A BACKPACK MMS APPLICATION

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ABSTRACT

Over the years, MMS systems have demonstrated that accuracies suitable for all but the most demanding cadastral and engineering applications can be achieved. This result, combined with a reduction in both the time and cost of data collection, made MMS a very interesting technology potentially able to meet the demand of GIS operators for rapid spatial data updating. However, the high costs involved in the arrangement of such systems did not favoured their growth in the market, so that MMS are still today mainly operated by the companies or institutions that build them. To allow a wider community of spatial data user to benefit of mobile mapping applications - in particular the lower costs and greater efficiency of data collection – a portable systems, the Backpack MMS, was developed at the University of Calgary MMS in 2001. The research centre of CIRGEO re-implemented such system introducing a few significative changes due to the adoption of different hardware and software solutions with respect to the original project. Then, within a collaborative work with a research team of the Vesuvius Observatory, in summer 2006 this version of the Backpack MMS was tested in a real environment: the goal was to assess the effectiveness of the Backpack as a tool for mapping evacuation routes on areas subjected to natural hazards. In this paper we report a description of our system configuration and the results of performed test along with a few comments on practical issues that affected the final accuracy of mapped routes.

1. INTRODUCTION

Among other factors, the availability of enough accurate and up-to-date spatial data plays a great role for the effectiveness of mapping and Geospatial Information Systems (GIS) projects. Such data have been traditionally collected using terrestrial surveying techniques or by aerial photogrammetric surveys. In order to overcome some drawbacks of these techniques, i.e. to allow for a more rapid and dense data collection and to widen the coverage provided by the measuring sensors, Mobile Mapping Systems (MMS) were developed. By integrating various navigation and remote sensing technologies together on a common aerial or land-based platform, these multi-sensor systems allowed to exploit the peculiarities and the advantages of the individual technologies in order to increase the efficiency of data collection. Particularly, land-based MMS enabled less intrusive and more rapid surveys than other terrestrial techniques and, given the smaller camera-to-object distances, they could provide more complete coverage than aerial systems.
Over the years, MMS systems have demonstrated that accuracies suitable for all but the most demanding cadastral and engineering applications can be achieved. This result, combined with a reduction in both the time and cost of data collection, made MMS a very interesting technology potentially able to meet the demand of GIS operators for rapid spatial data updating. However, the high costs involved in the arrangement of such systems did not favoured their growth in the market, so that MMS are still today mainly operated by the companies or institutions that build them. Moreover, system complexity and the high level of expertise required to operate them, prevented so far their use by many smaller survey or mapping firms. Therefore, the benefits of mobile mapping – in particular the lower costs and greater efficiency of data collection – are still not being shared by a wide user community.

This paper reports on the results of the application of a pedestrian mapping system, the Backpack MMS, employed for civil defence purposes. This system was originally developed in Canada at the University of Calgary (Ellum, 2001), as an alternative integrated surveying system able to overcome the main drawbacks of current MMS, namely their high cost, large size and complexity. As portable system, the Backpack is potentially suited for all scenarios where environmental conditions make very difficult or even impossible to operate with "classical" van-based MMS. Testing of the system demonstrated that horizontal and vertical accuracies of 0.2 metres (RMS) and 0.3 metres (RMS), respectively, at a camera-to-object distance of approximately 30 metres, could be achieved. These values are consistent with the accuracies involved in most of GIS applications.
The Backpack system has been re-implemented by the research centre of CIRGEO, with some significative changes due to the adoption of different hardware and software solutions with respect to the original project. This portable MMS was then tested in a real environment: namely it was employed in summer 2006 within a collaborative work with a research team of the Vesuvius Observatory, a branch of the National Institute of Geophysics and Volcanology. The goal of the test was to assess the effectiveness of the Backpack system as a tool for mapping evacuation routes on areas subjected to natural hazards.
The paper is structured as follows. Section 2 provides with a short description of the test area, while Backpack components and sensor configuration are reviewed in sections 3 and 4 respectively. System calibration is then detailed in section 5, while the results of the testing of the backpack MMS are reported in section 5. Finally section 6 draws the conclusions.

