THE LASER IN VESSEL VIEWING SYSTEM (IVVS) FOR ITER: PRESENT STATUS AND NEW DEVELOPMENTS OF THE CONTROL PROCESSING AND DATA VISUALIZATION SYTEMS

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ABSTRACT

A prototype of the laser In Vessel Viewing and ranging System (IVVS) was developed at ENEA laboratories in Frascati. It is based on an amplitude modulated laser radar designed to withstand the severe ITER conditions. The system is able to perform viewing and ranging of in-vessel surfaces at the same time. The system has been conceived to be radiation resistant and the most critical part of the system, the fiber optic optical encoder, has been successfully tested by SCK-CEN laboratories in Mol under gamma irradiation at 15 KGy/h up to a dose of 2.47 MGy. The paper describes the architecture of the system with details on the control, processing and data acquisition equipments.

INTRODUCTION

Machines for thermonuclear fusion research, like JET and ITER [1], need periodic inspections to check for damage of the in-vessel components. In future reactors, where large amounts of neutron and gamma radioactivity will be produced, TV systems directly inserted in the vessel cannot be successfully used. To overcome this limit a prototype of a laser In Vessel Viewing and ranging System (IVVS) based on an AM laser radar scheme has been developed at ENEA laboratories in the framework of EFDA (European Fusion Development Agreement) activity. In the AM laser radar scheme [2] the laser beam amplitude is modulated (up to hundreds of MHz). Both the intensity and the phase shifting of the reflected beam (with respect to the launched one) are simultaneously measured. A highly accurate picture of the scene is obtained from the intensity signal, while the ranging can be performed with good accuracy using the phase shifting.

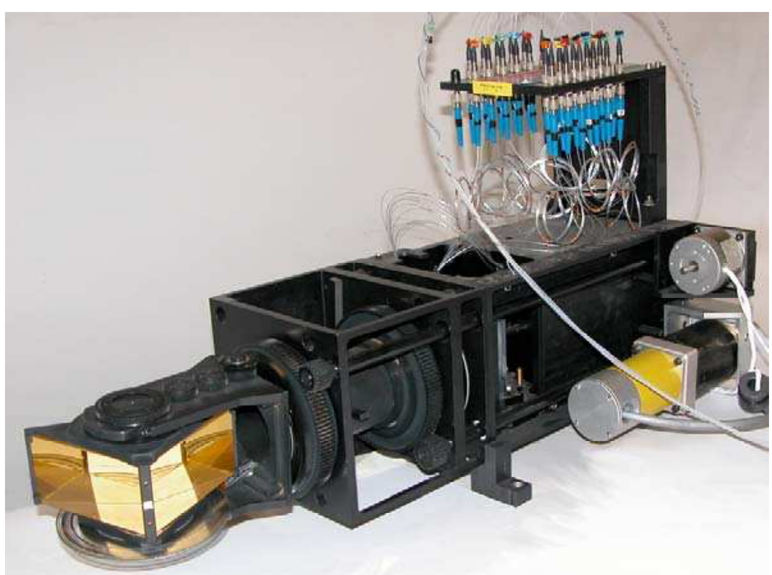

Figure 1: The IVVS system

SYSTEM MAIN CHARACTERISTICS

The main characteristics of the system are described in the following.

- The system was conceived to work in ITER environmental post pulse conditions: high vacuum, temperature up to 200 °C, high magnetic field up to 6 Tesla, high gamma radiation flux (15 KGy/h) and dose (2.5 MGy).

- The system produces three kinds of mages: a grey level coded image like a photo-camera, a colours coded image representing the range, a 3D image obtained merging the two previous. The CAD model of the scanned object can be superimposed to the 3D image.
- Auto-illumination: the laser spot is the source of illumination itself, no external illumination source is necessary. This characteristic allow the acquisition of images without shades.
- Large field of view: the system is able to acquire quasi-spherical images excluding an hidden solid angle less than 0.25π steradians over a full angle of 4π steradians.
- Depth of field from 1.5 to 7 metres without auto-focus.
- High lateral resolution, better than one millimetre. High-resolution images can be obtained also with stay time per pixel down to 20 μs.
- Variable resolution and acquisition times: setting the speed of motors is possible to obtain the desired resolution in the acquired image up to the limit of the optical resolution. The acquisition time can vary between 20 minutes and two hours depending on the desired resolution and scanned angle
- High dynamic range: tens of thousands of grey levels can be detected.
- Range measurement capability: the system is able to detect the ranges up to a 0.5 mm resolution with 3 ms of stay time per pixel.

