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ICCOPS

Intuitive Cursor Control by Optical Processing Software

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1. Introduction

For our group project we are using two cameras to track movement on a specified area in order to transform any surface into a touch screen. Similar technologies have made it possible, in combination with a projector, to transform regular walls into smartboards. This way, presentations or lessons can be made more interactive. These technologies are however expensive. Prices around 400 Pounds make it hard for schools to provide an adequate number of these technologies to their teachers and therefore they still end up being forced to using blackboards and overhead projectors. This is why it was our idea to reduce cost significantly by using two webcams and writing the software ourselves. In the following we are going to show that it is feasible to provide a technology like this that can be sold at a price far below 50 pounds and still be very profitable.

2. Problem description and our solution

In most schools computers and projectors are available to the students and teachers, and in some cases even smartboards. However, blackboards and overhead projectors still constitute the main means of presentation in class. If smartboards are present, usually the number is limited and they are not accessible at all times. With smartboards, however, presentations and lessons can be designed more vividly and interestingly. In most subjects graphical and time variant graphics can help students understand the content better. Also, graphs in sciences can be drawn more accurately, movies and audio examples can be incorporated more easily into the lesson, and of course the internet can supply a vast amount of examples and knowledge to the lesson. This has been shown to have beneficial effects on the students, making it easier for them to actually understand the material they are being presented and focus more closely on the concepts, therefore being more efficient in their learning. Also, the further dimensions which can be added to a class have been shown to help students with hearing, visual or speech and language difficulties [7]. Moreover, it has been shown that in group projects where participants have to come up with creative ideas, smartboards have provided a significant advantage over traditional technologies since they were enabling a higher focus on concepts and therefore increasing productivity. [8]

Furthermore, a smartboard would constitute a significant organizational improvement. More lessons can be prepared in advance and the notes teachers take in class and the materials presented can be shared via the internet more easily. It can, however, only be used efficiently if the teachers have regular access to the boards. Most schools only have a limited number and the boards have to be reserved in order to be used. This prevents the teachers from having a deeper knowledge about the technology and therefore makes it very difficult for them to use it and incorporate it continuously into their lessons. [7]

Since smartboards are quite expensive and would have to replace the classic blackboard many companies offer mobile smartboards as an alternative. This technology is very similar to the one we were developing. The basic idea is implementing interactive boards by utilization of cameras pointed at a screen. They then detect when the screen is touched. Then image processing software is used to transfer the information from the cameras to the computer that is used in order to determine the point on the computer screen that corresponds to the point where the screen was touched. [9] [11]

From this we can see that this is a very small device since it only consists of two cameras that can be mounted on any surface. Furthermore, it incorporates all the advantages that a smartboard offers, however, it is portable, and can be therefore used in any environment. Unlike smartboards, it does not require a significant change of the learning environment which would include a replacement of blackboards by smartboards but instead could be implemented quickly from one day to the next. Lastly, it does not require a lot of resources, so it seemed like it would be feasibly to improve this technology on a software level and without the scientific research that is needed to improve the hardware of common touch screens.

This could lead to the solution of the problem with these mobile smartboards, which are quite expensive. They cost around 400 pounds per piece and therefore many schools are hesitant to buy them [10] [12]. If they break or if they are not received well by students of teachers, this is a lot of money that is being wasted which cannot be spent on the students' education.

Therefore it was our idea to take a closer look at the technology. As the mobile smartboards consist only of two cameras and software, we saw that potential since the cost of the resources can be kept quite low. In our research about this topic we saw that we could use MATLAB to easily access a USB camera and import and process captured frames [1]. With two cameras capturing the entire screen surface from two different angles we could detect position and proximity with respect to the screen.

3. Implementation of the idea

For implementing the touchscreen, two cameras are placed on opposite sides of the screen, both of them capturing the entire screen area.

