Myopoint: Pointing and Clicking Using Forearm Mounted Electromyography and Inertial Motion Sensors

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ABSTRACT
We describe a mid-air, barehand pointing and clicking interaction technique using electromyographic (EMG) and inertial measurement unit (IMU) input from a consumer armband device. The technique uses enhanced pointer feedback to convey state, a custom pointer acceleration function tuned for angular inertial motion, and correction and filtering techniques to minimize side-effects when combining EMG and IMU input. By replicating a previous large display study using a motion capture pointing technique, we show the EMG and IMU technique is only 430 to 790 ms slower and has acceptable error rates for targets greater than 48 mm. Our work demonstrates that consumer-level EMG and IMU sensing is practical for distant pointing and clicking on large displays.

Author Keywords
pointing; large displays; electromyography;

ACM Classification Keywords
H.5.2. Information interfaces (e.g., HCI): User Interfaces.

INTRODUCTION
Using a bare human hand for distant pointing and clicking is advantageous [9]: hand movement can be used for pointing, and finger movement for "dwell-free" clicking. However, tracking hand and finger positions with enough fidelity in a large physical space across various environmental conditions remains challenging. For example, computer vision is susceptible to occlusion and lighting, and without additional markers, vision-based tracking of hands at arbitrary orientations over a large area is difficult.

An arm-mounted inertial measurement unit (IMU) provides motion and orientation tracking suitable for pointing with minimal environmental interference, but detecting a click requires additional sensing. On-body computer vision is one approach [4], but inter-finger occlusion and lighting interference remain problematic. Sensing hand poses through muscle activation using Electromyography (EMG) eliminates occlusion and lighting issues and can be reliable, non-invasive, and portable [7, 8]. Previous work combining EMG and IMU for cursor control has focused on gesture detection and recognition algorithms, not user interaction [3, 10].

We present Myopoint, an EMG and IMU pointing and clicking technique using a consumer Myo arm band device (`http://www.thalmic.com`). Myopoint translates and extends a relative pointing technique developed for ideal hand tracking by Vogel and Balakrishnan [9]. We extend their interaction language for activation, clicking, and clutching; we provide a tuned pointer-acceleration transfer function; and we develop input filtering techniques to compensate for involuntary hand movements when clicking and false posture recognition from fast arm movements. To evaluate Myopoint, we replicate Vogel and Balakrishnan's experiment and use their data as a between-subjects benchmark. We show that Myopoint is only 430 to 790 ms slower over the tested range of index of difficulty (3.37 to 7.98 bits) with a 15% error rate for 48 mm targets and 5% for 144 mm targets. Our work demonstrates that consumer-level EMG and IMU sensing devices are practical for fundamental pointing input.

RELATED WORK
Vogel and Balakrishnan [9] evaluated device-free pointing and clicking using absolute ray-casting and position-based relative cursor control. They found relative had lower error rates and comparable selection times when clutching was minimized. They used a high-quality Vicon motion tracking system with hand-mounted reflective markers – reasonable for a laboratory, but impractical for real-world use. We translate their relative technique to a practical real-world device and use their experiment results as an ideal upper bound on for relative performance comparison. Note that subsequent barehand pointing research has not changed relative pointing interaction — the focus has been evaluating un-instrumented tracking (e.g. [1]) or using barehand input for other purposes.

IMUs measure relative motion that can made suitable for relative cursor control. Glove mounted IMUs require physical buttons for clicking [2] or extra finger-mounted IMUs for gestural clicking [6]. Kim *et al.*'s Digits [4] is a gloveless wrist-mounted system combining a vision tracking system for hand postures and an IMU for arm motion. They demonstrate a basic pointing and clicking application without evaluation. The wrist-mounted device is bulky and using computer vision means inter-finger occlusion and lighting interference remain.

