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Geoscientific Instrumentation Methods and Data Systems
Discussions

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Interactive comment on "Possible application of a compact electronics for multilayer muon high-speed radiography to volcanic cones" *by* H. K. M. Tanaka and I. Yokoyama

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Reviewer 1

The number of channels to be readout (196) is not so high, the splitting of the readout modules quite simple (x-y hodoscope), the number of channels per plane limited (11 to 14 per direction), the data rate relatively low wrt the HEP standards. The ïňAgure of merit of the present system should be emphasized throughout the paper by quantitative statements rather than qualitative statements such as 'the system should be faster', 'the performance should be better' etc. In particular it seems that the present paper gives a comparison between an old muon radiography performed in 2007 and a MURG08 readout system, ie the previous version of the MURG12. This should be clariïňĄed in the paper by the authors and the performance of all systems should be quantified in terms of data transfer, charge readout resolution, power consumption, memory and cpu load, expected limits of the system etc. The proposed system uses standard elements both in the analogic and in the digital stages (SiTCP, FPGA, CPU, network). Throughout the paper the terms 'operation failure' is used without definition and/or examples. Does the system suffer from data transfer limits, cpu overload or ?

- The authors added the description about the important issues for outdoor muon measurements which are not considered in general HEP experiments. The RAS (relaiability, availability and surveylability) of MURG08 is inherited by MURG2012. Other quantitative issues are added. The added parts are highlighted with red color.

In outdoor cosmic ray muon radiography measurements, it is necessary for us to collect a sufficient number of muon counts to visualize the inside structure of a gigantic body. For this purpose, our scintillator-based detection system requires only 10-20 channels per plane. This requirement is justified by the following discussions. Firstly, the realistic active area of the detector may range from 1 to 5 m2, depending on the size of the housing. The detector size exceeding 5m2 is unrealistic for outdoor measurements. Since near horizontal cosmic ray muon flux is ∼10-2 sr-1m-2s-1 after passing through 1-km rock, depending on its average density, the muon counts ranging from 103 to 104 sr-1 day-1 will be detected with this size of the detector. In order to accomplish the measurement within a realistic observation duration (<1 month), it is therefore concluded that 10-3 sr is the lower limit of the solid angular resolution of the detection system in order to acquire the muon counts more than 100 (with less than 10% statistic error at one sigma CL). This angular resolution can be realized by placing two PSD planes consisting of 10-cm wide scintilltor strips at a distance of 3 m. On the other hand, one of the most important aspects to realize outdoor muon radiography measurements is the power consumption. The minimal system instruments obviously helps to reduce the power consumption. In conclusion, for our purpose, 10-20 channels per plane is sufficient for imaging a km sacle object such as a volcano in a realistic observation time. Our present development of MURG12 employs much faster FPGA (1050 MHz clock) in comparison to prior version of MURG (50 MHz clock). However, the power consumption per channel is slightly reduced from 0.11 W to 0.10 W including the consumption by the power supply.

One another important requirement for the electronics is higher availability (the ability of the users to access the system) to general users. Uchida et al. (2009 and 2010) developed MURG08 for non-particle physicist users. In this system, In order to increase the availability, the tracking analysis algorithm is also incorporated into FPGA so that users can monitor the single counting rate of each channel as well as the 2-dimensional histogram of the muon counts as a function of azimuth and elevation angle only by accessing the web browser equipped on the electronics board via the internet. Thus far, this system has been used in various outdoor targets (Tanaka et al., 2009, Tanaka et al., 2010, Tanaka et al., 2011), and the long term (> 1 year) stability and reliability have been confirmed. There are two ways to apply MURG08 to the multi-layered PSD system: (a) software-based parallel processing 48-channel MURG08 modules; and (b) redesigning MURG08 to realize a complete hardware processing. Firstly, software-based parallel processing MURG08 modules was tried with a power effective laptop computer ($\sim$10W). In a track reconstruction software, a buffer is allocated in a memory for positioning and timing data that correspond to $\sim$2000 muon tracks. When operation failures occur, this buffer is rapidly consumed by unprocessed data and eventually the process stops. We found that this parallel processing system could successfully handle 4 planes, each with 11 X and 11 Y strips, but operation failure occurs if the number of channels increased more. The operation failure rate depends on the combination of the planes but it is roughly 140, 1200 and 1600 tracks/h for 2, 3 and 4 planes each with 14 X and 14 Y strips. We therefore redesigned MURG08 to keep its availability, but can process 7 planes, each with 14 X and 14 Y strips without any CPU load.