2. THE TEST SITE: STROMBOLI ISLAND

The test site was set on Stromboli, the northernmost of the Aeolian Islands, a group of volcanic islands located between Sicily and the southern part of the Italian mainland (Figure 1).
The summit of the volcano is at 924m (msl), while its base is between 1500 and 2000m below the sea. On a surface area of only 12.6 square kilometres, two settlements were built on the opposite sides of the island: Stromboli in the Northeast and the tiny village of Ginostra in the Southwest (Figure 2).
Stromboli is the youngest stratovolcano of the Aeolian islands and is located at the margin of the abyssal plain in the southern Tyrrhenian sea. This volcanic island is remarkable because of the length of time for which it has been in almost continuous eruption. For at least the last 2,000 years, the same pattern of eruption has been maintained, in which explosions occur at the summit craters at intervals of minutes to hours. This type of very mild explosive eruption is known as Strombolian activity when observed at other volcanoes. The continuous mild explosive eruptions are also occasionally punctuated by much larger eruptions, which may generate earthquakes, pyroclastic flows and tsunamis (Rosi et al., 2000).
Large eruptions occur at intervals of years to decades, and the most recent large eruption began in 2002, causing the closure of the island to non-residents for several months. The largest eruption of the last hundred years occurred in 1930 and resulted in the deaths of several people and the destruction of a number of houses by flying volcanic bombs.
There are three active craters at the peak. A significant geological feature of the volcano is the "Sciara del fuoco" (*Sciara of fire*), a broad channel on the north western side of the cone, visible on the right of figure 1.
Eruptions from the summit craters typically result in lava rolling down this channel. During the night, the glittering "*Sciara of fire"* can be seen from the boats and from the nearby island of Panarea. During the day, the smoke of the peak joins the steam raising up from the water that cools down the red-hot lava detritus which have plunged into the water after sliding down the slope of the coast. The white houses of the little village create a unique contrast with the black lava background, dotted with dark-green bushes.

Figure 1: View from North of Stromboli island.

Figure 2: Map of Stromboli island.

3. BACKPACK COMPONENTS

The three sensors used in the Backpack MMS were a NovAtel double frequency GPS receiver, a Leica digital compass/ inclinometer and a Nikon pro-sumer digital camera. While the latter was used to capture the images from which measurements were made, the former two sensors provided the navigation data (i.e. positions and orientations of the camera).
The choice for a NovAtel receiver (DL4) was mainly due to the particular features that are implemented in the Novatel products which make them very suited for sensor integration. For example, in the DL4 all data are embedded into a single data stream. Within the data stream, different types of data – such as satellite ephemerides or range measurements – are contained within individual logs, listed in chronological order and identified by unique headers. The structure of the logs and the data stream is provided by NovAtel, what facilitates their use in other systems. A further interesting feature of DL4 receiver is the *pass-through* logging. With this option the receiver is able to accept, time-tag, and embed in its own data stream ASCII or binary data that it receives from other devices or sensors. However in our implementation, such option was not used as we adopted a slightly but substantially different system configuration with respect to Ellum (see section 4).
The digital compass/inclinometer used in the Backpack system was a Leica Digital Magnetic Compass (DMC-SX), shown in Figure 3. The small size, light weight and low power-consumption, made indeed the Leica DMC well-suited to the Backpack MMS. Additionally, the Leica DMC-SX provides the user with several internal routines to perform calibration for both soft and hardmagnetic disturbances. Accuracies and other specification of the DMC-SX are shown in Table 1.
As imaging sensor we adopted a Nikon D200 prosumer digital camera, released on the market in November 2005. Two key characteristics have drawn our attention towards such camera. Firstly the D200 could be directly connected through a special cable to a GPS receiver, allowing the user to capture images just when a position fix is available. This event is sent to the camera through the NMEA 0183 message (version 2.01) and displayed to the user by a flashing icon on the LCD display. After the shutter has been pressed, the GPS time is stamped on the captured image. This solution allowed not only to synchronize the image capture with GPS data acquisition but also to keep somehow the whole system camera-centric instead of computer-centric. Indeed, as already highlighted by Ellum, it is better to

have the image capture controlled by a user pressing on the shutter than a user manipulating a computer.

