A User-based Mid-air Hand Gesture Set for Spreadsheets

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ABSTRACT

The spreadsheet is one of the most popular general user interfaces. Table manipulation, such as cell insertion and removal, is usually performed by selecting a menu command or using shortcut keys. However, the enormous number of shortcut keys makes them difficult to learn and remember. We sought to design a mid-air hand gesture-based interface for table manipulation in spreadsheet applications. As hand gestures and table manipulations are both spatial in nature, there should be a natural mapping between them. In this paper, we performed two user studies to derive a user-defined gesture set allowing 13 types of table manipulation. In the first study, we collected mid-air hand gestures devised by participants for manipulations implemented in existing spreadsheet software. In the second study, we asked other participants to vote for their most preferred gestures. We analyzed the characteristics of the collected gestures and votes, and created a final user-defined gesture set.

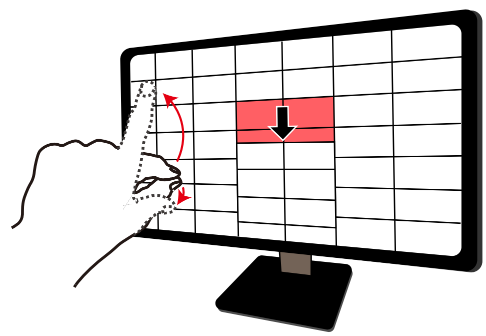

Figure 1: Illustration of our interface. By performing a "vertical pinch gesture" with one hand in front of the display, the user can move selected cells in the desired direction and insert new cells at that position.

CCS CONCEPTS

• **Human-centered computing** → **Gestural input**; Graphical user interfaces; *User centered design*; • **Applied computing** → **Spreadsheets**.

KEYWORDS

Gesture interface; Natural User Interface (NUI); User-base gestures; Table manipulation; Spreadsheet.

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1 INTRODUCTION

Spreadsheets, such as Microsoft Excel[1] and Google Sheets[2], greatly facilitate data editing, management, and analysis, and allow the creation of two-dimensional tables using a general user interface (GUI) [1]. These Spreadsheets are used not only by those involved in data management, but also by students and office workers. Most table manipulations in spreadsheet software are performed by selecting an item from the tab menu at the top of the window, or from a pop-up menu displayed by right-clicking the cursor. Frequent table manipulations, such as inserting and deleting cells, are performed in the same way as infrequently used functions. Therefore, the user has to search for the desired menu item each time, increasing the risk of error [13]. In addition, a pop-up menu often hides target cells. To solve these problems, many spreadsheet programs provide shortcut keys, but these are often difficult to remember and may take a long time to learn [23].

We developed a mid-air hand gesture-based interface for frequently used table manipulations of spreadsheet software (Fig. 1). As a step toward developing a final gestural interface, we performed a user elicitation study to create a hand gesture set based on user-based gesture generation [14, 18, 21]. We report on two studies. In the first, we asked participants to define gestures for 13 types of major table manipulations and collected a total of 111 gestures. In the second study, we recruited another group of 10 participants and asked them to vote on their favorite gestures for each type of table manipulation. We created a final hand gesture set by considering the votes and common features of the voted-for gestures.

[1]https://www.microsoft.com/ja-jp/microsoft-365/excel
[2]https://www.google.com/sheets/about/

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Finally, we discuss the feasibility of the proposed interface based on detailed analysis of the gesture set, and discuss possible implementation issues.

2 RELATED WORK

2.1 Spreadsheet Software Interfaces

Gary et al. [19] used a smartphone to interact with a spreadsheet on a tablet. By placing the side of the smartphone against the screen of the tablet, the user selected cells and ranges, and input and edited cells on the smartphone screen. This solves the screen-obscuring problem; the display and manipulation screens of the spreadsheet software are separated. However, the smartphone manipulations remain menu-based and the probability of incorrect manipulation increases because the manipulation screen is reduced to the size of the smartphone screen. Zgraggen et al. [27] proposed a highly intuitive manipulation system using handwritten gestures to enter data into spreadsheet cells. This solves the problem of input into small cells, but deals with data input only; the system does not address the problem of table manipulation using menus and shortcut keys.