3.1. The mathematical background of the implementation

Because the cameras are not looking at the screen perpendicularly, the coordinates for the pixel positions on the screen and on the camera recording of the screen are quite different, though there is a unique function for every physical orientation setup, i.e. relative orientation and position of cameras and screen in 3D space, that correlates coordinates of recorded image of screen to actual screen pixel coordinates like $x_{screen} = f(x_{camera}, y_{camera})$. An illustration example of such a function can be seen in figures 1 and 2. Obtaining and plotting the correlation of some sample points showed that this function can be approximated quite well by a surface polynomial of degree 3 for both argument axes (With x and y here the camera coordinates, mathematical method for obtaining the coefficients is described in [4]):

$$x_{screen} = \sum_{n=0}^{3} \sum_{m=0}^{3-n} A_{nm} x^n y^m$$

$$x_{screen} = A_{00} + A_{10}x + A_{01}y + A_{20}x^2 + A_{11}xy + A_{02}y^2 + A_{30}x^3 + A_{21}x^2y + A_{12}xy^2 + A_{03}y^3$$
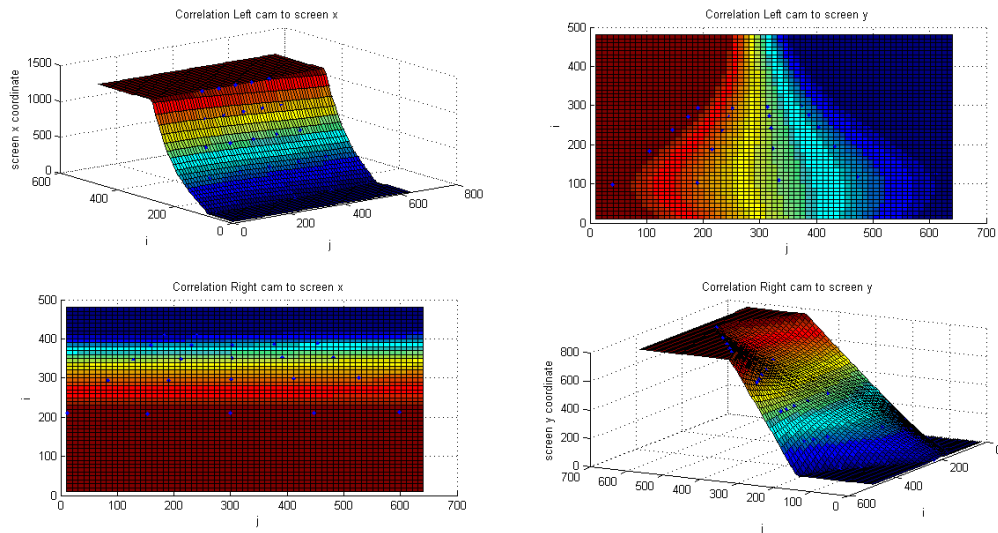

Figure 1: Illustration of correlating functions. i and j are camera image vertical and horizontal pixel coordinates respectively and the third axis is the corresponding screen pixel coordinate. Colours represent contour lines for the screen coordinate axis with red highest and blue lowest values. The blue dots represent information gathered from the sample points, which were equidistantly spread throughout the screen area.
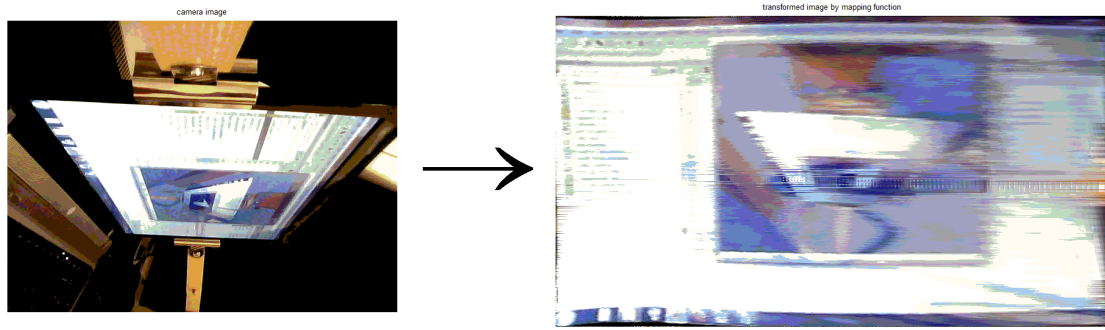
Figure 2: Visualization of the operation of the mapping functions. The picture on the left is taken by a camera recording the screen from the side with a resolution of 480*640 pixels and the picture on the right is created by applying the function on every screen pixel of the recording from the camera image. By this can be seen that indeed this function gives a good correlation between the recorded image and the physical screen area.

