Optimization of the virtual mouse HeadMouse to foster its classroom use by children with physical disabilities

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ABSTRACT

This paper presents the optimization of a virtual mouse called HeadMouse in order to foster its classroom use by children with physical disabilities. HeadMouse is an absolute virtual mouse that converts head movements in cursor displacement and facial gestures in click actions. The virtual mouse combines different image processing algorithms: face detection, pattern matching and optical flow in order to emulate the behaviour of a conventional computer mouse. The original implementation of HeadMouse requires large computational power and this paper proposes specific optimizations in order to enable its use by children with disabilities in standard low cost classroom computers.

1 Introduction

This paper presents the optimization of an already developed virtual mouse, called HeadMouse, in order to foster its classroom use by children with physical disabilities. The virtual mouse has application when a user cannot use the standard mouse of a personal computer. The virtual mouse is based on the detection and interpretation of small head movements and facial gestures of a user. These movements are captured with a standard webcam camera embedded or attached to the computer screen and faced to the user head.

The virtual mouse combines different image processing algorithms such as face detection, pattern matching and optical flow to emulate the behavior of a computer mouse. The head movement is converted in cursor displacement and different facial gestures (mainly mouth opening and forced eye blink) are interpreted as different configurable click actions: left click, double left click, right click, and drag and drop click.

The implementation of HeadMouse is optimized to reduce the physical effort and stress of the user when performing the head movements and the facial gestures required to use a computer and to access to all the Information and Communications Technology (ICT) capabilities.

The operation of HeadMouse, based on the real time application of image processing algorithms, requires large computational power and this paper proposes specific adaptations and optimizations in order to enable its use by children with disabilities in standard low cost classroom computers such as the Classmate PC (Figure 1).

Fig. 1. Notebooks designed for children: Classmate PC.

1.1 New Contributions

The new contribution of this paper is the optimization of an already developed absolute virtual mouse (described in [PALLEJA, T. et al., 2009] and [PALLEJA, T. et al., 2013]) in order to reduce its computer requirements and to foster future usage by children with physical disabilities in low cost classroom computers.
This new contribution will have application when a child with a physical disability cannot use the conventional computer mouse or touchpad and will contribute to give the same rights, learning opportunities and learning facilities to all the students.

1.2 Problem definition

According to the document about "Inclusion of People with Disabilities, European Strategy for equal opportunities" [PUBLICATIONS OFFICE, 2007], published by the Office of Publications, European Communities, people with disabilities represent at least 16% of the total population of the EU in working age. More than 45 million people in Europe (one of six) aged between 16 and 64, have serious and permanent health problems, or a disability.
In the specific case of people with motion disabilities originated by spinal cord injuries; in Spain there are between 1,200 and 1,500 new cases each year with a total estimate of 38,000 people with spiral cord injuries that will increase to 45,000 people in 2015. According to the Study "Disability, a prospective vision" [ASPAYM. 2005], the youth are the most affected group and accessibility to ICT is presented as one of the biggest challenges for people with motor disabilities.
In this direction, the proposal of this work is the optimization of an already developed virtual mouse controlled by small head displacements in order to allow its use in low-performance notebook computers designed for classroom use by children.

1.3 Notebook usage

A notebook is a small and low-cost portable personal computer which has been mostly oriented into tasks of training in schools and colleges. However, this usage can create new barriers of accessibility for children with physical disabilities. In this context, the use of accessibility tools such as the virtual mouse HeadMouse can contribute to reduce these barriers of accessibility.
An example of notebook computer used in this work is the initiative promoted by IntelTM Classmate PC (Figure 1) that has the following features:

- Atom processor N270 1.6 GHz with 1GB RAM and 60GB disk.
- Operating system: Windows XP.
- Front integrated camera (webcam).
- Swivel screen 8.9'' with a resolution of 1024x600 pixels.
- Resistive touch screen, sensitive to the pressure made by a pen device.
- Two USB.
- LAN connectivity.
- WiFi connectivity.

The application scenario of a notebook is a typical classroom usage:

- Classroom environment with notebooks as computers.
- Notebook screen used to show the slides or information presented by the teacher.
- Notebook used to access and read information.
- Notebook used to develop motor skills by using educational games.
- Notebook used to create academic works.

2 HeadMouse application

The HeadMouse application is the result of a research project under development at the Accessibility Chair of the University of Lleida, (Jaume II, 69, 25001 Lleida, Spain) funded by Indra (Julián Camarillo, 16-20, 28037 Madrid, Spain) and Fundacion Adecco (Príncipe de Vergara, 37, 28001 Madrid, Spain). The hypothesis of the HeadMouse project was that some image processing algorithms used in robotics to detect the face of people and to track their relative displacement in a sequence of images could have also application in establishing an accurate control of the computer screen pointer.