SYSTEM ARCHITECTURE

Optical Layout

Two main blocks compose the IVVS electro-optics scheme [3]: the active module and the passive module. The “active module” was designed to be placed outside the bio-shield and hosts the laser, the photo-detectors and all the related active components. The “passive module” is part of the scanning head and hosts the passive optical components of the optical transceiver. The two modules are connected by means of radiation resistant optical fibers. An 80 mW, 840 nm laser diode is modulated at 79.5 MHz frequency. The sounding beam is transmitted to the prism and then to the target. The rotating prism scans the overall scene over a 165 x 360° field of view and a fraction of the backscattered light is collected by the transceiver, which is composed by two optical sections operating on the same optical axis. The first section is a small aperture optical system that sends a coherent focused laser beam onto the target, the second section is 50 mm aperture optical receiver used to collect all the incoming incoherent power. To increase the ranging accuracy and decrease the viewing time a large number of speckles are collected using a coherent bundle of single mode optical fibers and the received optical signal is fed onto an avalanche detector in the control room.

Mechanical Layout

The probe scanning head has been designed taking into account 1) the space envelope, 2) the inner components assembling procedures, 3) the mechanical, electrical, and optical connections assembling procedures, 4) the optical fibers bending radius and the operating requirements [4]. The probe weight is approximately 30 Kg. The rotation speed ripple is controlled using very accurate gearing and a gear play recovery system. The prism position is detected by means of two optical encoders modified to meet the vacuum and radiation specifications. The titlt encoder disk is fixed to the prism while the pan encoder disk is fixed to the inner pipe. The encoder disks are read by means of optical fibers.

GAMMA IRRADIATION TESTS

The present version of the IVVS probe (see Fig. 1) was designed to be tested under laboratory conditions, but it was conceived to cope with the ITER thermonuclear and mechanical constraint. It contains only passive components made from materials (stainless-steel or SiC and fused silica) already tested in the framework of dedicated ITER Task and found suitable for operation under the ITER FEAT operating conditions. A dedicated irradiation test was performed on the fiber optic optical encoder to verify the encoder under ITER irradiation conditions. The encoder is made from BOROFLOT glass and is driven with an 860 nm light source. The test was performed by SCK-CEN laboratories in Mol on a sub-assembly prepared by ENEA. The dose rate was of 15.24 KGy/h and a total dose of 2469 KGy was reached. An increase of the total optical loss of 2.7 dB was found after a total dose of 2469 KGy at a moderate temperature. This loss can be well tolerated by the encoder electronics and doesn't affect the encoder reading.

CONTROL/ACQUISITION/ELABORATION SYSTEM

The Control/acquisition/elaboration system layout is shown in Fig. 2. The remotely placed optical module, named ACTIVE MODULE, hosts the 840 nm laser source, the optical sensors and related electronics. The laser beam is sent via a coherent optical fiber to the receiving optical module, named PASSIVE MODULE, which is integrated in the scanning head; here the beam is focused and the back-scattered light is collected and sent back. This signal is then processed in the RADAR ELECTRONICS equipment to obtain the amplitude and phase shift of the received signal. The SCANNING HEAD drives the two rotations of the prism. The two angular coordinates of the prism are read using two fiber optic OPTICAL ENCODERS. A dedicated VME CONTROL & ACQUISITION SYSTEM controls all the function of the system and also acquires all the information. The data are then acquired processed and displayed in THE WORK-STATION using a dedicated software. All the electronic equipment is placed in the control room.