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Obvious statements may be avoided in a high level scientiïňĄc paper. It is evident that increasing the number of PSD will help deïňĄning straight lines and will further reduce BG contamination either by random hits or by correlated or uncorrelated cosmic showers.

-The authors think this is not obvious for geologist audiences.

Also obvious that the reduction of BG level will result in a global reduction of the exposure time.

-The authors also think this is not obvious for geologist audiences.

All parameters involved: acceptance, angular resolution, detection surface, exposure time, foreseen density measurement accuracy etc should be discussed accurately in the paper. 'To resolve the internal structure of the edifice' is also a vague statement. What is the level of accuracy required to quote that the structure is resolved.

- The authors added the description about the requirement for the detector size, time, angular resolution for the typical gigantic volume measurements.The added parts are highlighted with red color.

A discussion may be useful on the various cuts used to define a muon track (single hit, x-y coincidence, straight line within 200mrad cone). Are these criteria validated on Monter-Carlo simulations and experimental data? Since the system freezes the data taking conditions it is mandatory to evaluate the performance of the different triggering levels.

-This will be reported in another paper.

The general features of the muon tomography (BTW radiography rather than tomography) may be avoided since they are well known (cosmic muons properties, muons absorption in the rock etc). In the technical parts of the paper, please focus on the technical aspects of the muon detection. Concerning the second part of the paper, observation of Usu volcano, it should be stressed what kind of improvement is expected with the use of the new system (exposure time, resolution, detection surface etc).

-We added the following phrases: Some volcanos have a lot of parasitic cones like Usu volcano. In order to comprehensively understand the formation history of such volcanoes with muon studies, it is obvious that we need to image many of these cones. The authors are anticipating that more efficient muon imaging will be possible by speeding up the muon measurements with a system with higher reliability, availability, and stability. The authors understand that the journal does not focus on only the high energy instrumentations, but also geoscitntific application. In order to interpret the result we obtained, the radiographic results obtained in 1910 lava dome must be volcanologically discussed by comparing with other geophysical measurements and the lava dome (1944 lava dome) with the same origin with the prior radiographic measurement result. It seems rather verbose but please understand our intention.

"SpeciïňAc comments on technical part: p4,l3: better spatial resolution than seismic tomography: to be deïňAned However, the spatial resolution (up to 10 m) of the image is better than the one obtained by the seismic tomography (normally up to 500 m if we use natural earthquakes). - p5,l18: definition of structure resolution, what means' to resolve internal structure'? to detect the density anomaly of 30% through 500 m rock. - p5,20: quantify 'faster' It is redundant and deleted. - p6,9: operation failures meaning? Observation system: Defined in the text. p7,11: conïňAguration discussion: are 11 boards required? constraints on the power consumption? Survey of existing ASICs for the same functions? The daughter board mounted on the main board plays a role as a signal filter as well as a LEMO connector adapter. The adopter space is necessary. Connector adopters are not essential in the experiment, but is essential to achieve high availability to volcanologist users. - p8,13: 14 planes, 196 scintillators: drastic constraints? to be discussed. (14 channels x 14 layers) - p8,18: one hit events only, what about delta rays or accompanying gammas? a signal from one strip or adjacent two strips Delta rays do not have enough range to hit all the layers (30g/cm2). Gamma recoils will not hit all the layers (30g/cm2). - p9,8: DAQ PC=external memory device?

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(for parallel processing as well as external memory device). - p9,17: LEMO connectors interesting?) Yes, for the RAS purpose. Described in the text. Test measurement with multi-PSD system - MURG08 used, not MURG12, why not wait the use of MURG12? Described in the text. - p12,6: comparison not clear, between 2007 and MURG08 and MURG12? Described in the text Reviewer 2 This is a useful paper, although there is not a strong link between technical improvements, and their application to tomography of a particular volcanic area. I agree with the previous comment that more quantitative information on the advantages of the MURG12 over the MURG08 would be desirable. It appears from the paper that the MURG08 could handle 4 planes, each with 11 X and 11 Y strips, whereas the MURG12 handles 7 planes, each with 14 X and 14 Y strips, but this could be clearer. What proportion of data was lost with the "relatively high operation failure rate" of the MURG08?

