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Monitoring Area-wide Variation of River Water Color by Video GIS Sampling Technique+

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비디오 GIS 샘플링 기법에 의한 하천색조의 광역 변화추세 감시+

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요 약

항공 비디오의 가장 큰 장점은 협각조망범위에 동영상을 제공함으로서 저렴한 경비로 소폭/장거리 지상물체를 감시하는 최적의 원격탐사도구로 알려져 있다. 선형감시에 대한 비디오의 이와 같은 이론적인 장점에 의거하여 하천수질을 모니터링 하기 위한 비디오 샘플링 기법이 본 연구를 통해 제시되었다. 본 연구의 근본적인 의도는 전통적인 샘플링에 기반을 둔 현장조사의 개념을 디지털 비디오의 해석기법에 연계시키려는 것이었다. 특정 지점에서 시료를 채취하는 현지 샘플링조사와 동일한 방식으로 장거리에 걸친 하천의 수질감시를 위해 원격동영상을 컴퓨터 모니터에 디스플레이 하면서 비디오 샘플지점을 선정하여 수질을 감시하였다. 비디오 샘플링 기법은 하천 색조의 변화실태에 대한 가상현실의 형태로 정보를 제공했다. 다양한 샘플지점에서 나타나는 하천 색조의 변화추세를 가시적으로 파악할 수 있었으며 전통적인 현장 샘플링 방법으로는 추적하는 데 한계가 있는 특정오염원에 기인한 하천수질의 광역적인 변화패턴을 파악하는 데 상당한 가능성을 보여주었다. 이와 같이 영구적으로 보전된 영상기록은 오염 물질의 이동확산 등 수질환경의 광역적인 변화 추이에 대한 시각적인 정보를 제공하고 있어 현장샘플링과 동시에 사용할 경우 하천수질감시에 있어 상당히 유용한 도구가 될 수 있음을 보여주었다. 본 연구를 통해서 제시된 비디오 샘플링 기법이 도로, 철도, 송유관 등 다양한 선형지형지물의 환경감시에 효과적으로 사용될 수 있을 것으로 사료된다.

주요어: 비디오 샘플링, 하천색조, 원격탐사

+ The video GIS (Geographic Information System) means an integrated approach between remote sensing and GIS using airborne video as a database.

I. Introduction

Environmental monitoring for 'corridor target' is different from the traditional targets of 'area-based' mapping. The corridor itself is linear and generally very long (hundreds or thousands of kilometres) and very narrow (10-1000meters). The types of ground targets, which fit these criteria, include crosscountry pipelines, electric transmission lines and overhead cables, but also include railways, roads, highways and coastlines. A river in general is one among many corridor targets that require regular environmental monitoring in accordance with government environmental regulation (Um and Wright, 1996). At present, monitoring programmes for corridor target have been mainly based on field sampling, which relies on attributes of an area at one point in time, reflecting an emphasis on the small number of in-situ data. One of the major disadvantages of traditional field monitoring is that it is costly, laborious and time consuming due to the large number of samples required. Nevertheless, sampling errors can be quite large, especially where geographical variation seriously occurs in the field (Um and Wright, 1998). Furthermore, point observations have the disadvantage that they provide only limited information on historical trends and spatial distribution of the river water quality variation. Present ground-based regular inventories are not practical in terms of either cost or scientific reliability. In this regard, many water authorities have been seeking to strengthen its ability to use remote sensing in water resources management such as modelling and diagnostic studies.

For the requirements of corridor monitoring, various sensors can be deployed from satellite or aircraft (from photographic cameras to scanners and complex imaging spectrometers). Satellite image resolution is currently limited to a minimum mapping unit of 1m (panchromatic) or 4m (multispectral) per pixel. It is too coarse a resolution for monitoring river corridors as narrow as 50m or so. For this type of narrow target, it will still be necessary to use aerial photography to obtain specific fine details on a larger scale. Aerial photography is one of the oldest and most widely applied sensors, capable of recording information in the visible and near-infrared wavebands onto photographic film. Large-scale photography has often been used for this type of application to investigate detailed ground features (Majenyi, 1969; Olson, 1981; Jadkowski et al., 1994). However, many inconveniences involved in the collection and processing of data, such as the cost, have proved a barrier to its widespread use for this type of application. If digital remote sensing techniques are applied, the film image and hard copy must be digitized into machine-readable picture elements (pixels) and stored on computer-compatible media, such as tape or disks. The cost of scanning conventional aerial photography would be prohibitively expensive for a long and narrow river flow. Furthermore, manual handling of hundreds or thousands of hard-copy aerial photographs may prove to be unmanageable.

Traditional sensors are basically designed for site-by-site assessment for a specific ground target. They do little to address the overall impact of such corridor on the landscape. Furthermore, if large areas are to be covered to detect sufficient ground detail, the cost disadvantage will apply to the whole coverage. To fulfill the data requirements of corridor monitoring it is sufficient to have information along a line in the vicinity of the corridor. There are many inherent drawbacks for the traditional remote sensing systems to be incorporated within a monitoring programme for the long narrow target. Clearly, economic factors hinder the use of standard area-based remote sensors in this type of application. This is one reason why most of the information for strip features at lower level is currently gathered from ground survey. Corridor monitoring represents a potential application for remote sensing which is largely unfulfilled (Um and Wright, 1999a; Um and Wright, 1999b).

