Seamless Design Space Exploration for Automotive Systems

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***Abstract*— The paper reports a successful design experience, revealing: the value of open-software and design frameworks to shrink up design time; the need of deserving significant effort and time to the conceptual phase of the design; the still significant importance of board-level design, especially when different volumes can produce changes in the cost-effectiveness analysis. The system we developed (BikerEye) seats on top of a free-version of a vehicular wireless platform tailored for the two wheels market. BikerEye is a multimedia system whose goal is to enhance the capability of a motorbike driver with a camera, a microphone and some recording capability. The paper compares some of the main design alternatives according to a set of metrics and highlights the role of software w.r.t. dedicated hardware in providing flexibility to the design.**

I. Introduction and Paper Goal

Embedded system designers have to face a number of severe constraints, including performance, size, cost, time-to-market, power consumption, etc, before committing the final implementation of a product. The main problem is to tradeoff such goals while maintaining sufficient flexibility to enable design space exploration and a time-to-prototype of a few months.

The goal of this paper is to report a successful design experience, revealing:

- The value of open-software and design frameworks to shrink up design time;
- The need of deserving significant effort and time to the conceptual phase of design;
- The still significant importance of board-level design, especially when different volumes can produce changes in the cost-effectiveness analysis.

The system we are considering as a running example is a project called BikerEye, sitting on top of a free-version of DVD, the vehicular wireless platform developed at CEFRIEL [1], tailored for the two wheels market.

BikerEye is a multimedia system whose goal is to enhance the capability of a motorbike driver (already connected to the wireless navigation and telematic functions of DVD) with a camera, a microphone and some recording capability.

The focus of this paper is on the comparison of the main design alternatives according to a set of metrics and the role of software w.r.t. dedicated hardware in providing flexibility to the design.

II. System Architecture

After some interaction with the project stakeholders, the following main functional requirements have been identified.

- Acquisition of still images, compression and storing in JPEG format.
- Recording of a voice-commented video, with compression of both data flows and storing in MPEG-4 standard.
- Realization of mechanisms for user authentication to prevent tampering of images.

In addition to these functional goals, other constraints have to be highlighted, related to the application field and realization technology.

- Form factor and energy consumption to allow integration into vehicular environments.
- Cost, flexibility and reliability, to meet a mass market.
- Integration of the new application software with existing development platforms, while allowing easy replacement of components and retargeting of code.

The preliminary analysis of BikerEye functional requirements, leads to the identification of three main functionalities (acquisition, communication and processing) interfacing the vehicle through DVD, as shown in Fig.1. The data acquisition subsystems are a microphone for the audio, a

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camera for the video and a helmet where devices are mounted on, to capture the viewpoint of the driver in a distract-free manner. Communication and computation capabilities are provided by the platform, in which both hardware and software components coexist. Processing mainly involves audio and video codecs and manipulation algorithms, editing procedures, security checks.

The vehicular platform architecture is based on commercial hardware components (COTS) and some open source libraries, to shrink up time-to-prototype while evaluating at no cost alternative realizations. The choice of the design granularity, at the function level, allows to plug-in hardware or software modules without introducing heavy redesign steps.

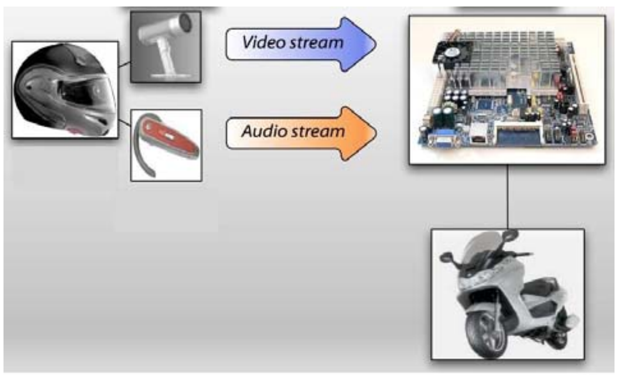

Figure 1. Architecture of BikerEye (left) and link to the vehicle via DVD (right).

The software layer is based on a free version of the DVD that sits upon the Linux operating system, as shown in Fig.2.

Ready-to-use and well tested components as well as standardized interfaces were exploited to integrate both Hw and Sw components. This allows minimizing the effort dedicated to the development and testing phase of the system while providing the flexibility to evaluate different choices for each component the system must integrate. The result is a flexible architecture which allows concentrating on the proposed parameters without affecting the evaluation with undesired effort in the tuning of the system.

