Application of Real Time Wireless Communications-Positioning Technology for Visualization of Velocity Distribution in Flood

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Abstract

This paper describes the real time wireless communications and positioning technology that applied the electronic Rover-based system developed in this paper, and actual onsite measurement results are presented. This paper also calculated the velocity-field that can express the velocity distribution of rivers through a post-processing process using the measured results. The developed system enables five electronic Rovers to be operated in one frequency band, respectively, by dividing the frequency band into three bands, and therefore, the velocity can be measured by using 15 electronic Rovers. The electronic Rover system can measure actual flow paths using the latest GPS technology, through which the system is judged to contribute to the improvement of hydrometric accuracy. The electronic Rover system can calculate accurate flow velocity by applying various real time wireless communications technologies, in addition to GPS-based positioning technology. Because the system can carry out measurement and analysis with little manpower, regardless of site conditions, hydrometric efficiency is expected to be enhanced when floods occur.

Keywords: Electronic Rover, GPS, RF, Velocity, Velocity-field

1 Introduction

Since CDMA mode mobile communications were commercialized in 1996 in Korea, IT technologies have been greatly developed up to the present LTE, regarding which a service was launched in 2011. Together with such rapid developments, smartphones have quickly proliferated around the world, including Korea, since 2009. Recently, the shift into the Internet of Things (loT), a mature concept, with which communications can be made with all sorts of devices, lies ahead [1]. Wireless communications technology development and the extensive diffusion thereof has caused innovation in existing conventional disciplines and technological fields. The civil engineering field is no exception, and sensor networks and real time control technology using wireless communications system have spread far and wide. For water resources and river fields, the operation of sluice observation stations and flood forecasting systems were embodied through existing VHF narrow band wireless communications networks and ICT conversion technology, and IT technology applied in the sluice measuring field has recently been developed. GNSS (Global Navigation Satellite System), which started with the U.S. GPS satellite in the late 1970s, has been hugely developed, and is extensively used in various fields including geography, transportation, agriculture, and civil engineering. Additional developments and operations, such as the modernization project of Russia's GLONASS, the European Galileo system, and China's Beidou/Compass system, have been recently carried out [2]. With all these developments, satellites are being more widely utilized and positioning accuracy is also expected to increase. The ultra small GPS that can be mounted in a module

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form with current technology can have 60 or more channels, and has its own satellite calibration function. Therefore, 2m horizontal location accuracy can be obtained. Although sluice measuring technology is simultaneously developing in step with the development of positioning technology, the technology to measure the flow velocity of floods that cause loss of life and damage to property on a recurring basis each year has yet to be sufficiently developed and applied. The flow of rivers during flooding that causes scouring, sedimentation, and river bank erosion, not only changes river topography but affects various river facilities including bridges, banks, weirs, sluices, and fishways. Therefore, gauging flow measurement during floods is a very important task. However, direct velocity measurement at night and under adverse conditions is very difficult due to the dangers posed. The possibility of losing expensive equipment in dangerous situations when torrents occur during flooding is high, and no matter how much sensor technology is developed there is significant risk when measuring is conducted by entering a river. With all of this, direct measurement is difficult. For flood flow measurement, a flow measuring technology using the existing stick-shape floats, which is mostly limited to the measurement of flow, which is a river's total flow, has been continuously used [7]. Given such a backdrop, this study developed a system combining cutting-edge wireless communications technology and GNSS to achieve the goal of visualizing velocity distribution during flooding. Through the system, velocity distribution in floods can be safely measured. The data obtained using such a method can become the hydro-geographic information combining water resources information and positioning information [5], [6], [3]. The data can be used together with hydro-geographic information, such as recent depth of water measurement data using an eco-sounder equipped with GPS, or 3-dimensional flow velocity measurement data of ADCP (Acoustic Doppler Current Profiler) combining GPS positioning information. The data can also be used to comprehensively analyze river flow characteristics, combined with aerial images or satellite images.