Water resource managers are continually being faced with the challenge of monitoring the stream with reduced budgets and personnel. It is suggested that videography has many inherent advantages for corridor target monitoring. Video could provide a permanent visual record for a variety of spatial characteristics of effluent dispersion. When video is evaluated in terms of information required for river water monitoring it would be a powerful tool for quantifying aerial extent and analysing pollutant dispersion trends along the river. Intensive video sample survey over important sites can overcome the lack of spatial visual record from field sampling. In spite of the inherent advantages of video for corridor target, it is noted that major concerns of water resources authorities have not been well incorporated into much of present remote sensing practices. In this regard, a recent research project set out to evaluate the potential of "Video Sampling" for river corridor monitoring. This paper first introduces the relevant background information for the proposed research, followed by descriptions of the study site and the data used. For the sampled images, the water color was investigated based on the aerial association of effluent plumes and in comparison with the field sampling data. Further discussion evaluates the limitations of the video sampling techniques (e.g. influence of light conditions).

II. Background for video sample survey

The important element in remote sensing applications for corridor target is the required optimal swath width. Field of View (FOV) differences provided by various remote sensing sensors will find application at different scales. Sensor sizes in solid-state video cameras are usually much smaller than the formats of conventional photographic film (36mm by 24mm for small format, 55mm by 55mm for medium format photography) as shown in Fig. 1. The angular FOV of the imaging device must first be carefully considered when trying to obtain remotely sensed data of a long, narrow target. Wide-angle imagery, such as from airborne line scanner and photography, covers a larger area of land surface than a smaller format system operated at the same altitude and with the same focal length lens. Any single-scene image collected via such systems covers a wide area of surrounding features in addition to the corridor site. Such an image will, therefore, include a considerable redundancy of information, which is not needed for the corridor monitoring (Um and Wright, 2000).

The cost of corridor mapping with aerial photography would be a good standard against

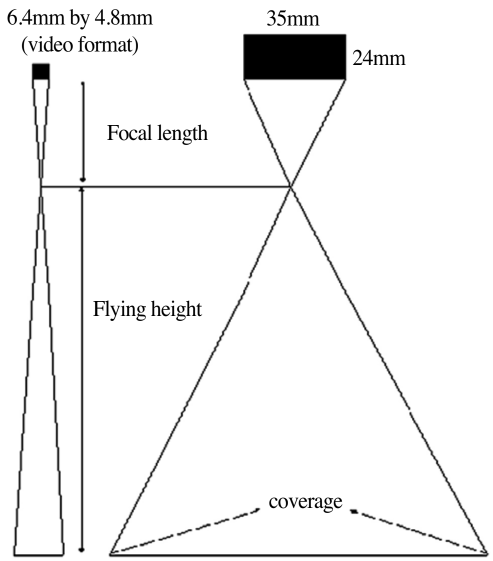

Fig. 1. The relationship in ground coverage between video sensor and photographic film(small format) at the same altitude and with the same focal lens.

which a video sensor could be readily compared. To monitor a 400km length of corridor with aerial photography of 100m swath width, the number of photographs required is estimated at around 10,000 frames. As soon as large areas are involved, regular photographic survey appears to be uneconomical or impractical. The cost would be increased several times for multi-day, month, year monitoring. It is considered too expensive to monitor a long narrow river corridor frequently by aerial photography and it would be unrealistic to expect photographic survey to be of much use for river water resource management.

The high cost of photo acquisition, particularly for a scattered corridor target such as a stream, is a significant disadvantage of the photographic survey method. With airborne video, the linear extent of hundreds of kilometres of a stream corridor could be recorded all on the same day. The time and cost of photographic processing are virtually eliminated by providing instantaneous video-taped imagery, much more quickly than with photography. It is much less expensive than most other remote sensing systems. Due to such low-cost data acquisition, this technology may have a particular value in highly changeable areas, such as a stream corridor, where day-to-day, week-to-week and seasonal changes are common. Large-scale changes in water quality could be monitored and thus monthly or seasonal survey results could be updated on a site-specific basis.

Additionally, in a temperate region such as the Korea, there are only a few months in the year with necessary bright light conditions for aerial photography. On the whole, the reduced illumination conditions of winter do not favor aerial photography. The almost all-weather capability of video, due to the high light sensitivity of the CCD (Charge Coupled Device) sensor, could assist in the multi-seasonal monitoring requirement for a river. Many remote sensing specialists accustomed to interpreting aerial photography or analyzing digital images now have a 'moving window' with which to view the dynamic ground features that are required for inventorying and managing (Maggio and Barker, 1988). The use of such information, integrated with field survey techniques, can aid in the delineation of specific areas where these land cover types have the highest potential for polluted runoff and where nonpoint source runoff has the highest potential impact to the receiving water body.

