Camera-Link and Synchronism in Automotive Multi-Vision Systems

Conference Paper · November 2008

DOI: 10.13140/RG.2.1.3819.7603

1 author:

Marc Azzopardi
University of Malta

Camera-Link® and Synchronism in Automotive Multi-Vision Systems

M. A. Azzopardi
University of Malta

ABSTRACT

Cameras are excellent ways of non-invasively monitoring the interior and exterior of vehicles. The motivations for cabin monitoring are largely safety related and include occupant detection, occupant classification, and driver vigilance/drowsiness monitoring. Exterior vehicular monitoring has wider motivations including road surface condition monitoring, lane-departure warning systems, blind spot warning, collision warning/mitigation/avoidance, vehicle security, traffic sign detection and adaptive cruise control. The large number of cameras envisaged, necessitates the development of a novel, high performance methodology for interfacing several cameras to a central processing hub over a single lightweight cable whilst preserving a high degree of synchronicity between stereovision or multivision sets. Such a solution, which is also backward compatible with the Camera-Link® standard, is thus presented. This results in substantial cabling, weight and cost savings while simultaneously guaranteeing superior performance. A stereovision design and implementation is presented that makes use of prototype, ultra-high dynamic range, automotive-grade image sensors developed by ATMEL Grenoble SA as part of the European FP6 Project - SENSATION (Advanced Sensor Development for Attention, Stress, Vigilance and Sleep/Wakefulness Monitoring).

Key-words: Active & Passive Safety, Integrated Safety Systems, Sensors, Driver Assistance Systems

1. INTRODUCTION

Over the coming years, one of the areas of greatest research and development potential will be that of automotive sensor systems and telematics [Turner, 2000]. In particular, there is a steeply growing interest in the utilization of multiple cameras within vehicles to augment vehicle HMI for safety, comfort and security. These are emerging as viable alternatives to systems such RADAR, SODAR and LADAR (or LIDAR) which typically either have poor lateral resolution or require mechanical moving parts [Hoffmann, 2006]. Moreover, cameras can be used to satisfy several applications at once by re-processing the same vision data in multiple ways, thereby reducing the total number of sensors required to achieve equivalent functionality.

The list of conceived automotive camera applications is ever-growing, with some reports claiming that as many as 10 to 20 will be required per vehicle [ABI-Research, 2007]. The incomplete list includes: occupant detection systems, occupant classification, driver vigilance and drowsiness monitoring, road surface condition monitoring, lane-departure warning, blind spot warning, collision warning/mitigation/avoidance, vehicle security, parking assistance, traffic sign detection, adaptive cruise control, night vision etc.

M.A. Azzopardi is with the Department of Electronic Systems Engineering, University of Malta, Msida, Malta.
Email: maazzo@eng.um.edu.mt

Several of these applications involve the use of stereovision and multivision sets of cameras operating in tandem in order to extend the field of view, to increase diversity and ruggedness or to allow stereoscopic depth estimation. In each of these cases, even a slight frequency or phase difference between the image sampling processes of the cameras would lead to difficulties during transmission and post processing. This problem becomes particularly acute at high frame rates, when capturing high speed motion like driver eye blinks or the road surface beneath a moving car. Proper operation usually rests on the ability to achieve synchronised, low latency video capture between cameras in the same multivision set in order to guarantee temporal correspondence between the video sources. Moreover, this requirement extends to the video transport mechanism which must also ensure synchronous delivery to the central processing hubs.

Interface throughput is another major concern since high resolutions are desirable and the frame rates required (per second) can reach into the high hundreds. While serial transport protocols such as the Ethernet-derived GigE-Vision standard can sustain up to 750 Mbit/sec [Fraunhofer, 2007], they have poor temporal characteristics, including high latency, poor determinism and substantial timing jitter, and even so, this is only possible by using Jumbo Framing (a non-standard proprietary technology) [Pan, 2003] making them rather unsuitable for high performance vision applications [Sony-Vision, 2008]. CPU utilisation may also be unacceptably high. Multimedia-oriented protocols such as USB2 and IEEE1394 (Firewire) only partially address these problems through the inclusion of special isochronous modes of operation. However, the accuracy is limited to no better than ±125μs, [U, 2004], and synchronous transport of multimedia streams over intrinsically asynchronous protocols poses complexities that outweigh the benefits [Edens, 1998]. On the other hand, parallel video bus standards such as RS422 and RS-644 (LVDS) are low latency, highly deterministic, synchronous and relatively jitter free by design. They also offer impressive throughput. Of course, the down side of any parallel bus is a severe limitation in length due to skew as well as the need for thick expensive cables.

Camera-Link®, a proven machine-vision interface standard recently developed by the major players in the market [AIA, 2006], straddles the two domains and derives the best benefits from each; having the performance, simplicity and Quality of Service (QoS) of a parallel bus while having the desirable cabling benefits of a serial bus. Indeed, fibre optic implementations of Camera-Link® take the length limit to the kilometre range [Phrontier, 2008] [Thinklogical, 2008]. Fibre implementations can also boast of galvanic isolation, heat/fire resistance and the lowest possible specific weight. Needless to say, Camera-Link® in its latest incarnations easily makes it one of the best candidates for a lightweight, high-fidelity interconnect in automotive vision systems.

In this paper, a dash-board-mountable automotive stereovision camera system intended for driver head localization, point of gaze detection and eye blink rate measurement is presented. This was developed as part of a large FP6 Integrated Project - SENSATION (*Advanced Sensor Development for Attention, Stress, Vigilance and Sleep/Wakefulness Monitoring*). The overarching goal of SENSATION was to develop non-invasive sensors, including stereovision cameras, for general human vigilance monitoring. Stereovision methods are ideal for the automotive case and offer many cues which allow driver vigilance to be reliably quantified. The system here presented employs a novel low-cost method of addressing the synchronization problem and demonstrates a novel method for reliably transporting high speed, synchronized, stereovideo over a single Camera-Link® interface. These methods are readily extendable to multivision systems [Azzopardi, 2008]. The camera system is built around a matched set of prototype, ultra-high dynamic range, automotive grade, image sensors specifically developed and fabricated by ATMEL Grenoble SA for this application.

