

TouchScope: A Hybrid Multitouch Oscilloscope Interface

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ABSTRACT

We present TouchScope, a hybrid multitouch interface for common off-the-shelf oscilloscopes. Oscilloscopes are a valuable tool for analyzing and debugging electronic circuits, but are also complex scientific instruments. Novices are faced with a seemingly overwhelming array of knobs and buttons, and usually require lengthy training before being able to use these devices productively.

In this paper, we present our implementation of TouchScope which uses a multitouch tablet in combination with an unmodified off-the-shelf oscilloscope to provide a novice-friendly hybrid interface, combining both the low entry barrier of a touch-based interface and the high degrees of freedom of a conventional button-based interface. Our evaluation with 29 inexperienced participants shows a comparable performance to traditional learning materials as well as a significantly higher level of perceived usability.

CCS CONCEPTS

- **Human-centered computing** → Touch screens; User studies;
- **Applied computing** → Computer-assisted instruction;

KEYWORDS

Oscilloscope; multitouch; touchscreen; tangible; learning; complex interface

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1 INTRODUCTION

Oscilloscopes are a valuable tool for analyzing and debugging electronic circuits. However, they are also complex scientific instruments with a steep learning curve. A novice in front of an oscilloscope is usually faced with an array of more than 20 knobs and buttons and requires dedicated learning materials or a very long phase of trial and error before being able to productively use the device.

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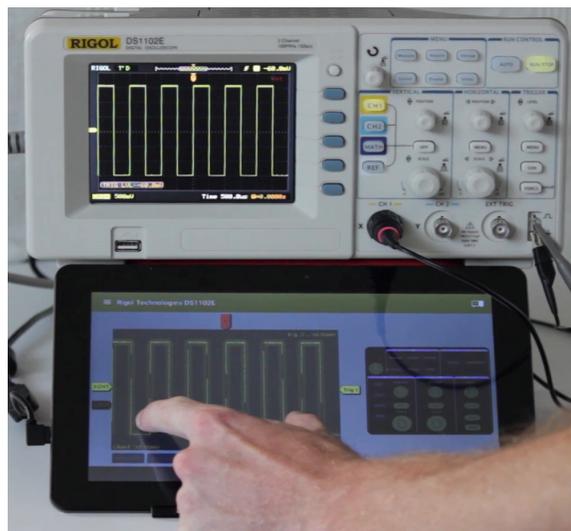


Figure 1: Tablet device running TouchScope app (bottom), synchronized with Rigol oscilloscope (top)

A very common task on an oscilloscope is one of scale selection: two knobs are generally used to adjust the horizontal (time) and vertical (voltage) scale to display a suitable section of one or more waveforms. The same applies to offset selection, which is also performed using two additional knobs. Taken together, these tasks can be reframed as panning and zooming on an infinite canvas, similar to a map. Consequently, there exists a widely-used mapping between these tasks and common multitouch gestures, i.e. pinch-zoom and drag.

TouchScope builds on this similarity by extending an off-the-shelf oscilloscope with a secondary multitouch screen. Common gestures can be used on this screen to modify the waveform display, which is mirrored on the oscilloscope itself. Simultaneously, a virtual button panel is shown which dynamically highlights the buttons/knobs on the oscilloscope that correspond to the current operation to help with mentally connecting the two interfaces. Consequently, this dual interface can be used by novices to quickly learn the basic concepts of waveform analysis using widely-known gestures, while at the same time allowing a seamless transition to the more complex, 'traditional' oscilloscope interface later on.

2 RELATED WORK

Although the basic concept of a touchscreen-based oscilloscope has been patented as early as 1986 by Tektronix [14], most currently available devices do not offer this type of interface. While some

high-end oscilloscopes such as the KeySight InfiniiVision 4000 X series do have touch interfaces [5], these tend to mirror common WIMP concepts without taking advantage of the full capabilities of a multitouch screen. In addition, there exists a complementary class of measurement devices which are designed to use a tablet as their main interface. While the signal circuits inside are very similar to those of 'regular' oscilloscopes, they lack any dedicated user interface and can only be used in conjunction with a tablet. Some examples for these devices include the Oscium iMSO-104 [3], the LabNation SmartScope [6] or the OsciPrime [9], which served as inspiration for the touch-based component of our system.