Historically, the invention of remote sensing technology was due to the human desire for presenting a pictorial view of the earth's surface. In reality, the use of remote sensing data to maintain a permanent visual record for a ground target was the most useful application for many different types of applications. People are likely to respond with "Just show me!" because they catch on more quickly when they can see how something is done rather than reading or listening to instruction. Likewise, many types of environmental information cannot be conveyed effectively with words alone. This information requires a much richer mode of communication that not only includes visual elements to enhance the spoken word, but also captures movement and visual expression. Experience has shown that a verbal or narrative record is inadequate, and it is much better to complement this by extensive videographic coverage.

In this context, a single aerial photograph presents a picture of a portion of the earth's surface. Because the single aerial photograph is limited in area, groups of photographs are combined into mosaics to provide the aerial picture of larger areas. The increased need for presenting a pictorial view of the earth's surface has led to aerial mosaic as a means of showing a complete view of large areas. However, certainly to achieve the area-wide visualization, human labor and cost required in the time-consuming mosaicking process would be the serious constraint. For long-narrow target and large-area mapping, a mosaic of multiple frames is required, which would involve additional processing and the use of complicated geometric and radiometric matching routines. With airborne video, dynamic stereo coverage is achieved in each single flight line by recording a very large number of individual frames within a very short time interval. Such dynamic stereo coverage makes video the best means of recording a large number of ground features over a given time interval, which is a main requirement in the case of monitoring a long river corridor. Visual interpretation of moving video, whether vertical or oblique, offers a perspective that can aid in understanding the spatial extent of features which is difficult to achieve through other means. For the moment, in terms of cost, analogue and digital video recording is the only available remote sensing system offering the advantage of dynamic stereo coverage. Aerial video is a technology that fills a niche that conventional aerial photography cannot meet. Corridor monitoring represents a potential application for remote sensing which is largely unfulfilled.

III. Study site and data acquisition

1. Experimental site

The Nakdong river basin (NRB) was selected as a case study site throughout the experiment (Fig. 2). The NRB is located in the eastern side of the Southern Korean Peninsula. NRB is not an economic or administrative unit, it is a natural drainage unit (between 127°29′ E and 129°18′E, between 35°03′ N and 37°13′N). The river basin covers an area of 23,817 km^2, which is 24% of the total area of South Korea. The middle and northern belts of the river vary from low-altitude uplands to rolling hills while the southern part of the river consists of lowlands and wetlands. The extension of river covers 521.5km and during the project, the experiment was mainly carried out in

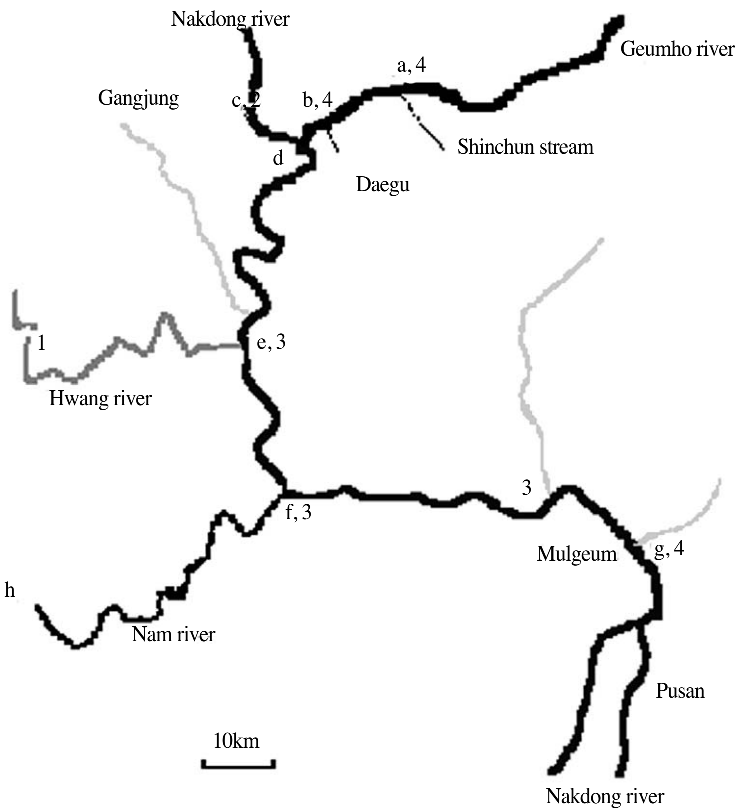

Fig. 2. Location map of the study site. The video sampling points are marked as "a to g" while water quality grading is indicated as "1 to 4".
Water quality grading is made based on the BOD (Biochemical Oxygen Demand) value of field sampling stations; 1 (below BOD 1), 2(below BOD 3), 3 (below BOD 6), 4 (below BOD 8)

the southern part of the river (ground coverage: around 150km long, Point a to g in Fig. 2). A series of tributaries along the Nakdong River (NR) were used for this video sampling survey.