2. CONVENTIONAL TECHNIQUES

As already mentioned, the effective application of stereovision or multivision systems depends on the ability to generate and transmit synchronized video signals from two or more cameras respectively. This problem is non-trivial and there have been numerous attempts to address it, as evidenced by the several related patents issued.

The oldest methods of synchronisation between multiple cameras date back to the 1980's when the 'genlock' (generator lock) principle, [Kovaks, 2007], became commonplace for use in video broadcasting houses, video editing and special effects [Trammell, 1986]. This was, and still is quite adequate for TV broadcast systems. However, it is fails as the frame rates and pixel rates increase due to the transportation lag incurred in transferring a genlock signal between cameras. Electromechanical synchronisation techniques were also proposed, [Tashiro, 1994], but quickly fell into disfavour as electronics gradually took over every aspect of the field.

Some techniques rely on post processing (frame shifting) to achieve synchronisation. The relative frame lag is measured either by comparing recorded motion present in the two video streams, [Chen, 2002], or by actively inserting artificial optical cues into the field of vision of the cameras [Trinkel, 2002]. This avoids the need for explicit synchronization and is touted as a means of reducing costs but there are a number of scenarios where the net complexity and cost is increased by the need of the additional post processing step. Moreover, this technique is not universally applicable such as in cases where there is no motion in the captured sequences or where interference with the scene is not acceptable. This method of synchronization is additionally limited in the accuracy it can achieve since the resulting video sequences could still be misaligned by as much as half the inter frame duration, on average.

Schemes that involve the transfer of vertical or horizontal or synchronization pulses between the cameras in a multivision system, [Tserkovnyuk, 2005], [Cooper, 1999], have similar shortcomings to the Genlock concept, from which they are derived. PLLs and DLLs can be used to compensate or delays but this adds significant complexity and ultimately limits the pixel clock rate. Store and forward techniques proposed by the same authors [Cooper, 2004] also add complexity and cost, and unavoidably introduce a small but distinct latency in the delivery of the video data which may be a significant disadvantage for certain high speed applications.

3. SYSTEM ARCHITECTURE

The stereovision system implemented and presented here was meant to demonstrate the feasibility of achieving a steady stream of high speed, precisely synchronized stereovideo over a standard interface when using typical CMOS automotive-grade image sensors.

The method proposed involves the use of matched cameras or image sensors which are subjected to a common clock as well as identical operating conditions thereby guaranteeing an identical internal state and synchronized output timing behaviour. Compared with other synchronization techniques, this significantly reduces latency and again keeps the costs to a minimum and lends itself for a complete solution.

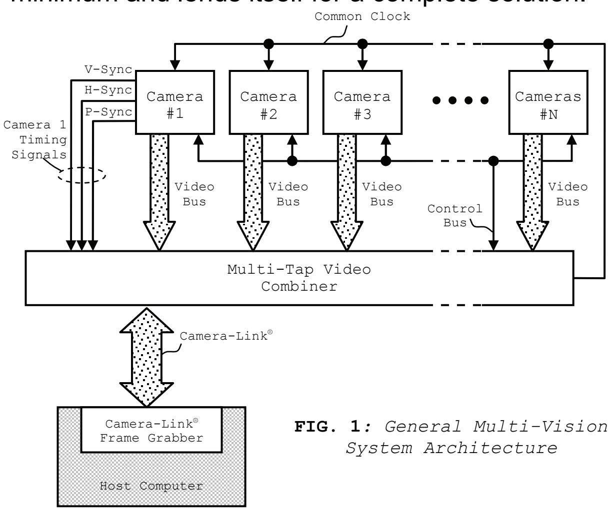


FIG. 1: *General Multi-Vision System Architecture*

Flexibility, minimal weight, low latency, high performance, high reliability and low overall cost were the major objectives of this undertaking.

To this effect, the generic architecture shown in FIG. 1 is proposed. Any number of identical cameras are symmetrically connected to a central video combiner. The cameras are perfect replicas of one another and the image sensors are taken from matched sets which have been produced in the same fabrication run (from the same silicon wafer) to guarantee equivalent performance and timing characteristics when supplied with a common clock. To further reduce variability even the cables connecting the cameras to the combiner are of matching length and composition.

The video combiner has a number of roles, the most important being that of ensuring that every camera is operating under the same programmatic and electrical conditions at all times and its internal architecture conforms to this principle at every level.

4. CLOCK MODULATION

A major challenge often encountered in such situations is that of simultaneously initializing or re-programming all the cameras in the system. This is quite problematic considering that the majority of CMOS image sensors are configured over relatively slow serial interfaces. In practice commands have to be sequentially delivered to each of the cameras and for certain commands this process invariably results in frame/line phase misalignment between the cameras.

This problem has been neatly resolved by recognizing that the CMOS image sensors are fully static state machines. This allows their clock to be halted and restarted at will without any lasting consequences. Thus, before delivering commands to the image sensors, the common clock is halted. This conserves the machine state. Only after all the commands are sequentially sent to all the cameras is the clock re-started. The overall effect is equivalent to having reconfigured all the cameras at the same instant.

However, not all camera commands require such a procedure. Some commands do not affect synchronization and it may even be desirable, in certain cases, to be able to apply different operating parameters to different cameras. One such example is pixel gain and another is integration time. Thus, the solution adopted in this design involves marshalling all the commands and distinguishing between those that are synchronization safe from those which are not. Only those commands that affect synchronization are intercepted for halted-clock execution.