2.2 The Mid-air Hand Gesture Interface

The mid-air hand gesture interface does not require a controller and functions even when a user is not close to the device. Many studies aimed to use such interfaces in public displays [22], large displays [4], smart homes [15], and virtual reality/mixed reality (VR/MR) systems [26]. In addition, mid-air hand gestures have also attracted attention for their use in 3D modeling due to their spatial aspect. Sanmothi et al. compared mid-air hand gestures and tangible user interfaces (TUI) with object in hand and traditional mouse/keyboard for operations such as moving, zooming, and rotating 3D objects [7]. The results showed that the combination of mouse/keyboard with hand gestures improved the user experience. Chen et al. examined the usability factors of manipulating 3D digital contents using mid-air hand gestures [5]. The results showed that ensuring the robustness of gesture recognition is very important. Here, we focus on manipulating spreadsheet cells. Mid-air hand gesture interaction with a vertical display is associated with the so-called gorilla arm syndrome, which is caused by holding the arm against a vertical display for a protracted period [12]. In our interface, however, this does not occur; hand gestures are executed only as needed so the arms can often relax. In addition, the display is not touched; the user can gesture with the elbow resting on a desk.

2.3 The User-based Gesture Set

Recently, gesture sets for gesture-based interfaces have attracted increasing attention, as they are more learnable, recallable, and guessable than developer-based gesture sets [10, 11, 16, 17, 24]. Wobbrock et al. [25] created a user-based gesture set for a tabletop touch display. They showed participants a video of many changing figures and asked them to associate touch gestures with the changes. Chan et al. [3] assigned one-hand-only user-defined aerial hand gestures to 34 common commands. As this was demanding, ultimately, one-handed micro-gestures were combined with mouse or keyboard operations. Epps et al. [8] developed a user-based gesture set for touch interactions on a tabletop interface. As the simplest possible gesture, finger-pointing with the index finger was unsurprisingly favored.

3 GESTURE ELICITATION STUDY

We adopted a user-based gesture generation approach based on previous studies [17, 24, 25]. We selected the following 13 table manipulations, all of which are on the pop-up menus of Microsoft Excel and Google Sheets.

- *Insert Rows* (I_{row})
- *Insert Columns* (I_{column})
- *Insert Cells Shift Right* ($I_{cell\text{-}right}$)
- *Insert Cells Shift Down* ($I_{cell\text{-}down}$)
- *Delete Rows* (D_{row})
- *Delete Columns* (D_{column})
- *Delete Cells Shift Left* ($D_{cell\text{-}left}$)
- *Delete Cells Shift Up* ($D_{cell\text{-}up}$)
- *Copy*
- *Cut*
- *Paste*
- *Ascending Sort* (S_a)
- *Descending Sort* (S_d)

3.1 Gesture Collection

Standardized gestures for table manipulation are currently lacking, so we collected samples of hand gestures that users commonly associate with spreadsheet manipulations.

3.1.1 Participants. We recruited 12 graduate and undergraduate students, 2 of whom were female; the mean age was 21.8 years (standard deviation [SD] = 0.94 years). All participants were right-handed so usually operated a mouse with their right hand. They self-rated their proficiency (1 = beginner, 2 = elementary, 3 = intermediate, 4 = advanced, 5 = professional) and use frequency of spreadsheet software (1 = never used, 2 = rarely used, 3 = sometimes used, 4 = often used, 5 = used daily) on 5-point Likert scales. As the scores ranged from 2 to 4 points, all participants were intermediate users.

3.1.2 Procedure. We explained all 13 table manipulations to the participants using two spreadsheet software windows to this end (Fig. 2a). The left window showed the cells before execution of a manipulation, and the right window the cells after execution. The name of the manipulation was displayed at the top of the screen. The target cells were colored; for example, inserted cells were red, deleted cells were blue, copied/cut/pasted cells were yellow and sorted cells were graduated from red to blue (the background color).

We asked each participant to devise and perform a mid-air hand gesture corresponding to the manipulation shown on the screen. Both two- and one-handed gestures were allowed, as was use of a mouse. We asked them to explain their intentions aloud while devising and performing the gestures.