The NRB has a particular problem in availability of drinking water due to river pollution and a large degree of dependence on rain water. The Government has spent a large sum of money to build waste treatment facilities, reservoirs and dams for water storage. The NRB receives a variety of organic wastes, some of which are detrimental to human health and aquatic organisms. Urban areas, farms, factories, and individual households all contribute to contamination of the Nakdong river. This contamination is greatly important because about 25% of total population in Korea relies on the NRB as a source of drinking water. As an ancient inland mountain river system, the NRB area plays an important role in meeting industrial, recreational, and environmental needs of the public.

As shown in the Fig. 2, the distribution of contaminants along the NR depends on the nature and location of their sources, the degree of wastewater treatment, the stability of the contaminants, and their dilution by receiving waters. Many tributaries such as the Geumho, Hwang, and Nam Rivers have significant effects on the organic chemistry of the NR. Waste concentrations are typically greatest in the Geumho river (GR), which receives heavy organic contaminants from Daegu metropolitan area. Thus GR running in the city is a highly significant contributor of water, sediment, and contaminants to the Middle NR and its effluent characteristics are markedly different from those of the freely flowing middle and lower river. The BOD (Biochemical Oxygen Demand) distribution in the Fig. 2 distinctively shows the changing trends of water quality in the NR and its main tributaries. There are pronounced differences between the two drinking water sources, with northern Gangjung reservoir (water quality grading: 2) receiving natural currents of NR, while the southern Mulgeum (water quality grading: 4) was trapping sediments and chemicals associated with runoff from industrial sources.

2. Video flight

In designing an airborne video flight system, many options affect the quality of the data that can be acquired. These include flying height, camera characteristics, ground coverage and image motion determination, which are all closely interrelated. At the stage of flight planning, one of the important tasks was the choice of lens coverage angle. Since the target was considerably narrow, it was necessary to produce a quite large-scale video of the river corridor. This trade-off between coverage and ground resolution is a consideration in most remote sensing missions. It was assumed that the appropriate combination of lens setting, altitude and shutter speed could be determined to produce the most useful ground resolution of imagery for the specific missions under investigation in terms of navigation and resolving power. Consequently, missions of multiple passes from four different altitudes were planned over the study sites to obtain imagery with a wide range of ground coverage under different focal lengths and shutter speeds, as presented in Table 1.

The flight took place on 20 November 1999 and 21 November 1999 (representing the peak autumn dry season), at 09:00 and 12:00 hours, local standard time (LST). This is the season when the river water quality is in worst condition due to reduced volume of water flow. The three video cameras (Sony DCR-TRV900) were mounted inside the rack of the photographic camera (23cm by 23 cm format) of the light aircraft (TU-206G) and locked in a vertical downward position to avoid vibration. The auto-aperture function was used, based on pre-setting of the shutter speed. To calibrate the video camera for accurate colour recording in different lighting

Table 1. Specifications for the video flight: flying height, shutter speed, focal length, cross-track ground coverage (in meters)

focal lens (mm) / Height (m)/shutter (second)	30mm	5.9mm	4.3mm
1600 1/2000s	341.3	1735.6	2381.4
2000 1/1500s	426.7*	2169.5	2976.7
2500 1/1500s	533.3	2711.9	3720.9
3000 1/1000s	640	3254.2	4465.1

* Estimation of across-track ground coverage = (across-track format size of video camera: 6.4mm)
* flying height (2000m)/focal length (30mm) = 426.7m

conditions, white balancing had been performed prior to the flight, by pointing the camera at a white object for reference in a typical manner. Before take-off, the system was switched on and tested to check that all equipment was working and that a clear image was assured.

The imagery acquired from the video-flight was played back using video capture board (All-In-Wonder TM128). The capture board is a graphics display device that linked video input and output devices to the computer. It captures a selected video image from the camera or video-tape, stores the scenes in computer memory and displays the scenes on the analogue red-green-blue color monitor. The quality of the imagery was generally good for subjective analysis. The high contrast between water body and riparian vegetation has produced excellent video imagery. Although the image quality was acceptable, the video did miss the initially planned coverage, which had various altitudes and focal length settings. Many video 'footpaths' had not followed the target precisely enough. Most of the video had not fully covered the river at the center of the image, which would be a necessary requirement for further video sampling. Such problems faced in this project could be overcome by present available technology if more money could be spent [In this case, due to cost and weather, a repeat flight was not feasible]. Initially, it was expected that such narrow ground coverage would cause great problems in orienting oneself during flight. It was considered that a helicopter might be the best choice of platform for this type of narrow target. However, the hire cost is expensive at more than three times that of a light airplane.

In addition, display errors due to aircraft tip and tilt can be avoided if a gyro-stabilized mount is used to maintain the sensor system in a vertical position during the flight. Such gyroscopic compensation would definitely help reduce the loss of ground coverage introduced by the roll of the aircraft. This equipment makes the camera maintain a vertical position within one sixth of a degree. However, the user of the remote sensing imagery must be aware of the trade-off involved in using a gyro-stabilized mount. A gyro-stabilized mount adds to the expense and complexity of installing equipment into a light aircraft (Bobbe and Ishikawa, 1992). The lower cost systems are inevitable to fully realize the potential of airborne remotely sensed data within the larger marketplace.