A camera controller residing in the video combiner module controls the delivery of the common master clock to the cameras by means of a clock gating circuit. This clock gating circuit is capable of synchronously interrupting and reconnecting the clock without causing any glitches at the output that might adversely affect the sensors.

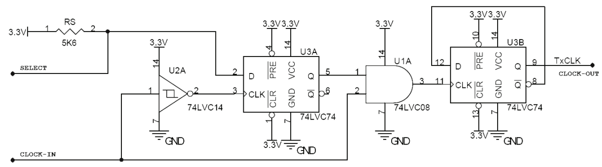


FIG. 2: *A Clock Gating Circuit*

The clock gating circuit shown in the schematic of FIG. 2, takes a clock and a select line as inputs. This input clock must run at twice the frequency required by the cameras. When the select line is held at logic low, the AND gate U1A isolates the output D-flip-flop U3B which holds its last held state, interrupting clock transfer. When the select line is held high, the AND gate U1A relays the clock to the output D-flip-flop U3B which divides the frequency, producing a clean 50% duty cycle clock signal. The negative edge triggered D-flip-flop only conducts changes in the select line to the AND gate U1A at the negative edges of the incoming clock which satisfies set-up time requirements of the output D-flip-flop U3B.

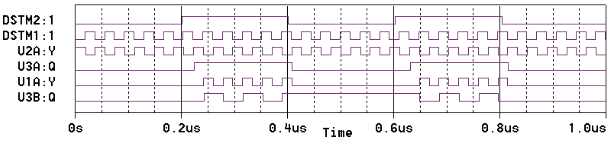


FIG. 3: *Glitchless Operation of Clock Gating Circuit*

Referring now to the simulation result shown in FIG. 3, several signals are shown describing the operation in time of the clock gating circuit when supplied with clock signal DSTM1:1 and select line signal DSTM2:1. U2B:Y shows the inverted clock which is fed into D-flip-flop U3B. U3A:Q shows the re-synchronized select line pulse. U1A:Y shows the gated clock. U3B:Q shows the gated output of the circuit after frequency division.

The camera controller consists of a low cost 8-bit Microchip PIC16F877A microcontroller embedded into the video combiner. It is programmed to execute the flowchart shown in FIG. 4 which is here described in terms of the stereovision implementation of the proposed system but is easily extended to systems involving more than two cameras. This flowchart describes a simple but novel method for ensuring the preservation of synchronized camera behaviour during the power up sequence and also during any configuration changes performed in the cameras.

After power-up, the controller initializes the interrupts handler and enables or disables the relevant interrupts in the microcontroller. Next, the I/O ports are initialized followed by the initialization of the RS232 and I^2C hardware ports. Next, the cameras are reset by issuing a reset pulse on the dedicated camera reset lines. At this point the clock is halted in preparation for the initialization of the two cameras. The initialization of the second camera is performed after the initialization of the first camera but this does not pose a problem so long as the clock remains halted. Then the clock is restarted and the Camera-Link® interface is powered-up. After sending a welcome message over RS232 the controller enters into a wait state. If a command is received during this time, it is first validated and if it is not found to be valid the controller discards it and re-enters the wait state. If the command is on the other hand, valid, the command is accepted and classified depending on whether it is synchronization safe or not. If it is synchronization safe, it is executed and the cameras are updated.

If the command is not synchronization safe, the clock is halted, the command is executed, the relevant registers within the camera are updated and finally the clock is restarted.

After completion of command processing, the cameras controller re-enters the wait state in order to accept new commands.

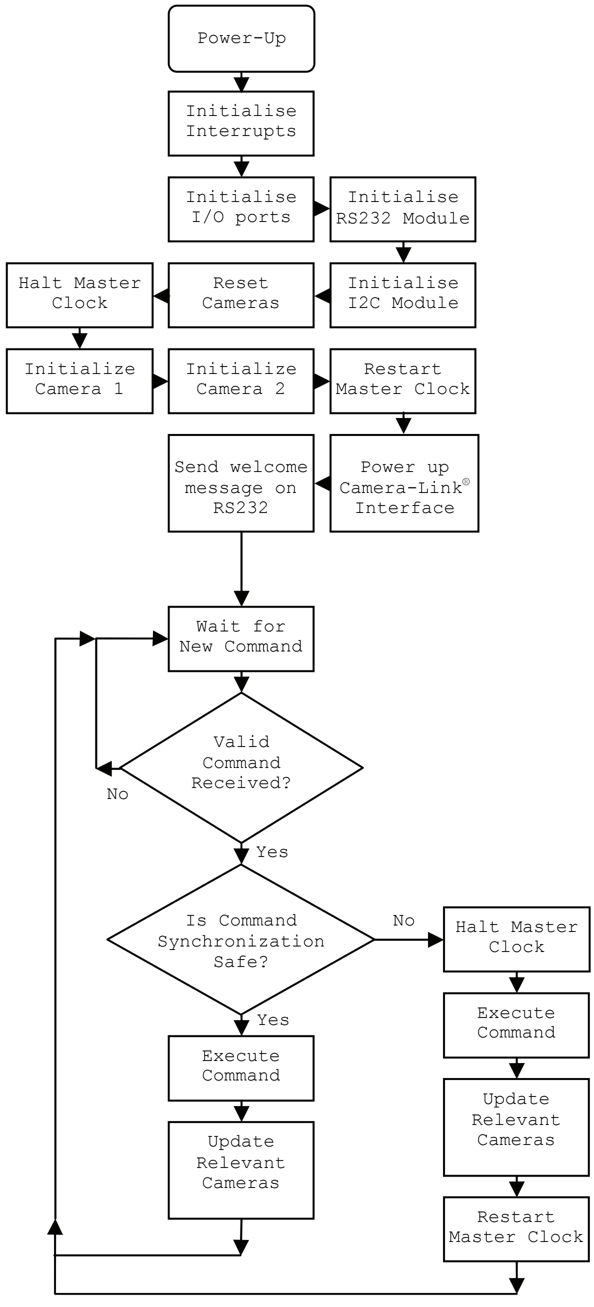


FIG. 4: *Command Marshalling by the Camera Controller*

5. VIDEO MULTIPLEXING

The second major role of the video combiner module is to multiplex the video streams onto a single interface. It starts by collecting the video data from each camera, which at this point can be assumed to be in near perfect synchronism. The corollary of this is that the frame, line and pixel synchronization signals from all the cameras are practically indistinguishable and all but one can be discarded.