We combined the *Copy&Paste* and *Cut&Paste* functions because they are usually employed sequentially and are difficult to understand individually. For example, *Cut* renders selected cells blank, and can be confused with deletion, while *Copy* does not change the table. Thus, *Cut&Paste* and *Copy&Paste* are easier to understand. Therefore, *Paste* was not performed in isolation, but rather as a

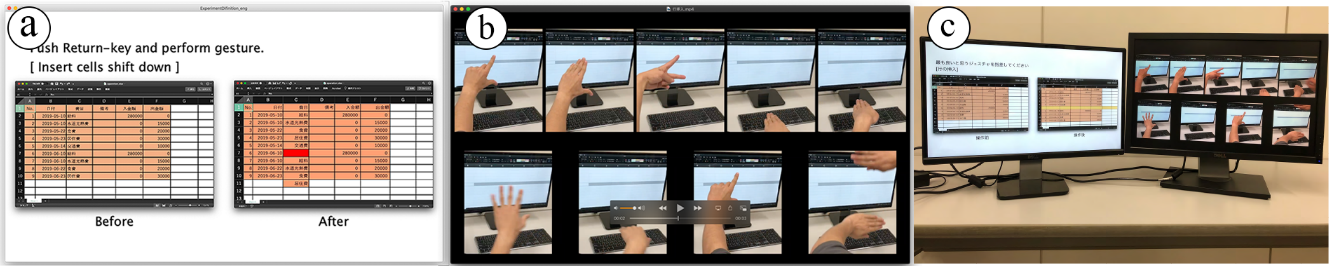
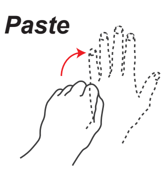


Figure 2: The screen presented to the participants and the setup for the gesture evaluation study. A: Example instruction window presented to participants in Studies 1 and 2 (I_{row}). B: Example screen showing the gesture videos presented to the participants in Study 2 (I_{row}). C: The experimental setup for Study 2.

component of both *Cut&Paste* and *Copy&Paste*. The total number of tasks was 12.

After performing each gesture, all participants were asked whether they found it easy to devise the gesture (1 = very difficult, 2 = difficult, 3 = ordinary, 4 = easy, 5 = very easy) and how satisfied they were with it (1 = very low, 2 = low, 3 = ordinary, 4 = high, 5 = very high), again, using 5-point Likert scales. We recorded all gestures using two cameras. All participants performed the tasks, in random order. The number of gestures calculated thusly: $12_{participants} \times (12_{tasks} + 2 \text{ paste gestures}) = 168_{gestures}$.

3.1.3 Results. Some gestures were not performed above the desk, so were excluded; 158 gestures were finally included in the gesture selection study. First, we analyzed all gestures in terms of the number of hands used (1 or 2), the direction of hand movement, the numbers and the directions of moving fingers, and the plane of the palm. Then, we unified identical gestures. For example, all effective gestures for *Paste* were unified into one *Grip-out* gesture (Fig. 3, left).



Feature	Value
Number of hands	1
Hand direction	Not special
Number of fingers moved	5
Palm plane	Front

Figure 3: The *Grip-out* gesture (left) and analysis results (right).

On the other hand, the gestures for *Sort* (S_a and S_d) were not unified; 12 different gestures for each of S_a and S_d were evaluated. We included 7 gestures for *Cut*, 8 for each of I_{column} and *Copy*, and 9 for each of the other commands, giving a final total of 111.

In cases where the participant struggled to devise a gesture, the gesture was often complex (e.g., two-handed). In such cases, the ease and satisfaction scores were low. For example, seven participants indicated that creation of a gesture for *Copy* was the most difficult, and eight devised two-handed gestures for *Copy*. All of the collected gestures were dynamic, involving hand movement or a change in hand shape. In other words, static gestures (wherein a hand was briefly fixed in a particular position) were not presented by any participant. Two types of gestures were used to control cell movement (insertion and deletion). Sometimes, the gestures were directional (e.g., horizontal pinch-out was used for cell insertion/shift right, and vertical pinch-out for cell insertion/shift down). Gestures occasionally had two steps: a manipulation gesture followed by movement direction gesture. For example, palm-opening was used for cell insertion followed by fist movement in the direction of cell movement. Furthermore, in the context of insertion and deletion manipulations, participant 5 (P5), P9, and P11 found it difficult to distinguish the gestures for rows, columns, or cells; for example, they used the same gestures for I_{row} and $I_{cell\text{-}right}$.

