ravenous land for different combinations of optical and SAR data sets. In the final step classification of human settlement, fallow land and gullied/ravenous land with different combinations of radar and optical data sets using Maximum likelihood classifier (Robert, 1983) was attempted. Analysis of results obtained from classification and reparability analysis is discussed in the next section.

4. Results and Discussion

False color composites (Figures 1) of IRS LISS-III data for December, February and March covering full crop growing season clearly indicated that at most of the places, signatures of human settlements (both rural and urban) are mixing with that of fallow land and gullied/ravenous land. Mixing of human settlements with that of fallow land can be minimized by using optical data of the February month as in the month of February most of the agricultural land is crop covered. However, overlapping in the signatures of human settlement and gullied/ravenous land still exists even in the case of optical data acquired for the month of February. In contrast to this, human settlements like villages, towns and cities are clearly seen as bright spots on SAR imagery as shown in Figure 1 (A).

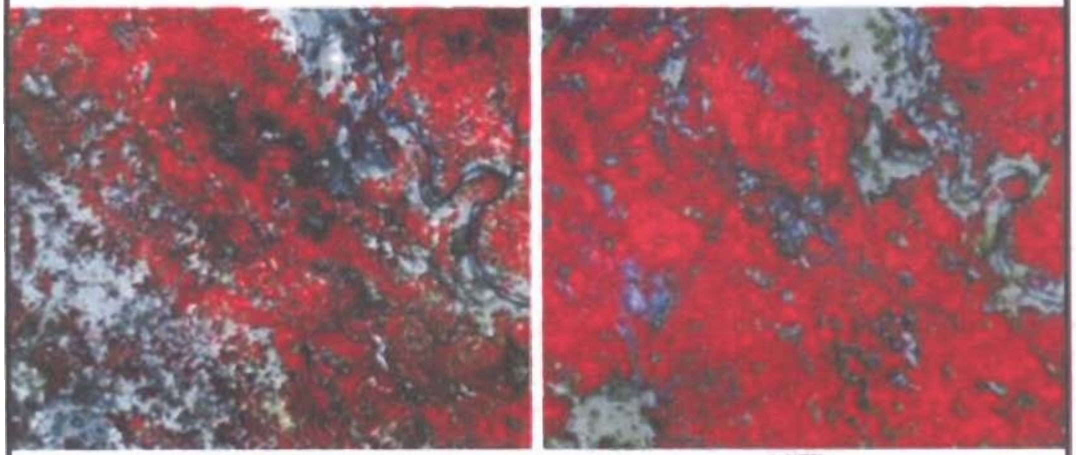
Results of reparability analysis (Richards, 1986) based upon Bhattacharya Distance are given in Table 2. It was observed from the results of reparability analysis that for all the combinations involving SAR data, Bhattacharya Distance (BD) was always higher as compared to other combinations where optical data alone is involved. Even in the case of SAR data alone, reparability between settlement-fallow was 1.97506 and between settlement-gullied/ravenous was 1.96800. It strongly recommends that SAR data alone can be used for the detection of human settlement by means of digital classification technique. Analysis of results obtained for reparability between fallow land and gullied/ravenous land clearly indicated that reparability between these two classes was very poor for all the data sets, when they are used alone. It was found to be 0.08049 for SAR data alone, 0.89504 for IRS LISS-III 20-Mar-2000 data alone, 1.50557 for IRS LISS-III 01- and gullied / ravenous land on all the three scenes of optical data) Feb-2000 data alone and 1.47188 for IRS LISS-III 15-Dec-2000 data alone. It has suggested that though SAR data alone is sufficient for the detection of human settlements, SAR data alone can not be used for land use /land cover mapping. Hence feasibility of use of digital classification techniques for the detection of human settlements was demonstrated by classifying various combinations of optical and SAR

Data sets using maximum likelihood classifier. For arriving at a comparative evaluation, digital classification of a total of seven combinations of optical and SAR data sets have been used. Results of classification output (confusion matrix) for these combinations are given in the form of tables from Table 3 to Table 9.