3.2. Implementation of the touchscreen

In our implementation design a black pen is used for interaction with the screen, because the screen itself is always brighter than the black pen even if something black is displayed. The specific procedure to find the pen tip in the camera image is shown in the flowchart of figure 3.
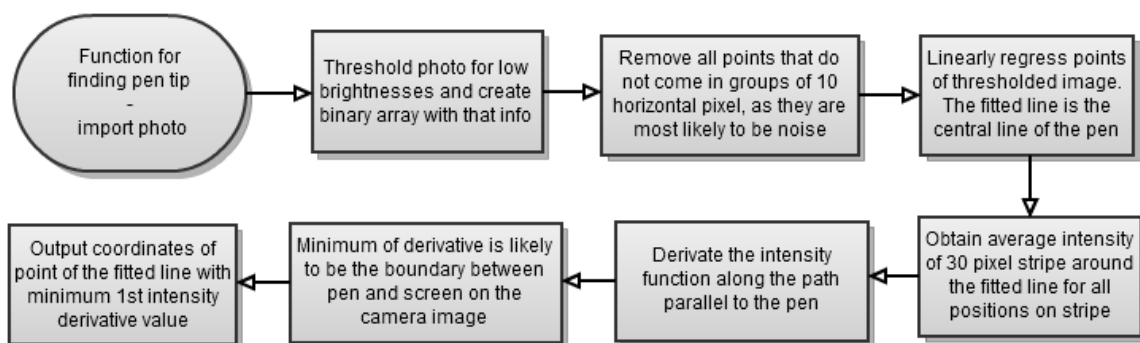

Figure 3: The algorithm for finding the pen tip is implemented in 7 intermediate steps: A specific brightness is then set as threshold and every pixel of the whole RGB image is tested with this. The result, after some noise clearing, gives a binary image including several (not all) points representing the pen. A straight line is then fitted through these points, which runs nearly parallel along the centre axis of the pen on the camera image. A function for colour intensity along this line is then created and filtered with a running average filter for noise reduction. As the pen is black the intensity function along the line through the pen drops fast when it enters the area of the pen, so the 1st derivative of the function has a negative peak there. Programmatically therefore, the pen-screen boundaries are taken to be at the point where the derivative of the intensity has its global minimum.

Two cameras looking to the screen from different sides (ideally opposite sides) are necessary for the implementation. If the pen does not touch the screen, there will be parallax errors towards different directions since cameras are recording the scenario from different sides. The coordinates obtained by the two cameras for the pen tip will translate to different screen pixel coordinates like on the right side of figure 4. If the pen touches the screen however, they will match like on the left side of figure 4. So by comparing the obtained screen pixel coordinates from the two cameras the program can tell if the pen is touching the screen or not, even at very small proximity. A program as shown in the flowchart of figure 5 can then control cursor events by checking how close the obtained pen tip coordinates are. If the absolute distance is less than some pixels the user is holding the pen on the screen so the cursor is moved and the virtual mouse simulates a button-pressed state. Else it simulates a button release.
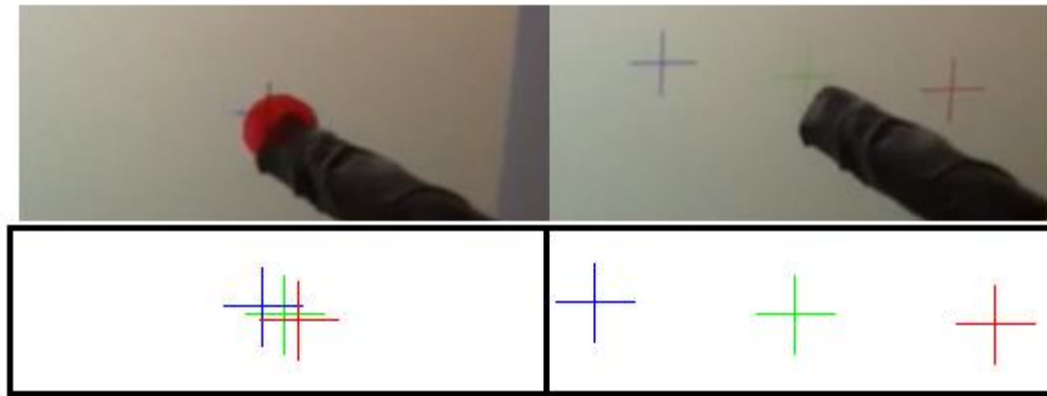
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Figure 4: Cross centres represent obtained screen pixel points of left camera (red), right camera (blue) and mean value (green). Left photo and image illustrate case when pen is touching the screen; right ones illustrates case when pen is held slightly above the screen.