3.2 Gesture Selection

The gestures were voted on by new participants. We asked them to vote for the most appropriate and intuitive gestures. As only *Grip-out* was used for *Paste*, it was adopted without first being voted on. The remaining 12 manipulations were voted on.

3.2.1 Participants. We recruited 10 new graduate and undergraduate students, including 1 female, with a mean age of 22.8 years (SD = 1.39 years). All participants were right-handed so usually operated the mouse with their right hand. The 5-point Likert scales described above were employed; all participants were intermediate users of spreadsheet software.

3.2.2 Procedure. We showed the participants all table manipulations and the gestures to be voted on via two displays (Fig. 2c) similar to those used above to explain the manipulations. Figure 2b shows the gesture choices for row insertion/shift down. All candidate gestures were tiled and repeatedly played on another display. Also, we played videos of the first author executing each gesture (recorded from behind). The participants were asked to examine the gestures and vote for the best one. The total number of votes was 120 ($= 10_{participants} \times 12_{tasks}$).

3.2.3 Results. Figure 4 shows the voting results. Overall, changes in the hand shape (red arrows in Fig. 4) were preferred to hand movements. Of all votes, 56.3% were for gestures that changed the hand shape only, 33.3% for gestures that moved the hand without any change in shape, and 10.4% for gestures that changed the hand shape and also moved the hand. In terms of insertions (rows,

