Preventing Repetitive Strain Injuries In Computer Mouse Use Using Capacitive Multitouch Sensing Technology

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1 ABSTRACT

To raise people's awareness of their posture and grip on their computer mouse in order to prevent RSI and Carpel Tunnel Syndrome, we hereby present an adaptable measure device that can be attached to the mouse easily, to identify grip and posture problems when using a computer mouse. The device is realized with the multi-touch technology, and trained with Support Vector Machine learning model. Additionally, we provide an evaluation method and user test setup to validate the design.

2 INTRODUCTION

Through tangible devices, we communicate and interact with the computers that we use ever so often. Keyboards, sketchpads, trackpads and mouses, all influence the way we interact, and how we posture ourselves behind the computer or laptop. A good posture when using these devices is important in preventing issues like RSI and Carpel Tunnel Syndrome [27]. Recently, research has been done in applying machine learning (ML) models to give people feedback on their posture [22, 34], as well as introducing ergonomic [24] versions of mouses to aid people in having a good grip, and better posture when working on a computer.

In this paper, we propose an additional way to measure and identify grip and posture problems when handling a computer mouse. This will be done through using the multi-touch technology. Using relatively cheap materials, we present a simple modification which can be added to a large variety of mouses.

3 RELATED WORK

With the widespread implementation of graphical user interfaces (GUI), computer mouse use has been a key activity in personal computing, generally used between one to two-thirds of the time during computer work [17, 20]. With the

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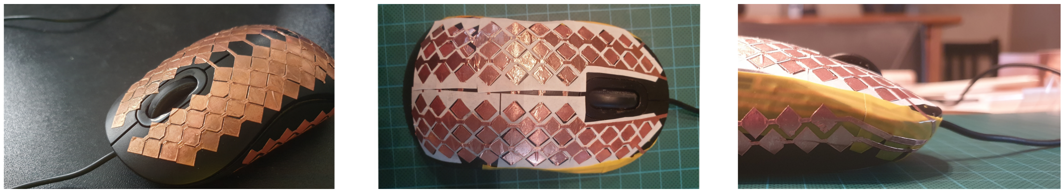

Fig. 1. From left to right: 1. Version 2 of the traces on the mouse. 2. Final version of the traces placed on the mouse with insulation layer. 3. Close up of the direction of the traces in the final version (See also figure 7 in the appendix.

development of information technology, the opportunities for using computers at home and in the workplace have increased dramatically.

A previous review only indicated a limited causal correlation between mouse use and diagnoses such as tension neck syndrome, forearm disorders and wrist tendonitis [36]. However, literature has shown that increased computer use can lead to multiple repetitive strain injuries (RSIs) including asthenopia, stiff shoulder and lower back pain [9, 35]. Input devices include keyboards, touchpads, stylus pens and mouse. It has been reported that mouse usage, such as clicking and dragging is one of the main causes for RSIs such as mouse arm syndrome [41]. Some studies on RSIs caused by mouse usage suggested a number of causes of work-related physical stress: (1) the mouse is positioned too far from the keyboard[13, 19, 43]; (2) increase in supination/pronation of the forearm because of the mouse shape [11, 14, 30, 40, 41]; (3) precision and high-speed work [40]; (4) lifting/extending fingers over the buttons to prevent inadvertent button activations [38].

It is commonly accepted that the use of PC mouses designed to reduce forearm pronation is less likely to cause musculoskeletal injuries when compared to more conventional designs [28]. Alternative computer mouse designs have been evaluated [25], as well as the design of external devices such as wrist rests [23]. Requirements and recommendation for PC mouses design have been summarized in both ISO 9241 [1–4] as well as scientific publications [6–8, 10, 18, 29, 33, 39, 41], and [28] provides a list of requirements for computer mouse design.

However, these evaluations are mainly focused on reducing forearm pronation and overall posture of the back, arm and wrist of the user. These requirements also highlight the need for minimizing finger extension or other movement/positioning that could cause finger strain and prevent the need of firm gripping of the input device. State-of-the-art computer mouses are only designed for good posture but are unable to measure or provide feedback to the user when misuse occurs. In the next section, we will present a concept using ubiquitous computing techniques combined with machine learning in order to measure positioning of the hand and fingers on the mouse and provide haptic feedback after a short period of incorrect positioning of the hand.

4 DESIGN

The creation of our proof of concept prototype was done through several steps and iterations. This includes the form and shape of the used multi-touch pad, the circuitry and our ideas for the feedback design.

