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The Mobile Drawing Assistant*

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This paper presents a prototype system that combines novel kinds of hardware devices, such as wireless multimedia players and wireless projectors, with an intelligent sketch-based drawing application running on wireless Tablet-PCs. It provides a mobile assistant that can be used by a teacher to communicate graphic information to students in a very intuitive and friendly way, allowing the creation of exact geometric constructions using freehand drawings. Hardware requirements to support this application are described and a pilot experience where the prototype system was used is presented.

Keywords: freehand sketching; sketching recognition; wireless projection

INTRODUCTION

IN MANY ENGINEERING DISCIPLINES, displaying and creating geometric constructions during an explanation to the students is performed by the teacher directly on the blackboard. To achieve the drawing skills to create acceptable drawings on the blackboard is not a trivial task. Even if the complexity of the constructions is medium, in many cases, teachers are forced to show slides with the complete geometric construction already done. Slides are often not the best didactic resource if the teacher is trying to explain the process of creating a geometric construction. Slides provide static information, whilst a teacher drawing on the blackboard provides dynamic information, and often this dynamic characteristic is needed to understand a concept or the associated process.

One alternative, avoiding the direct creation of constructions on the blackboard, would be for the teacher to use a computer drawing application, and use a videoprojector to display their screen content. This approach has some drawbacks: sometimes students can be distracted by the software used by the teacher. In practical cases or problem realization classes, students are required to participate in the problem resolution; this means that the application used by the teacher must also be familiar to the students, and this is not always possible.

A second option could be to use an interactive electronics whiteboard (IWB) to capture the attention of the whole class [1]. These devices support touch interaction or employ an electronic pen instead of a keyboard and mouse interaction. If combined with the proper software they can provide a very stimulating tool to improve both teaching and learning processes.

However, another approach might be to combine Tablet-PCs with wireless projection systems. It provides an alternative that is as effective as an IWB but is clearly cheaper. In this paper we analyse current technology to support wireless projection, concluding that at its current development level it provides an interesting alternative to IWBs.

We believe that sketch-based interaction is one of the most promising approaches to deliver friendly and powerful educational applications. In our case, we have developed a drawing application that exploits freehand sketching, which is a typical skill developed in the freshman engineering courses. This application can be run on a Tablet-PC connected to a wireless projection system. Here we give an example of a mobile assistant that can be used by teachers and students, which is cheaper than an IWB set up, and gives mobility to the teacher and allows flexibility to explore innovative teaching methods.

HARDWARE REQUIREMENTS

At INFOCOMM 2001 (a US annual A/V trade show) Texas Instruments demonstrated the first wireless presentation example delivering a PowerPoint presentation from a notebook to a prototype projector using the 802.11b protocol. A year later, in the autumn of 2002, Tablet-PCs were launched on the market with the introduction of Microsoft's Windows Tablet-PC Edition. This hardware combination presented new alternatives to more expensive hardware such as electronics whiteboards [2] to create interactive scenarios where a teacher can present and create graphic content

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during a class, using drawing tools equivalent to chalk on a blackboard.

However, the first generation of wireless projectors revealed the limitations of Wi-Fi's 802.11b protocol for showcasing multimedia content and online interaction. They were suited for static presentations but not operative for implementing an interactive sketching application. In the summer of 2004 the first wireless projectors supporting the faster 802.11g protocol appeared on the market. At the same time, second generation models of Tablet-PCs came out using much faster Centrino processors, more RAM and faster graphics processors, also incorporating 802.11g wireless connectivity.

The current generation of Tablet-PCs, provides ultralight computers (weighing as little as 1 kg) with powerful processors and screen sizes from 9 to 14 inches, supporting at least XGA (1024×768) resolution. They provide enough computing power and resources to cope with online freehand sketch recognition and beautification that, combined with an 802.11g wireless connection, allows one to display online interaction with a sketching application on a big screen using a wireless enabled projector.

Two approaches can be found to achieve wireless projection, as shown in Fig. 1. The first one is to incorporate wireless capabilities to an ordinary videoprojector. Usually it is provided by the PCMCIA card connectivity that is available in many videoprojectors. The second approach is to implement video capabilities into a wireless access point, increasing the processing power of these devices and incorporating the typical video connectors. This last approach is very interesting and exploits a standard wired projector infrastructure. Both approaches require installing specific software on the PC to intercept the video frame buffer, and applying compression techniques, then the frame buffer is sent to both projector and access points. It also means that it is necessary to incorporate some computing capabilities in both kinds of devices, this increases its final price with respect to a standard unit.