2 Real Time Wireless Communications Technology Applied to the System

2.1 Application of Wireless Communications Technology

Because Korea is perfectly equipped with 3G or higher levels of wireless communications infrastructure including LTE nationwide, data communications are possible anywhere in Korea, except some mountainous highlands. However, commercial communications are difficult to apply to rivers in nations with inferior communications infrastructure and where there are few people in some areas . Also, the fact that equipment may not be recovered should be considered when seeking to take velocity measurements during floods. As an alternative, Bluetooth, WiFi, and VHF or UHF band wireless communications can be considered. Bluetooth is actually difficult to apply to large rivers, and WiFi technology also has difficulties in terms of application, except for the long-distance WiFi technology that has been developed recently. In this context, the currently available technology is VHF or UHF band wireless communications technology. However, such technology may present allocation and frequency band width problems. Actually, in a development stage a band that does not cause many problems, including frequency permission problems, should be selected. This study used frequency in the band between 420 457 MHz corresponding to specific output for data transmission among the frequencies of UHF. Meanwhile, flows can rapidly change during flooding, and therefore, the velocity measuring time should not be long. Because a river flows along a narrow width, the water surface width increases during flooding and inundation can be caused. In this regard, many Rovers are essential to efficiently measure velocity distribution during floods. For this reason, this study divided frequency bands into three and several units of equipment could be used simultaneously, instead of reducing band width for data transmission. This system can simultaneously operate 15 Rovers, enabling the operation of up to five Rovers per frequency.

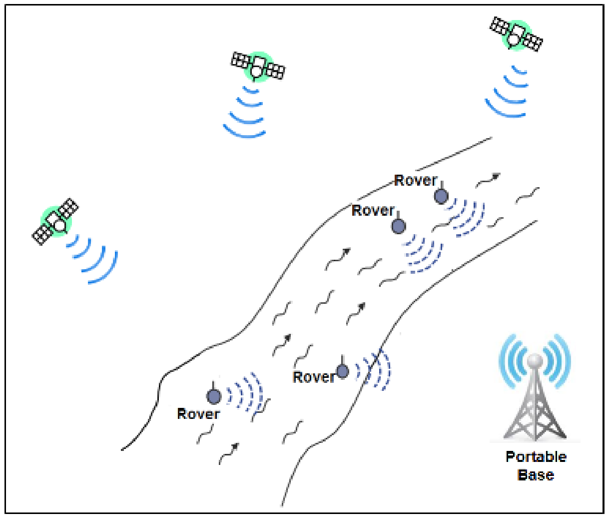


Figure 1: Rover-Base system to Measure Flow (Revised from [4])

Figure 2: System Composition (Left: Rover board, Middle: Rover, Right: Base with PC)

2.2 Positioning Technology Application

The positioning technology using a navigation satellite has various accuracy scopes, depending on use purpose. RTK or VRS can conduct millimeter-grade horizontal positioning, but such technology is expensive and is difficult to use when equipment is placed in remote places since calibration is necessary. However, a recent module chip using single positioning technology or SBAS (satellite calibration) technology offers 2m- grade accuracy. A river is an open area and there are not many electromagnetic wave obstacles including buildings and trees, and its width surpasses 100m in many cases. Therefore, the horizontal difference of velocity is relatively small within several meters, and such accuracy can be accepted. Furthermore, 0.1m/s-grade speed accuracy is possible in the case of moving equipment and accuracy may be higher than in the static state. Lastly, equipment may not be recoverable when taking velocity measurements during floods, and therefore, the manufacturing of a cheap module is necessary. In consideration of all these factors, flood measurement is judged possible with just a single positioning-possible GPS module. This study manufactured a Rover system equipped with a GPS module based on the SiRF chip that provides 2.5m in single positioning and 2.0m horizontal accuracy and 0.01m/s speed accuracy in the case of SBAS calibration. An individual Rover is in responsible for collecting satellite data and transmitting the data to the base. The Rover converts received GPS coordinates to $GPRMC code, one of the NMEA codes, and then takes only minute and second codes in terms of time, and takes just minute codes in terms of longitude and latitude up to four decimal places, and sends them to the base. By transmitting only minimum positioning information as such, several Rovers can share one frequency (channel) while minimizing confusion. By taking the degree values of longitude and latitude inputted by user setting in the system, the ultimate data is stored in the computer connected with the base (Table 1).