(A)
Standard-6 beam mode (43°) Radarsat SAR Image acquired on 12-Apr-2000 showing human settlements as bright scattered spots

(B)
IRS LISS-III image acquired on 15-Dec-1999 (human settlements are mixing with gullied/ravinous land and fallow land)



(D)
IRS LISS-III image acquired on 20-Mar-2000 (human settlements are mixing with gullied/ravinous land and fallow land)

(C)
IRS LISS-III image acquired on 01-Feb-2000 (human settlements are mixing with gullied/ravinous land)

Figure 1 : Geo-referenced images from optical and SAR sensors showing parts of Agra, Mathuea and Bharatpur districts, India. (Human settlements like villages, towns and cities are clearly seen on SAR imagery as bright scattered spots, where as they are mixing with fallow land)

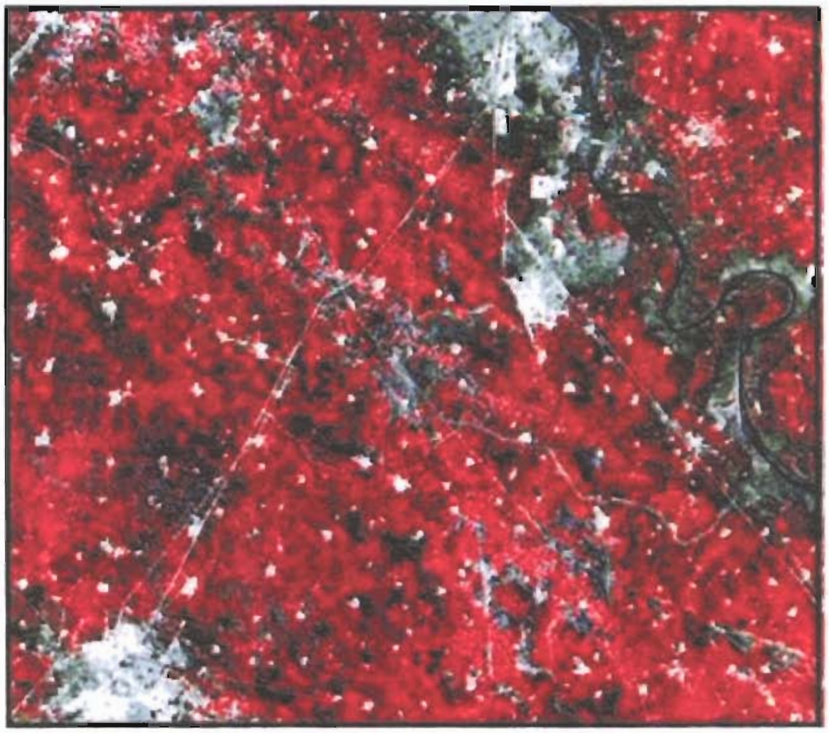


Figure 2 : Higher incidence angle Radarsat-1 Standard-6 beam mode data merged with optical data of 01-Feb-2000 (Human settlements like villages, towns and cities are clearly seen on the merged imagery as bright scattered spots along with distinct tone of fallow and gillied / revenoue Land)

Table2 : Results of reparability analysis between settlement, fallow land and gullied / ravenous land based up on Bhattacharyya Distance (BD) for different combinations of optical and SAR data

Data Set Used	Bhattacharyya Distance (Bd)		
	Settlement - Fallow	Settlement Gullied/ Ravenous	Fallow Gullied/ Ravenous
SAR alone	1.97506	1.96800	0.08049
IRS (March) alone	0.73377	0.82740	0.89504
SAR + IRS (March)	1.98015	1.98257	1.01369
IRS (February) alone	1.25112	1.30089	1.50557
SAR + IRS (February)	1.99281	1.98690	1.57307
IRS (December) alone	1.46154	0.77801	1.42160
SAR + IRS (December)	1.99269	1.98034	1.47188

Table 3: Confusion matrix for settlement, fallow land and gullied / ravenous land using SAR data lone.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	00.67	98.23	01.10	00.00
Fallow	00.00	01.75	72.52	25.73
Gullied / Ravenous	00.00	01.07	42.90	56.03
				Average accuracy: 75.59%

Table 4: Confusion matrix for settlement, fallow land and gullied / ravenous land using IRS LISS-III (March) data alone.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	03.97	71.49	11.43	13.10
Fallow	01.89	06.57	66.47	25.07
Gullied / Ravenous	02.34	16.84	39.71	41.11
				Average accuracy: 59.69%

Table 5: Confusion matrix for settlement, fallow land and gullied / ravenous land using IRS LISS-III (February) data alone.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	01.34	89.73	03.30	05.63
Fallow	01.03	02.15	86.82	10.00
Gullied / Ravenous	01.81	12.90	09.54	75.75
				Average accuracy: 84.10%

Table 6: Confusion matrix for settlement, fallow land and gullied / ravenous land using IRS LISS-III (December) data alone.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	0.161	87.86	04.45	06.08
Fallow	00.56	05.85	82.55	11.04
Gullied / Ravenous	01.49	17.86	14.21	66.43
				Average accuracy: 78.95%

Table 7: Confusion matrix for settlement, fallow land and gullied / ravenous land using optical (IRS-March) and SAR data.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	06.83	92.55	00.57	00.05
Fallow	03.23	00.65	75.58	20.53
Gullied / Ravenous	04.52	01.05	28.02	66.42
				Average accuracy: 78.18%

Table 8: Confusion matrix for settlement, fallow land and gullied / ravenous land using optical (IRS-February) and SAR data.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	06.77	93.10	00.02	00.11
Fallow	03.39	0.00	87.53	09.08
Gullied / Ravenous	05.04	00.17	07.44	87.35
				Average accuracy: 89.33%

Table 9: Confusion matrix for settlement, fallow land and gullied / ravenous land using optical (IRS-December) and SAR data.