In order to multiplex the video streams over a single interface, the video combiner emulates a multi-tap video source to simultaneously transmit all the streams together with a single set of synchronization signals. This exploits the fact that most off-the-shelf machine vision frame grabber hardware is already equipped to handle and de-multiplex multi-tap video. The classic way of transporting multi-tap video was to have parallel data links. However, this defeats the light weight and low cost objectives. A different method is therefore required.

Camera-Link® natively caters for multi-tapping and the official specification already defines several modalities for transporting multi-tap video over a single interface. Provided that the video streams are in perfect synchronism, (as would be the case had they come from a real multi-tap camera), they can be transmitted over Camera-Link® without any additional processing or buffering.

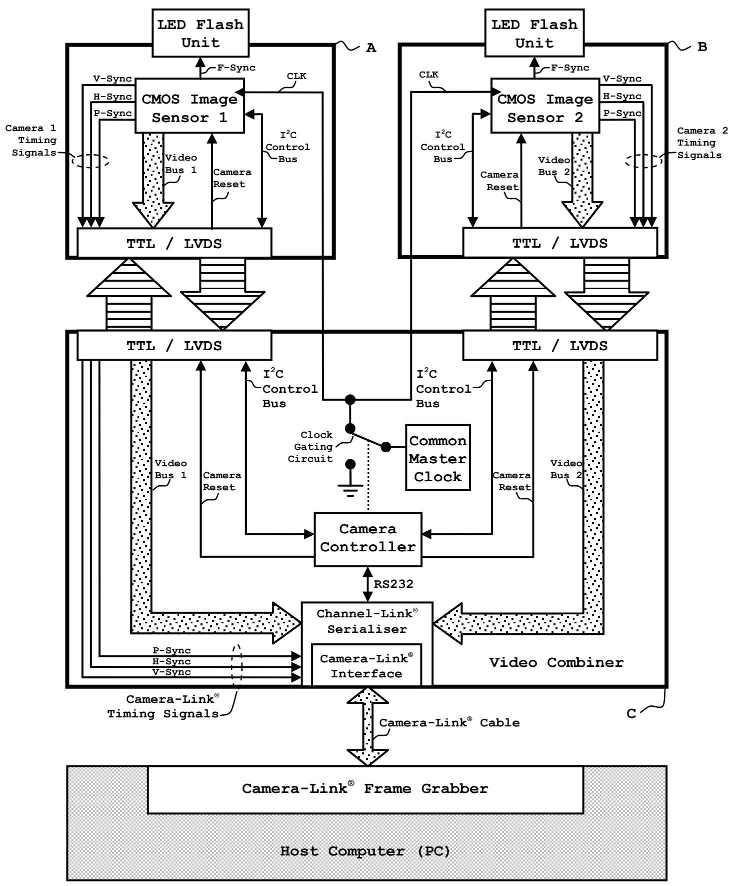


FIG. 5: *A Stereovision Implementation*

The drawing in FIG. 5 shows, some architectural detail of the stereovision camera system. It comprises two cameras (A and B), a stereovision video combiner (C), a Camera-Link® cable, a Camera-Link® frame grabber, and a host computer.

As previously mentioned the cameras are identical in every respect. The left camera is operated as a master while the right camera is operated as a slave but this distinction is merely the result of the way the outputs from the cameras is treated by the video combiner. Each camera comprises a CMOS image sensor which triggers an LED flash unit using a dedicated flash sync pulse. The image sensor generates TTL timing signals and drives a video bus while it accepts a clock, an I^2C serial control bus and a TTL camera reset signal.

The cameras are connected to the video combiner with a high integrity bidirectional LVDS link which carries the video bus and the timing signals towards the combiner and carries the camera reset and control bus towards the cameras. TTL to LVDS transceivers at both ends, perform the conversion in both directions.

The video combiner comprises, amongst other things, a common master clock, a clock gating circuit, a camera controller, a Channel-Link® serialiser and a Camera-Link® Interface. The Channel-Link® serialiser takes the two video busses and the Camera-Link® timing signals and serializes them onto four high speed differential serial lines. These are then mapped onto the Camera-Link® interface as defined by the standard and finally transmitted over the Camera-Link® cable to the frame grabber. The host computer ultimately receives and de-multiplexes the video data to produce a wide stereo-image.

6. IMPLEMENTATION RESULTS

The stereovision system was implemented using the following core components:

- Atmel AT76C410AB Prototype Automotive Image sensors
- Arizona Microchip PIC1LF877A 8-Bit flash microcontrollers
- National Semiconductor DS90LV048ATM LVDS to TTL Receivers
- National Semiconductor DS90LV047ATM TTL to LVDS Transmitters
- National Semiconductor DS90CR287MTD 28-Bit 85MHz ChannelLink® Serialisers
- Texas Instruments Excalibur PT4826N DC/DC Converters

All system modules were assembled in-house on 6-layer PCBs which were fabricated at Beta Layout GmbH. The camera controller was programmed in a hybrid C/ASM language. FIG. 6 shows photographs of the finished camera modules while FIG. 7 shows the video combiner.