3.3. Operation enhancement

In order to decrease the runtime of each cursor state update the processing is done by a separate routine calculating outcomes of all possible positions of the pen tip and saving them in four arrays (one array for one axis for one camera). So the main loop that controls the cursor state and loops forever only has to sense the coordinates of the pen tip and look up the corresponding screen pixel coordinates in the precalculated arrays, i.e.

LeftCam_X_screen=LeftCam_X_map (LeftCam_X_pentip, LeftCam_Y_pentip).

3.4. Alternative approach

In the design presented so far any black and thick enough stick can be used for the touch pen. Adding electronic components to the tip can enhance the operation of the system by reducing the hardware and making the system respond faster and more accurately.

In detail, making the pen - including the pen tip – luminescent, for examples with LEDs, makes it much easier to detect by the camera by reducing the exposure time and searching for bright elements in the picture. This also has the effect of reaching higher frame rates for the system, as each frame needs less time to be obtained. Thus the system becomes faster and more accurate.

Further, the utilization of two cameras is only necessary to detect proximity of the pen tip to the screen. By adding a piezoelectric element at the pen tip, that can detect whether a touch occurs, the second camera becomes superfluous. A circuit evaluating readings from the piezoelectric tip with a wireless transmitter would be placed inside the pen communicating with a transmitter at the computer. Then the imaging module of the system would move the cursor and clicks would be transmitted through the wireless communication channel.

Summarizing the main advantages of each approach for an optical touch screen:

System with conventional pen	System with electronic pen	Benefits of better property
Needs 2 cameras	Needs 1 camera	Less computing, cost and setup
High camera exposure time	Low camera exposure time	Faster system response
Cameras detecting click	Click by wireless com. Channel	More reliable double-clicking
Noise affected pen detection	Easily detectable pen	Higher precision
Low cost pen	Pen has electronic components	Low cost pen and replacements
No battery needed for pen	Battery is needed for pen	Battery inconvenience avoided

Table 1: Listing pros and cons of the two approaches for a touchscreen implementation. At this stage it is not entirely clear which approach would be the most affordable one in general.