IV. Comparative evaluation of the video samples

For the interpretation of video samples, simple image processing procedures were applied in consideration of the information required for river water monitoring using Erdas Imagine 8.4 software (Um, 1997). Many of typical digital image processing has not been employed since visual information for the river was the main concern of the project; geometric correction, classification etc. Several diverse types of samples were selected by digitizing images based on predetermined criteria. All the samples took into consideration the significance of site and the concentrations of effluent plume: the cross section of the NR and GR and drinking water sources. First, visual interpretation (Table 2) had been made for the individual video samples to assess

Table 2. Visual interpretation based on color variation

	Tributaries	GR	Drinking water sources
Gangjung (c*)			light green
Shinchun stream (a)		blackish dark green	
Dalsu stream (b)		black mixed with white	
Geumho tributary (d)	light green in NR and blackish dark green in tributary		
Hwang tributary (e)	brownish green in NR and bright green in tributary		
Nam tributary (f)	dark green in NR and light green in tributary		
Mulgeum (g)			Green

* This code is marked in the Fig. 2

the validity of the sampling as a visual permanent record. Based on the interpretation of individual samples, comparisons for color changing trends among video samples were made to examine research questions concerning the contaminant transport from Gangjung to Mulgeum used as the drinking water sources for the Daegu and Pusan population. At the same time, the movement of a wide range of contaminants from major tributaries was investigated based on a comprehensive set of video samples.

1. Gangjung drinking water source (Fig. 3)[1)]

This is the place where the hydrologic characteristics is markedly different from those influenced seriously by tributaries since it is freely

1) The Original colour videl is here presented in black and white. However the description of video in this paper is based on the original colour video image since its information content and image clarity are even better than that in black and white.

Fig. 3. Gangjung drinking water source for Daegu metropolitan area A series of artificial embankments have been constructed to trap and store a certain amount of water that are being transported.

flowing without serious external input of contaminants. Relatively fresh water is carried from the upper NR currents flowing along the Southeastern mountainous area of Korea. This place is used as a reservoir for collecting drinking water for the Daegu metropolitan population (The third largest city in Korea). A series of artificial embankments have been constructed to trap and store a certain amount of water that are being transported upper river as shown in the Fig. 3. The embankments artificially deepen, widen, and slow the river above it, allowing water to settle in the reservoir. During the video cruise along the reservoir, water color was fairly uniform as light green, which is the typical color of the upper middle NR.

2. Shinchun stream and Dalsu stream (Fig. 4 and 5)[2)]

It is generally known in Korea that the Geumho river (GR) is the main contributor to the NR pollution. The GR receives strong concentrations of organic contaminants discharged from Daegu metropolitan areas. The Fig. 4 shows the cross section where the GR meets the Shinchun stream (lower left of the video sample). The Shinchun stream transports the pollutants discharged from domestic non-point source of the city. Furthermore, the GR receives contaminants discharged from the dyeing industry of the city in Dalsu stream as shown in the Fig. 5 while it is flowing downward. The industrial pollutants cause a compounding effect through interactions with domestic pollutants of the Shinchun stream in GR pollution. The color pattern of this area reflects a number of artificial influences.

2) The outfall of Shinchun and Dalsu stream carries sewage which has undergone wastewater treatment procedures in accordance with related government regulation, but a significant amount of suspended solid material is still discharged into the GR.

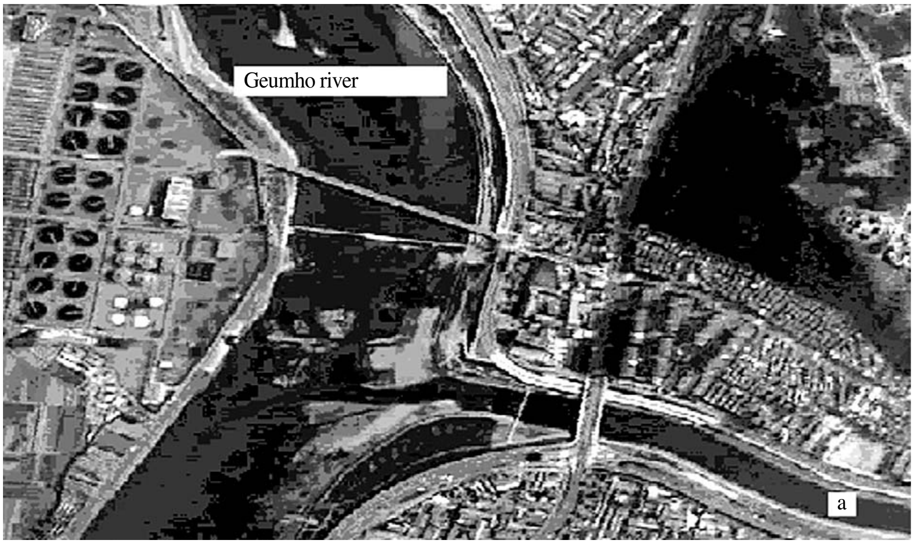

Fig. 4. The cross section where Geumho river receives domestic pollutants discharged from Daegu metropolitan area through Shinchun stream (marked as a in the figure).