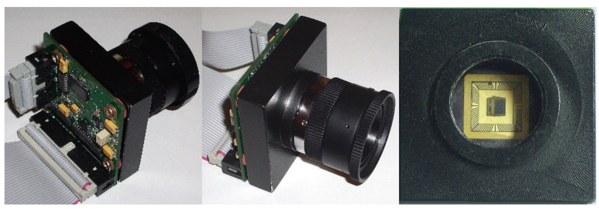


FIG. 6: *The Camera Modules*

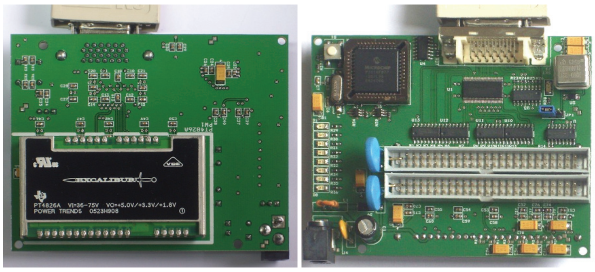


FIG. 7: *The Stereovision Video Combiner Module*

7. TESTING PHILOSOPHY

Four copies of the entire system were produced and in every case, testing was carried out over five stages to comprehensively assess different aspects of the stereovision camera system.

SYSTEM INTEGRITY – The first tests focused on the quality of the design, board-fabrication and assembly processes. These ensured that the final systems were free from manufacturing defects. Defects were identified and corrected.

STEROVISION SYNCHRONISATION – The second set of tests focused on the primary objective of the project – that of achieving unconditional precision synchronization and efficient video multiplexing. These tests validated the novel concepts developed during this project.

FIRMWARE STABILITY – All the software residing in the camera controller was meticulously tested and every possible execution path was verified to be able to guarantee stability in most scenarios.

IMAGE SENSOR PERFORMANCE – The prototype automotive image sensors had numerous novel features and performance attributes applicable to the automotive scenario. These were tested and compared with the manufacturer's expected behaviour [Atmel, 2006].

OPTICAL QUALITY – Finally the optical performance of the cameras was assessed and the data collected was used to perform fine adjustments to obtain focus uniformity and optical axis alignment.

8. TESTING METHODS AND RESULTS

HISTOGRAM TESTS are one of the most effective diagnostic methods for camera circuits. These quickly provide insight into the integrity of the entire video data path. Any stuck bits are quickly manifested as periodic gaps in the histogram. The periodicity of the gaps indicates the affected bit while the orientation (right or left handed) indicates the type of fault (stuck at high or stuck at low respectively). For an ***X*** bit image, the periodicity ***P*** of the histogram artefact indicates the affected bit ***B*** where: $B = X - \log_2(P)$.

FIG 8 shows the normal histogram of a complex image captured with one of the cameras.

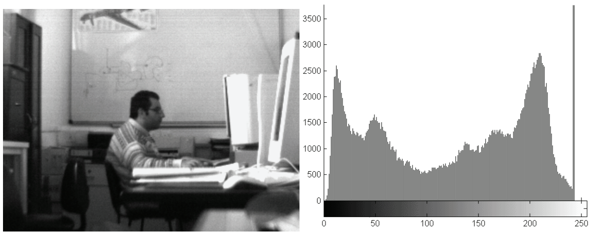


FIG. 8: *Histogram Test Results for normal operation*

VIDEO MULTIPLEXING TESTS were initially demonstrated without the use of any cameras. A chequer-board test image generator was constructed using a system of counters on an FPGA and the ensuing data was fed into a Channel-Link® serialiser, emulating a multi-tap video source. This in turn, delivered the test video streams to a frame grabber. The resulting images were carefully analyzed for picture tears and jitter but none were detected. FIG. 9 is a screen shot of the received test stereovision image as de-multiplexed by the receiving frame grabber.

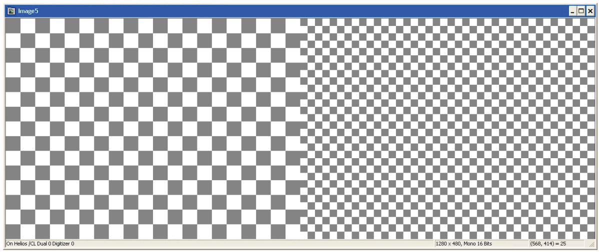
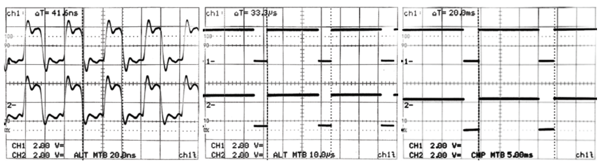


FIG. 9: *Multi-Tap Video Multiplexing Test*

SYNCHRONISATION TESTS were performed directly and indirectly. The former consisted simply in an oscilloscope comparison between the video synchronization pulses generated by the two cameras in the system. The slightest synchronization misalignment would immediately be apparent as a phase difference between these pulses. FIG. 10 shows the oscilloscope test results for the pixel, horizontal and vertical synchronization signals respectively. The top traces pertain to the master camera while the bottom traces are derived from the slave. The phase difference between the traces was immeasurable using a 2.5GS/s oscilloscope and stood substantially less than 1ns.



(a) P-Sync (b) H-Sync (c) V-Sync

FIG. 10: *Direct Synchronisation Test Results*

The indirect method of testing was that of operating the stereovision system while connected to the frame grabber. The slightest phase difference between the two cameras would cause easily detectable picture tears. FIG. 11 shows a stereovision capture test result, and as can be observed, no picture tears are present.