The idea of the initial proposal was the development of a virtual mouse based on the analysis of the images acquired by a standard image acquisition device (webcam type) pointed to the face of one user. The control of this virtual mouse requires slightly head displacement and can also detect some facial gestures to perform clicks. This virtual mouse has application in the case of a person with physical mobility disabilities that cannot use the conventional computer mouse.

The first version of the HeadMouse application was released in 2008 as a free downloadable application through Internet. Since this release, the HeadMouse project has incorporated new technologies and features with the final goal of simplifying the access of people with physical disabilities to ICT. The HeadMouse application is free and its latest version can be downloaded from the following websites:

http://robotica.udl.cat
http://www.tecnologiasaccesibles.com

The HeadMouse application has three main functional blocks that require specific image processing algorithms and methodologies: initial user detection, head tracking and facial gestures detection.

2.1 Initial user detection

The initial user detection in the images provided by the webcam of the computer is very important in order to automatically start and configure the virtual mouse. This detection is based on the use of the face detection algorithm proposed by Viola and Jones in 2001 [VIOLA, P. et al. 2001].

In this initial user detection stage the virtual mouse waits until a face is detected in front of the computer screen in a suitable position for computer use. Then the user must stay quiet a short period of time as an indication to start the tool. During this stage a window shows the face of the user and gives other useful information about the evolution of this stage (Figure 2). The virtual mouse is started when the position of the face of the user remains unchanged during 4 seconds. The area of the image that contains the face of the user is stored in the internal memory for later use. The implementation of the Viola & Jones algorithm in HeadMouse is fully described in [PALLEJA, T. et al., 2013].

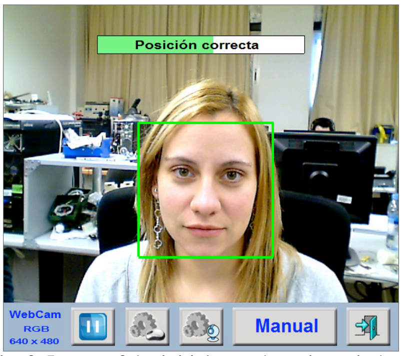

Fig. 2. Image of the initial user detection window.

2.2 Initial user detection optimization

The application of the Viola & Jones algorithm is computationally very expensive and, in the case of a low cost notebook, tends to saturate the CPU (or, at least, one of the CPU's) of the computer. This intensive usage also tends to slow down the execution of any other application and also reduces battery powered operation.

The optimization of this functional bloc was performed by establishing a time delay of 1.5 s between two consecutive applications of the Viola & Jones algorithm in case of not detecting any face in the current image analyzed. However, when detecting a feasible face in the image, the Viola & Jones algorithm must be applied to all images provided by the webcam in order to detect the user and to properly start HeadMouse. The average time required by the Classmate PC to process a color image of 640x480 pixels and apply the Viola & Jones algorithm was 28.8 ms in the normal mode and 0.278 ms in the optimized (no face detected) mode (Figure 3). This optimization represents a significant average CPU usage reduction of 99 %.

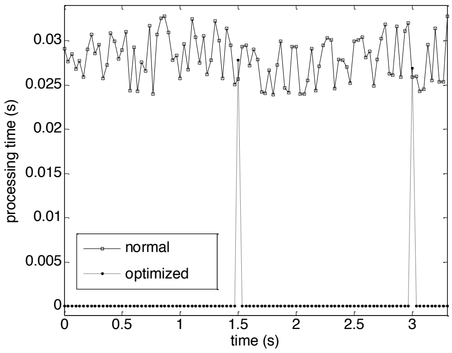

Fig. 3. Processing time required by the initial user detection stage in the case of no user in front of the PC.

Another optimization designed to foster classroom usage has been the inclusion of a pause button in the starting window of HeadMouse. This pause button is very useful to avoid involuntary virtual mouse activation during a supervised notebook use (for example by a teacher or a technician) in the classroom.

2.3 Head tracking

During normal virtual mouse operation the tracking of the head of the user is performed by applying template matching (TM) [BRUNELLI, R., 2009] algorithm between the image acquired with the webcam and the image of the face of the user previously stored in memory (used as a reference). The use of TM to track the head of the user is faster and more accurate than the Viola & Jones algorithm and is applicable in this case because the template is only slightly deformed (shifted) when displacing the head. Figure 4 shows the expected head displacement in one sample image acquired.