Table 1: GPS Information Generated on Rover, Transmitted Information, and Recorded Information

Item	ID	Time stamp		Latitude	Longitude	Speed	Course	Date stamp	Magnetic variation	East/West* Checksum
NMEA string	$GPRMC	224213	A	3631.4712,N	12719.1362,W	2.8	231.8	130694	004.2	W*70
Rover transmission	-	4213	-	31.4712	19.1362	-	-	-	-	-
Receiver user setting	-	-	-	36	127	-	-	-	-	-
Output data	-	4213	-	3631.4712	127.1362	-	-	-	-	-

The electronic Rover system developed in this study can accurately calculate velocity by tracing flow paths through the real time acquisition of absolute positioning information determined by GPS satellite. Due to the latest GPS technology developments mentioned above, accuracy has been greatly improved in single positioning. Because there is no structure to interrupt satellite signals in the wide areas around rivers, location errors are relatively small.

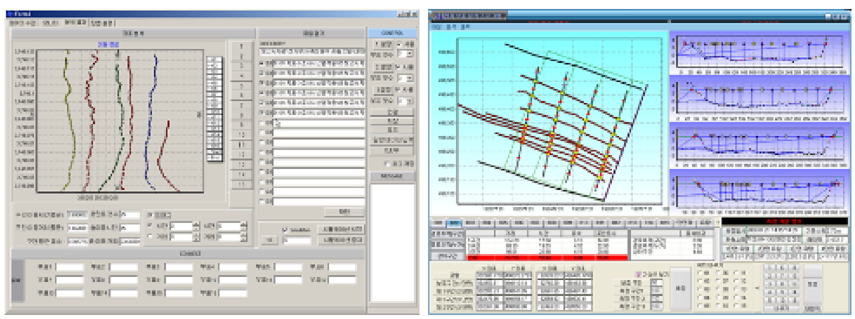


Figure 3: Electronic Rover System Screen

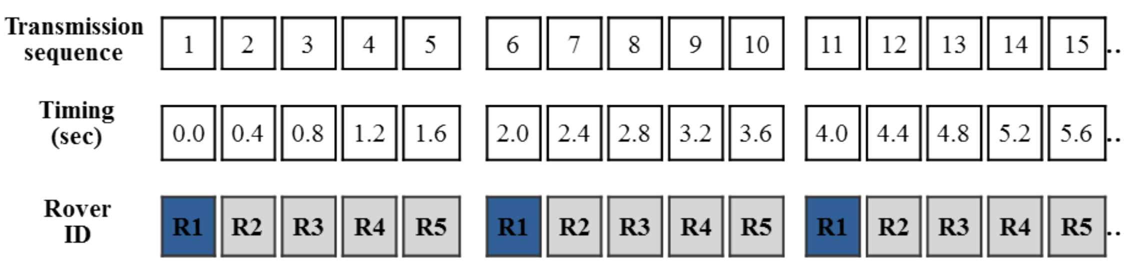


Figure 4: Electronic Rover's Location Information Collection Technique Using Time Sharing Technique

3 Onsite Experiment Using the System

The velocity measuring experiment using the electronic Rover developed in this system was implemented at two points on Guman Bridge in the downstream of the Bukhan River Hwacheon Dam and at Hapgang on the Miho Stream. The Hapgang point is a curved river shape, and the Guman point has the straight shape of a river channel. They present the proper flows required for the flow of Rovers, respectively. At the Guman point, the flow was measured by waiting for the flow to be in a constant line with Hwawhcoen Dam's discharge time in the upstream at the usual reserve water level. In doing so, when the dam discharge starts, the water level and flow change. Therefore, measurement was conducted in conditions in which the dam discharge flow lasted for quite a while, in consideration of more difficulty in comparing flow, as measuring point is farther. Measurement was carried out under conditions where there were no or light winds. At the Hapgang point, onsite actual measurement was conducted during the flood season to try out the Rovers.