FIG. 11: *Indirect Synchronisation Test Results*

This should then be compared with a control test in which the clock gating function was deliberately disabled during the initialisation sequence. FIG. 12 shows the resulting picture tear in the slave camera image (ie: the left half), as expected.

IMAGE SENSOR PERFORMANCE was tested in a number of ways. The sensors were engineering samples and the tests were mostly intended to check whether these prototypes were operating as expected but also to ensure that the overall camera design is well behaved in all conditions.

The Nominal Photo-response Characteristic of the cameras was measured directly using a Mastech LX1330B Digital Luxmeter. A 75W incandescent lamp at a colour temperature of 2820K was used as a reference light source. The luminous exposure (in Lux.seconds) was modulated by adjusting the distance between the source and the cameras, by using mesh filters and finally by altering the total integration time at the sensors. This gave a wide enough range for luminous exposure. FIG. 13 shows the resulting response.

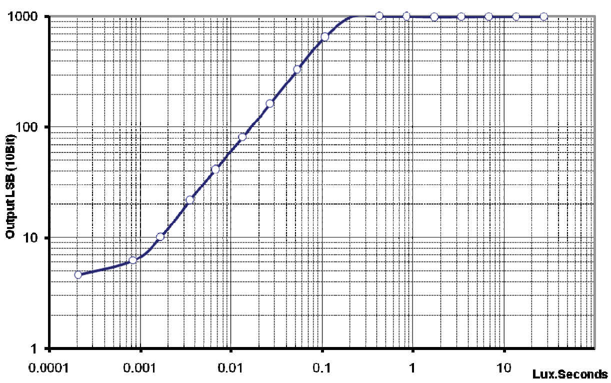


FIG. 13: *Nominal Photo-response Test Results*

The photo-response characteristic was linear for the most part but non-linear at the higher light levels. This combination permitted excellent behaviour at normal illumination levels but at the same time it extended the dynamic range to an impressive 123dB, [Berger, 2006], to allow the cameras to handle direct sunlight. This is a distinguishing feature between automotive-grade image sensors and other sensors. FIG. 14 shows the resulting images before (left) and after (right) compensation for the nonlinear characteristic.

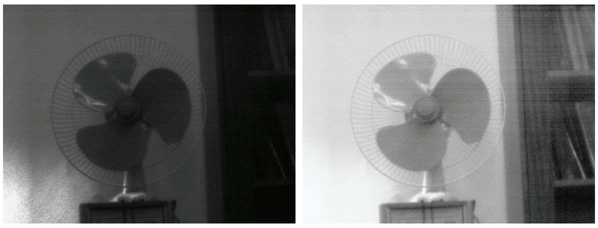


FIG. 14: *Before and After Nonlinearity Compensation*

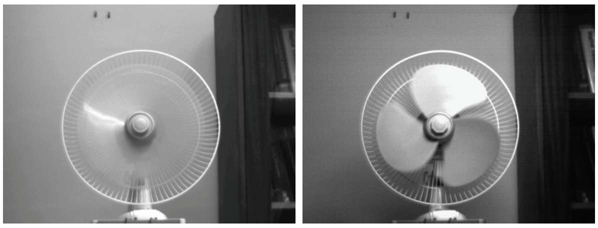
Adjustable Dynamic Range: The image sensors also have the capability of altering the partitioning between the linear and nonlinear portion of their photo-response characteristic. This allows the user to sacrifice linearity in return for better dynamic range performance. This can also be rapidly adjusted in real-time which allows machine vision algorithms to optimize the dynamic range depending on the operating circumstances.

The advantage of an adjustable dynamic range is clearly demonstrated in a particularly challenging scenario as shown in FIG. 15, where a modestly illuminated background is contrasted with a bright fluorescent lamp shining directly into the camera lens. The left image was taken with the camera running with its nominal dynamic range and shows severe over-exposure. However, after adjustment the result is the image on the right which shows distinct background and foreground features with little, if any, over-exposure.

FIG. 15: *Dynamic range test results*

High Speed Operation is another essential feature of automotive cameras. This impinges directly on the ability to faithfully capture fast moving objects. In the SENSATION project, fast eyelid blinking movements and eye saccades had to be closely monitored and measured and any motion blur would have been a severe handicap. This automatically required the use of a global shutter together with a sustained frame rate of at least

200Hz and integration times as short as 1ms. These features were tested using a *fan test* in which a rapidly spinning fan propeller was imaged under various conditions. FIG. 16 shows a fan spinning at its maximum speed of 1311 RPM (19.9m/s) imaged once with an integration time of 16ms and another time with an integration time of 1ms. Integration times as short as 125μs are possible but at 1ms it can be seen that there is very little motion blurring and no motion distortion.



(a) 16ms (b) 1ms

FIG. 16: *High speed Operation at Full Resolution*

Region of Interest (ROI) mode: In order to allow very high frame rates without overwhelming the internal image sensor ADC with samples and the host computer with data, a special region of interest (ROI) mode is included. This restricts the field of view to a small portion containing the object of interest and can be resized and shifted in real-time to track the object. The reduced number of pixels allows substantially higher frame rates to be achieved - up to 750Hz for 10000 pixels. The cameras also allow sequential tracking of multiple ROIs – up to 8 can be defined. FIG. 17 shows a test target image and FIG. 18 shows its decomposition using the Multi-ROI feature.