The trial configuration used is based on a Linksys Wireless-G Presentation Player that can act as a 54Mbps access point, and also provides standard VGA connectivity. It is important to note that software used to send compressed video to the visualization device can interfere with graphic hardware acceleration capabilities in the PC. In our case, hardware acceleration was reduced to a minimum, in order to properly display the OpenGL graphics used by our application. To compensate for this, it is important to choose a powerful processor to power the Tablet-PC, because most of the graphic processing must be done by the CPU. In last generation Tablet-PCs powered with 'dual core' processors this will not be a problem. In our case, the chosen combination of Tablet-PC and multimedia access point has proved very effective, giving an acceptable frame rate.

In the near future, the increasing power of embedded processors, the improvement of encoding techniques and the development of newer protocols in the 802.11 family (protocol 802.11n will provide a $4\times$ throughput improvement over 802.11g) will assure that video content will be able to be delivered to any display device via a wireless connection and higher resolutions and frame rates will be supported.

WIRELESS PROJECTION VS. INTERACTIVE WHITEBOARDS

Interactive whiteboard (IWB) technology is being adopted in developed countries as a tool to improve both teaching and learning processes. For example, the British government has invested more than £50 million in this technology, taking into account its ability to directly support interactive whole class teaching [3]. As seen in Fig. 2, a typical IWB installation comprises a touch whiteboard that receives the image from a projector connected to a computer that is controlled through touch interaction. The main obstacle to IWB's widespread adoption is hardware cost. However, we think that the combination of wireless projector and Tablet-PC offers advantages over an IWB set up. Here, we summarize some of them:

- Lower cost: multimedia access points are much cheaper than touch whiteboards.
- Mobility: the wireless set up can be moved easily. Tablet-PCs and projectors are easy to transport. Touch whiteboards are static devices.
- They are disabled people friendly: students with reduced mobility can use the system accessing the Tablet-PC. They do not have to go to the whiteboard to interact with the running application.
- More flexibility: it is possible to arrange more sophisticated interaction scenarios. For example,

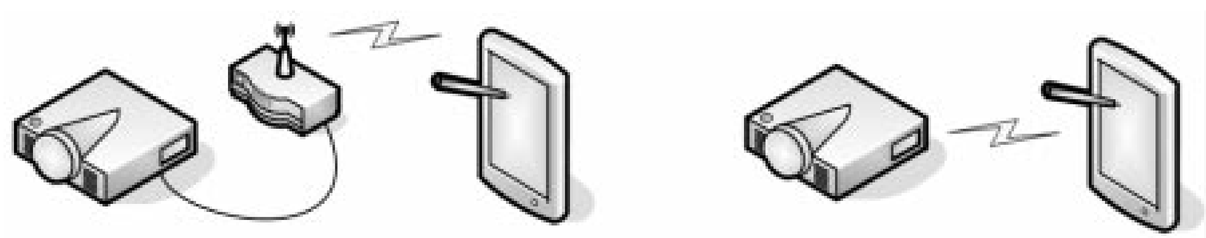


Fig. 1. Wireless connection alternatives: indirectly though an multimedia access point (left) or directly with a wireless projector (right)

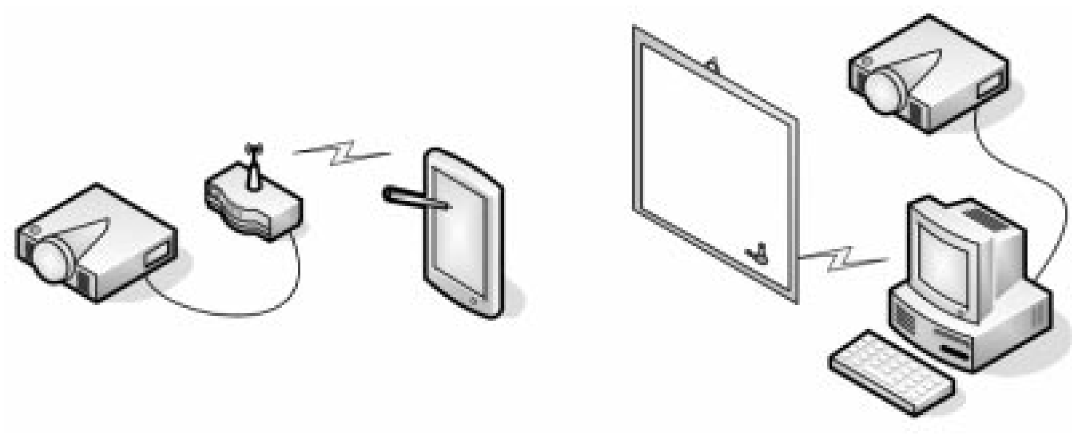


Fig. 2. Wireless projection versus IWBs.