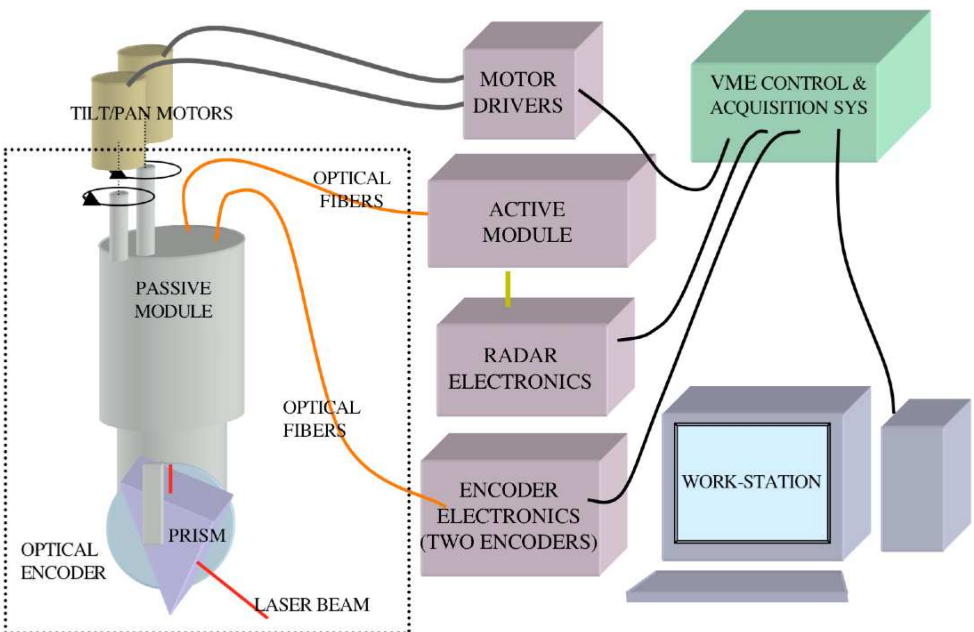

Figure 2: Control/acquisition/elaboration system layout

Radar Electronic Equipment

The Radar Electronic (R.E.) equipment (patented) is the most crucial component, it performs the amplitude modulation of the launched laser beam and the digital demodulation of the received back-scatter laser beams respectively. During the demodulation process, the amplitude of the reflected laser beam and the phase difference between the reference signal and the back-scattered laser beam are extracted. Then the Control and Data Acquisition System [5] acquires the amplitude and the phase.

The working frequency selected was 79.5 MHz, consequently the total range is about 1.875 m. This range is lower than the total operating range; nevertheless this is not a limit for in vessel viewing application, since the geometry of the zone to be viewed is known. The needed phase resolution is <0.1° to have a range resolution less than 500 μm.

In laser radar systems, the amount of the received power considerably depends on the nature of the scanned surface and on the laser beam incidence angle. To take into account such a high dynamic range, the system is based on a double channel configuration with an automatic change of scale. Each channel is in charge for a dynamic range of 30 dB, the change of scale is done by selecting the output channel in real-time, depending on input power level. This architecture permits to maintain the 0.1 degree of phase accuracy over a 60 dB dynamic. Two different implementations has been developed using different digital technologies. The digital architecture (excluding the input amplifier and filter stages) has been adopted in order to obtain maximum repeatability and accuracy.

The first implementation (see Fig. 3) is based on a digital receiver sub system followed by a parallel pipeline of 4 digital signal processors type TMS 6701. Each of them is capable of 1 GFLOPS (Giga Floating Point Operations per Second) computing power. An architecture based on VME commercial boards has been chosen for the Digital Receiver and Processing Unit. The RF Analogue Interface has been developed using commercial blocks such as oscillators, amplifiers and filters. The digital input section is provided with four fast high precision A/D (model AD6644) with 14 Bit resolution and 65 MSample/s in order to obtain the maximum accuracy. The direct digital down conversion using sub-sampling technique (also called direct IF conversion) has been adopted to increase the modulation frequency. The system was designed to have a programmable output frequency in a range varying form 100 KHz to 100 Hz [6].