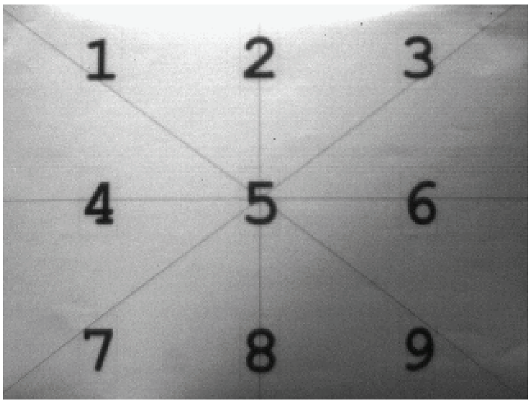


FIG. 17: *ROI test target image*

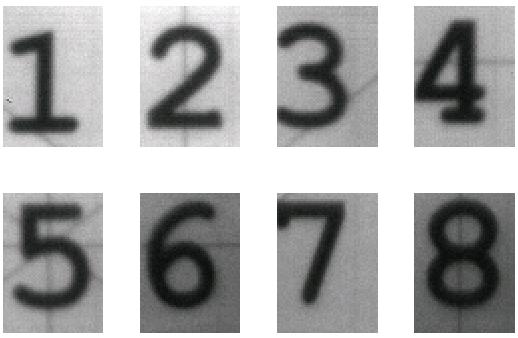


FIG. 18: *8-Way Multi-ROI decomposition*

9. SUMMARY OF RESULTS

Various other results and system characteristics are summarised in TABLE 1.

Parameter	Result Achieved
Resolution	640 x 480 Progressive scan
Output Format	10 bits digital
Sensor Fabrication Technology	0.18 μm CMOS monochrome
Resolution	640 x 480 Progressive scan
Optical Format	1/3"
Colour Depth	10 bits monochrome
Pixel Size	6μm x 6μm
Pixel Rate	Max 27MHz
Integration Time	20.8μs up to 1.36s
Optical Dynamic Range (non-lin)	123 dB
Sensor Power supply (Analogue)	3.3 V
Sensor Power supply (Digital)	1.8 V
Spectral range	350 – 1,050nm
Electronic Shutter	Global Shutter
Anti-Blooming Feature	Yes
Region of Interest (ROI) Mode	Yes
Multiple ROI Mode	Yes: 8-Way
Sensor Configuration Interface	I^2C
Camera Configuration	Software
Camera Configuration Interface	Serial: RS232
Camera Frame rate (full format)	59.8 fps Max @ 24MHz
Camera Frame rate (10k ROI)	750 fps Max @ 24MHz
Camera Pixel Rate	24MHz (max 27MHz)
Image Transport Lag	1 frame duration
Configuration Interface Speed	9,600 or 19,200 Baud/sec
Camera Dimensions (W x H x D)	54 x 54 x 37 mm^3
Video Interface	Single Base Camera-Link™
Safely Aspects	Over-voltage, over-current, polarity-inversion protected
Stream Synchronisation	< 1ns (<< 1 pixel clock cycle)
Power Supply	36V to 75V dc
Power Consumption (at 50 fps)	3.44W
Image Sensor Package	CLCC 84
Lens Port	C-Mount
Operating temperature	*0° to +40°C*

TABLE 1: *Summary of Results*

The stereovision system was finally deployed for driver vigilance monitoring in a luxury test vehicle; "The Lancia Thesis 2.4 20V Emblema" at FIAT, Turin which was then tested successfully at the Centre for Research and Technology Hellas (CERTH) in Thessaloniki. FIG. 19 shows a photo of some of the equipment installed in this vehicle.

FIG. 19: *System installed in a Lancia Thesis Emblema*

10. DISCUSSION

In this paper, a method is presented which exploits the similarity of behaviour and performance of matched cameras (or image sensors) by subjecting them to a common clock as well as managing their operating conditions, thereby guaranteeing an identical internal state and synchronized output timing behaviour which will in turn permit the combined transmission over great lengths over a single standard interface.

This method not only addresses the issue of generating accurately synchronized video signals in a simple and very economical way, but also avoids the need for transferring frame or line synchronizing pulses between cameras. This avoids the delays associated with the transmission of such pulses making it applicable to systems requiring very high speed operation without posing serious restrictions on the relative positioning of the cameras. Much higher frames rates can be realistically achieved this way. This method also avoids the need for a "store and forward" mechanism and hence does not incur any of the cost, complexity and latency associated with internal buffering used in other methods.

In addition, the high precision synchronisation afforded by this method allows the aggregation of multivision cameras into a system that mimics a multi-tap camera. This allows the combined and faithful transmission outputs of several cameras over a single Camera-Link® connection over substantial distances. The method presented here extends, without violating, the provisions for multi-tap video as laid out in the Camera-Link® specification.

11. CONCLUSIONS

The system presented here offers a complete, high accuracy and high performance video multiplexing solution for multivision applications in general. However, the system was designed, built and tested for the automotive environment and was even built around the latest automotive image sensors, making it as realistic to the application as practically possible. The demonstration system produced is of course in an experimental prototype phase in many respects and future work will be placing all of the interface logic into an FPGA or ASIC which will reduce size and power consumption by a further 80% at the very least.

However, the most significant contribution is the very substantial reduction in the required cabling with the associated weight and cost savings. This method makes it possible to break new barriers in this regard which will be particularly attractive in the automotive sector.

12. ACKNOWLEDGMENTS

This project was partially funded by the EU through the IST-507231 SENSATION project. I wish to acknowledge the SENSATION project consortium for their valuable contributions to this work.

13. REFERENCES

[ABI-Research,2007] ABI Research, "Camera-Based Automotive Systems Regional Forecasts and Key Competitive Assessment for Driver Assistance Technology", Market Research Report, RR-CBAS, ABI Research, 2007, New York, USA.

[AIA, 2006] AIA, "Camera Link® - Specifications of the Camera Link® Interface Standard for Digital Cameras and Frame Grabbers", Version 1.2, AIA (Automated Imaging Association), Jan 2006, Michigan, USA.