Fig. 5. The cross section where Geumho river receives industrial pollutants discharged from Daegu metropolitan area through Dalsu stream (marked as b in the figure).

Concentrations of the black color are typically greatest at the point where the GR meets the Shinchun stream and Dalsu stream. The industrial wastewater has significant effects on the organic chemistry of the GR. The color difference between Gangjung (Fig. 3) and Shinchun (Fig. 4) is due to the greater amounts of organic contaminants discharged from the city. The blackish color mixed with white remains up to the zone where the GR flows into the NR since there is no significant factor to decrease the color intensity by dilution.

3. The rendezvous zone of NR and GR (Fig. 6)

The transport of contaminants from GR to downstream destinations of NR is a water-quality issue of national concern. The identification of effluent dispersion trends in the cross section of NR and GR as shown in the Fig. 6 is the most important issue in preserving the water quality of the NRB. Most existing field sampling stations, operated by central and local governments in NR, purposefully are located to monitor the influence of contamination by the GR. The dispersion pattern has researched at diverse manners by field environmental scientists and it is still left unresolved. The color of the water is no longer uniform along the length of the river, just as in the image of Gangjung and Shinchun (Fig. 3 and 4), and ranged from green to black. The characteristics of the water and the associated color intensity change dramatically over a very small area. An abrupt increase of the blackish color in the NR is due to contaminants input from the GR. The blackish plume is clearly delineated in the eastern area, as indicative of pollutant dispersion (or sediment of the contaminants) of the GR. The sampled images clearly show the fluctuating boundary between polluted, blackish water transported from the GR and clean water from main currents of the NR. The eddies and meanders of the cross section are also visible.

Fig. 6. The cross section of NR and Geumho river, an abrupt occurrence of the blackish color in the NR due to contaminants transported from the Geumho River.

The primary characteristics of western rendezvous currents are their velocity and volume of flow. Western boundary currents are very strong, quite wide due to the amount of water transported, and they exert a considerable influence on the dynamics of the entire river basin and the regional water quality. The effluent plume from GR is considerably narrow due to the influence of the natural water transported by the NR. The rendezvous zone marks the mixed pattern where the flow moves downward (Fig. 6). The along-river deflections of the plumes by the current are seen clearly in the Fig. 6 as the form of curvature of the eastern stream plume. Also, the flood countercurrent indicated by the deflected plumes represents evidence affected by a local topography. During the further video downstream tour from the cross section, the gradual decrease in color intensity was observed which indicated stream dilution by tributaries in the junction.

4. Hwang tributary and Nam tributary (Fig. 7 and 8)

Fig. 7 and 8 show two tributaries flowing along the rural, municipal and industrial sources (the Hwang tributary and Nam tributary), which hold different influences over water quality of the NR. A bright green color appeared in the sandy meanders of the Hwang tributary (Fig. 7) while slight dark green was observed in the Nam tributary. The bright green color of the Hwang tributary (Fig. 7) reflected in which wastewater is somewhat less concentrated. The color may be indicative of natural filtering theory, in which the sandy shore plays a significant role in purifying the river pollutants. It is apparent that the river outflow in Hwang tributary is enriched with more fresh water than that of Nam tributary, since the sandy filter breaks up the contaminant flow of the water easily. On the other hand, sediment of the industrial contaminants in Nam tributary was typically greater than those in the

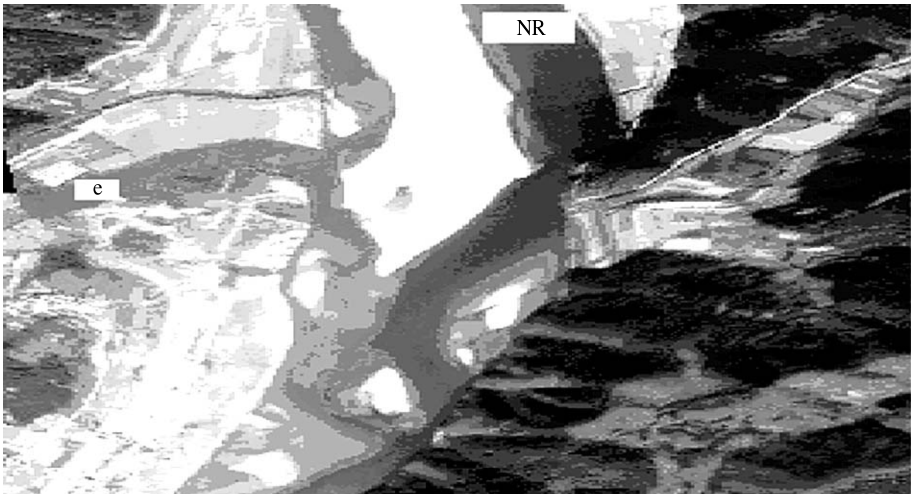

Fig. 7. Hwang tributary (marked as e in the figure).