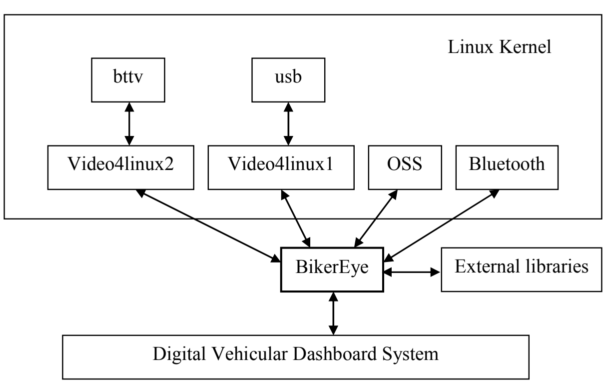

Figure 2. The software system architecture.

III. POPULATING THE DESIGN SPACE

Two sets of metrics have been defined to classify design alternatives. The former includes per unit and NRE costs, while the latter comprises system performances, for example in terms of quality of the output images and video, processing time and power consumption. Time to prototype in the perspective of expected time to market have been also considered, especially because of the design lifecycle for the automotive market is approaching 15-18 months, so that one/two months of delay can cost 30% of market loss.

Alternative Hw-Sw computing elements have been compared only for data intensive functions, i.e. mainly for the audio and video processing. Four different subsystems were identified: acquisition, communication, elaboration and application. For each set of components alternative implementations have been evaluated, based on real market commercial availability. Different requirements were considered when selecting the components. Structural requirements such as weight, dimensions and energy consumption must be taken into account for integration in an automotive environment; cost and reliability are two factors that influence the diffusion on the market; off-the-shelf components allow an easy integration with the DVD platform, etc.

For the acquisition, different audio and video devices were considered, including analog vs. digital as well as wireless vs. USB cameras. Acquisition devices based on analog technology allow a good image quality and off-the-shelf components which are resistant to ambient conditions are already available. USB acquisition devices allow keeping costs low, while suffering for low quality and resistance. Wireless devices are the least invasive in respect of the environment but they offer low quality and resistance too, raising the costs in respect of the previous solution. As far communication is concerned, two candidate technologies have been selected: a wireless link based on Bluetooth technology and cable links.

For the elaboration subsystem, two devices were evaluated. The first option allows keeping costs low while offering basic features: the software application will implement the requested features to complete the scenario. The second option exposes more complex features, allowing keeping system load low – and thus power consumption – while raising costs.

The application was designed to be highly modular; its architecture is based on well designed interfaces, allowing to include software modules as well as to exploit specific capabilities the Hw provides without requiring heavy redesigns or modifications. This design allows keeping the effort low while exploring the solution space. The application includes also features related to functional requirements such as automatic brightness calibration, blur filters, frame entitling and logo addition, and the insertion of security controls to detect malicious data modification. This allows a more detailed accounting of the design and development phases for automotive systems where complex user requirements have to be considered.

The overall analysis leaded to the definition of the following two reference designs (summarized in Tab.I);

Solution 1 includes an analog acquisition device, a BT878A for the elaboration step, and software-based solutions for the compression and further elaboration of the acquired images and video sequences. This solution allows having a good quality of the acquired multimedia information and an excellent resistance to external environment and vehicle conditions.

Solution 2 is based on USB solutions; the selected hardware device integrates video elaboration features, keeping the software requirements lower. This solution allows keeping costs and power consumption low while not providing the same degree of resistance as Solution 1.

These two candidate implementations have been evaluated and compared according to some metrics, the most relevant summarized in Tab.II and represented graphically in Fig.3. We analyzed first of all the overall cost, considering a COTS implementation that is suitable for the two-wheel markets with low medium volume, for both solutions. In addition the operating environment has been considered in terms of size, weight and physical resistance of the realization, using a qualitative ranking (High-Low). Flexibility and quality of the solution are more related to the management of the design process and market positioning, instead of the operating constraints. For this reason, they have been considered separately w.r.t. other parameters.

The graphical representation of the above mentioned evaluation figures is depicted in Fig.3, where we have not adopted any goal function to compare the alternatives.

TABLE I. CHARACTERISTICS OF THE TWO REFERENCE DESIGNS.