Recent work exploring EMG for interaction suggests an alternative method for clicking. Saponas *et al.* develop EMG classification techniques for recognizing finger grip gestures un-

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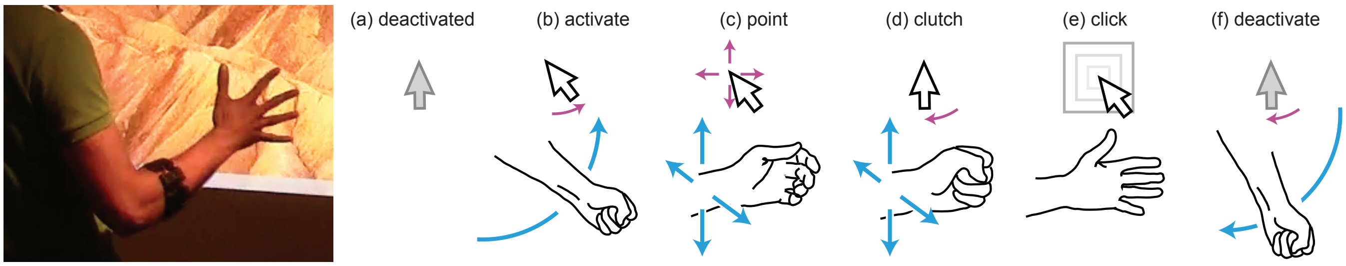

Figure 1: Myo armband (left) and Myopoint interaction (right): (a) initially deactivated; (b) activate by raising clenched fist and releasing; (c) point by moving arm with relaxed hand; (d) clutch with clenched fist; (e) click by spreading all fingers; (f) deactivate by lowering clenched fist and releasing.

der load [7] and pinch-gestures [8] and demonstrate EMG for discrete event input. Xiong *et al.* [10] and Forbes [3] report on mouse input techniques combining arm-mounted EMG and IMU. Forbes combines continuous EMG and IMU for cursor control, while Xiong at al. use IMU for cursor control and EMG postures for mouse control modes and events. Both projects are focused on classification algorithms, not interaction — no human performance evaluations are conducted. There has been no systematic design or validation of a combined EMG and IMU gloveless pointing technique.

MYOPOINT

The Myopoint pointing and clicking technique is built for commodity EMG and IMU sensors. We use a Myo armband, a low-cost consumer device. It may be less sensitive than lab-based EMG and IMU sensors, and it uses proprietary EMG classification and IMU fusion, but we consider these design constraints to develop a real-world pointing technique.

Myo Device

The Myo is a 40 mm wide, 11.5 mm thick, 95 g band worn on the upper forearm. Eight dry electrodes are arrayed around the arm on elasticised segments for EMG sensing and the IMU is a 3-axis gyro, accelerometer, and magnetometer. When placed on the arm, a one-step calibration compensates for handedness, electrode offset, and inter-person EMG differences. During use, on-board processors classify EMG sensor data to determine if the hand is at rest or forming one of 5 hand postures. IMU data is fused and filtered to provide forearm orientation and acceleration. EMG posture events are sent with minimal lag and IMU state is updated at 60 Hz.

Relative Pointing Interaction Technique

Despite its capabilities, the Myo is not originally intended for pointing and clicking. Myopoint translates and extends Vogel and Balakrishnan's *Relative Pointing with Clutching* technique [9]. We also use a neutral 'safe hand' for pointing cursor control (Fig 1c) and a clenched fist 'Grip Clutch' to disengage from the cursor (Fig 1d). Detecting fine finger movements to enable Vogel and Balakrishnan's AirTap click technique is not yet possible on the Myo. We use a finger spread posture to click (Fig 1e). Spreading is a 'click down' and releasing is a 'click up'.