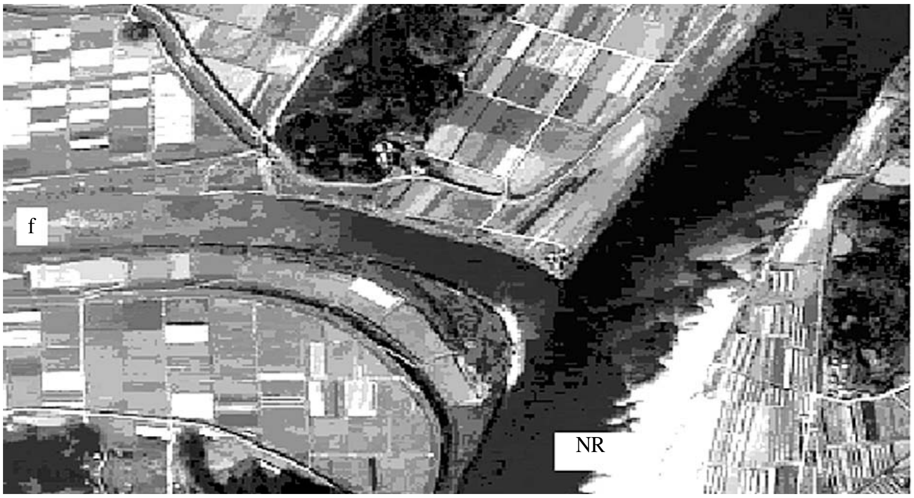

Fig. 8. Nam tributary (marked as f in the figure).

Hwang tributary. The Jinju industrial complex is located in the vicinity of the Nam tributary. The elevated concentrations of pollutants derived from the industrial complex are transported into the Nam tributary. The color of the tributaries reflects the difference between contaminants (or sediment of the contaminants) introduced directly through onsite industrial discharges (Nam tributary) and those introduced through municipal wastewater (Hwang tributary).

Figure 7 and 8 show two tributaries flowing along the rural, municipal and industrial sources which hold different influence over water quality of the NR. It is apparent that the river outflow in Hwang tributary flowing along the rural/municipal source is enriched in bright green while sediment of the industrial contaminants in Nam tributary appears as dark green.

5. Mulgeum drinking water source (Fig. 9)

Fig. 9 shows a Mulgeum drinking water reservoir, which serves as a source of drinking water for Pusan metropolitan city (The second largest city in Korea). It is generally known in Korea that the Mulgeum drinking water reservoir has been seriously polluted by industrial discharge and sewage effluents, which are transported from the Daegu metropolitan area. It is hard to identify such evidence with video sampling survey. The blackish plume of the Geumho tributary did not appeared any longer here (even the trace of sediments). The image shown did not indicate a remarkable difference in color intensity between tributary and main flow of the river. Because the tributary is not supplied by any serious sources of contaminants, the green color remained at the surface of the water. An important feature in the optical intensity of narrow tributary (marked as rectangle in Fig. 9.) was the role of the hydrological parameters. The velocity and volume of the mainstream looked very strong and wide due to the amount of water transported, thus the water color in the tributary was similar to the main stream by the influence of the natural water transported by the NR.

Spatial variations of optical intensity along the length of the NR demonstrated the interplay between the input sources that increased their concentrations and the processes of dilution and decomposition. The low concentrations in the Gangjung increased rapidly only as the blackish plume from the Geumho river entered and mixed. Therefore, the most obvious features of the optical intensity profiles shown were the high concentrations in rendezvous zone of the Geumho tributary and the NR. It is confirmed by

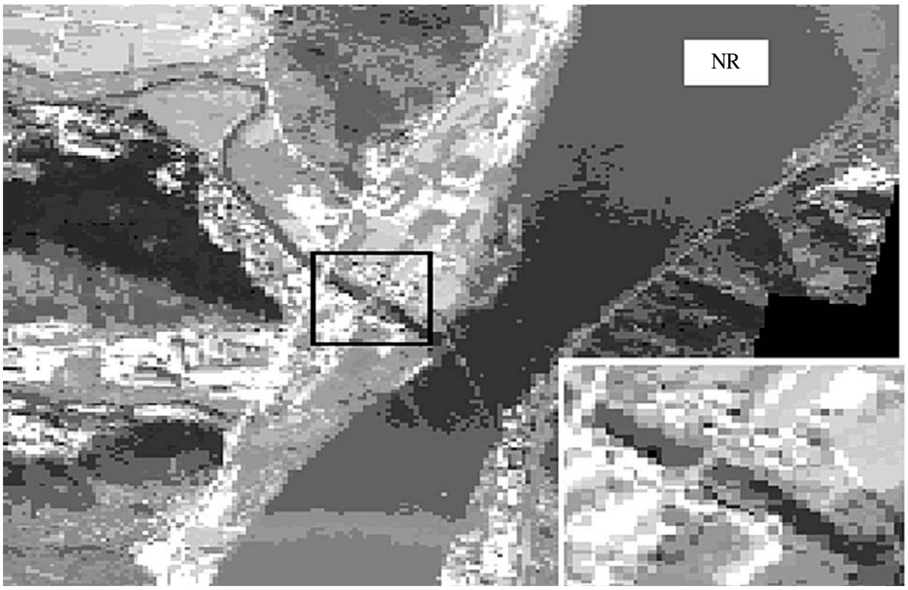

Fig. 9. Mulgeum drinking water source. The video sample shown here does not indicate remarkable differences in color intensity between tributary (marked as rectangle) and main flow of the river. Magnified portion of the tributary is presented in the lower right corner of the figure. The blackish plume of Geumho tributary no longer appears here.