Table 1. Price comparison

IWB configuration		Wireless projection	
Concept	Medium price	Concept	Medium price
Entry level PC	\$500	Entry level Tablet-PC	\$1100
Standard IWB 60’	\$1500	Multimedia access point	\$200
		Screen	\$100
Total price	\$2000	Total price	\$1400

in a class where each student is provided with a Tablet-PC, everybody could perform his/her own exercise and then show it to the rest of the class, taking control on the wireless projector.

Thus we can conclude that a wireless projection scheme provides just as many or more benefits than an IWB set up, but at a lower cost (see Table 1).

INTERACTION WITH AN ELECTRONIC PEN

As commented in [4], one of the reasons that justifies the use of IWBs is that they provide a friendly alternative to mouse and keyboard. Both teachers and pupils find the interaction by touching or drawing on a screen more natural than using conventional PC input devices.

The introduction of IWBs or wireless projection systems must be accompanied by the introduction of software applications adapted to this kind of user interaction. However often it is difficult to find software with these characteristics. Fortunately, the launch of the Tablet-PC in 2002 has created a new market for applications that use an electronic stylus as the primary input. In the future we could see that applications in this niche market can be easily adapted to the educational world.

Some interesting examples of research systems that use interaction based on sketching with a digital stylus are:

- PerSketch [5] is a perceptually supported image editor that uses an image processing approach to perform covert recognition of visual structures as they emerge during a sketching session.
- SILK [6] allows the designer to quickly sketch a graphical user interface using an electronic pad and stylus. It recognizes widgets and other interface elements as the designer draws them.
- ‘Back of an Envelope’ [7] emphasizes recognition and interpretation of graphic input, which is intended to be customized to the domain and to the individual end user. It has been used to index and retrieve items in databases. It has also been used as an interface to simulation programs, and for defining Webpage layout (Webstyler).
- Tahuti [8] is a dual-view sketch recognition environment for class diagrams in UML. The system is based on a multi-layer recognition framework that recognizes multi-stroke objects by their geometrical properties, allowing users the freedom to draw naturally as they would on paper.
- ASSIST [9] enables the sketching of simple two-dimensional mechanical systems in a natural fashion, i.e., without explicitly informing the system what is being drawn. It interprets the sketch as the user draws and can simulate the design at any time during the design process.
- EsQUIsE [10] is an interpretative tool for free-hand sketches to support early architectural design. It is capable of capturing the lines, interpreting them in real time and compose the

technological and functional model of a building being designed.

Drawing on the blackboard

As noted in the introduction of this paper, drawing on a blackboard is a skill that requires time to acquire. To compensate for this, the combination of new hardware devices as IWBs and Tablet-PCs with advanced software could provide an interesting option. In many cases, the automatic conversion of freehand sketches into perfect line drawings would help the teaching task.

In order to provide both teachers and students with a friendly environment to promote interaction and discussion, we have adapted and applied the concepts of augmented paper and minimal interface (see references 11 and 12 for more details) to offer a similar experience to drawing on real paper or a standard whiteboard.

The augmented paper concept relates to the fact that the application operates in the same way as drawing with a pencil on paper. The idea is to draw approximately what you want to get. The system analyses your strokes in real time and adjusts and beautifies them, creating exact geometric constructions from approximated freehand drawings. We could term this a 'What You Draw is What You Get' approach.

The minimal interface idea is very important in an educational context. The user interface must be as unobtrusive as possible. We don't want the students to be distracted by menu navigation or icon selection. Simplicity also means a steep learning curve, as any user can learn to use the software very fast quickly; it usually only takes minutes.