TouchScope now combines these two complementary concepts by adding a multitouch-capable, tablet-based interface to a standard oscilloscope. Both interfaces are always synchronized, i.e. display the same section of the waveform, but allow to manipulate and analyze the data using native interaction concepts. As mentioned above, our intention is that this dual interface will help novices in their learning process. Marshall et al. [7] have conducted an extensive review of tangible interfaces for learning and conclude that, depending on the task, tangibles may indeed aid learning, as it helps novices to form a mental model of the task [4]. However, although the oscilloscope in our case technically forms a tangible interface, it does not follow any design principle generally regarded useful for tangibles.

Several researchers have studied how touch-based and tangible interfaces compare for the same (or at least similar) tasks. Tory and Kincaid [15] compared touch screens, touch screens with overlays, and physical devices for parameter control with respect to speed, accuracy, and eye fixation time. They observed that physical knobs and sliders produced the fastest times for task completion and the least eye fixation time. However, their study simulated physical controls on the tablet, e.g. dials, which might not be considered a natural gesture on a touchscreen device. Our approach is to convert those physical operations into common-day multitouch gestures and see how well they transfer back to the physical controls.

Brown et al. [2] compared touch screens and tangible objects on touch screens. While tangible objects controlling a touch screen is different from physical controls on a device, many of the concepts are the same: a set of objects that have certain operations, each object controls a certain function, and the objects are real 3D tangibles. In their study, they report that although the physical controls are easier to use on average, it was more satisfying for the participants to use their hands on the touch screens.

Learning with touch screens has been used for creative tasks such as oil painting [13], but also for training tasks such as for paramedics in disaster operations [8]. In the painting scenario, brush behavior is simulated on the tablet to teach users the fundamentals of this art style. Artists found the system believable despite being simplified. The paramedic training tool simulates tasks such as disaster triage on a large-scale multitouch tabletop. Gesture based interactions simulate the patient's behavior to be as realistic as possible, e.g. by requiring bimanual interaction for certain operations. Also in a medical context, Quarles et al. [10] present a mixed-reality learning system for an anesthesia machine. Their results support our choice of approach of a hybrid interface to assist with learning tasks.

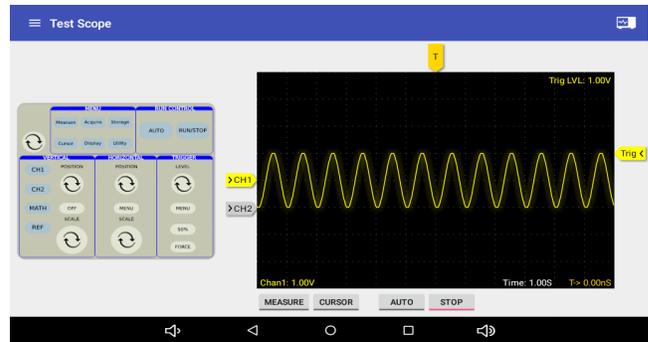


Figure 2: TouchScope hybrid main view on tablet screen. Left: virtual button panel mirroring physical oscilloscope controls; right: signal view with cursor and trigger level handles. Note that the virtual button panel can be hidden to maximize screen space for the signal view.

3 TOUCHSCOPE

3.1 Hardware and Software Components

The main components of our setup are a Rigol DS1102E dual-channel digital storage oscilloscope, and a Blaupunkt 10" tablet running Android 5.0. The oscilloscope is directly connected to the tablet, which acts as USB host. The scope acts as an *USB Test and Measurement Class (TMC)* device [17], using a custom plain-text protocol to read data from and control the scope. The low-level TMC protocol was re-implemented in an Android app based on the open-source *usbtmc* driver from the Linux kernel, which unfortunately is not present on most Android devices. The custom control protocol was also implemented in the app based on the Rigol programming guide [11]. Building all required communications protocols directly into the app has the further advantage of better portability.