Table 1: Leica DMC-SX technical specifications.

Angle Accuracies	
Azimut	0.5° (2σ)
Pitch range/accuracy	+/- 30° / 0.15° (2σ)
Roll range/accuracy	+/- 30° / 0.15° (2σ)
Magnetic Parameters	
Range	+/- 100 µT
Resolution typical	0.01 µT
Noise	< 0.02 µT
Measurement Rate	
Standard	30 Hz (up to 150Hz in raw data mode)
Optional	60 Hz
Physical Parameters	
Weight	< 28 g
Dimension	31 mm x 33 mm x 13.5 mm
Other	
RS 232 Serial Interface. Max. baudrate 38400. Internal magnetic calibration procedures	

Figure 3: Leica DMC-SX.

Table 2: Nikon D200 technical specifications

Sensor resolution	2560 x 1920
Lenses	18-55mm f/3.5-5.6G AF-S DX Zoom-Nikkor
Image resolution	3.872 x 2.592 [H] 2.896 x 1.944 [M] 1.936 x 1.296 [L]
Focal length	27 – 82.5 mm (on the 35 mm format)
Power supply	Rechargeable Li-Ion battery, MB-D200 battery pack (optional), AC Adapter (optional)
Other functions	GPS interface, wireless connection (optional)
Weight	920 g (inc. battery)
Shutter speed	30 to 1/8000 sec.
Aperture range	f/3.5 - 5.6 (Max. aperture) f/22 – 38 (Min. aperture)
Image file formats	NEF (12-bit RAW) - JPEG (EXIF 2.2)

The second key advantage by using the Nikon D200 was the ability to fix the focus at a specified setting. This feature was also very important because it allowed to hold fixed the interior geometry of the camera between exposures and therefore to consider it the same for all images in the adjustment during data processing. Main specifications for the Nikon D200 are listed in table 2.

4. SYSTEM CONFIGURATION

The global architecture of the Backpack MMS is shown in Figure 4. In this arrangement, the DMC makes continuous measurements of roll, pitch, and yaw angles. Though this solution is not required for a portable system like the Backpack, making continuous measurements allows to simplify the system because it removes the need to communicate with the DMC while surveying. Therefore, once the DMC is started, the logging software no longer has to interact with it. The measurements from the DMC are sent to the laptop PC where they are stored in a log file along with GPS time data. Actually, sensor synchronization is based on the NMEA message which is sent from the Novatel DL4 receiver to both the Nikon camera and the PC. In our arrangement the purpose of this message is twofold. Firstly, when output by the receiver, it will indicate to the user that a position fix is available and that the image being captured can be georeferenced. Secondly, from the NMEA message content the GPS time can be extracted and used to time-tag the DMC data and to synchronize the CPU clock. It is important to note that the camera itself is responsible for storing the images and that the GPS receiver only marks the times of image captures through the NMEA interface. It is also worth noting that the native GPS connection provided with the D200 avoided the occurrence of the side-effect described by Ellum, i.e. the image quality degradation due to the use of the external flash for GPS-camera synchronization.


Figure 4: Connections between Backpack MMS components.

The physical arrangement of the sensors in the backpack MMS is shown in Figure 5.

The key goal when designing and assembling the portable system was the minimisation of disturbances in the magnetic field of the DMC. This was done by locating the DMC as far away as possible from potential disturbances and by using magnetically neutral materials where possible. To this aim the GPS antenna, the digital camera and the DMC were fixed on a T-shaped aluminium stick, while the laptop, GPS receiver and power supplies were placed in a rucksack whose inside was properly padded with amagnetic material.

Figure 5: Phisical arrangement of Backpack components.