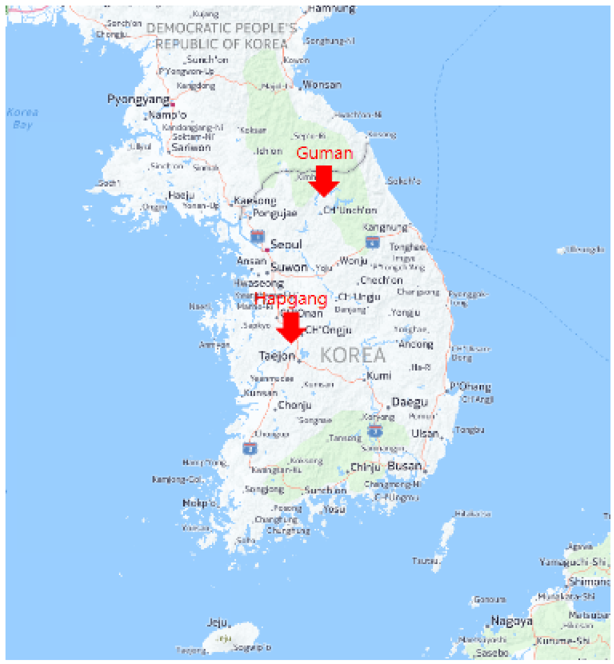
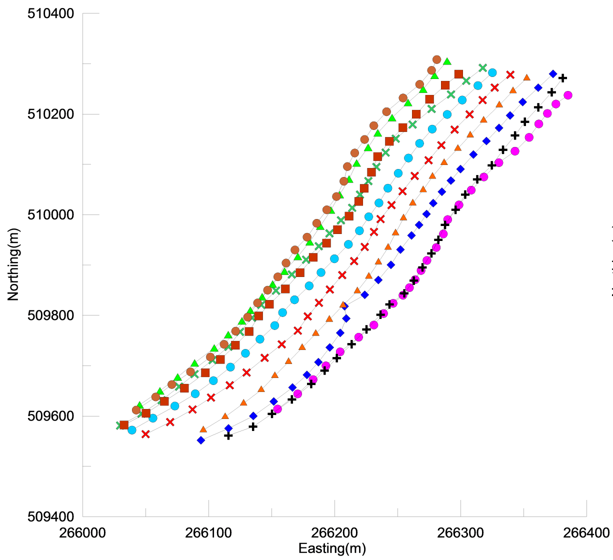


Figure 5: Onsite Experiment Locations

Table 2: Basic Information at Onsite Measuring Points

River	Point	Latitude and longitude	River shape	Details of measurement	Flow condition	No. of Rovers
Bukhan River	Guman	127-47-00, 38-07-00	Straight line	Flow velocity	Low water level period	10
Miho Stream	Hapgang	127-19-07, 36-31-28	Curve	Flow velocity	Flood period	10

Because several Rovers need to be placed for onsite experiment, a bridge at the target point was used. To secure the natural flow of the Rovers, they were put in place by connecting them with stick-shaped paper floats. The float's centroid was balanced with sand at its lower part to make it stand vertically when it was thrown into the water. After the Rovers were prepared by connecting them with the floats, they were placed in turn and switched on to connect each Rover with the collection base. After calculating the river width in advance, several Rovers were put in place by adjusting the distance between them. The placed Rovers' flow trajectory was collected through connection with the collection base, and the velocity was calculated using GPS and a watch.