4.1 Design of the multi-touch area

The soft multi-touch pad, as shown in the paper on the Multi-Touch Kit (MTK) [32], is designed in the shape of a 2D diamond pad, which can be attached to any surface. The diamond pad we used has gone through several iterations, of which pictures can be seen in Figure 1 and in the Appendix Figures 5, 6 and 7. The different pads are modelled on the Targu AMU20EUZ computer mouse.

4.1.1 Location of touch pad. In all iterations, the diamond pad covers both sides of the mouse, in order to detect touching of the thumb, ring finger and little finger. It also covers most of the top area of the mouse, to detect the second and third digits touching the left and right-clicking areas. This top area can also detect the palm of the hand touching the back of the mouse, which we assume would be able to be used as an indicator for the wrist angle.

4.1.2 Overlapping issues and mask between layers. In the first model (Figure 1.1 and Figure 5), one can see that the squares touch and overlap one another at some points. To fix this, size of the squares was changed from 6 to 5mm, so that they would have extra space to fold over the curved surface of the mouse. Additionally, a protective layer was added between the traces in a later version. This protective layer, which can be seen in Figure 1.2 and 1.3, consists of a number of small pieces of the insulation, as creating one mask is quite difficult when working with a curved surface.

4.1.3 Direction of the traces. In the first models, the traces on the mouse go towards the back of the mouse. However, as shown in the third image in Figure 1, they go towards the front in this last model. The precise setup can be seen in Figure 7. This decision was made when it was pointed out to us how much more natural it felt to have a wire come from the front of the mouse, rather than from the back. We agreed and changed the design accordingly.

4.2 Circuit

The circuitry used for the design is very similar to that of the multi-touch kit as described on their GitHub page [15]. The only difference is our usage of an Arduino Nano (tinytronics' model ARDNANOCH340). This choice was made, as a problem was found in the usage of our specific Arduino Uno R3 (tinytronics' model ARDUNO) when using the code and setup of the MTK. The Uno and the Nano boards have the same processor (ATmega328P), and with a small modification to the MTK library, this setup worked reliably.

The usage of the Nano has another advantage, the size of the board. This Arduino board is a lot smaller than the Uno. When wanting to make a working prototype, a small computing unit is favourable, should we consider building it into the mouse, or create a shell over a consisting one.

The circuit's schematic can be seen in Figure 8.

4.2.1 Future circuit. For future work, the Muca board [5] could be used instead of the multiplexer. A circuit is proposed in Figure 9. The usage of this board would open up the possibility of greatly increasing the number of touchpoints that are on the mouse, thus increasing the 'resolution' of the multi-touch area.

4.3 Machine Learning

4.3.1 Support Vector Machine. For our design, a linear Support Vector Machine (SVM) was used as the ML model. This model is a supervised learning model, which means that the data that is given to the model is labelled. Using the data, the SVM learns to classify certain postures. By creating data sets from the postures done by a physiotherapist, we can confidently identify the 'bad' from the 'good' postures by using their examples.

The SVM constructs a hyperplane -often visualised as a line-, which can be used for regression or classification. The 'correctness' of the model is determined by the functional margin. This margin is determined by the distance between the hyperplane and the nearest point of any class in the train-data.

W	Correct posture: relaxed, no flexing of the fingers or pressure on the mouse.
X	Pressure of the fingers
Y	Claw pose, the fingers are flexed and press with the tops of the fingers on the mouse
Z	Hovering over the mouse, the fingers barely touch the mouse, while the hand does rest on the back of the mouse.

Table 1. Labels of poses in the machine learning model

Kappa statistic	0.8466
Mean absolute error	0.2706
Root mean squared error	0.3402
Relative absolute error	74.4521 %
Root relative squared error	79.8008 %

Table 2. Evaluation tests ML model

An SVM was chosen as it is a relatively simple model that does not use excessive amounts of computational power, while still providing a reasonably accurate result.

4.3.2 Data and Data sets. In order to train a model for our mouse, a set of 'correct' postures is needed, as well as a set of 'bad' postures. This training set is created by a licensed physiotherapist. Pictures were taken much like Lee et al. [21].

To properly train the model, a test and train data set were created with the labels as described in Table 1 and shown in Figure 3. The physiotherapist had the following points to mention about these grips on the computer mouse: In image A1, the wrist angle is neutral, whereas in A2 an extension in the wrist angle can be seen. In B1 there is extensor tendon relaxation, in B2 the same tendon contracts. C1 shows dip and pip joints in neutral positions, and C2 shows dip and pip joints flexion. Lastly, D1 and D2, in 1 the second and third digit are relaxed, whereas in 2 a contraction of the digits can be seen. The aforementioned postures and positions of the hand and palm are based on the anatomical model proposed by [31].