5. SYSTEM CALIBRATION

Prior to test the portable system in a real environment, it was calibrated using a suited target field. Calibration is a necessary step that allows not only to estimate inner and exterior orientation parameters of the camera and to verify the performance of the DMC but in case of integrated systems this step allows to estimate the relationships between the various sensors as well. The calibration field we used, shown in Figure 6, was approximately 10 m wide, 7 m high and 1 m in depth. For ease of calculation, a local level co-ordinate frame was established. In this coordinate system, the easting axis was roughly aligned with the depth of the target field, and the northing axis was roughly aligned with the width of the target field.

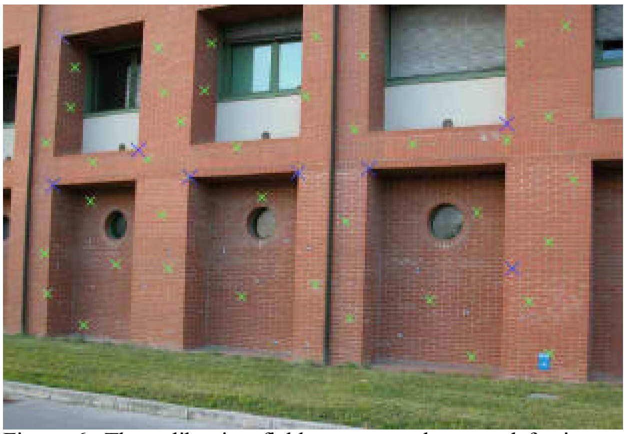

Figure 6: The calibration field; green markers used for image measurements, blue markers for topographic measurements, b/w targets for both kind of observations

The calibration field was firstly surveyed and adjusted using GPS and total station measurements. Then in a second stage we calibrated the Nikon camera alone: due to time constraints this operation could be done only once, therefore we did not have the chance to verify the stability of the camera's interior orientation. Finally, exterior orientations of the images acquired with Backpack were accurately estimated by including the measurements from all the images in a combined photogrammetric/terrestrial adjustment: at this step the interior orientation and lens distortion parameters of the camera derived from previous calibration were included as weighted parameter observations. The positions and orientations calculated in the combined photogrammetric/terrestrial adjustment were considered as "true" quantities for the comparisons. The initial terrestrial network adjustment, the combined adjustment, and the photogrammetric adjustments were all performed using a bundle adjustment package.

The images for the calibration were taken at three object-to-camera distances of approximately 5m, 10m and 20m – hereafter referred to as the "near", "middle" and "far" images, respectively. The image resolution was set at the maximum value, that is 3.872 x 2.592 pixels. At each of six stations - 2 near, 2 middle and 2 far- one image was collected for a total amount of 12 exposures. The DMC was also calibrated for hardmagnetic and softmagnetic disturbances, using the internal routines provided by Leica and prior data processing the azimuths were corrected for magnetic declination. The DMC attitude angles were collected at approximately 1 Hz, as this was the data rate we planned to use in the real case scenario.

Table 3 shows the comparison between the measured L1/L2 Carrier Phase Differential GPS positions and the camera positions determined from the combined photogrammetric/ terrestrial adjustment, while Table 4 reports the differences between the attitude angles measured by the DMC and the "true" attitude angles. The object space accuracies for the near, middle and far images are shown in Tables 5, 6 and 7 respectively.

Table 3: L1/L2 Carrier Phase Differential GPS Position Differences

Exposure Number	Coordinate differences (m)			Distance differences (m)
	Easting	Northing	Height	
1	-0.056	-0.015	0.034	0.067
2	-0.030	-0.046	0.061	0.082
3	-0.074	0.033	0.033	0.087
4	-0.071	-0.024	0.029	0.080
5	-0.103	-0.007	0.027	0.106
6	-0.074	0.043	0.029	0.090
7	-0.040	-0.016	0.050	0.066
8	-0.068	0.061	0.036	0.098
9	-0.030	0.038	0.045	0.066
10	-0.057	0.021	0.019	0.063
11	-0.056	-0.084	0.041	0.109
12	-0.058	0.029	0.022	0.068
Average	-0.058	-0.028	0.035	0.082
RMSE	0.064	0.040	0.037	0.084