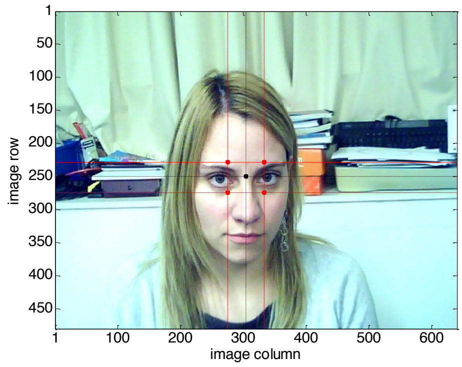

Fig. 4. Expected user displacement: reference head point (black) and extreme displacement of the reference point (red).

The basic template-matching algorithm consists in sliding the template over the search area and, at each position, computing distortion, correlation or similarity between the template and the image. Then, the position with maximum correlation or similarity represents the instance of the template into the image under examination and also the relative displacement of the head of the user that is transformed into cursor displacement on the computer screen. The implementation of the original TM algorithm in HeadMouse is fully described in [PALLEJA, T. et al., 2013].

2.3 Head tracking optimization

The application of a TM algorithm in a complete image is computationally more expensive and less precise than the Viola & Jones algorithm [PALLEJA, T. et al., 2013]. The effect of this intensive application usage also tends to slow down the execution of other conventional large applications such as word processors and spreadsheets or navigators. Note that a virtual mouse must be used always in conjunction with other programs so any effective reduction of the CPU usage will have also large effect in the overall notebook usage performances.

The optimization of the application of the TM algorithm has been performed by applying a pyramidal search strategy method [ADELSON, E.H., et al., 1984] and stopping the TM search when the computed similitude value does not improve the minimum value found in previous

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evaluations [VANDERBRUG, G. J. et al., 1977], [LI, W. et al., 1995]. Additionally, the TM pyramidal search is started in the position found in the previous search. These proposed optimizations must reduce the computational cost required for head tracking in the case of small or no head displacement.

The average time required by the Classmate PC to process a color image of 640x480 pixels and apply the TM algorithm was 22.6 ms in the normal mode and 3.71 ms when applying the proposed optimizations (Figure 5). This optimization represents a significant average CPU usage reduction of 83 %.

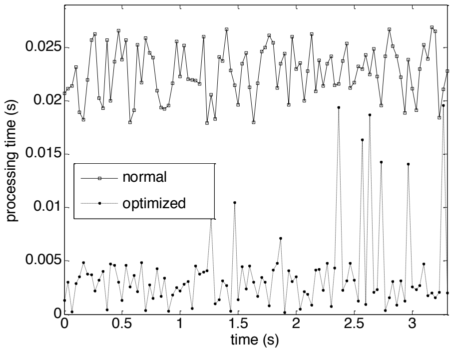

Fig. 5. Processing time required by the head tracking stage.

2.4 Face gesture detection

The detection of facial gestures is a useful feature that allows the association of different specific click actions. This detection is performed by computing the optical flow in the area of the image corresponding with the face of the user. The optical flow implementation in HeadMouse is based on regional TM techniques [BARRON, J. L. et al., 1992] as it is assumed that face gestures generate significant shifts in the face area.

The computation of the optical flow of a complete image can be computationally very expensive. The original implementation of HeadMouse reduces the computation of the optical flow to the region areas corresponding to the expected position of the eyes and mouth of the user [PALLEJA, T. et al., 2009] to reduce the processing time required by this stage.

2.5 Face gesture detection optimization

The computation of the optical flow of parts of the face of the user is computed by applying a TM strategy and the optimization of this stage is performed by applying the same optimizations as in the case of the head tracking. However, this computation is applied to limited areas of the face and originally required very low computation time so any optimization of this procedure must have practically no impact in the overall processing time required by the virtual mouse.

The average time required by the Classmate PC to compute the optical flow in limited areas of the face of the user was 3.85 ms and 3.62 ms when applying the proposed optimizations (Figure 6). This poor improvement (6%) was also originated by the fact that the TM positioning error increases as the size of the reference images decreases and by the fact that the face of the user is almost continuously in movement and this movement is also evidenced by the partial optical flow performed.

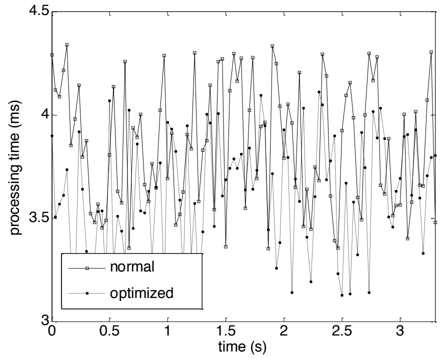

Fig. 6. Processing time required by the head tracking stage.