We extend Vogel and Balakrishnan's work by adding activation and deactivation gestures to address Midas touch. Saponas *et al.* [7] used a non-dominant fist to delimit every dominant hand EMG posture. Myopoint is designed to be single-handed and used for longer periods of time, so we use a combination of EMG pose and arm orientation to activate and deactivate the pointing mode. Raising the arm with a clenched fist and releasing activates pointing (Fig 1a). Clenching the fist while lowering the arm and releasing deactivates (Fig 1f). Since a fist is also used for clutching, this does not interfere with cursor position and extends the metaphor of "clench to clutch" to "clench and drop to deactivate." Saponas *et al.* [7] stress the importance of visual feedback for EMG interaction. We translated Vogel and Balakrishnan's audio and visual feedback and extend the 'dangling cursor' clutch visualization to also fade out when Myopoint is deactivated.

Vogel and Balakrishnan use a scaled version of the Windows XP pointer acceleration function tuned for their motion tracking system and absolute hand position sensing. The Myo has different device characteristics and reports relative forearm orientation velocity in rad/s. Following guidelines from Nancel *et al.* [5], we designed a new pointer acceleration function to transform v_{arm} (rad/s) to v_{cursor} (mm/s):

$$v_{cursor} = v_{arm} \times \left(58.28 + \frac{5060.14}{1 + e^{-1.45 \times (vel_{arm} - 1.66)}}\right)$$

Although the Vicon technique also supports wrist movement, it is primarily tuned for forearm movement like Myopoint.

Correction and Filtering

Combining EMG and IMU input together can produce side-effects such as tense EMG hand postures causing unintended IMU arm movement, and fast IMU arm movement causing unintentional EMG pose recognition. We minimize these side-effects with three correction and filtering techniques conservatively tuned to avoid blocking intended clicks. In our experiment, these are logged to assess frequency.

Click position correction – The 'finger spread' hand posture reduces side-effect movement when clicking, but when performed quickly, unintentional movement can make the cursor "jump" when forming the posture (click-down) or releasing (click-up). To avoid this, we implemented a corrective mechanism built on the observation that people slow down just before clicking. When a click-down or -up posture is detected, we examine recent movement and use a cursor location corresponding to minimum velocity. Based on pilot studies, we examine a 250 ms window for click-down and 500 ms for click-up. In both cases, we ignore 25 ms preceding the click posture due to EMG lag. When clicking on targets, the click-up window often overlaps the click-down window so both have the same corrected cursor location. This increases click stability while still enabling dragging. Since the correction occurs after unintentional motion, the cursor may appear to jump back. This visual jump could be avoided by buffering cursor movement, but the extra lag would impair usability. We found that once people understood the system was correcting click positions, they ignored the visual jump and simply expected click events to occur where they intended.

Movement-induced false positive posture filtering – Moving the arm quickly or extending it very far can activate forearm muscles leading to false-positive hand postures recognized by the EMG system. Since users briefly slow down before clutching or clicking, we use speed thresholds above which click and clutch postures are ignored. Based on pilot data, we use a threshold of $V_{ignore} = 1.0$ rad/s to reduce unwanted events while keeping false negatives to a minimum.

Unlikely posture sequence filtering – When quickly switching from 'fist' to 'neutral' the EMG recognizer can misclassify the final 'neutral' posture as a 'finger spread'. This causes an unintentional click-down immediately after a clutch release. People are unlikely to perform these events so rapidly, so we ignore click-downs within 250 ms after a clutch release.

EXPERIMENT

We evaluate Myopoint accuracy and speed using a near-replication of Vogel and Balakrishnan's experiment design, task, and large display [9]. Our intention is to give more substance to our comparison than usual high-level discussions using summative data. Using their original data, a between-subjects comparison can benchmark Myopoint performance.

Participants and Apparatus

We recruited 7 'expert' participants from Thalmic Labs who use the Myo daily (for purposes other than pointing) and 7 participants from the general public. Since the Myo device is unfamiliar, balancing for expertise (EXP) is important. All 14 participants (1 female) were right-handed and none had experience with the Myopoint technique or distant pointing. Participants stood 2m from a 4.6 by 1.4m (3840 by 1200 px) front-projected display with two side-by-side HD projectors. Vogel and Balakrishnan used a 5.0 by 1.7 m (6144 by 2304 px) display. Our display width is smaller, but above the maximum target distance of 4.02 m and our 0.83 px-per-mm density is comparable to their 0.81 density.