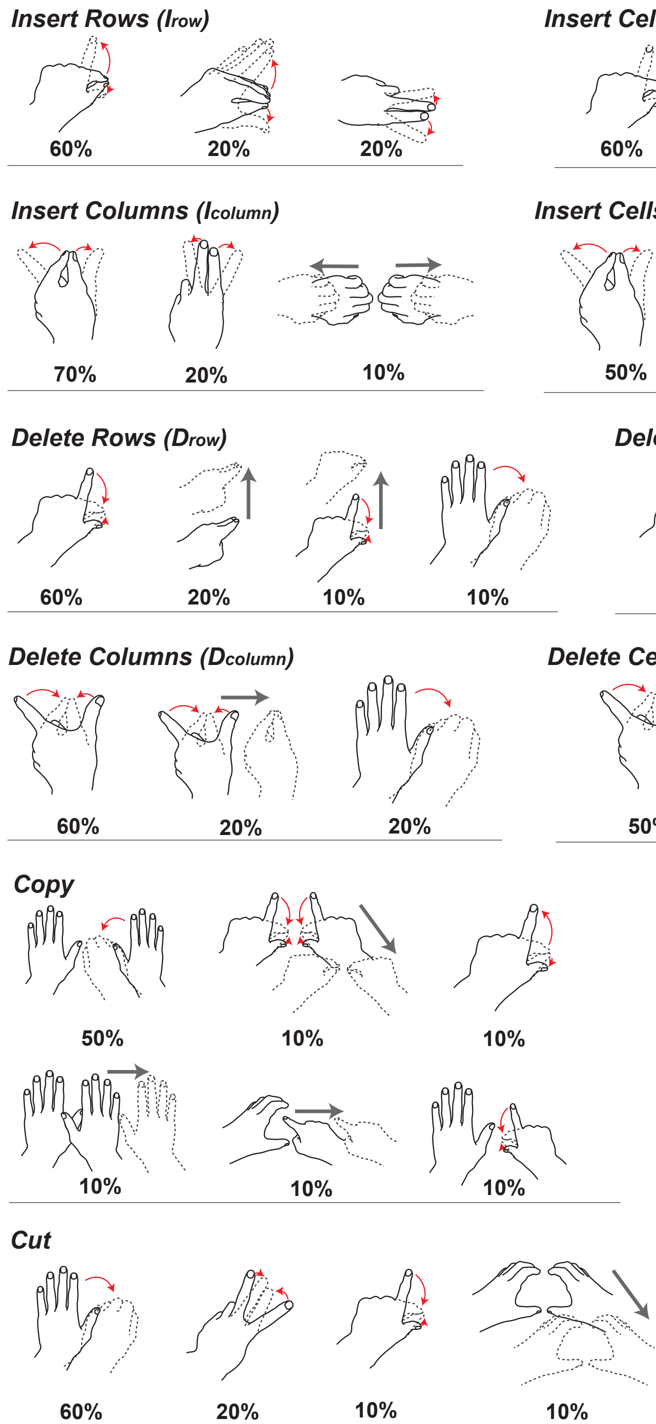


Figure 4: The gestures selected for table manipulations and percentages of participants who selected these gestures. Red arrows indicate changes in hand shape and gray arrows denote hand movement.

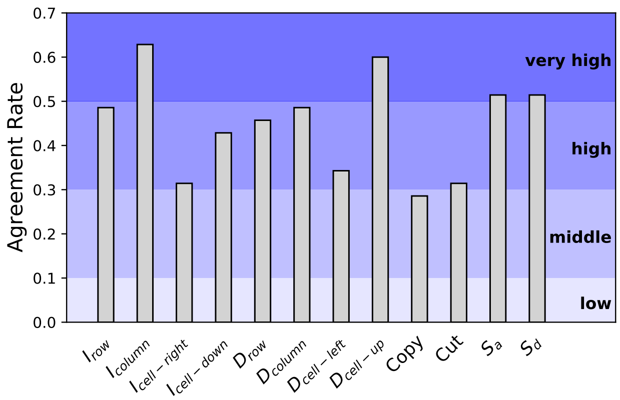


Figure 5: Agreement rate [$\mathcal{AR}(r)$] for all manipulations.

columns, cells shifted right, and cells shifted down), most participants preferred *Pinch-out* at the location where new cells were to be inserted. Similarly, for deletions (rows, columns, cells shifted left, and cells shifted up), most participants preferred *Pinch-in* of the deletion area. For ascending and descending sorts, most participants preferred the *Forward-twist* and *Back-twist* (where the hand is twisted forward/backward after first assuming the pinch-out shape). All favored gestures received over 50% of all votes.

Based on previous studies [6, 9, 20, 25], we derived agreement rates between the selected gestures and functions. The agreement rate [$\mathcal{AR}(r)$] for manipulation r is given by Equation 1:

$$\mathcal{AR}(r) = \frac{|P|}{|P|-1} \sum_{P_i \subseteq P} \left(\frac{|P_i|}{|P|} \right)^2 - \frac{1}{|P|-1} \tag{1}$$

where $|P|$ is the number of participants (10 in this study), and $|P_i|$ is the number of participants who selected gesture i. Figure 5 shows the preferred gestures, vote counts, and agreement rates. We classified the gestures according to Vatavu and Wobbrock [20]. Four manipulations exhibited very high agreement ($\mathcal{AR} > 0.5$), seven high agreement ($0.5 \geq \mathcal{AR} > 0.3$), and only one medium agreement ($0.3 \geq \mathcal{AR} > 0.1$), so the $\mathcal{AR}$ was high. Therefore, we used the gestures that obtained the most votes.

Several participants commented favorably on our interface. They appreciated the fact that one-handed gestures could be combined with mouse selection. P4, who could not remember any developer-defined shortcut keys, stated that he would be able to learn our interface easily.

4 GESTURE SET

Based on these results, we defined the final gesture set shown in Figure 6. There is no inconsistency because there is no overlap; the gestures are symmetrical and consistent. The key features are as follows:

- Both *Insert* and *Delete* use pinch gestures; *Pinch-out* is assigned to *Insert* and *Pinch-in* to *Delete*;
- The direction of the pinch finger movement corresponds to the direction of cell movement after manipulation. For example, I_{row} is assigned to vertical pinch-out. Thus, all rows below the insertion point move downward;
- The same gesture is assigned to row, column, and cell manipulations. The area selected before manipulation distinguishes the type of manipulation;
- *Forward-twist* and *Back-twist* are assigned to S_a and S_d; the hand is twisted forward/backward in the pinch-out shape. Thus, the direction of index finger movement determines the sort type (ascending or descending), which is easy for users;
- The *Copy*, *Cut*, and *Paste* gestures match the functions. *Copy* and *Cut* feature hand grasping, which matches the "Read from Cells" function. *Grip-out* is assigned to *Paste*, thus matching the function.