For our model, the testing set is twice as big as the training set [26]. With this, we hope to reduce overfitting. Using this setup, the model's evaluation will be more representative of the performance of the model. In total, we have 16698 lines of data. Six lines code for one pose. Each of the four poses has between 500-700 instances of that pose in the dataset. This results in a total of 2783 instances.

4.3.3 Evaluation of the model . Using code from Rong Hao's GitHub repository [16] the SVM was tested on accuracy using a set of tests. An overview of the results can be seen in Table 2.

The Kappa statistic for this model is rather high. As Cohen [12] suggested, the Kappa result of 0.8466 is interpreted in the 0.81-1.00 range and is listed as an almost perfect agreement. The Kappa statistic is different from the percentage of 'correctly classified instances' - 88.836% in this case- for it also considers the possibility of an agreement happening on accident.

The mean absolute error and the root mean squared error are mostly an indication of how accurate the prediction of the model is. Often a lower number is better, a 0 indicating a 'perfect model' however, one must be cautious of overfitting the model to the testing data. An overfitted model might give great results in the test and train data, but

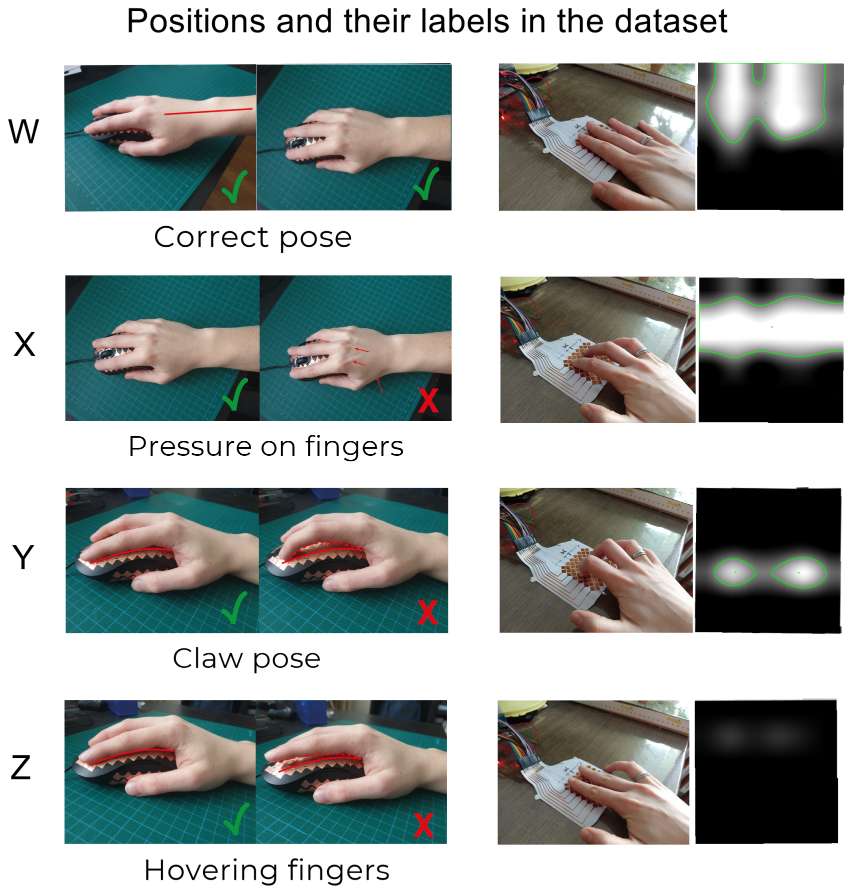

Fig. 2. Images of the different poses, on the mouse and on the MTK and their labels in our dataset.

perform badly when 'deployed in the real world'. The root mean squared error of 0.3402 in our model, indicates that the model is relatively accurate.

The relative absolute error is the magnitude of difference between the model's approximation and the exact value, divided by the exact value. Both this value and the root relative squared error are rather high.

From this, we would conclude that, even though our model seems quite accurate, it might be slightly overfitted for our test set.

4.4 Feedback design

For our final design, we would like for users to receive both haptic feedback and augmented feedback [42] when our tool identifies a bad grip on the mouse. This could be used to enhance the users' awareness and knowledge about the position of their hand and fingers, which would reduce forearm pronation and overall posture of the back, arm and wrist of the user.