	Solution 1 **Analog system**	**Solution 2** **USB system**
Video acquisition	Viosport Adventure Cam II	Webcam (STV0676+VS6502)
Audio acquisition	Analog Microphone	Analog Microphone
Video communication	Composite video cable	USB Cable
Audio communication	Analog audio cable	Analog audio cable
Video conversion	BT878A	Not necessary
Audio conversion	Soundcard VIA	Soundcard VIA
Image compression	Software based	Software-based
Video compression	Software based	Software-based
Audio compression	Software based	Software-based

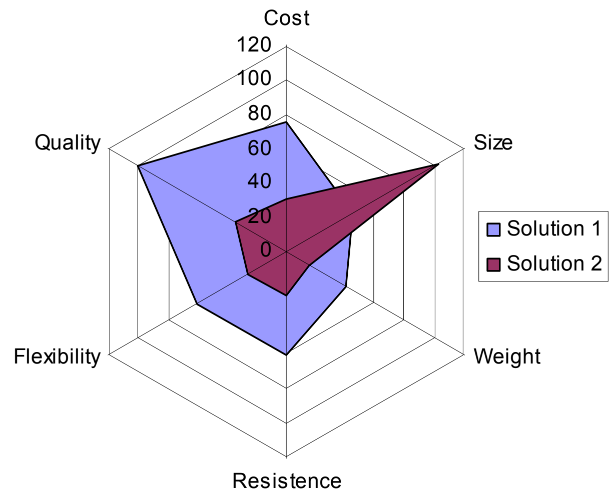

Figure 3. Comparison of the two design alternatives of TABLE II.

TABLE II. COMPARISON OF ALTERNATIVE SOLUTIONS.

	Cost	**Size**	**Weight**	**Resist**	**Flex**	**Quality**
Sol. 1	102	20 (ø) x76	180+160	High	High	High
Sol. 2	31	80x47x86	80	Low	Low	Low

IV. DISCUSSION

The final tradeoff between the solutions has to consider some feeds regarding the application context, pricing and expected volumes: our choice for the realization of the prototype is Solution 1, based on BT878A. Such choice (see Fig.3) gives less importance to the form factor, weight and cost, when compared with quality and flexibility of the implementation.

The biasing is fully justified during the “seed” stage of a product, when frequent tunings of the design requirements are expected and the feedbacks coming from the testing of samples by final users are crucial to gain acceptance, i.e. moving towards the real industrialization. Cost and size reduction, can be considered in a later phase of the development, when the viability of the product is demonstrated.

During the development, it has been shown that is possible to quickly achieve a fully functional prototype, based on open software (in a high-demanding application field), to be used for testing, demonstration and tuning of product specification. This significant result produces a valuable reduction of the overall design time, with an improved management of the development risk. Despite the short design time, the quality of the results is good.

The software uses FFMpeg library for the video elaboration, Lame library for audio elaboration and Freetype2 library to manage the fonts of the text appearing overlapped to the video.

Fig.4 shown one of the BikerEye output, where the user can take snapshots with some overlapped information.

Figure 4. Processing of still images, with overlapped information.

Due to the granularity of the Hw and Sw components and the saving of the typical overheads in achieving commercial agreements, we were able to redirect the effort in the evaluation and tuning of the architecture.

The development phase accounts 1 PM while the design space exploration required 2 PM. The achievement of 3 PM for the time-to-prototype is a valuable driver for the selection of commercial partners and the optimization of the product industrialization. The final realization can consider other commercial Sw components, instead of open code, but having in the hands a really working reference prototype design it is a crucial milestone for the success of the product.

V. CONCLUSIONS

The paper presented a design experience for a multimedia system targeting the automotive market. Such application field is characterized by short time to market and the need of extensive and time-consuming testing of prototypes, with the risk of achieving the right product too late, when the market is no longer attractive.

To cope with such requirements, we presented an approach based on the use of COTS and breadboard (a mature technology, still popular and flexible for the application field) and some figures of merit for the design space exploration. Moreover, we fully based the design of the candidate solutions on the availability of free software, to show the lower boundary for the time-to-prototype that it is possible to achieve.

The obtained results are promising; in three months we delivered a fully functional running system, in a form usable for user testing and suitable to become the base for product industrialization.

Our previous experience in similar design based on commercial solutions reveals that, considering all the delays in achieving a proper set of agreements with the suppliers, we achieved at least a speedup of 50%.

REFERENCES

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