Note that an intermediate system with a luminescent pen but no piezoelectric component or with a piezoelectric component and not being luminescent can also be designed. The former one would probably inherit most benefits without making the pen itself too costly.
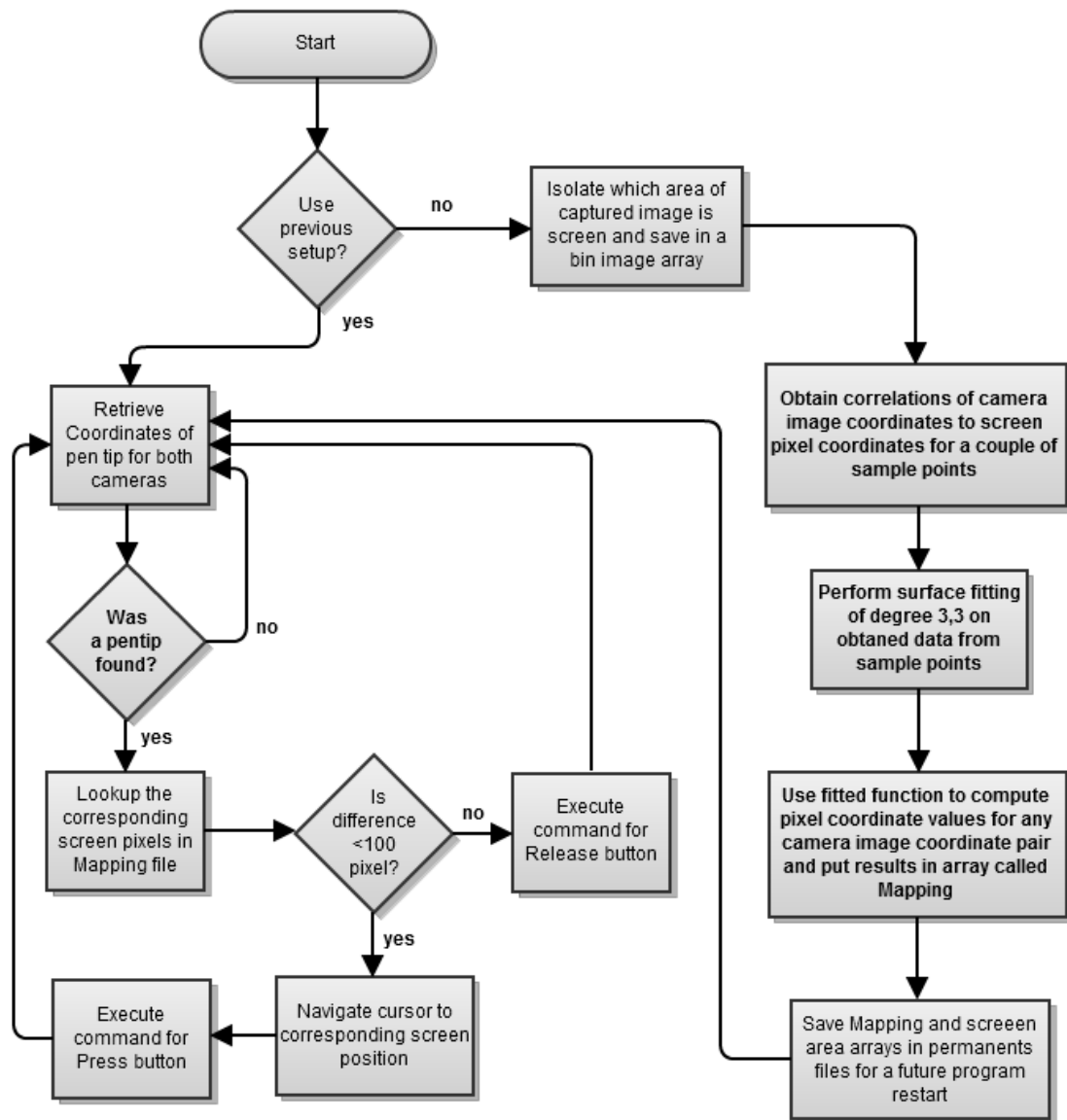

Figure 5: Flowchart illustrating the working principle of the touchscreen on high level

4. Laser tracking introduction

At the moment interaction with a pen is described. A further functionality of cursor control via a laser pointer can be implemented by very similar principles as can be seen by looking at the program flowchart in figure 6. There are several benefits in doing this including bigger range, ability to point to something more accurately, and opportunity to use only one camera instead of two if just the laser cursor control is needed. A technology like this would be ideal for presenting rather than teaching.

4.1. Implementation of the laser cursor control

For making the laser move the cursor, the exact same principles apply as for the touchscreen, with the only difference that the position marker is the laser dot and not the pen tip and that only one camera is necessary, as the dot always appears on the screen surface.

The software locating the laser dot reduces the camera exposure time to such a small value that everything appears dark expect high intensity light sources, which includes the dot on the projection created by the laser pointer. (As the laser pointer we used is green) Searching the recorded camera frames for pixels with high green brightness, i.e. >150, gives all the points the laser dot is sighted. The centre of mass of these points is then taken to be the position the user is pointing to with the laser pointer.