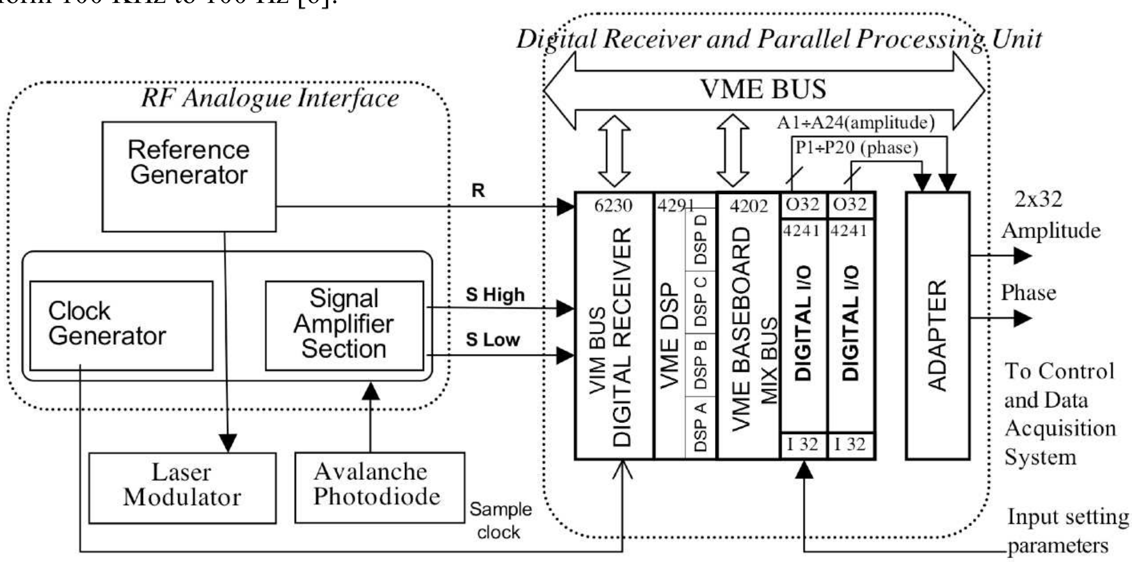

Figure 3: Radar Electronics (first implementation)

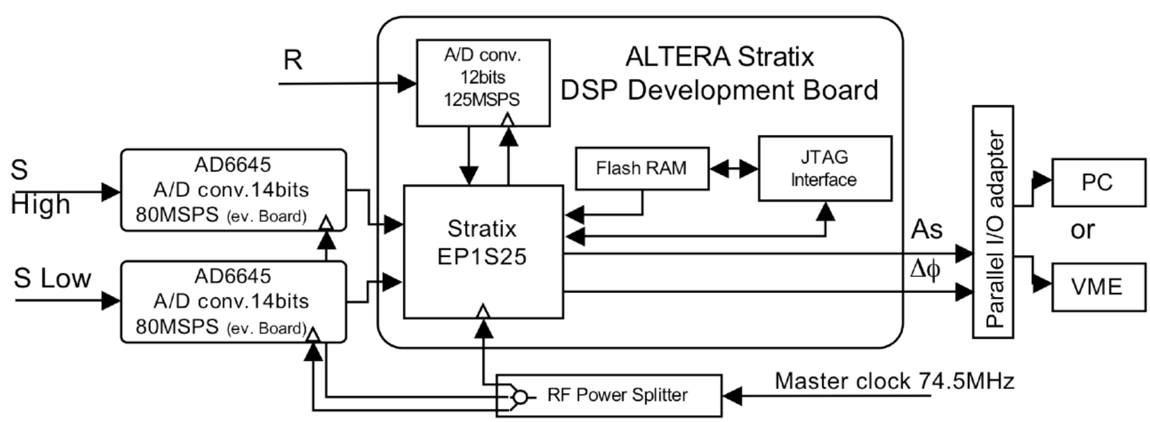

Figure 4: Radar Electronics (second implementation)

Starting from this, a further development has been done to increase the speed of the digital processing system up to 2.5 M measures/s to approach the speed of the standard TV camera. Furthermore the new system has an input bandwidth of 200 MHz then the laser modulation frequency can be increased, consequently improving the range resolution of the laser radar, which is proportional to the modulation frequency. The sampling frequency was increased from 61 MHz to 74.5 MHz consequently improving the SNR (Signal to Noise Ratio) of the system. To reach the sub-microsecond speed it was necessary to implement the mathematical algorithm in a custom highly parallel hardware architecture using an FPGA. Looking to the good results of the system previously developed was decided to maintain the same acquisition front-end. In this case, the latest release of the analog to digital converters has been used (model Analog Devices AD6645). At the same time the software algorithm previously used was completely redesigned and optimized to be used in a single FPGA hardware architecture, thus improving by 25 times the speed in comparison with the previous system. Figure 4 shows the new radar electronic architecture.