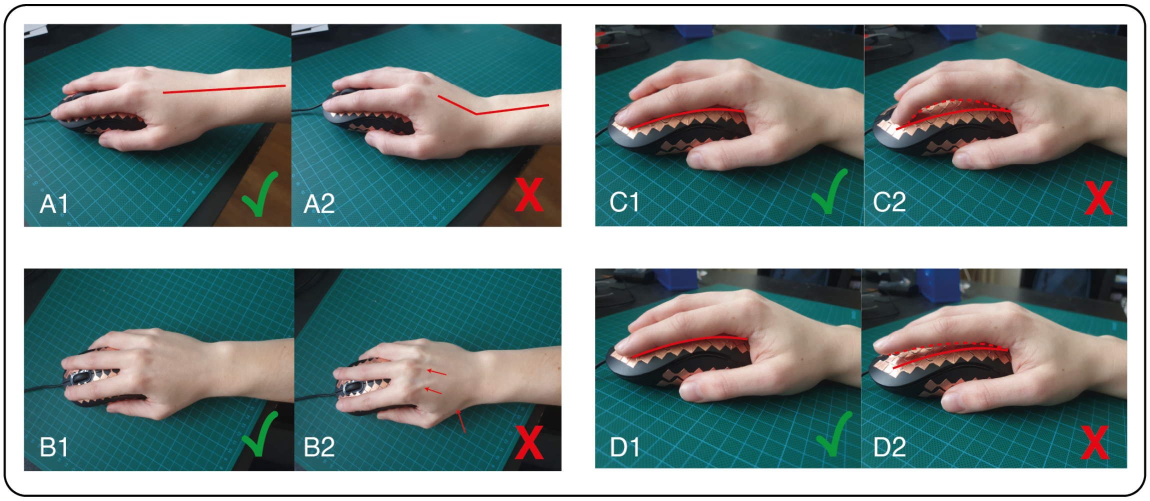

Fig. 3. Images of wrong and right positions as instructed by a physiotherapist. (A1) Wrist angle neutral, (A2) wrist angle extension, (B1) extensor tendon relaxation, (B2) extensor tendon contraction, (C1) dip and pip joints neutral, (C2) dip and pip joints flexion, (D1) second and third digit relaxation and (D2) second and third digit contraction [31].

4.4.1 Mouse vibration. A computer mouse is a sophisticated control device. The design of vibration feedback needs to be carefully addressed because vibration may cause the mouse to move. This would be at odds with the accuracy of the mouse that it currently has controlling the computer.

There is relatively little research on the vibration feedback in a mouse. How the amplitude and frequency of vibration affect the user's experience remains to be explored. The vibration feedback is mostly focused on the design of the game mouse, which is used to amplify gaming experiences by combining the visual with other senses. For example, the Logitech BB haptic SM35 Vibration Gaming Mouse provides all sounds expression with real-time vibration, thus provide multi-sensory force feedback.

In this design, the user's vibration feedback is provided by a tactile feedback motor in the palm area, which is prompted by two short vibrations in succession, a commonly used feedback pattern. A vibration motor is running at 3V and rotating at 9000± 2000 rpm to provide palm area vibration. How the user interprets the vibration frequency and the signal it sends will have to be investigated in a usability test.

4.4.2 Computer pop-up. In order to provide specific knowledge to the user on their grip when the mouse vibrates, a computer pop-up will be used to give information. It will contain specific feedback and could even give short exercises to stretch the fingers or relax the muscles. Safety Screen developed by Samsung in 2016 [37] keeps children' eyes from a safe distance from the screen using this kind of notices. However, in order to minimize the impact of pop-up prompts on normal work, such feedback should be less frequent and not interrupt the user's workflow every single time. Thus the pop-up does not appear every time a wrong gesture is detected, but serves as an enhanced reminder when the frequency or duration of the wrong gesture occurs regularly. Further research has to be done to determine the preferred timing of the reminder. Pop-up window emerges from the upper right side of the screen and it stays a few seconds then automatically disappears. The message conveys where should user relax and how through a dynamic GIF.

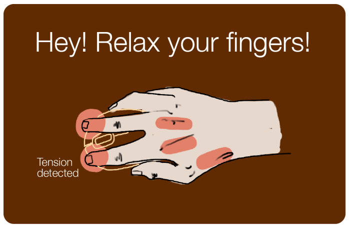

Fig. 4. Computer screen pop up interface

We imagine that the feedback combination discussed above enhances the users' awareness and knowledge about the position of their hand and fingers in a non-intrusive way, thus may noticeably reduce forearm pronation.

5 EVALUATION

In order to properly evaluate our design, we propose a longitudinal between-group study, in which one group uses a mouse which can identify and notify a user about their grip, and a group with the same mouse without that functionality. This would allow us to determine if the mouse and the notifications have a significant influence on the appearance rate of RSI in these individuals.