Table 4: DMC-SX attitude angle differences

Exposure Number	Angle differences (°)		
	Roll	Pitch	Azimuth
1	-0.206	0.608	0.739
2	-0.261	0.384	0.671
3	0.334	0.550	0.867
4	-0.518	-0.137	0.851
5	0.273	0.420	0.261
6	-0.574	0.399	-0.319
7	-0.061	0.533	0.976
8	-0.556	-0.195	0.605
9	0.249	-0.422	0.507
10	0.609	0.570	0.394
11	-0.293	0.261	-0.295
12	-0.306	0.474	0.560
RMSE	0.389	0.437	0.631

Table 5: Statistics of object space coordinates (appr. 5 m camera-to-object point distance)

Image measurements	Horizontal (m)		Vertical (m)	
	Mean	RMSE	Mean	RMSE
2	0.07	0.08	0.12	0.12
4	0.05	0.05	0.11	0.12
10	0.02	0.03	0.06	0.07
15	0.02	0.03	0.05	0.05

Table 5: Statistics of object space coordinates
(appr. 10 m camera-to-object point distance)

Image measurements	Horizontal (m)		Vertical (m)	
	Mean	RMSE	Mean	RMSE
2	0.12	0.13	0.18	0.19
4	0.09	0.10	0.16	0.16
10	0.05	0.05	0.10	0.10
15	0.04	0.04	0.09	0.09

Table 5: Statistics of object space coordinates
(appr. 20 m camera-to-object point distance)

Image measurements	Horizontal (m)		Vertical (m)	
	Mean	RMSE	Mean	RMSE
2	0.31	0.32	0.44	0.45
4	0.30	0.31	0.42	0.43
10	0.18	0.18	0.30	0.30
15	0.13	0.13	0.24	0.24

The statistics of object space coordinates show that tables for each camera-to-object distance (near, middle and far), the mean of the differences is nearly as large as the RMS error. As already pointed out by Ellum, this results indicates that the relative accuracy of the object points is much better than their absolute accuracy. Besides, this is confirmed by the standard deviations of the co-ordinate errors (not reported in the tables above) which indicate that the internal agreement of the object space coordinates is at approximately less than 1 cm for the near, 4 cm for the middle and 10 cm for the far images.

6. TESTING THE BACKPACK MMS

In summer 2006, within a collaborative work with the Vesuvius Observatory in Neaples, we had the chance to test our version of the Backpack system in a real environment, the island of Stromboli, in southern Italy. The goal was to assess the capabilities of this pedestrian MMS to map escape pathways in areas subjected to natural risks, like landslides, floodings and volcanic eruptions.

As the Backpack was dismounted for the trip, it was necessary to calibrate it again on site. This operation was carried out with the same approach described in previous section but using only the artificial targets, as the walls of the buildings were quite featureless (Figure 7). System calibration resulted approximatively 3-4 cm worse than the previous one, .

Figure 7: Typical path in Stromboli island

Our initial objective was to map a few pathways connecting the shoreline and the village with the volcanic cone, a very attractive touristic destination during summer season. The trails were chosen according to the evacuation plans defined by the research team of the Vesuvius Observatory. Unfortunately, due to higher volcanic activity, we were not allowed to climb till to the volcan peak, but we could start or surveys from a maximum height of 150 m. We tested our system along three itineraries, moving from the slopes of the volcan towards the coast of the island, therefore partially crossing the village. A GPS master station was placed on a point of an existing GPS network covering the whole island, the maximum distance to the Backpack was limited to 1 km. On average we covered a distance of 1.5 km, stopping about every 15-20 m and acquiring two images from different viewpoints at each station. Setting this rather short distance between capture positions was necessary for two main reasons: to avoid "data holes" between consecutive images and to be able to detect correspondences on image pairs with sufficient accuracy. Indeed, after a preliminary survey we had realized that using a higher depth of field (therefore stopping at farther distances) could have led to problems when selecting points at object-to-camera distances beyond the mentioned limit. An example of the routes we surveyed are shown on a 1:5000 map in figures 8 and 9: here the blu points do not represent the capture stations. In total, about 500 images were collected during a three-days survey. As for the calibration, image resolution was set at the highest value (3.872 x 2.592) and the DMS data rate was set to 1 Hz. One month work with two operators was then needed for data processing, the most of the time being spent for point matching. Figure 10 shows an example of the pathway recovered from the images collected with the Backpack MMS. Here, the line tickness is proportional to the measured road width.