Class	Pixels Classified (%)			
	Unclassified	Settlement	Fallow	Gullied/Ravenous
Settlement	07.19	92.60	00.06	00.15
Fallow	02.49	00.39	83.13	13.98
Gullied / Ravenous	04.57	00.37	10.95	84.11
				Average accuracy: 86.61%

The confusion matrix is arrived at by marking test windows consisting of 9 pixels (3x3) at the center of each of the class. Following combinations have been attempted :

1. RADARSAT-1 Standard-6 SAR (12-April-2000) data alone (Table 3)
2. IRS LISS-III 20-March-2000 data alone (Table 4)
3. IRS LISS-III 01-February-2000 data alone (Table 5)
4. IRS LISS-III 15-December-1999 data alone (Table 6)
5. Multi-sensor optical and SAR combination : SAR and IRS LISS-III 20-Mar-2000 (Table 7)
6. Multi-sensor optical and SAR combination: SAR and IRS LISS-III 01-Feb-2000(Table 8)
7. Multi-sensor optical and SAR combination : SAR and IRS LISS-III 15-Dec-1999 (Table 9)

The study of the outcome of the classification results given in Table 3 through Table-9 shows that classification accuracy for human settlement was highest at 98.23% when SAR data alone is used. However it should be noted that the overall classification accuracy for the case of SAR data alone is poor owing to lot of mixing between the fallow and gullied/ravenous classes.

A comparison of classification accuracies for human settlement between classifications using single date optical data confirmed that amongst optical data, February data is most suited for classification of human settlement with the classification accuracy being 89.73%. Optical data for the month of March was found to be least suited with the least value of classification for human settlement being 71.49%. However, combined use of optical and SAR data has shown an increase in the classification accuracies from 89.73% to 93.10% in case when SAR was used along with IRS LISS-III February data and from 71.49% to 92.55% in case when SAR was used along with IRS LISS-III March data. Here it is required to emphasize that with the use of multi-sensor data set (i.e. IRS LISS-III February + SAR & IRS LISS-III March + SAR) the classification accuracies for human settlement in the both these cases (93.110% and 92.55%) is lower to that of the classification accuracy of human settlement with SAR data alone (98.23%) but the over all classification accuracy has increased due to better classification of fallow and gullied/ravenous classes.

Comparison of results obtained from reparability analysis and maximum likelihood classification pointed out that detection of human settlement on optical data using digital classification technique leads to relatively poor classification accuracies as compared to SAR data. It is observed that for detection of human settlement, SAR data alone is best suited but it is not adequate enough when land cover mapping is also attempted. Combined use of SAR and optical data was found to be able to cater to human settlement as well as land cover mapping with adequate classification accuracies. This fact is clearly depicted in the image shown in Figure 2 generated by merging SAR data with that of optical data of 01-Feb-2000. The merged data has been arrived at by IHS transformation.

5. Conclusion

The present study demonstrated the potential of SAR in detection of human settlements using digital classification. The outcome of the study demonstrated the usefulness of combined use of SAR and optical data when human settlement and land cover mapping both are attempted. Owing to the sensitivity of SAR backscatter to the physical properties of surface objects such as surface roughness, orientation and dielectric behavior, many land cover objects which appear identical on an optical imagery appears quite different on Radar imagery. This increases the potential of SAR data in the field of human settlement mapping and monitoring apart from just detecting. As there are a number of digital classification techniques available in the literature, in future various digital classification techniques like object oriented classification approach (Kressler et al., 2002 and Hofman, 2001) can be evaluated for human settlement classification. In this study, confusion matrix arising out maximum likelihood classification technique showed that use of SAR data along with optical data adds additional discriminating power for the detection and detailed mapping of human settlements along with other land cover classes. Study clearly indicated that it is possible to digitally map human settlement with the help of SAR data.

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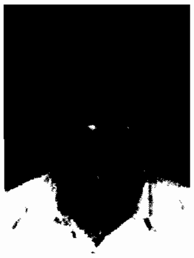

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