3.2 Hybrid Interface

The core part of our system is the hybrid interface. On the scope as well as on the tablet, identical waveforms are displayed at all times, and any manipulation on one device also affects the other. The most fundamental operations on the scope (adjusting time/voltage scale and offset) are mapped to pinch-zoom and pan gestures on the tablet. Secondary operations (time/voltage measurements, trigger, probe settings) are accessed using touch-based handles and popup menus (see also right-hand side of Figure 2).

Horizontal zooming/panning will control the time scale and offset for all waveforms, while vertical zooming/panning will only affect the selected waveform. Selection is performed by a single tap on the corresponding waveform, which will then be displayed in bold. A virtual button panel mirroring the button/knob layout on the oscilloscope can be added to either side of the central waveform display (to account for left- or right-handed users). Any touch-based operation will cause the corresponding virtual buttons to highlight and animate, e.g. a horizontal pinch-zoom which changes the time scale will also highlight and rotate the virtual "HORIZONTAL SCALE" knob, dragging the trigger level handle will highlight/rotate the virtual "TRIGGER LEVEL" knob etc. Note that this

virtual button panel is not interactive and can be hidden if only the touch-based interface is desired.

4 EVALUATION

We performed an initial, informal evaluation of our system with 5 experienced users who were already familiar with oscilloscopes to identify bugs and major usability issues, followed by a main study focusing on novices and their learning performance. We pose two major research questions: 1) can a participant who learned on the tablet perform the final tasks on the oscilloscope just as well as a participant who learned on the oscilloscope?, and 2) is there a difference in participant's level of satisfaction after completing the learning phase?

4.1 Main Study

Our main study consisted of two phases, a learning phase designed to familiarize the participant with oscilloscope concepts and controls, followed by a test phase with measurement tasks to be completed. As we wanted to study learning effects, our setup necessarily follows a between-subjects design. Consequently, each participant completes the learning phase either on the tablet or the oscilloscope, while the subsequent test phase always takes place on the oscilloscope and is the same for all participants. The oscilloscope was connected to a MXG-9802A function generator that generates suitable waveforms for the test tasks. All interactions were recorded on video with the participants' informed consent. Before starting, demographic data as well as data on prior experience with both oscilloscopes and tablet devices in general was recorded. After the learning phase, participant satisfaction was measured using an adapted SUS [1, 12] questionnaire. During and after the test phase, we measured accuracy of results, task-completion times, and assistance count.

The learning phase first introduces the participant to the oscilloscope itself and to the basics of signal analysis. The accompanying document that is handed out is based on several existing tutorials and courses for oscilloscopes, such as the EECS 100/43 tutorial from UC Berkeley. Four sections with small tasks to be completed cover the following topics: horizontal controls (time), vertical controls (voltage), trigger settings, and measurements. In the measurements section, concepts such as period, frequency and amplitude are also introduced so that these concepts are known to the participant for the following test phase. An example task for the horizontal controls is to 'adjust the scale of the waveform to $200\mu s$ ', or for trigger settings, to 'move the trigger level to the middle of the signal'. A 1 kHz square wave signal from the oscilloscope's own test source was used for these basic tasks.

The subsequent test phase consists of three tasks: 1) achieve a stable display of at least one period of an unknown waveform (for a 12 MHz triangular wave), 2) determine the amplitude and period of the waveform from task 1, and 3) find the frequency of a second unknown waveform (for a 21 Hz sinusoidal wave). We noted that even for the experienced users, the transition from 2nd to 3rd task was difficult due to the large difference in wave frequency.

Our study was completed by 29 participants (12 female/17 male) between 21 and 30 years of age, who were students and employees of our local university. All participants had an engineering background

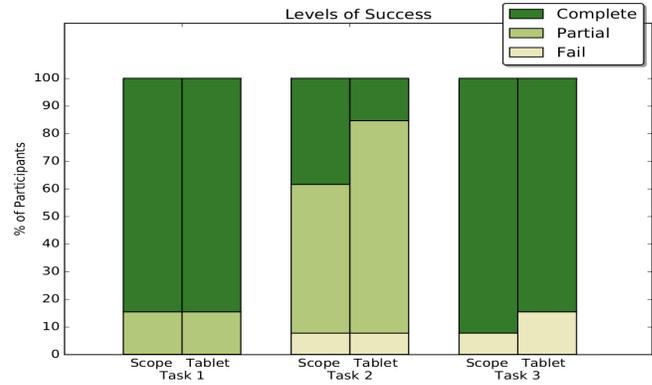


Figure 3: Levels of success.