Control/acquisition system

The IVVS control and data acquisition system was developed by IST (Istituto Superior Tecnico) Portuguese in collaboration whit ENEA, it is composed of a supervisory workstation connected by a 100 Mbit/s Ethernet channel to a 12-slot VME crate.

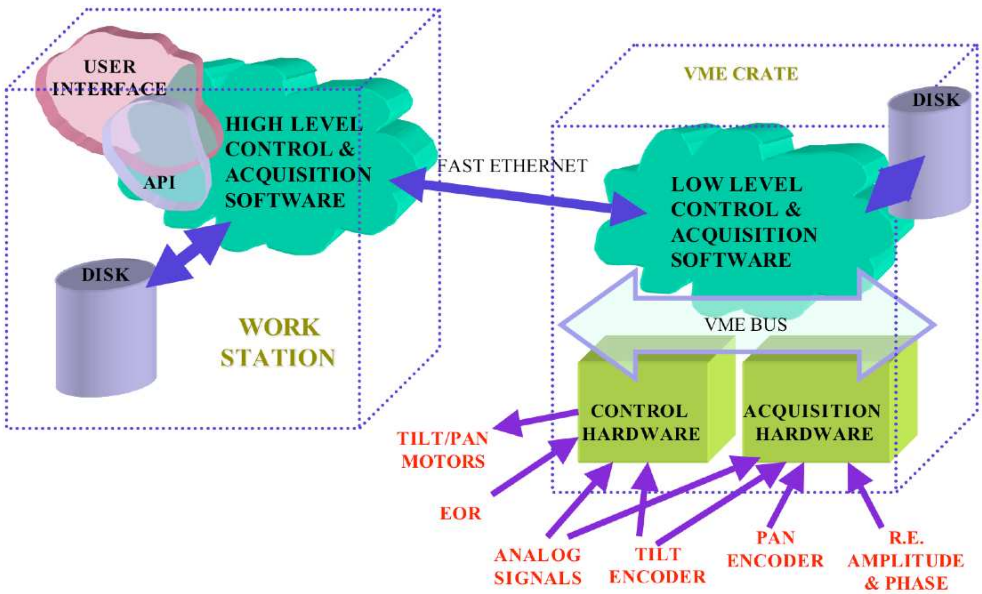

Figure 5: Control/acquisition system

This system houses a PowerPC604R CPU module, with 64 Mbyte RAM, 9 Gbyte hard disk and the LynxOS operating system and a custom developed intelligent control and data acquisition module, which controls the operation of the in-vessel scanning laser and acquires and stores the in-vessel high-resolution images. Furthermore it monitors external error events. The LynxOS operating system has been chosen since it is very suitable for time-critical applications. All these functions are controlled by a suitable software interface that is provided with an API library interface.

Fiber optic optical encoder

To read the two angular positions of the prism a fiber optic optical encoder has been developed.

The encoder disk has a resolution of 5000 marks and it is read using ten 300 μm silica fused optical fibres. A dedicated electronic system sends the light to the encoder tracks and converts the received light in an electrical signal. The system include also a decoding circuit that perform a by 4 multiply of marks reaching 20000 pulses per turn and a programmable gate generator to switch off the laser. The electronic drive give out the analog signals relative to the two tracks of the encoder, they are used by the reconstruction software, which uses a dedicated algorithm to increase the angular resolution by a factor 40.

Data Acquisition and visualization software

The visualization code was developed using C/C++, OPENGL and the scripting language LUA (a powerful tool developed by Tecgraf in Brazil) as glue for the various functionalities. Particular care has been devoted to design graphical interfaces for all the operations. The main software characteristics are described in the following.

- Control and data acquisition: the software controls all the system functions and acquire several GBytes of data for each image. It interfaces the software library provided by the IST.
- Image construction: the encoders reading are used together with the acquired Amplitude and Phase generated by the Radar Electronics to construct the 2D and 3D images.
- Preview: It is possible to show a preview of the acquisition while it is in progress.