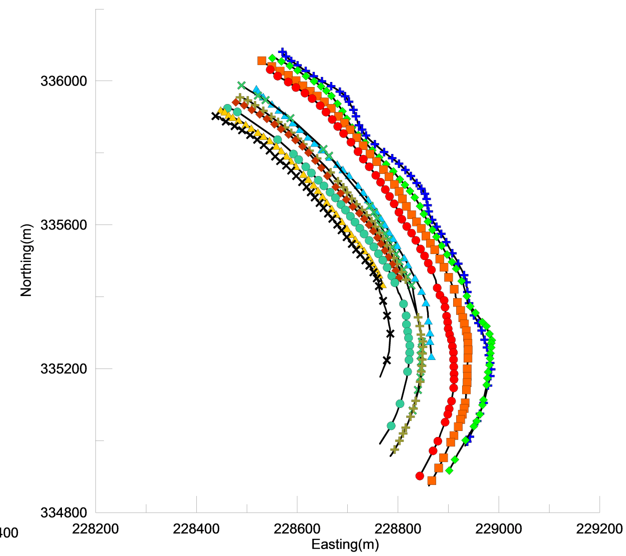


Figure 6: Actual Path Measured by electronic Rovers in the Straight Line River Channel (Guman)

Figure 7: Actual Path Measured by electronic Rovers in the curved part of river (Hapgang)

4 The Velocity Calculation Method Applied to the System and Comparison of Results

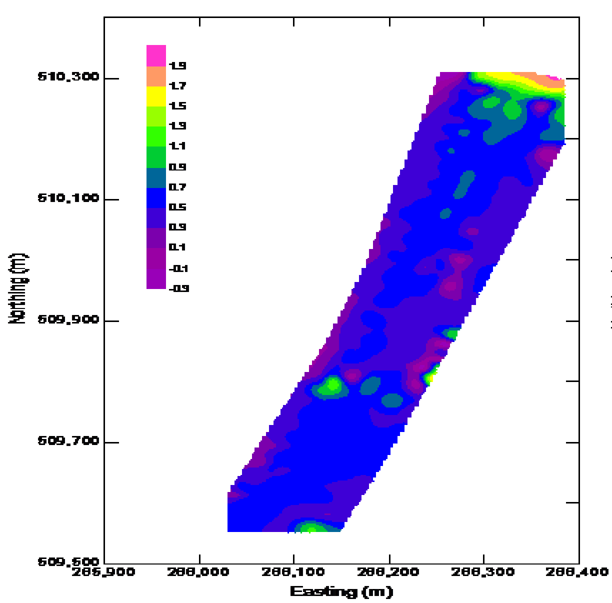
4.1 Collection of real trajectory

Figure 6 shows the case of actual measurement using the electronic Rover at Guman point, among the points where an onsite experiment was carried out. The Guman point shows a straight section generally. In Figure 6, each dot shows the trajectory of the electronic Rovers, and it exhibits the longitude and latitude coordinates received by the GPS by converting them to TM coordinates at the central origin. The communications status of the Rovers was relatively good, and Rovers communicated normally. A total of ten Rovers were put in place and those flowing in the central part of the river tended to go straight, but the rovers on the left and right sides of the river showed a tendency to gather in the center of the river.

Figure 7 shows the situation of a river where there is a curved part like the Hapgang point on the Miho Stream, not a straight river shape. This demonstrates that the electronic Rover system can express and calculate to the point beyond visibility, after passing through the curved part. Although some Rovers ceased to send signal as they deviated from the communications-possible distance (about 1km), it can be clearly seen that many electronic Rovers passed through the curved part. The usability of the electronic Rover is judged to be enhanced in that flow situation can be viewed up to the point, where things could not be seen within visibility.