Requirements for a drawing assistant

We can summarize some interesting requirements for a drawing application in this context:

- Simple interface based on sketch interaction, which allows the teacher to concentrate on the explanation and not be disturbed by complex interactions with the software.
- Support for complex geometric constructions providing automatic trim/extend operations and online beautification. If automatic beautification does not provide the expected result the user should be able to impose and edit geometric constrains.
- Dimensional control over the recognized geometric entities using the dimensional tools employed in technical drawing. For example, to create a circle with the diameter of 25 units, we could approximately draw a circle and then insert a diameter dimension of 25 as its dimension text.
- Recording capabilities for future play back of the explanation. It can also be used to deliver partially solved exercises to be completed by the pupils.

In order to satisfy these requirements we have adapted part of a previous application [13] used to build 3D objects from parametric 2D sections created by freehand drawing. The application internally uses a parametric geometry engine that takes care of dimension changes, updating the geometric constructions in a coherent way.

Geometric domain and gesture alphabet

The application interprets strokes that can be recognized as geometry (line, arc, circle and ellipse) or constraint (dimension, parallel, perpendicular, tangent, concentric, horizontal or vertical). Furthermore, drawing entities can be removed using a scratching gesture. This not only allows errors to be corrected but also enables more complicated shapes to be drawn by refining 'simpler' forms. Some of the gestures that the system currently supports are included in Table 2. It is possible to add new gestures to the system as the gesture recognizer can be trained providing new gesture samples.

Application building blocks

At present the system uses writing pressure to decide if input corresponds to geometry or gesture strokes. The criteria are that drawing by applying high pressure on the stylus means a geometry stroke; otherwise the stroke is analysed as a gesture. Both geometry and gesture analysers make use of two geometric signatures: the direction and curvature graphs of each stroke are calculated.

The Geometry recognizer applies a mean shift procedure [14] to smooth the two former signatures and find changes in direction of strokes, and perform vertices detection. Strokes with a path length less than a length threshold are then deleted and, finally, geometric entities are identified and their control parameters obtained.

Table 2. Some supported gestures

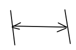
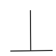
Gestures	Meaning
	Concentric
	Dimension
	Diametral dimension
	Tangency
	Vertical
	Horizontal
	Parallel
	Perpendicular
	Delete

Fig. 3. Constraints dialog box.

The Gesture recognizer uses pre-processing image analysis techniques to smooth and remove noise from the stroke. The size of the sketch is then normalized to provide the same concentration of digitized points along the sketch and the two geometric signatures are then computed. Next, a fast Fourier transform (FFT) is applied to the spectrum domain of the two previous signatures. As the final step, a standard non-linear discriminant analysis is used to classify the gestures, attending to Fourier descriptors of digital signatures.

The application uses the geometric kernel ACIS to store the recognized geometric entities, and the 2D DCM constraint manager from the UGS D-Cubed company to manage the geometric and dimensional constraints of the drawings.

Sketching procedure

Users introduce the geometry, creating a free-hand sketch directly onto the screen of the Tablet-PC. They can add, delete or edit the dimensional and geometric constraints in the sketch using the gesture alphabet in Table 2.

The parametric engine cleans up the input data and adjusts the edges to ensure that they meet precisely at common endpoints in order to get geometrically consistent figures, filtering out all defects and errors in the initial sketches that are inherent to the inaccurate and incomplete nature of the sketches. Constraints are controlled by a dialog box as shown in Fig. 3. The user can choose the constraints for the system to automatically use to control the sketch. Users can also manage the enhancement action, modifying the tolerance values used to decide if a geometric constraint is verified.

Figure 4 shows an example of dimensional control using the sketching application. In this example the user uses just one stroke to create the whole polyline in Fig 4(a). The application then shows the enhanced version [Fig 4(b)], where the

