# A modular DSP system for use in embedded electro-optic applications

**Li Lanjun[1], Tim. A Clarke[2]**

**1. South-Central Institute of Technology, Hunan**
**2. Optical Metrology Centre, City University, London, UK**

**Abstract**

*This paper describes the development and application of a modular DSP system using the Analog Devices 2101 processor. Two non-contact applications are described - measurement of pipe cross-sections and 3-D measurement using multiple camera views.*

## 1. INTRODUCTION

Many commercial off-the-shelf DSP processing solutions exist but it is often the case that they are not the right size for embedded applications or they cannot interface easily to real-time data streams. The requirements of two projects described here fit into both categories and so a proprietary solution was required. A series of stackable modules were designed and constructed. This paper reviews the operation of these modules, the software required to operate them, and some results from their use in two different application areas.

## 2. *DSP-90* MODULES

**2.1 DSP-90.** The DSP-90 module uses an Analog Devices ADSP2101 fixed point processor operating at 20 MHz. The processor has 16K words (16-bit) of data and 16K words (24-bit) of program memory, of which 2K words of data memory and 1K words of program memory are on-chip. 128 words of the external data memory space is used for memory-mapped I/O ports. The rest of the external data and program memory spaces are filled with 30nS SRAM. The 16K words (24-bit) of boot memory space is occupied by a 70nS EPROM.

**2.2 GPIO-90.** The GPIO-90 module provides two functions only. Input Output (IO) ports and FIFO ports. Four IO ports are provided which can be read or write 8 bit data in latched or strobe mode. These ports can be used for a variety of purposes depending on how many are used for the main DSP-90 hardware. Options that currently exist are the operation of two DC Motors using a pulse-width-modulation (PWM) controller that is part of the PWM-ENC-90 card. Obvious uses with *3-D NET* are pan and tilt mounts, synchronisation of flash lighting, and illumination of LED targets.

**2.3 VFE-90.** The video processor board is a mixed-mode circuit, comprising both analogue and digital circuitry. Analogue circuitry is concerned with video conditioning, whilst digital circuitry is utilised for hardware processing of the digitised video signal, and for interfacing with the DSP-90 system. In both applications very bright signals are produced and a single threshold is all that is required to isolate the features of interest. This operation often represents a significant proportion of the processing time. The approach used in the VFE-90 module is to perform this operation in hardware. To achieve this one of the GPIO-90 ports is used to load a digital threshold level into a latch. The line-by-line video signal is A-D converted by a 10 bit Burr Brown converter and the output is compared with the threshold level. If this is the first edge encountered in the line the pixel location of this pixel is stored in a 16 bit word First In First Out (FIFO) buffer along with its intensity value.

**2.4 ETHER-90.** The Ethernet communications module uses the NE2000 chipset which is almost a ***de facto*** standard for 10 Mbits/second Ethernet. The module requires a packet driver in the same way that a PC does. The packet driver senses when data arrives and interrupts the DSP-90 processor so that the data can be collected. When a packet is required to be sent to another Ethernet address the DSP-90 sends the data to the ENET-90 board in the correct manner and initiates the sending process.

**2.5 MOTOR/ENC-90.** This module provides two Pulse Width Modulation controlled DC motor outputs. Small DC motors can be driven directly. The DSP-90 processor can change the speed of the motor by writing to a port. 10 speed levels can be set. In addition two optical encoder inputs are provided for up to 5000 step incremental encoders. The two quadrature inputs plus the home pulse input are used to count the current angular position of the encoder. This position is read via the FIFO ports into the DSP-90 processor.

**2.6 PWER-90.** In many applications it is necessary to mount the instrument many metres from a power supply sometimes in an electrically noisy environment. This module uses up to three DC-DC converters to allow a wide band input signal (9-18 Volts, or 18-36 Volts) to produce the voltage levels required. The inputs are protected from over and under voltage. CCD cameras, lasers, and motors can be driven from the same supply if necessary.