Furthermore, the same operation enhancements as described above are then also applied to the laser cursor control application.
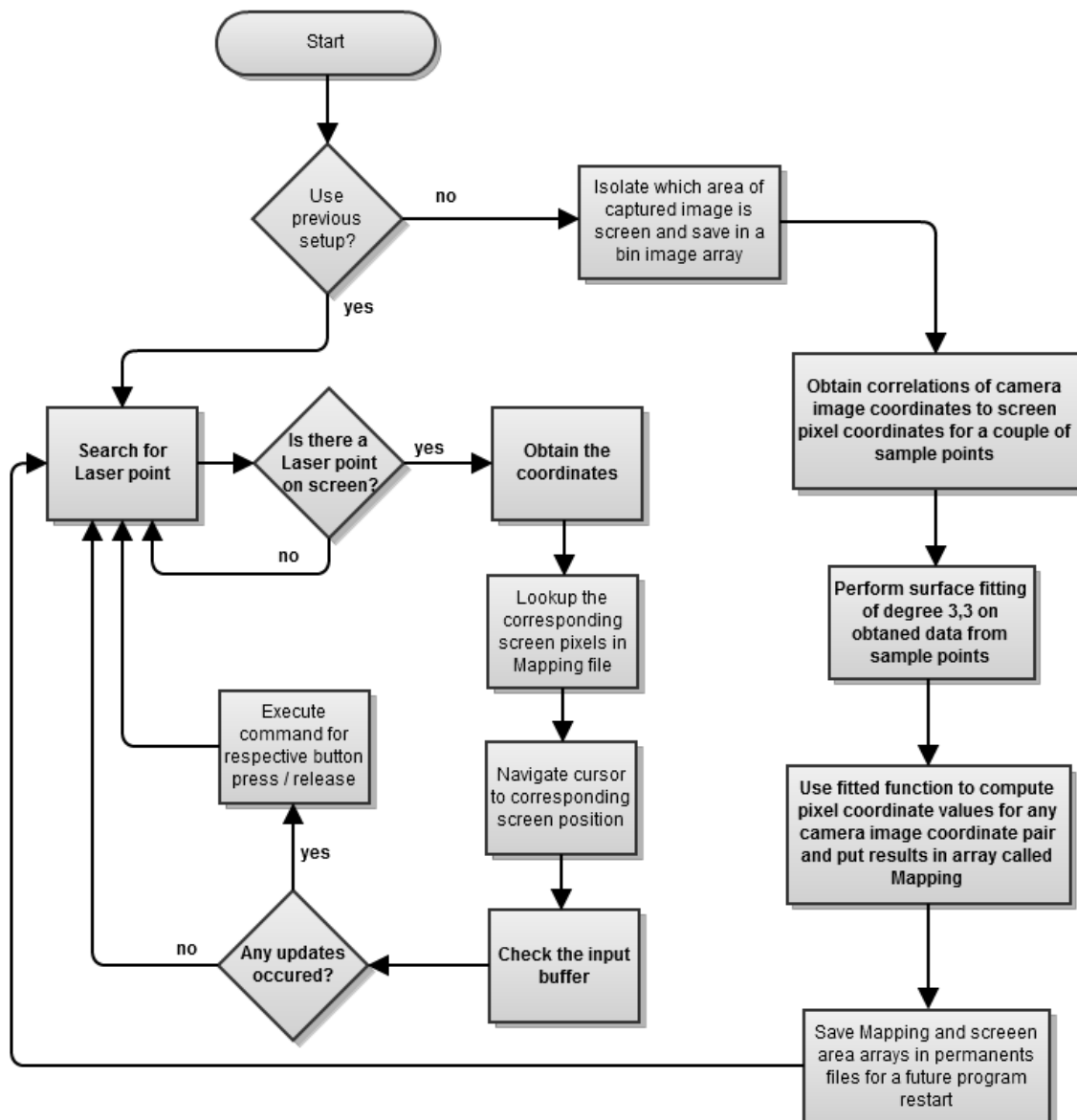

Figure 6: Flowchart illustrating the working principle of the laser controlled cursor on high level

4.2. Clicking

Click events can be done by the user with two separate tactile switches next to laser pointer and a microcontroller (uC). Clicking info can be either send wirelessly with the uC to an input buffer

accessed by the program or by letting the uC switch the laser light on and off (e.g. two flashes for left click, three for right click). The second method would be inefficient as it would add to the processing time which needs to be kept as low as possible (to reduce lag) so using a separate communication channel is a better solution. Further buttons can later be added to this with ease, for functions like zoom.