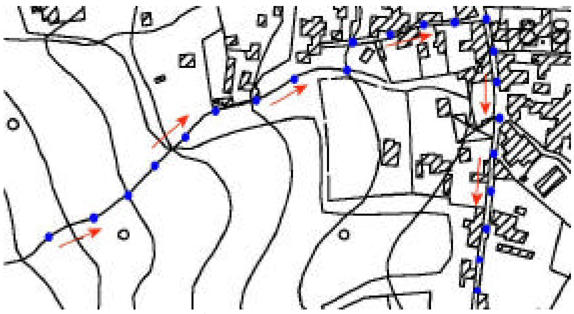

Figure 8: Route N. 1

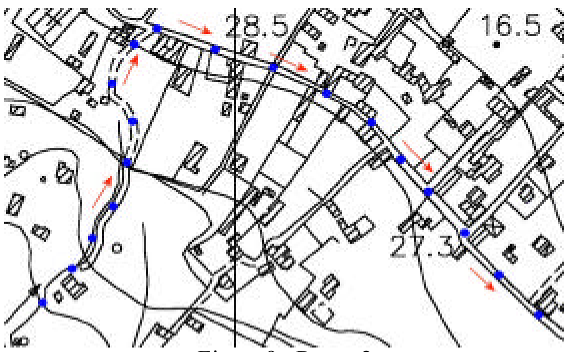

Figure 9: Route 2

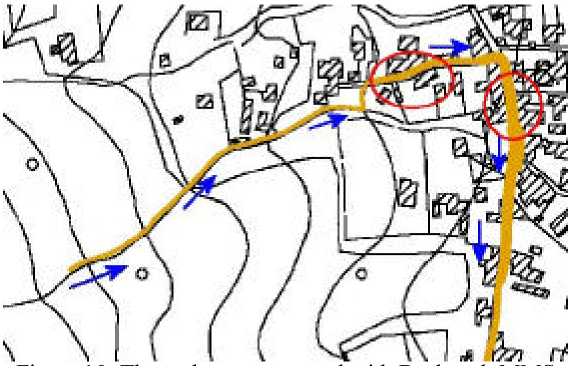

Figure 10: The pathway recovered with Backpack MMS overlaid on Route 1.

A few comments have to be done about the achieved results. Apparently figure 10 shows a good agreement between the pathway recovered from the Backpack data and the underlying map, however a closer look would reveal residual displacements ranging from 60 cm to 1.5 m, in terms of absolute positioning of the surveyed paths with respect to the corresponding routes on the map. Concerning the relative accuracy, we found better results when looking at the distances measured between some check points distributed along the routes (Figure 10). To this aim we used both natural features and artificial targets placed on walls or on the ground. By comparing the distances measured with the Backpack and corresponding "true" values, we found that in this case differences were ranging between 20-40 cm. Higher discrepancies occurred mainly in the dirt parts of the routes, off the built-up area. Similar results were also obtained for the routes 2 and 3. To explain such accuracies various factors have to be taken into account.

Poor imaging geometry: for each stop point, all collected positional and image data have been fed in a bundle adjustment, which provided the adjusted parameters for camera positions and orientations and the adjusted coordinates of selected image points. As we took only two images per stop point the resulting network geometry resulted suboptimal. On the other hand, using more viewpoints would have considerably increased not only the survey time but also the processing time, as more points should have been extracted from the images.