## 3. PIPE CROSS-SECTION MEASUREMENT APPLICATION

**3.1 Optical triangulation.** The pipe cross section measuring instrument uses the well known principle of optical triangulation to measure distance. A laser to illuminate a surface and a linear CCD camera is used to detect the diffuse reflection of the laser spot.

**3.2 Mechanical configuration.** The laser beam and CCD camera assembly are mounted so that they can be rotated such that the laser beam describes a cross-section of any surface.

**3.3 Optical configuration.** The use of external moving parts cause difficulties to manufacture and seal in hazardous environments. In this case the optical triangulation head rotates inside a glass envelope.

**3.4 Operation.** In operation the optical triangulation head is rotated using the motor board and the image data and encoder output is sampled at the same time to provide a distance and angle measurement. This process is repeated until a complete profile has been collected.

## 4. PIPE CROSS-SECTION MEASUREMENT SOFTWARE

**4.1 Image processing.** The image of the laser spot requires to be processed to determine its subpixel location. The FIFO buffers are continually being filled with image date from the sensor. To process the most up to date information the FIFO buffers can either be reset or read until the empty flag is raised by the FIFO. At this point the resulting data consisting of the position along the CCD linear array of the first point to be above the threshold and the subsequent intensity values until the image goes below the threshold are retrieved and a simple centroid calculation and addition of the offset is used to produce the subpixel location of the laser spot.

**4.2 Software tools.** To facilitate the operation of the profiling device a number of tools are provided for the user. These range from a visualisation of the laser image to checks on the angular rotation angle or distance being measured. To operate the system the user selects a project and commands the device to collect a profile. If the software has been downloaded then a profile is collected otherwise the program is downloaded to the DSP that is running a monitor program.

**4.3 Data collection and storage methods.** Data collected from system are stored as both raw cartesian co-ordinate data as an ASCII file or in the popular and general purpose DXF file format for subsequent viewing or analysis.

## 5. RESULTS

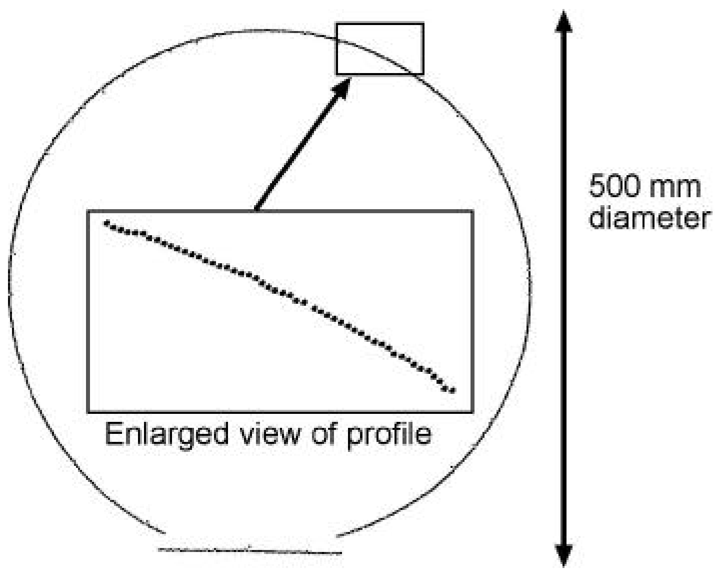
**5.1 Speed of operation.** The time taken for a collection of a profile is dependent on the mode of operation. Under normal circumstances it takes a second or two to gather a few hundred points and transfer the data to the host computer. The maximum speed of operation is of the order of 1000 measurements per second.