3 Classroom usage results

The most interesting programs for the children (especially in the early stages) use to be drawing programs that use to take advantage of the touch screen capabilities of notebooks. The use of these kinds of programs by children with disabilities is a challenge because apparently simple drawing actions are composed by complex actions. For example, the creation of a line requires a hold down action, a drag action and a hold up action.

The operation of virtual mouse HeadMouse has been revised to automatically perform these actions with two click actions. The first click is then used to simulate a hold down action and to automatically start the drag operation. The second click is then used to stop the drag operation and to simulate a hold up action.

Figures 7 and 8 show some drawings performed with the free drawing program Sketch-Paint [Sketch-Paint, 2013] on a Classmate PC. This program is especially interesting for its simplicity and coloring options. For example some initial drawings can be defined as a foreground masks (mask behind) so any new painting or manual filling action will not modify (or get out of) the foreground limits of the drawing and generate very satisfactory results. For example, Figure 7 shows an initial black and white image that must be manually filled by children with custom colors. This manual filling operation requires some concentration and motor contributes to improve the motor control especially at early stages.

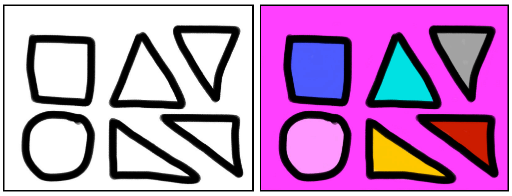

Fig. 7. Example of coloring a black and white drawing with the Sketch-Paint program on a Classmate PC.

Figure 8 shows another drawing example performed by configuring the sensitivity of the displacement to its lowest value. Then, larger head rotations are converted in small pointer displacement and the drawing of lines and round lines with HeadMouse are largely improved. In general, this modification in the configuration of HeadMouse can be avoided if the drawing program has an internal option to refine the drawings by means of a spline interpolation.

Finally, the optimizations proposed in this work also improve the usage of other accessibility programs such as VirtualKeyboard [VirtualKeyboad, 2013] (Figure 9) in order to type or fill academic works that require other additional applications. In this particular case VirtualKeyboard is constantly querying an internal dictionary in order to make predictions of complete words and reduce the writing effort.

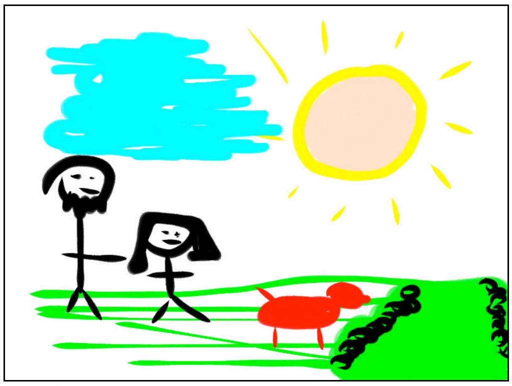

Fig. 8. Example of drawing created with the sketch-paint program on a Classmate PC.

Fig. 9. VirtualKeyboard [VirtualKeyboad, 2013].

4 Conclusions

This paper proposes the optimization of the virtual mouse called HeadMouse created by the Accessibility Chair of the University of Lleida. The main goal of the optimization process is to foster the classroom usage of HeadMouse by children with physical disabilities. This virtual mouse has application in the case of children with physical mobility disabilities that cannot use conventional input devices such as the mouse or the trackball.

The original design of HeadMouse has three main functional blocks that require specific image processing algorithms. The first block provides initial user detection in order to initialize the interaction with the virtual mouse and control the pointer device of the computer. The optimization proposed in this block has reduced by 99% the CPU usage and processing time when no user is in front of the computer. The second block provides head tracking in order to control the displacement of the pointer with small head displacements or rotations. The third block provides face gesture detection in order to perform different click actions. The optimizations proposed in this paper have been reduced by 83% and 6% the CPU usage and processing time required in the second and third block.

The optimized version of HeadMouse has been tested in a typical notebook computer such as the Classmate PC by using a drawing program, other accessibility tools, and other office programs for document editing. The overall reduction of the CPU requirements of HeadMouse has improved the simultaneous usage of other applications in a notebook type PC.

Finally, the proposed overall optimizations have also improved HeadMouse usage in other powerful desktop PC computers so an adaptation initially planned for children with disabilities will have also a general application.

5 Acknowledgement

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