(26 from computer science), which is the intended target group for our application. Those participants who reported medium to high previous expertise with tablet devices were intentionally placed into the group which started the learning phase on the tablet, as we want to assume prior familiarity with common multitouch gestures such as pinch-zoom. Otherwise, difficulty in interacting with the tablet might confound the results.

4.2 Results

To answer our first research question, we look at accuracy of results, task-completion time, and assistance count.

When analyzing accuracy, we define two thresholds for those answers which produced numerical results and classify the answers as complete success when within the first threshold, partial success when within the second threshold and failure when outside of both thresholds. The results are illustrated in Figure 3. As the data is categorical, the non-parametric Chi-square test was used to determine significance. For task 1, $\chi^2(1) = 0.000, p = 1.000 > 0.05$. For task 2, $\chi^2(2) = 1.815, p = 0.404 > 0.05$. For task 3, $\chi^2(1) = 0.000, p = 1.000 > 0.05$. Consequently, for all tasks, there is no significant difference for accuracy of results.

Similar results were observed for assistance count, as illustrated in figure 4. We categorize the data into zero, one, or two or more times where the participant required assistance. For task 1, $\chi^2(2) = 4.254, p = 0.119 > 0.05$. For task 2, $\chi^2(1) = 0.217, p = 0.642 > 0.05$. For task 3, $\chi^2(2) = 1.467, p = 0.480 > 0.05$. Consequently, for all tasks, there is no significant difference for assistance count.

Finally, for our first question, we also looked at task-completion time, i.e. time between the participant having read the task description and giving an answer (see Figure 5). According to [16], 3 samples which were more than 3 standard deviations above the mean were removed as outliers. As task-completion time is ratio data, we used a parametric test. A prior Shapiro-Wilk test confirmed that for all three tasks, the data is sufficiently normally distributed ($W_1 = 0.92, p_1 = 0.06 > 0.05; W_2 = 0.98, p_2 = 0.86 > 0.05; W_3 = 0.98, p_3 = 0.86 > 0.05$), so that we used two-tailed t-tests to check for significant differences. For task 1, $t(24) = 1.806, p = 0.085 > 0.05$. For task 2, $t(24) = 1.667, p = 0.109 > 0.05$. For task 3, $t(24) = 1.663, p = 0.109 > 0.05$. Following these results, we can conclude that there is also no significant difference regarding task-completion time for any task.

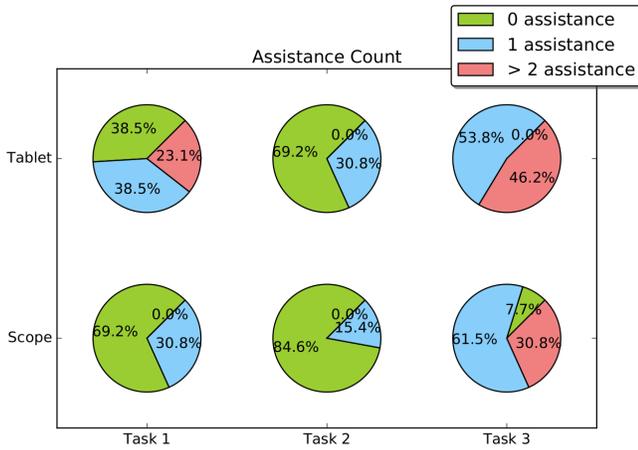


Figure 4: Assistance count.