visual permanent record of the optical samples that pollutant input from tributaries is the most contributing geochemical implications to the occurrence and fate of blacking plume or sediments. The video sample provided unique information on the spatial distribution of the major plume trajectory through a visible summary of their range of effluent concentrations and the aerial color association in individual samples for a given stretch of the river.

V. Discussion

Remote sensing for corridor target, such as a river, has been researched for the past twenty years or so, with a focus on satellite or aerial photography (generally not for operational application). The operational transfer of the research output relies heavily on the initial understanding or assumption of client need, the sensor and ground target. Much of the earlier corridor research might be conducted by initially inappropriate remote sensors. Such practices have resulted in the expenditure of time, labor and money on solving problems, which were largely irrelevant in an operational environment. By tackling such previous practices, it was demonstrated that video sampling provided an effective means of significantly improving estimates of stream flow.

It is necessary to translate the scientific results of this investigation into usable and realistic terms and variables required for the water resources managers, for more effective management. However, the analyses reported in this project were concerned with the investigation of a limited number of experimental sites and controlled conditions. A number of factors were found to influence the quality of the video sampling, the most important being prevailing light conditions. Although the video is far more tolerant of light variation and low light conditions than conventional aerial photography, light angle and intensity had a profound effect on image quality. The analysis of using video sample was complicated by the presence of substantial radiometric differences between scenes. Because video has no on board calibration system, there were uncorrected radiometric differences between data acquired during video flight. In addition, contrast enhancement procedure was applied to the certain video samples to emphasize particular features of interest (e.g. plume trajectory). This may have lead to the loss of the color fidelity of video samples. There should also be drift in the radiometric performance of the video sensor itself. In general, bright sunlight was best where subtle color changes were involved while an overcast sky, giving a soft shadow hindered the accurate estimates of stream flow for this application. A relatively low sun angle giving strong shadows was worst, since color fidelity was of primary interest. In this regard, matching light conditions to end-use would be an important component of tailing the system to a particular application (Hosking et al., 1992).

In addition, many of the results reported in this project are to some extent site dependent (i.e. not replicable elsewhere), although there would be the same limitations in most environmental research involving field study sites. Conditions at the experimental sites may be different, and variables such as imaging conditions and site thematic classes differ in their behaviour. In practice, however, it is impossible to observe everything in the field, which is an inherent limitation of any scientific experiment. The performance evaluation for the video sampling is no longer independent, objective and free from the human analyst's own values. These mean that the results could not be exactly repeatable if the analyses were to be performed by someone else: different observers notice different things. To be statistically meaningful, many separate interpretations would be required and this would have been even more time consuming. For an operational video sampling survey, a complete analysis with respect to the client's need would have to be made for several hundred kilometers of stream flow. This was not feasible in the context of this project.

Moreover, many of the basic issues in 'video sampling', newly suggested in this project, are still at the investigation stage. Furthermore, while the initial results provided by this study are promising, to validate the repeatability of results from such a basic approach to a more complicated real field applications, further work is required. Many of the issues unsolved in this pilot project could be improved by better equipment at present and in the future. Under better conditions of illumination, and using superior equipment, video sampling could prove to be a realistic technique to be used for this type of application and might yield superior results to those obtained (Um and Wright, 1999c). The fundamental investigation presented in this paper, has laid a foundation for the development of an operational video sampling technique.

VI. Conclusion

This study has, for the first time, established the new concept of Video Sampling. The video sampling has demonstrated a potential as a new monitoring tool for geographical variation of river water quality. Video imagery provided a permanent visual record for a variety of intriguing questions concerning the transport and storage of contaminants in large rivers. At the same time, it created a highly comprehensive set of data describing the movement of a wide range of contaminants from major tributaries. When video sampling is evaluated in comparison with data from field sampling it was shown to be a powerful tool for describing aerial color extent and analysing effluent dispersion trends along a narrow river corridor. Some of the findings in this pilot project represented new information, whereas many of the results confirmed previously known aspects of the contaminants distribution in the river.

However, in this project, observations were subject to various inherent limitations, such as personal subjectivity and error in identification of the ground condition. Many inventorying and monitoring problems are not solved entirely by any one approach: no single data-acquisition methodology can satisfy all of the monitoring needs. Airborne video sampling, aided by the use of conventional sampling, can complement the present field survey in an optimal way. This method will provide information efficiently, that is both scientifically justifiable and practically understandable by the public. The observations obtained from this project have implications for the suitability of the video sampling for strip target monitoring in general and other levels of monitoring for a strip target could be adjusted, based on the understanding of the inherent capability of video sampling shown in this project.

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