[Atmel, 2006] Atmel Imaging, "Automotive B&W VGA CMOS Image Sensor", AT76C410ABA Preliminary Datasheet, Rev. 0.5, Atmel Corporation, Mar 2006, Grenoble, France.

[Azzopardi,2008] Azzopardi, M. A., "Method for Synchronizing Stereovision or Multivision Camera Systems for combined transmission over Camera-Link®", Malta Patent, No: MT#4230, University of Malta, Filed Sep. 2008, Valletta, Malta.

[Beecham,2008] Beecham, M, "Global market review of driver assistance systems - forecasts to 2014", 2008 edition, Just Auto, Chapter 3 - Technical review. Aroq Ltd., Jul 2008, Worcestershire, UK.

[Berger, 2006] Berger P. D., "CMOS High Dynamic Camera", Sensation, Characterisation Report, Atmel Corporation, Mar 2006, Grenoble, France.

[Chen, 2002] Chen, Tsuhan, et al., "Frame synchronization in a multi-camera system", US Patent, No: US#6340991, Primary Classification: 348/513, AT&T Corp, Jan 2002, Pennsyl., USA.

[Cooper, 1999] Cooper, A. N. et al., "System and method for synchronization of multiple video cameras", US Patent, No: US#5995140, Primary Classification: 348/159, Ultrax Inc (US), Nov 1999, Texas, USA.

[Cooper, 2004] Cooper, A. N. et al., "Digital camera synchronization", US Patent Application, No: US#20040017486, Primary Classification: 348/211.100, Jan 2004, Texas, USA.

[Edens, 1998] Edens, G., Hoover, D., Meike, R., Ryan, T., "Synchronous network for digital media", US Patent, No: US#6611537, Assignee Centillium Communications, Inc., Filed May 1998, Canada.

[Fraunhofer, 2007] Fraunhofer, "GigE/Gigabit Ethernet standard investigation", Fraunhofer Institute for Photonic Microsystems (IPMS), Aug 2007, Dresden, Germany.

[Hoffmann,2006] Hoffmann, I, "Replacing Radar by an Optical Sensor in Automotive Applications" *Advanced Microsystems for Automotive Applications*, Springer Berlin Heidelberg, Book Chapter, pp 159-167, Jan. 2006, Berlin, Germany.

[Kovaks, 2007] Kovacs, J. "An Overview of Genlock", Application Note No:5, MicroImage Video Systems, available at: http://www.mivs.com/ technical/appnotes/an005.html, Oct 2001.

[Matrox, 2007] Matrox Imaging, “Matrox Helios eCL/XCL”, Datasheet/Brochure, Matrox Electronic Systems Ltd, Apr 2007, Quebec, Canada.

[Pan, 2003] Jacob Pan, “Enhanced TCP/IP Performance with AltiVec” White paper, Freescale Semiconductor, Inc., Motorola Literature Distribution, Jan 2003, Colorado, USA

[Phrontier, 2008] “Camera Link Fiber Extenders” product brochures available at: http://www.phrontier-tech.com, Phrontier Technologies LLC, Aug 2008, California, USA.

[Sony-Vision, 2008] Sony Imaging, “Can GigE Vision deliver on its promise?”, Technical White Paper, available at: http://www.sony-vision.com, Sony Image Sensing Solutions, Jan 2008, Surrey, UK.

[Tashiro, 1994] Tashiro, A. “Method and apparatus for synchronizing two cameras”, US Patent, No: US#5307168, Primary Classification: 348/64, Tashiro, Atsushi, Sony Electronics inc (US), Apr 1994, New Jersey, USA.

[Thinklogical, 2008] Thinklogical, “Camera Fiber-Link” product brochures available at: http://www.thinklogical.com/product.asp?ID=32, Thinklogical, 2008, Connecticut, USA.

[Trammell, 1986] Trammell, J. E., “Apparatus for synchronizing two video pictures by controlling vertical synchronization of a video camera”, US Patent, No: US#4568976, Primary Classification: 348/516, Feb 1986, New Jersey, USA.

[Trinkel, 2002] Trinkel et al. “Synchronization of a stereoscopic camera” German Patent, No: DE#10,044,032, March 2002, Untermaubach, Germany.

[Tserkovnyuk, 2005] Tserkovnyuk, Walter V., et al., “3D camera”, US Patent, No: US#6950121, Primary Classification: 348/47, Vrex Inc. (US), Sep 2005, New York, USA.

[Turner,2000] Turner, J. D., Austin, L., “Sensors for Automotive Telematics” *Meas. Sci. Technol.* 11, R58-R79, Issue 2, Feb. 2000, Berkshire, UK.

[U, 2004] U, J., Suter, D., "Using Synchronised FireWire Cameras for Multiple Viewpoint Digital Video Capture", Technical Report, Electrical and Computer Systems Engineering, Monash University, November, 2004, Clayton, Australia.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AIA – Automated Imaging Association
CCD – Charge Couple Device
DLL – Delay-Locked Loop
DSNU – Dark Signal Non-Uniformity
FPN – Fixed Pattern Noise
FVAL – Frame Valid
HMI – Human Machine Interface
H-Sync – Horizontal Synchronization Signal
LADAR – Laser Detection and Ranging
LVAL – Line Valid
LVDS – Low Voltage Differential Signal
NIR – Near Infra Red
OCS – Occupant Classification System
ODS – Occupant Detection System
OPS – Out of Position Sensing
OWS – Occupant Weight Sensor
PLL – Phase-Locked Loop
PRNU – Photo response Non uniformity
P-Sync – Pixel Synchronization Signal
QoS – Quality of Service
RADAR – Radio Detection and Ranging
ROHS – Reduction on Hazardous Substances
ROI – Region of Interest
SODAR – Sonic Detection and Ranging
TWI – Two Wire Interface
V-Sync – Vertical Synchronization Signal