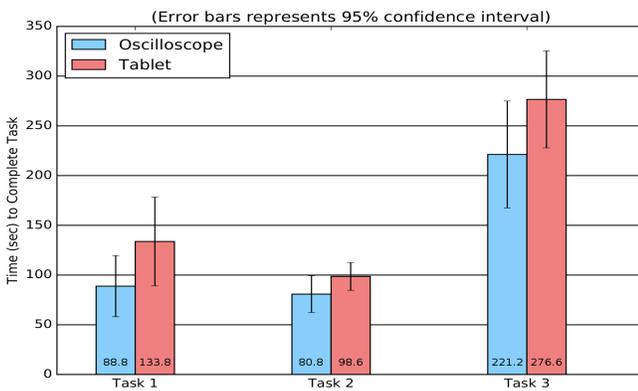


Figure 5: Task-completion times.

Consequently, we can answer our first research question: as there is no significant difference between groups for any combination of task and measure, we have to accept the null hypothesis, i.e. that there is no difference in the learning performance of our participants for both tablet-based and scope-based learning. We note that, descriptively, the performance across all measures was slightly worse for those participants who learned on the tablet, although this was below the threshold of significance. This may, potentially, be due to the small additional mental load that is required for transferring the operations learned on the tablet to the oscilloscope despite our hybrid interface.

Regarding our second research question, we now look at the SUS scores collected after the learning phase (see Figure 6). The SUS score is a value between 0 and 100 and can therefore be interpreted as ratio data. A Shapiro-Wilk test shows that the data is normally distributed ($W = 0.97, p = 0.48 > 0.05$) and a subsequent one-tailed t-test shows ($t(26) = 2.019, p = 0.028 < 0.05$) that there is a statistically significant difference between conditions.

We can conclude that the perceived usability of our tablet-based interface is significantly higher (mean SUS score of 58.7 for learning

on the scope, and of 70.0 for learning on the tablet). This result confirms our prior assumption that an oscilloscope is an intimidating tool for inexperienced users, and that our TouchScope interface presents an alternative method of learning and operating such tools that is less complex and more approachable for novices.

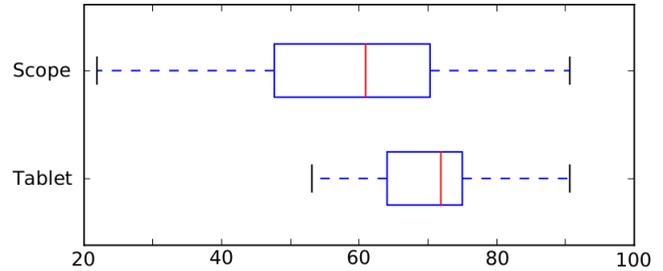


Figure 6: SUS Scores for post-learning-task satisfaction.

Post-task comments from participants also support this notion. While some people (4 out of 29) were fond of the physical controls of the oscilloscope, more (8) found the controls confusing and thought there were too many buttons and menus, e.g. describing them as "chaos of dials" or simply "a lot of buttons". The virtual button panel was sometimes found to be confusing: several (6) participants tried to adjust the virtual controls, which was not possible. On the other hand, most participants (12) on the tablet enjoyed how minimalistic the interface was, noting it was "simple", "straight-forward" and "very easy to learn on".

5 CONCLUSION & FUTURE WORK

We have presented TouchScope, a hybrid touch-based interface for common oscilloscopes. Our main contributions are a combination of multitouch-based and knob-based interfaces to adjust the signal view, a user study focussing on learning performance, and an open-source implementation of the hybrid interface. TouchScope is designed for easy learning of oscilloscope operation by using widely-known touch gestures for interaction while simultaneously highlighting the corresponding oscilloscope controls. Our study participants showed comparable performance to a traditional learning process, while at the same time reporting significantly higher perceived usability during learning. For a complex tool such as an oscilloscope which can seem overwhelming to novices, an easily accessible and satisfying learning tool is a valuable addition. The TouchScope app is available as open-source at <https://github.com/mmbuw/touchscope>.

In the future, it would be advisable to expand our study and use a 2x2 between-subjects design, in which two additional groups of participants complete the test tasks on the touchscreen device, instead of on the oscilloscope. This approach would allow to eliminate any potential bias due to prior tablet experience, and would also allow comparison of the interface performance itself. A prolonged study in an unsupervised lab setting could also provide valuable insights. Finally, more complex test tasks, such as calculating offsets between two different waveforms on two channels, might reveal additional areas of improvement for the interface.

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