Task and Stimuli

Like Vogel and Balakrishnan, we had sets of a Transition Task followed by a Sequence Task. In both tasks, the current target was rendered as a blue circle on a black background and the next target rendered as a blue outline.

Transition Task – This simulates transitioning to the pointing technique. After the cursor and target appear at controlled locations, the participant activates the technique and selects the target. The initial cursor position relative to the target is controlled. Note that Vogel and Balakrishnan use a synthetic activation technique, we use our real Myopoint activation.

Sequence Task – This simulates continuous pointing usage. Immediately after selecting the transition target, the participant selects a sequence of 6 more targets at controlled distances and randomized directions. Participants had to successfully select each target before the next would appear. After the sequence task, the participant used the deactivation gesture to simulate a transition back to a non-pointing task.

Design and Protocol

We used the same three levels of D and W as Vogel and Balakrishnan: D = 4020, 2680, 1340 mm; W = 144, 48, 16 mm (index of difficulty, ID = 3.37 to 7.98 bits). This is a repeated measures mixed design where TASK, D, and W are within-subjects and TECH is between-subjects. TECH = *Myopoint* or *Vicon*, where Vicon is Vogel and Balakrishnan's complete data set for their Relative Pointing with AirTap technique.

Participants first completed the default Myo calibration, then a 5 minute Myopoint learning session, then 1 block of practice trials, and then 3 blocks of measured trials. Each block had 3 sections of tasks, one section for each width (W was held constant throughout a section). The order of width sections was Latin square balanced for measured blocks. Each section had 3 sets of the two consecutive tasks: one target selection in the Transition Task followed by 6 selections in the Sequence Task. All target distances were presented randomly an equal number of times within each section and task. Participants could rest between sections and a 5 minute rest between blocks was enforced. Participants did not report substantial fatigue during the 45 to 60 minute experiment.

In summary, the experimental design was: 3 blocks $\times$ 3 sections of target widths $\times$ 3 sets of tasks: Activation Task (1 target) followed by Sequence Task (6 targets) = 36 task sets per participant (36 targets selected in Activation Task, and 216 targets selected in Sequence Task).

Results

Trials were successful if both click-down and -up were inside the target, otherwise the trial is an error. Requiring down and up on target is more stringent than Vogel and Balakrishnan's error analysis, but we feel more realistic.

Initial analysis revealed 207 click-down errors occurring within the first 300 ms of a trial, i.e. after a successful release event. We consider these click-down events misclassified as it is unlikely that users spread, then relaxed their hand to click twice within 300 ms. To correct for this, we ignore all click-downs occurring within 300 ms after a click-up. This removes 357 errors including the ones above. It also removes 81 click-downs used for successful trials, which likely were lucky erroneous clicks. For consistency, we remove these trials. Fig. 2b illustrates the reduction in error from this post hoc "300ms filter". Below we discuss how this 300 ms rule could form a real time filter.

Error trials were excluded from time statistics and Fitts' models (17.9% of trials, on par with 18.4% in the Vicon study). Median times were used to compensate for non-normal time distribution (flagged by the SAS JMP REML normality test). Multi-way ANOVA was used with post-hoc Tukey tests.

Error Rate

We found a significant effect of W ($F_{2,26} = 33.12$, $p < 0.0001$) on ERROR. As expected, error increased as W decreased (.05, .15, .37, all significantly different) (Fig. 2b). Between-subject

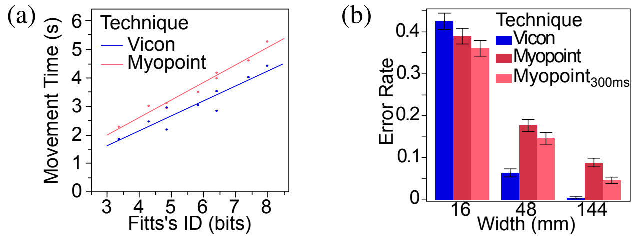

Figure 2: (a) time by ID; (b) error rate by W (*Myopoint* bar is without the "300ms filter", *$Myopoint_{300ms}$* is with it, error bars are SEM).