Poor image point measurements: as shown in figure 11 (see yellow circles) in most cases it was very difficult to the operator to easily and accurately identify matching points lying on both side of the trails. This task revealed to be very challenging overall along the route off the village were only natural features could be selected (see figure 12). As already pointed out by Ellum, the more points can be matched the higher would be the accuracy of corresponding adjusted coordinates. In our case we were able to use just 4-6 points per image on average, though more points could be sometime selected from image pairs acquired when moving through the built-up area.

Light conditions: shadows and sunlight often prevented us to mark the image points on the right location, so that the width of the pathways resulted too wide or to narrow than it actually was. This difficulty can be clearly observed again in figure 11, when looking at the two yellow circles on the right of the image: the shadow projected on the ground from the small wall running at the side of the street did not allow to select the right matching points, rather they were placed just on it, resulting in a slight enlargement of the street. In addition sunlight influenced the image acquisition, forcing often the operator to change the lens aperture to avoid under- or over-exposures. Of course even this factor contributed to increase the survey times and despite the attempts made to compensate light changes, in some cases collected images resulted too bright or too dark, limiting the accuracy in image point determination.

Multipath and Satellite geometry: from data analysis we have recognized that major shifts from the route, reported on the map, occurred in the village, overall when moving through narrow streets with buildings facing on both sides. This sort of "canyoning" effect produced two negative consequences: from one hand it limited the view of the sky, reducing the number of visible satellites and increasing often the PDOP value, from the other hand it favoured the occurrence of multipath phenomena which undoubtely affected the GPS measurements. The red circles in figure 10 indicate two areas where the geometry of the houses made very difficult to survey the Route 1: time was lost there while waiting for an improvement of satellite geometry.

Figure 11: Features used to evaluate the relative accuracy.

Figure 12: View of the Route 1

Datum transformation: after the coordinates of all collected points were adjusted, we converted them from the WGS-84 reference frame to the national one. For this task we used Windatum (Coren et al., 2007), a freeware software developed by a research team of OGS (National Institute of Oceanography and Experimental Geophysics) available on the Internet. Unfortunately we could not use a set of local transformation parameters but a more general one, covering whole Italy. It is therefore likely that even the datum transformation partially contributed to above mentioned shifts, in terms of absolute positioning, between pathways surveyed with the Backpack MMS and that reported on the map.

Magnetic disturbances: the orientation sensor adopted in the Backpack, the Leica DMC, is quite sensitive to nearby ferrous materials or any other kind of magnetic field source. During our surveys we could not avoid to pass near clearly visible metallic objects nor we can exclude that other unrecognized magnetic sources could have affected the DMC measurements. However we were not able to determine how much this sensor could be influenced by such disturbances.

5. CONCLUSIONS

In this paper we have presented an application of the Backpack MMS to a real case scenario: the mapping of escape pathways on a volcanic island for civil defence purposes. Three different routes were surveyed collecting images and both positional and orientation data. Achieved results showed in most cases that the Backpack performed better in terms of relative accuracy than in absolute positioning. On the other hand the latter is affected by several factors which can be only partially compensated for.

The test has also shown that this pedestrian system can potentially solve the need for detailed surveys on natural risk areas where classical van-based MMS cannot operate. However several improvements have to be done in terms of portability, flexibility and ease of use of the system. For instance the weight of the Backpack is of concern: in our case the operators had to bring in the rucksack about 10 kg of material, distributed between batteries, laptop PC and GPS receiver. A possible solution could be to use a pocket PC instead of a laptop, given that the computer is needed only for sensor sychronization and for the DMC data storage. Moreover power consumption has to be considered: using a small 12V/15A recheargable lead battery the system could be continously operated for about 2.5 hours, after this time we had to stop the system in order to change the supply. In total three batteries were needed to survey each route. Further improvements can also be made to increase the accuracy of position and attitue data. The DMC is one of a handful of devices that can provide the attitude of the Backpack MMS. However other kind of orientation sensors, less sensitive to magnetic disturbances could be investigated. RTK GPS would certainly help the operator during survey by indicating the current positioning accuracy in real time, alternatively a GPS antenna, more effective for multipath rejection, could be tested.

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