- Filters: the 2D viewers can apply filters to the data to help distinguish features. There are a number of built-in filters: equalisation, LUT remapping, apply thresholds, convolutions etc. .
- Exporting data: The IVVS visualisation software can export to common graphic format both for 2D images (TGA, PNG) and for 3D images.
- Comparing data: The software can compare the current reconstructed model with a previous one (a reference one from CAD data or from another acquisition)

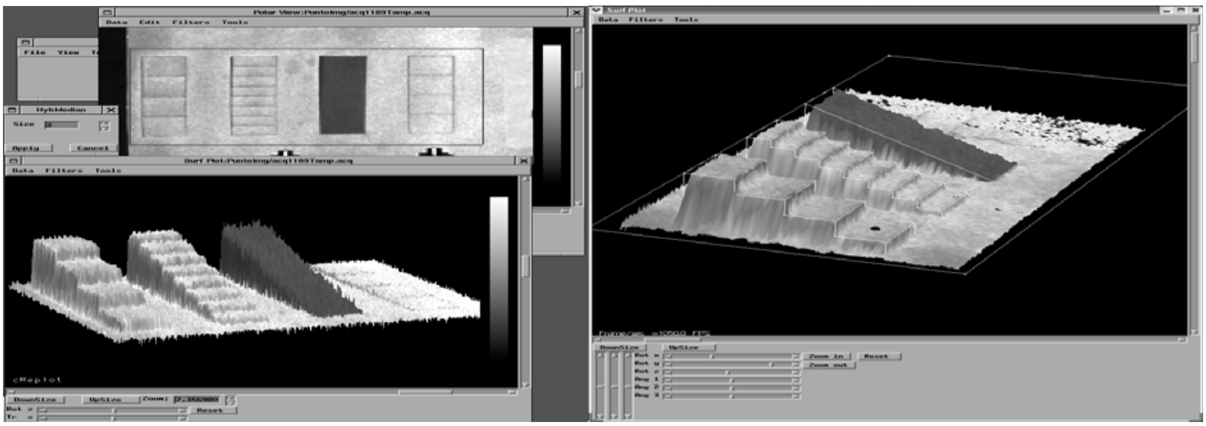

Figure 6: Software Interface

NEW DEVELOPMENTS

Two new main developments are underway. The first concern the development of a no radiation resistant thinner scanning head (60mm of diameter) to be used for in-door or out-door survey, using the same control/acquisition architecture. The second concern the update of the second version of R.E. using the same FPGA hardware architecture to add the following functionality:

- the increase of the laser modulation frequency from 79.5 to 200 MHz;
- the inclusion of all the functions of the data acquisition system interfacing a Linux PC;
- the use of a new double modulation processing technique to extend the total working range.

CONCLUSIONS

The general concepts used to develop the IVVS in vessel viewing system and its control/processing architecture have been demonstrated to be sufficiently general. The system is capable to work in ITER environmental post pulse conditions but can be used also for different survey purposes. The intensive use of FPGA permits the size reduction of the control/acquisition/processing hardware and the increase of performances of the system.

REFERENCES

[1] R. Aymar, “The ITER reduce cost design,” Fusion Engineering and Design, vol. 49-50, pp. 13-25, November 2000.

[2] D.Nitzan, A.E.Brain, and R.O.Duda, “The measurement and use of registered reflectance and range data in scene analysis,” in Proc. IEEE vol.65, no 2, pp 206-220, February 1977.

[3] L. Bartolini et al., “Amplitude modulated laser in vessel viewing system (LIVVS) for ITER/JET,” Fusion Technology 1998, vol. 1, pp. 685-688, September 1998.

[4] C. Talarico, M. Baldarelli, A. Coletti, S. Lupini, C. Neri, M. Riva, and L. Semeraro, “Laser in vessel viewing system for activated areas: mechanical design, manufacturing and tests,” Fusion Engineering and Design, vol. 51, pp. 1001–1006, 2000.

[5] C. Correia, R. Pereira, N. Cruz, C. Neri, and M. Riva, C.A.F. Varandas, “The control and data acquisition system of a laser in-vessel viewing system,” Fusion Engineering and Design, vol. 48, Robert W. Conn, eds. North Holland, pp. 205-212, August 2000.

[6] C. Neri et alt., “Advanced digital processing for amplitude and range determination in optical RADAR systems,” IEEE Transaction on Nuclear Science, vol. 49, no. 2, pp. 417-422, April 2002.