analysis of Tech reveals no main effect but there is an interaction between Tech and W ($F_{2,193} = 6.42$, $p = .002$). Post-hoc tests did not find significantly different error rates between techniques for the same W, and the Vicon error rate for 48 mm targets is not significantly different than Myopoint or Vicon for 144 mm targets. For targets above 48 mm, Myopoint error rate is an encouraging 15.4% and for 144 mm, it is a practical 4.6%. Note that error rates reported in Vogel and Balakrishnan are lower since only click-down errors are considered.

Selection Time

We fit Sequence Task data for both Techs to Fitts' models. The models have similar slopes with Myopoint slower by 430 to 790 ms in the considered ID range (Fig. 2a).

$$\text{Myopoint} \quad R^2 = .97, \quad MT = 171.59 + 609.36 \times ID$$
$$\text{Vicon} \quad R^2 = .87, \quad MT = 28.93 + 528.32 \times ID$$

Clutching and Activation/Deactivation

We calculated the mean time spent clutching, pointing, and (de)activating in all Tasks and Techs. A between subjects ANOVA showed a significant effect of Task ($F_{1,24} = 14.52$, $p = .0008$) and Task × Tech ($F_{1,24} = 10.74$, $p = .0032$) on Clutch Time. Significantly more time was spent clutching in the Transition Task (363.6 ms) than in the Sequence Task (127.99 ms); this effect is increased with Vicon (491.88 and 53.67 ms), while the difference is not significant with Myopoint (235.32 and 202.32 ms). Note only Myopoint has a real activation technique, the median time to activate is 1816 ms, and 1140 ms to deactivate. High (de)activation speed was not emphasized to participants, so these are comfortable baselines.

Experts (E) and non-experts (NE)

Between-subject analysis revealed no significant effect of Exp on MT. There was a significant effect of Exp ($F_{1,12} = 7.24$, $p = .0197$) on Error: 15% for E, 23% for NE. This is explained by an interaction effect with W ($F_{2,96} = 16.19$, $p < 0.0001$): the only significant difference between E and NE is with 16 mm targets: 25% for E, 49% for NE. Fitts models (E: $MT = 90 + 594 \times ID, R^2 = .96$ and NE: $MT = 252 + 624 \times ID, R^2 = .95$) reveal a mostly constant difference. This suggests experts are more efficient at forming hand postures.

DISCUSSION

Some degradation in performance when moving from a Vicon to a consumer-level EMG and IMU armband is expected. Considering the Vicon as an ideal upper bound, Myopoint performance is quite good. Myopoint is slower for technical reasons: clicking with the hand spread posture is slower than small finger movements with AirTap, and despite our filtering, correction, and transfer function, very fast or careless clicks can still cause cursor jumps and participants were sometimes cautious. Further tuning may help.

Correction and Filtering – From our logs, the click position correction converted what would have been errors to successful selections 32 times per click down (0.9% of trials) and 316 times per click up (8.9% of trials). Our movement-induced false positive filtering was invoked 605 times (17.1 % of trials) and our unlikely posture sequence filtering rejected 225 false click events (5.4 % of trials). The data indicates our filtering corrects unintended movements symptomatic of any forearm-mounted EMG+IMU device. The thresholds may change, but we believe our algorithms would apply to other devices. The misidentified clicks within 300 ms of a previous spread pose suggest a simple additional filter.

CONCLUSION AND FUTURE WORK

Our work demonstrates that distant pointing interaction is practical for consumer-level EMG and IMU sensing. As future work, we are applying Myopoint to smartphones and head-mounted displays and are exploring panning and zooming techniques already prototyped in ideal, but impractical tracking environments. The intention is that by using consumer input devices as a practical constraint, we can translate, extend, and validate lab-based interaction technique research.

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