5. Prototype development

We constructed prototype systems for pen and laser pointer interaction. For the pen interaction two TRUST SpotLight webcam cameras were used with resolution of 640x480 pixels. For the laser pointer interaction the webcam HP TrueVision HD, with a resolution of 1280x720 pixels and which is integrated on the laptop was used.

5.1. The software command background for the prototypes

The program is written in MATLAB and uses the image acquisition toolbox [1] to obtain frames from the imaging devices. Processing is mainly done pixel by pixel with if statements and loops that are handling the uint8 parameters that represent RGB values of the pixels currently processed. Movement of the cursor and click events are handled by external JAVA classes [2] that are imported and executed from within the MATLAB program. Click events in the laser controlled cursor implementation are sensed by an external microcontroller sending click updates via UART [5]. During development a lot of information from [3] and [6] was drawn.

5.2. Operation of prototypes

Touch screen prototypes were developed on a setup as shown in figure 7 with two different pen styles, a simple black pen and a glowstick. Both worked well in the centre of the screen, though, the black pen's tip could not be reliably found when it was towards the edges of the screen. This happened because there was not enough pen area on the image of the screen recording of the camera to distinguish it from the noise with the routines we used. The glowstick however worked fine and could cover the whole of the screen area for interaction as can be seen on figure 8.

Figure 7: Experiments we did were carried out on a setup where the two webcams (indicated by red circles in the figure) were attached to the screen by clips as shown in the picture. The captured image of the left camera can be seen in figure 2.

The laser cursor control prototype was tested on a projector in a conference room and a lecture theatre. It worked accurately at both locations and it could reliably interact with the whole of the screen area. A photo of the testing can be seen on figure 8.

The response of each system can be compared in frames per second (FPS) or in megapixel per second (MP/s) processed. The results were acquired by letting the outer loop execute 50 times and the time was measured by using "*cputime*" [3] in MATLAB:

System	FPS processed	MP/s processed
Black pen	3.9	2.39
Glowstick	8.5	5.22
Laser control	7.3	6.73

Table 2: Comparison of the speed of the different prototype systems. It shows the trend that the brighter the object to be detected, the faster the system can work.

Note here that the Laser cursor system was processing frames of 3 times the amount of pixels but the touch screen systems were dealing with two camera frames for one system response frame.
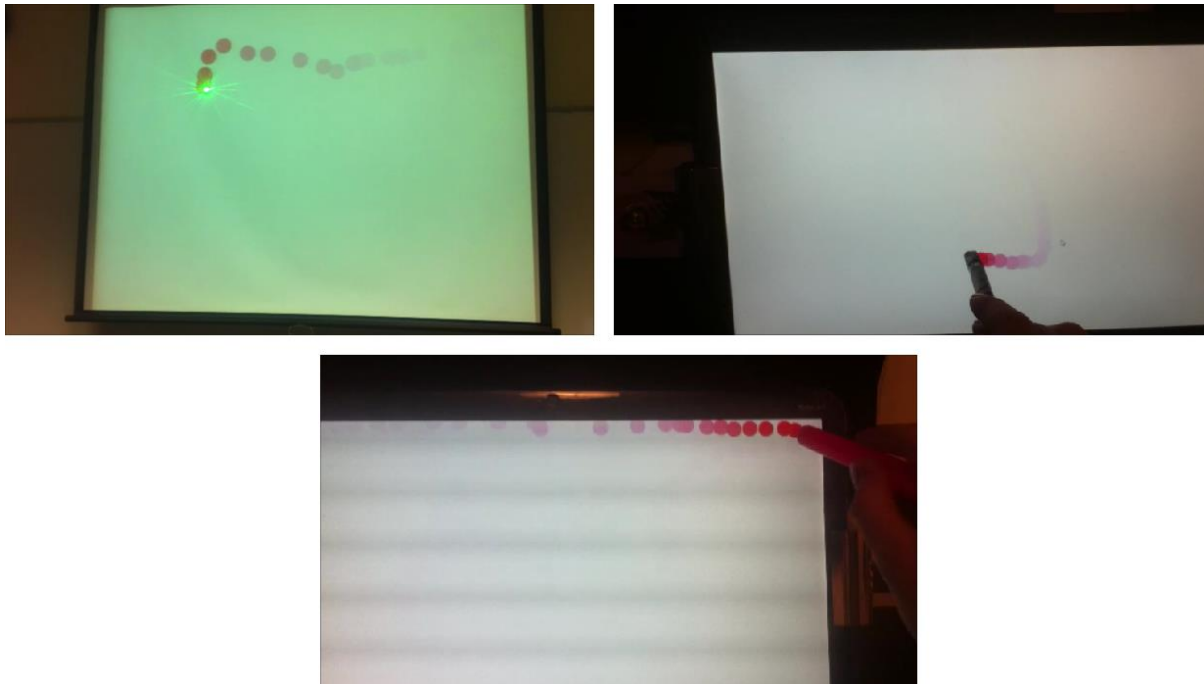