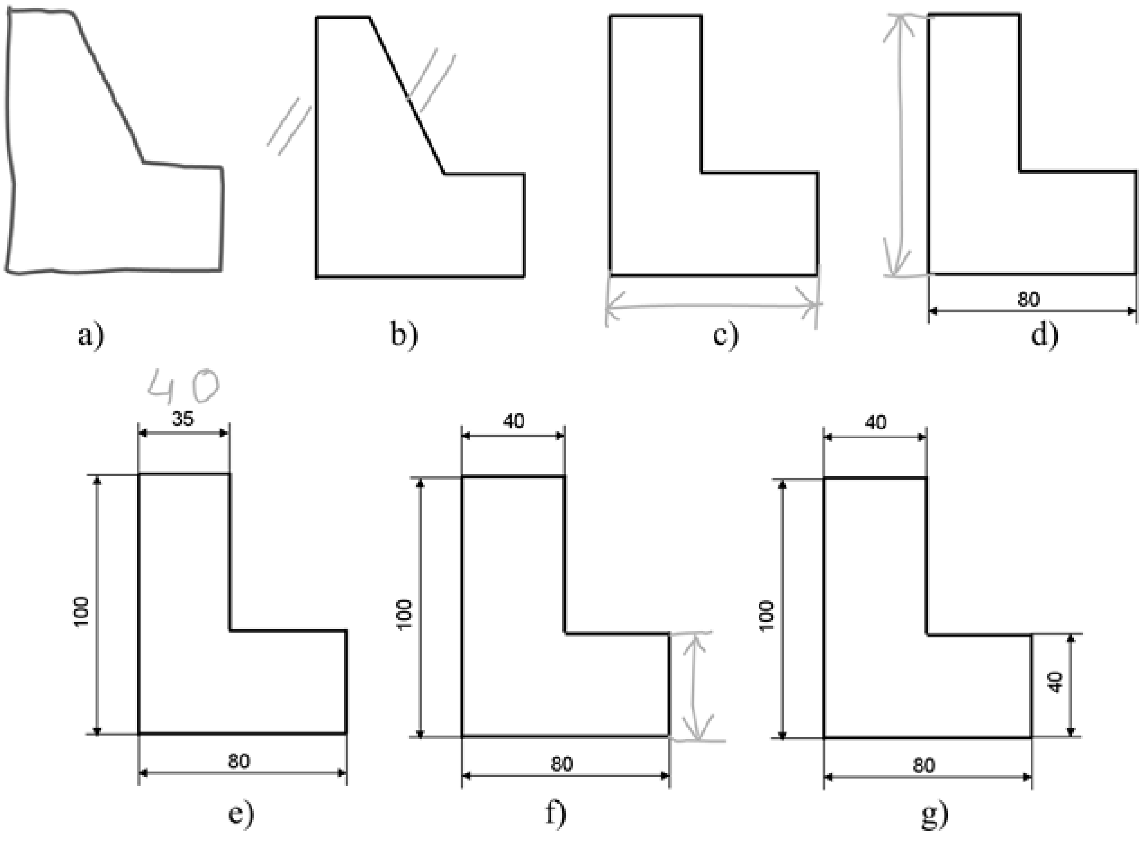


Fig. 4. Example of dimensional control.

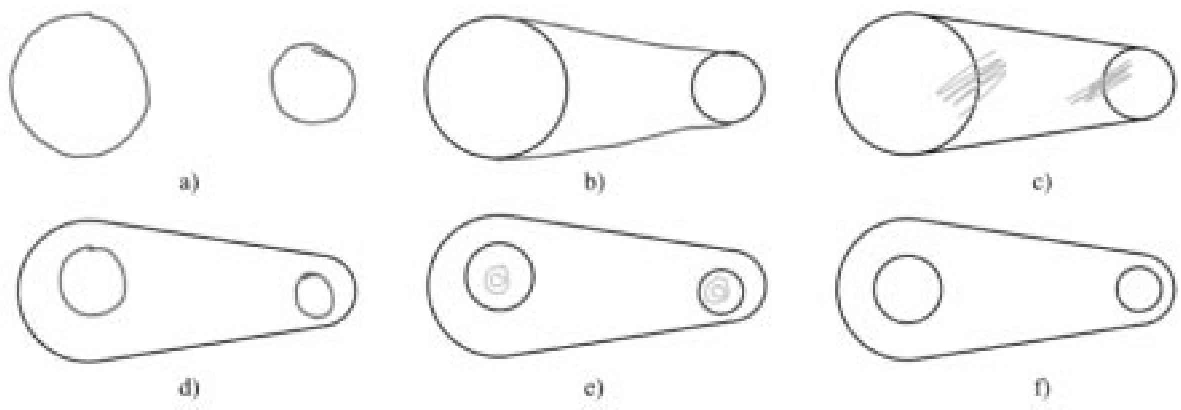


Fig. 5. Example of automatic trimming and constraint assignment.

user adds a parallel constraint, sketching the corresponding gesture.

Once the desired shape has been obtained, we can proceed with dimensional control. A first action is to draw in a dimension as in Fig 4(c), without the dimension text. This is interpreted by the application as a measure command, showing the current value of that dimension, as seen in Fig 4(d). If users want to change a dimension value, they have only to write in the new value next to the current one. The system then regenerates and displays the new geometry [Figs 4(e), (f)].