**5.2 Assessment of accuracy.**

Optical triangulation systems usually have a non-linear characteristic. The accuracy varies with distance. The main influence of accuracy is the number of pixels in the sensor (in this case 512) and the subpixel spot location accuracy that can be achieved. Typically it is possible to determine the location of a bright spot with an accuracy of 1/30 of a pixel but Laser speckle causes some degradation of accuracy and it is possible that only 1/5 to 1/10 can be achieved in practise. As a result the device is expected to have an accuracy that varies from approximately 50 microns at a distance of 70 mm to 2 mm at a distance of 600 mm.

**5.3 Profile collection results.**

The results of collecting a profile of a 500 mm diameter pipe are illustrated in Figure 1.




## 6. MULTIPLE CAMERA 3-D MEASUREMENT APPLICATION

**6.1 Principles of photogrammetry.** Multiple views of an object are used in photogrammetry to provide high accuracy 3-D measurement. Due to optical triangulation geometry and the large number of observations compared to the number of unknown parameters it is possible to estimate not only the 3-D co-ordinates but also the camera calibration and orientation parameters. Retro-reflective targets and nearly coaxial lighting are often used to produce target images which are extremely bright and can be located to within a tenth to an eightieth of a pixel. As a result measurement precisions are often of the order of 1 part in 30,000 of the object space to 1 part in 120,000.

**6.2 Application.** In the current demonstration of this system a four cameras are arrange to view the object space in a symmetrical pattern with an included angle of around 90 degrees between the cameras. Objects being measured are targeted with retro-reflective targets. One of the current tasks is to measure the relative location of two aerospace components with respect to each other for use in embedded manufacturing processes.

## 7. MULTIPLE CAMERA 3-D MEASUREMENT SOFTWARE

**7.1 Image processing.** The DSP-90 module provides the processing power necessary to perform three essential operations. First the target images which are encoded and placed in FIFO’s must be read and the target images re-assembled and checked for size and shape, second the centroid of the images must be computed, and third the resulting image co-ordinates must be communicated to another processor using the Ethernet communications module. The image data are read by the DSP and the location of each section of image stored in a memory buffer (Pushpakumara et al, 1996). A line-by-line algorithm correctly associates the strips of image data by keeping track of the numbers of up going and down going edges for each line. The method of moments is used to compute the location of the centroid of the target image. This is an operation that the DSP is particularly suitable for, as it is capable of single cycle multiply and accumulate operations. The location of the targets along with a measure of its quality is then stored.

**7.2 Communications.** The target information, quality measures, and a frame ID number are either kept until the location data is requested by a processor, or continually sent to a selected processor using the ENET-90 module.

## 8. RESULTS

**8.1 Speed of operation.** A series of tests were conducted to assess the capability of the DSP system. The results show that for typical target sizes with a diameter of some 6 - 7 pixels (optimum of target image location ) some 170 target images could be processed in real-time and the results recorded by another computer.

**8.2 3-D co-ordinate estimation.** The part positioning demonstration used four Pulnix TM 6CN cameras that were pre-calibrated to a precision of 0.2µm rms (approx 1/40 of a pixel). The cameras were set up with a convergent angle of 60 degrees between the camera and the normal to the laboratory floor. The camera to object distance was 2.2 metres and the focal length of the lenses was 16 mm. The resulting 3-D precision of the object space co-ordinates was estimated to be 20 µm rms.

## 9. CONCLUSIONS

This paper has described an embedded DSP system for use in two specific applications: a sewer pipe profiling instrument and multiple camera 3-D measurement. The principles of operation of both systems are briefly described together with the software operation. Finally results are given for both systems illustrating that the DSP system is efficient in terms of processing power and very flexible.

## 10. REFERENCES


Pushpakumara, D.D.A. Gooch. R.M. and Clarke. T.A. 1996. Real time image processing and data communications for a 3-D measurement system. 15th National Information Technology Conference Proceedings, The Computer Society of Sri Lanka, pp. 1-9.

T. Clarke, L. Li, and X. Wang 1998. 3D-NET - A new real-time photogrammetric system. ISPRS Hakodate, Japan, pp.29-34.

**PAPER REFERENCE**

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