- The authors added the description to clarify the improvements from MURG08 to MURG12. Quantitative description about the operation failure rate and other quantitative issues are added. The added parts are highlighted with red color.

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PSD planes consisting of 10-cm wide scintilltor strips at a distance of 3 m. On the other hand, one of the most important aspects to realize outdoor muon radiography measurements is the power consumption. The minimal system instruments obviously helps to reduce the power consumption. In conclusion, for our purpose, 10-20 channels per plane is sufficient for imaging a km sacle object such as a volcano in a realistic observation time. Our present development of MURG12 employs much faster FPGA (1050 MHz clock) in comparison to prior version of MURG (50 MHz clock). However, the power consumption per channel is slightly reduced from 0.11 W to 0.10 W including the consumption by the power supply.

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14 X and 14 Y strips. We therefore redesigned MURG08 to keep its availability, but can process 7 planes, each with 14 X and 14 Y strips without any CPU load.

The volcanology results of Usu volcano are interesting, but there could have been more about the only actual results, the density distribution of Fig 6. Making some reasonable assumptions of the shape of the high density under Craterlet A, e.g. it is roughly circular, what density contrast is indicated, and how does this compare with the density difference between dacitic lava and the average density of Usu, or with the density variations seen in Showa-Shinzen?

- We added the following phrases. Since we did not have three dimensional tomographic information in 1910 lava dome, we cannot assume the shape of the conduit. However, by assuming the density of dacitic lava in 1910 lava dome and the surrounding soil are both close to the average dennsity measured in 1944 lava dome (Showa shinzan; 2.7g/cm3) and surrounding soil (1.8g/cm3) with muon radiography (Tanaka et al., 2007), it is concluded that the circular conduit cannot explain the data. As can be seen in Fig. 6, the measureed average density is 2.4 g/cm3 (by taking the average value between two independent measurements), and the muon's path length is 700 m. Therefore, we can calculate that the magma is ectended 470 m towards the direction parpendicular to the detector plane. On the other hand, the short axis of the magma measures about 100 m. Therefore, the shape of dike rather than conduit is reasonble to explain the muographic data.

What density variation is suggested by the gravity anomaly of Fig 9?

-The density measurements have been performed in 1950s. The data can be used for qualitative discussion (e.g., the spatial distribution of the gravity anomalies), but includes significant errors, and thus, it is difficult for us to quantitatively discuss about the density structure.

In the conclusions, the section p18,14-21 seems to mix the 1910 and 1944 eruptions, they need to be distinguished.

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This is about the comprehensive description of Usu volcano, not only MS mound. In order to avoid confusion, the authors added "third (34 year later)" in the text.

Technical Comments: (This could have been usefully checked at an earlier stage) p2, 2 and elsewhere "requiring" rather than "requesting". -Corrected p2,10 Delete "According" -Corrected p2,11 "has been" instead of "is are" -Corrected p2,25 "characteristic stages of a magma intrusion" -Corrected p3,18 Delete "he applied' -Corrected p3,24 Delete "for" -Corrected p4,28 "The larger" -Corrected p4,29 ", the longer"instead of "larger" -Corrected p5,1 "time" not "times" -Corrected p6,17 Delete "which is" -Corrected p6,20 "Each daughter" -Corrected p8,22 What is "octet coincidence", I get 6 adjacent angles being compared? -Corrected p9,22 What is "larger longer" saying? -Corrected p10,13 /h or h-1 -Corrected p10,27 perhaps "orally" rather than"legendarily" -Corrected p11,1 "directly" rather than "straightly" -Corrected p11,7 "large diameter" -Corrected p14,25 Fig7, not Fig 6 -Corrected p14,27 "dense" -Corrected p15,22 "dense material exists" Gravity anomalies. Use "positive" for "high" -Corrected Fig 4 NM and HM need explanation.in caption -Fig. 4. Topographic sketch map of Usu volcano. KP: Kompira craterlet group, MS: Meiji-Shinzan craterlet group, NM: Nishi-Maruyama mound, HM: Higashi-Maruyama mound, SS: Showa-Shinzan lava dome, YH: Yanagi-Hara mound. Muon detection system is placed at UVO: Usu Volcano Observatory in this map. Missing Reference: Kusagaya et al., 2012 -Added.

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