Handwritten number recognition is provided by the Windows XP Tablet PC Edition operative system. Of this way, we provide a very natural way of imposing the desired dimensions over the sketch.

In the second example, shown in Fig 5, a scratching gesture is used to refine the geometry. When the user draws this gesture, the application interprets this as the user wanting to delete those geometric entities intersecting the smallest quadrilateral that encloses the gesture. In this example, the tangency constraint is activated. So the lines drawn in Fig 5(b) are enhanced and converted into tangent lines in Fig 5(c). Next, a scratching gesture is applied to the two arcs in Fig 5(c), which are deleted. Finally two additional circles are drawn, and made concentric using the proper gesture as showed in Fig 5(e).

EXPERIENCE WITH THE PROTOTYPE SYSTEM

Initial trials with the system have shown promising results. The wireless projection approach shows a viable alternative to interactive whiteboards. The sketching application is very easy to use, and does not require much prior training, since its basic operation is similar to drawing on real paper. The software has been tested on Toshiba Portege 3500, Tecra M4 and Acer Travelmate C110 Tablet-PCs, whose details are given in Table 3.

From the initial test we can envisage two possible scenarios. One, where there is only one Tablet-PC available. The pupils and the teacher share one computer. In this situation taking control of the sketching application means getting access to the Tablet. This does not pose any problem, as most of the Tablets are relatively light. The teacher can move around the classroom interacting with the students. Disabled students can participate in class in the same way as the other students. We speak of this situation as a ‘hard sharing’ scenario.

The second scenario corresponds to a classroom where all the students have their own Tablets. This requires installing utility software to be installed in each Tablet, but then the teacher can manage the projector by means of the projector control software. In this way, the teacher can route a pupil’s Tablet content to the wireless enabled projector. This would be a ‘soft sharing’ situation, where screen content is shared rather than the Tablet itself.

Some instructors have noted that some surfaces of the Tablet-PCs reach a high temperature after some time in use. This is probably an important characteristic to check when buying a new tablet for in-class use, where it is will to be held in one hand. Also some users included observations about the slight offset that exists between the tablet-PC’s stylus point and the graphic cursor (usually due to bad screen calibration or the thickness of the protective screen that covers the TFT panel) but in general a good opinion was given on the quality of interaction. It is also important to note the positive attitude of students towards the Tablet-PCs and the pen interaction.

Table 3. Characteristics of the Tablet-PCs that were tested

Model	Screen size (inches)	Weight (kg)
C110	10.4	1.4
Portege 3500	12	1.9
Tecra M4	14	2.8

CONCLUSIONS

We obtained some interesting ideas from the users of the system. The first one concerns the weight. Convertible Tablet-PCs as listed in Table 3 are a good option to support pen-based interaction and conventional WIMP interface applications. However, they are heavier than comparable slate type Tablet-PCs. A first recommendation to improve the wireless projection scheme presented in this paper would be to use slate type Tablets or the lightest convertible models.

Forthcoming hardware such as the ultra-mobile PC (UMPC) initiative recently announced by Intel and Microsoft [15] offer an alternative to standard Tablet-PCs. A UMPC is a fully functional computer running Microsoft Windows XP Tablet PC Edition. This has all the functionality of a slate Tablet-PC but in a compact form factor: 7-inch screen sizes and weigh less than 1 kg, and provide WiFi and Bluetooth connectivity. Tablet-PC prototypes with a detachable touch-screen have also recently been presented. Once detached, the display acts as a Tablet PC and one can interact with it using a stylus. This configuration cuts the weight by at least a half, with respect to a conventional Tablet-PC.

These new hardware devices and the synergy with developments in consumer electronics, such as research in wireless transmission of high definition television (HDTV), will provide more options for wireless projection set ups in the near future.

The configuration used in the prototype system described in this paper requires reducing hardware acceleration provided by the GPU in the graphic adapter. Although this is not a problem for a sketching 2D application, other research applications developed by our group, which create 3D models from 2D axonometric sketches, offer poor performance if complex models are generated. This means a limitation of 3D interaction with a CAD application is expected to be used with the wireless setup.

Perhaps the most critical element in a wireless setup is the utility software that intercepts the video frame buffer and sends it to the wireless device. Before choosing which wireless equipment for video display to buy, the applications to be used should be carefully tested, because often the behaviour of utility software is very application dependent.

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