5 DISCUSSION

We enrolled only undergraduate and graduate students in their early twenties, and thus did not represent all users. Also, all of the participants had experience but none had extensive experience. We will recruit other types of participants, such as accountants and high-level administrators in future studies.

The only two-handed gesture was that for *Copy*. Although participants preferred this gesture, it is not consistent with the other ones. On a desktop PC, the user selects cells using a mouse or a trackpad. One-handed gestures free the other hand to use the mouse or trackpad. In future, we may restrict our gestures to one-handed gestures.

Our gesture set comprises bidirectional gesture pairs; the hand shape changes are identical but the order varies (e.g., *Insert* and *Delete*, S_a and S_d, and *Cut* and *Copy*). If the system fails to recognize one of these gestures (e.g., *Pinch-out* to insert), user backtracking to the start pose (e.g., *Pinch-in*) might be recognized as the opposite gesture (e.g., *Delete*). To avoid this, we need to incorporate gesture recognition feedback, such that the user waits until the system correctly recognizes the start gesture.

6 CONCLUSIONS AND FUTURE WORK

We develop a mid-air hand gesture-based interface for frequently used table manipulations in spreadsheet software. We employed a user-based gesture generation approach. In the first study, we collected gestures devised for 13 table manipulations. In the second study, the collected gestures were voted on by new participants. We defined the final gesture set by reference to the agreement among gesture features and votes, and excluded overlap to ensure consistency among the manipulations.

In future, we will evaluate whether the gestures are easily remembered and guessable. Also, the Leap Motion Controller that we currently use is unsatisfactory in terms of gesture recognition accuracy, so an improved system is required. Furthermore, we will also include other manipulations. Previous Studies have used pointing methods [2] to control vertical displays and VR/MR environments. We will add these features to our method and explore whether hand gestures can be used to select spreadsheet cells and ranges. Users prefer to control touch displays with the index finger [8]; incorporation of this feature may further enhance our system.

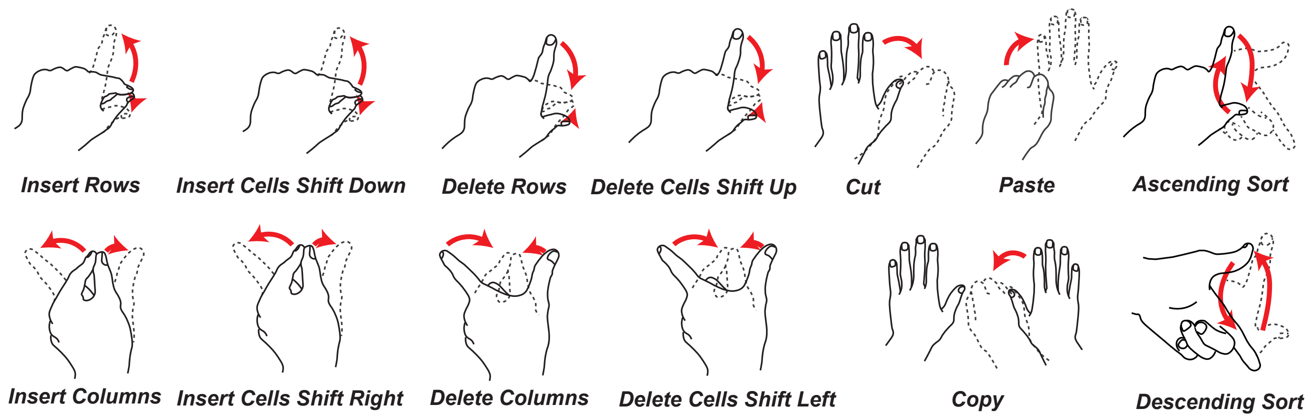


Figure 6: The final gesture set.

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