4.2 Velocity Calculation Method

Using the Rovers to understand the characteristics of river dynamics, point velocities are computed from the GPS-based position and time data. As the Rover reflects the velocity of the water column during the downstream drift, it can only ascertain depth-averaged flow velocity in a vertical manner as expressed in



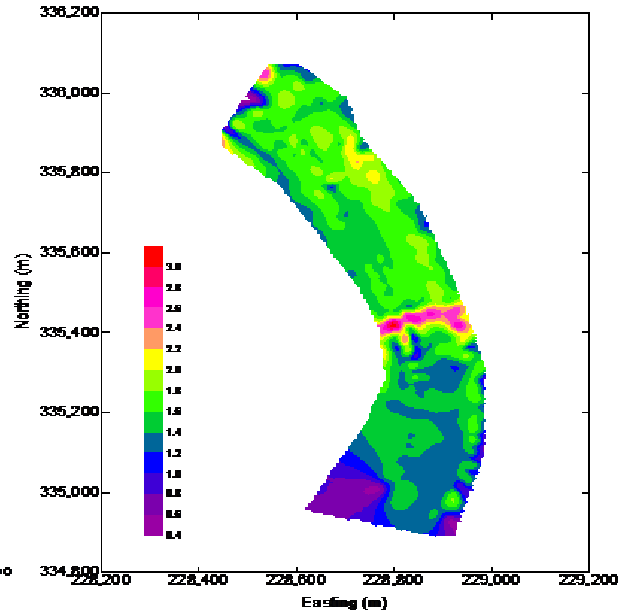


Figure 8: Velocity Distribution Using Velocity Calculation Results (Guman)

Figure 9: Velocity Distribution Using Velocity Calculation Results (Hapgang)

the following equation:

$$v = k\frac{l}{t} \tag{1}$$

Where, v is depth-averaged flow velocity, k calibration factor considering the draft of the rod-float (0.85 0.96), l length of the path, and t travel time. For calculation of instantaneous velocity vectors at every time step during the travel time, the Rover uses the following equation:

$$v_E = k\frac{l_E}{\Delta t} = k\frac{E_i - E_{i-1}}{t_i - t_{i-1}}, v_N = k\frac{l_N}{\Delta t} = k\frac{N_i - N_{i-1}}{t_i - t_{i-1}} \tag{2}$$

where, v_E and v_N are instantaneous velocity vectors expressed in the earth coordinate at time i, l_E and l_N are displacement, Δt is unit time span, and E_i and N_i are positions in the earth coordinates (TM or UTM). These velocity vectors are converted to longitudinal and transverse velocity components for computing discharge using cross-section direction according to the following equation [6].

$$v_x = -v_N \cos\theta + v_E \sin\theta, v_y = v_N \sin\theta + v_E \cos\theta \tag{3}$$

Where, v_x and v_y are longitudinal and transverse velocity, respectively, θ is an angle of cross-section from the east direction defined as perpendicular to the main direction of the flow. As these velocities essentially imply spatial and temporal instantaneousness, they may be cautiously averaged to represent mean flow characteristics under the assumption that flow and bathymetry should be approximately uniform.

Figures 8 and 9 show the diagrams made by using a commercial program that can draw velocity distribution, after calculating the velocities using the data collected by Rovers at Guman point and Hapgang point. Figure 8 demonstrates well that the velocity in the central part of the river is faster than the velocity at the edge of the river. Figure 9 shows well the section in which velocity was stagnant by the rock weir in the water located on the longitudinal central part of the river, and became rapidly faster in the section where the rock weir was passed through (pink colored).

5 Expression of Velocity-Field Using Post-Processing Process

The flow using only the positioning information obtained by electronic Rovers cannot acquire many measuring points, due to the characteristics of wireless communications, and has some deficiencies in demonstrating velocity distribution. Therefore, this study presented the velocity-field using two-dimensional velocity vectors using the velocity data collected by the electronic Rovers in order to supplement and compensate for this and to visualize the overall velocity-field during the flood. As no post-processing program that can calculate the velocity-field has been developed that can be used in the system in this study, this study developed a separate program that can create a display from a graphic program through the Fortran Programming. The program can ultimately calculate the location and two-dimensional vector speed in a text format and can generate output, and also an interpolation function was added to extract speed vector at certain intervals from the location where no speed vector existed. The equation for interpolation is shown below:

Where,

$$\begin{gathered} d = \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2} \\ d \ > \ want \ \ d \ \ and \ \ k \ < \ \frac{d}{want \ \ d} \\ x = \frac{(x_{i+1}-x_i)^2}{\frac{d}{want \ \ d}} \times k + x_i, \ \ y = \frac{(y_{i+1}-y_i)^2}{\frac{d}{want \ \ d}} \times k + y_i \\ u = \frac{(u_{i+1}-u_i)^2}{\frac{d}{want \ \ d}} \times k + u_i, \ \ v = \frac{(v_{i+1}-v_i)^2}{\frac{d}{want \ \ d}} \times k + v_i \end{gathered} \tag{4}$$

In case desired interpolation, $wantd$, is smaller than the straight line distance between two measuring points, d and $k \ < \ \frac{d}{want \ \ d}$, so new coordinates and new x and y directional velocities can be calculated. Figures 10 and 11 show the calculation of new two-dimensional velocity vectors by applying such interpolation between the measuring points. Figure 10 displays the velocity-field at Guman point on the Bukhan River together with aerial photo data. Actually, it is visually very good, since the flow size and direction of the overall river can be identified. Hapgang point on the Miho Stream in Figure 11 displays the velocity-field of the river together with aerial photo in the same manner as Figure 10. The reason why some velocity vectors in the lower part in this Figure are located in other places, rather than on the river, is that the aerial photo was taken during normal times while the velocity measuring period was during the flood season. Also, the two-dimensional velocity vectors are overlapping since the velocity became slow from the cross section point of the straight line upstream where a weir exists. As such, when electronic Rovers, with which real time wireless communications can be conducted, and GPS positioning is possible, are used, it was confirmed that the velocity distribution during floods can be quite specifically measured and expressed.

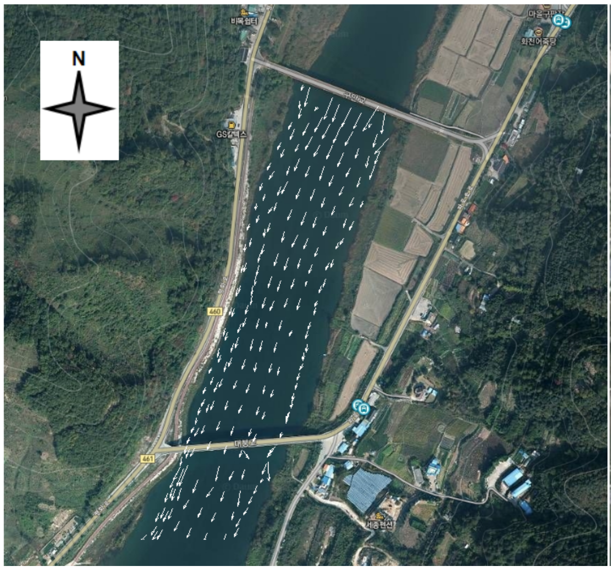


Figure 10: Expression of Two-Dimensional Vector-Field Using Post-Processing Process (Guman)

Figure 11: Expression of Two-Dimensional Vector-Field Using Post-Processing Process (Hapgang)

6 Summary and Conclusion

This paper described the electronic Rover system that was developed in this paper by applying real time wireless communications and positioning technology, and presented the actual velocity measurement results at the two points of the natural rivers in Korea. This paper also presented velocity-field using two-dimensional velocity vectors through a post-processing process. The details of this paper can be summarized as follows:

1) The system was made on the basis of GPS and real time wireless communications to obtain the velocity-field of natural rivers, and also it showed sufficient usability at two points.

2) In the case where accurate positioning and time information via GPS are used, good velocity measurement results that reflecting onsite conditions well are shown.

3) Visually excellent results were provided because the target river's velocity-field can be ascertained through the post-processing program(after the system was developed).

The system developed in this study can calculate more accurately the velocity by providing precise positioning information via GPS satellite. In addition, efficiency can be expected to be enhanced through real time measurement, collection and analysis of flow path information with not much manpower required - regardless of onsite conditions. Furthermore, the system is judged to be suitable for measuring the flow of rivers in developing countries where communications technology is rudimentary.

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