Figure 8: Experiment showing the accuracy of the prototypes. Top left picture shows the Laser Pointer cursor control, top right the touch screen with black pen and the bottom one with a red glowstick as a pen.

6. The final product

The final product would most likely be a combined system that incorporates both, touchscreen and laser pointer interaction, as the same basic resources (i.e. cameras and most of the software) can support both ways of cursor interactivity.

6.1. Process of adapting the system to new screens

It will not require much adjustment to adapt the system to new environments, as the existing code should already work for screens of any size, as long as the camera can capture the whole area. What needs to be done is only the calibration process to obtain the new translation functions for the new orientation and position of the hardware components. During that process the system displays several points on the screen, which the user simply has to click at. After this step the interactive screen can be used straight away.

7. Business Plan

The foremost application of our product would be as a portable smart board directed at applications in schools and universities. That way it would constitute a significant technological advancement from blackboards because it can incorporate multimedia tools such as the internet, videos, graphics, and software into the in class presentation on the same surface as notes are taken. Furthermore, notes can be saved on a computer and readjusted at another lesson and distributed easily to the entire class, so that more learning materials are available and a well-rounded education is not limited by the teaching equipment.

These are usually the advantages of regular smartboards but our application would make a replacement of blackboards that are still present in most classrooms superfluous. Our product can be mounted on any surface, with a variable size and the installation process is easy to do and does not require specialists. We simply need to mount the cameras on either side of the screen area, set up a projector and run the software.

Therefore, our product is one of the most up to date tools in the presentation market and is able to compete with any rival product. While this technology is new, there are already similar products by companies such as digitalblue (now!board) or vaborn (vaborn portable series). These products however are expensive (£300 -£500) [10] [12]. While this is still more cost efficient than regular smartboards that can cost up to £1300 [13], the purpose of our product is to enable absolutely every teacher to design their lesson as freely as possible. Depending on the desired accuracy of the screen we can reduce hardware costs down to £12 - cost of our prototype - and fashion a final product that could be sold at about £20. This would give our product a significant competitive edge because the prices of competitors cannot compare to ours.

Furthermore, we see that there is an infinite amount of possibilities to expand on this business model. One way to expand the product range would be to offer certain software upgrades that are custom tailored to our product in order to make life easier for teachers, for instance by providing software that makes the distribution of notes and contents easy. Also, we showed that we can incorporate laser pointers as a controlling tool which would offer applications in presentations at the workplace and maybe offer a cheap alternative to certain products in gaming.

8. Conclusion

From the above we can see that building a low cost interactive board with cameras and image processing software is indeed very feasible. Because of the computational principle of applying the perspective transform on the detected pen tip we could easily transfer the touch positions on the screen to the computer. This was the key to our low cost design since we only needed two ordinary webcams for the implementation. We focused on software development and were soon getting promising results. By setting various milestones to accomplish our final goal we could improve our product gradually. As a result we could see that it would be technically feasible and proved this by fully developing a functioning prototype. It would only need some minor modifications of software and hardware in order to be a fully marketable product.

This implies that the product would also be economically feasible because it would be far below the market price. This would solve the issues related to the use of smartboards in classrooms and could provide a solution that has just as many functions as smartboards or even more, as we included laser pointer interaction. Since we have transformed this promising technology from a high cost to a low cost product, lower budget public schools should in the future be able to access teaching possibilities that right now are only available to high elite education institutions.

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