However, due to the limited time we have for this study, in combination with the new COVID-19 measures, we present the following evaluation methodology: A licensed physiotherapist will use finished prototype with the ML model and test if the model can correctly identify all incorrect positions of the hand and fingers. This would be a clinical evaluation.

If the ML model is accurate, our device could also be tested by a small group of people (N = ± 5), from our direct households. They will use the mouse and be asked a set of questions about the usability and the experience. This will inform us about the quality of the different modalities of feedback. This will be the user experience evaluation.

5.1 User Experience Evaluation

The usability test would be conducted with the final mouse prototype to answer the following question. "Can the user identify their grip and posture problems and make an adjustment with the modified mouse?"

The test will seek five participants who use computers for a long time on a daily basis, for example, students and teachers, ranging from age 21 to 35. They may or may not have hand posture problems. They will first be introduced to the test. The test will last half an hour per person, participants will be asked to use the prototype mouse and laptop on a desk in a home/workspace setting for half an hour.

During which time, observers will take observation notes and take hand posture photos. Each wrong posture and feedback is marked with a dot. And mark users' reaction when they receive feedback from the mouse.

After the user test, each participant will be interviewed with the following questions. (1) Have you ever paid attention to the way you hold the mouse before conducting the experiment? (2) Do you have any pain or fatigue feeling in your wrist? And to what extent do you rate the feeling? (From 0 to 7, 0 stands for 'no pain at all', 7 for 'hurts very badly') (3) Is there anything uncomfortable or strange feeling when using the prototype? (4) Does the applied layer affect your use of the mouse? /Does the MTK influence your use of the mouse? (5) How efficient do you rate the mouse feedback to correct your hand posture? (6) How do you feel when you receive mouse feedback for bad hand posture?

5.2 Limitations

In this study, we presented the design and evaluation of a measurement device to identify grip and posture problems when handling a computer mouse. However, there are limitations to this study. In the following sections, we will elaborate on these limitations and present future work to address them.

Integration of the MTK. The integration of the MTK on the mouse can still be improved. Firstly, The fabrication of the prototype was done using low-fidelity materials and tools (e.g., scalpel, tape, and photographic paper). For future implementation, a vinyl-cutter would be preferred, since it is more accurate than a human hand for cutting the thin traces. Secondly, the hardware is developed for only one specific mouse, while it would be preferred to be generalizable for multiple models and types of mouses. The extra hardware could, for example, be incorporated in a case that can be put over any mouse, including the micro-controller that is currently detached from the mouse. This case will also protect the fragile traces that can easily be damaged if they are exposed.

Posture detection and classification. For the posture detection and classification, there is also plenty of room for improvement. Firstly, we only included right-handed postures in the training dataset and in the evaluation. The design should also facilitate correct posture recognition for left-handed individuals. Secondly, the training dataset was created by only 1 researcher and thus doesn't include multiple sizes of hands and correct postures. Further evaluation should be performed to see if the model is able to detect the correct grips of multiple individuals with different anatomical characteristics. Thirdly, the prototype is only aimed to measure posture and gripping behaviour of the hand, while research indicates that a correct posture of the wrist, elbow, shoulder and back is also very important in the prevention of RSI. Further research has to be done on how to combine the functionality of our design to the measurement of overall posture.

User feedback. The feedback to the user is only briefly explored in this project, and further research has to be done to evaluate and improve the user experience. Long-term evaluation needs to be done to evaluate if our design is able to prevent RSI and accommodate a pleasant user experience.

Evaluation. Due to the COVID-19 measures, we were not able to perform our intended user test. Further evaluation needs to be performed in order to clinically validate the detection quality of our proposed solution, as well as the user experience.

6 CONCLUSION

The main contribution of this design is to raise the users' attention to possible repetitive strain injuries, then help them identify their grip and posture problems and make adjustments with the modified mouse. Instead of redesigning the shape of the mouse to suit the needs of right-hand gesture, we approach the problem by providing an additional measure method by only looking at the hand posture and grip. The overall feasibility of the design is tested. The model training showed promising results with a right-handed postures' dataset. The measurement of wrist, elbow, shoulder and back posture can further be implemented to show more accurate results. Future applications of this design could be a tool for the evaluation of new mouse models that are currently in production. For example, in future ergonomic mouses. Producers of other products that require a specific grip (e.g., sports rackets, musical instruments, power tools, etc.) might also want to use this technology to see how they can improve the design of their product.

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6.1 Appendix

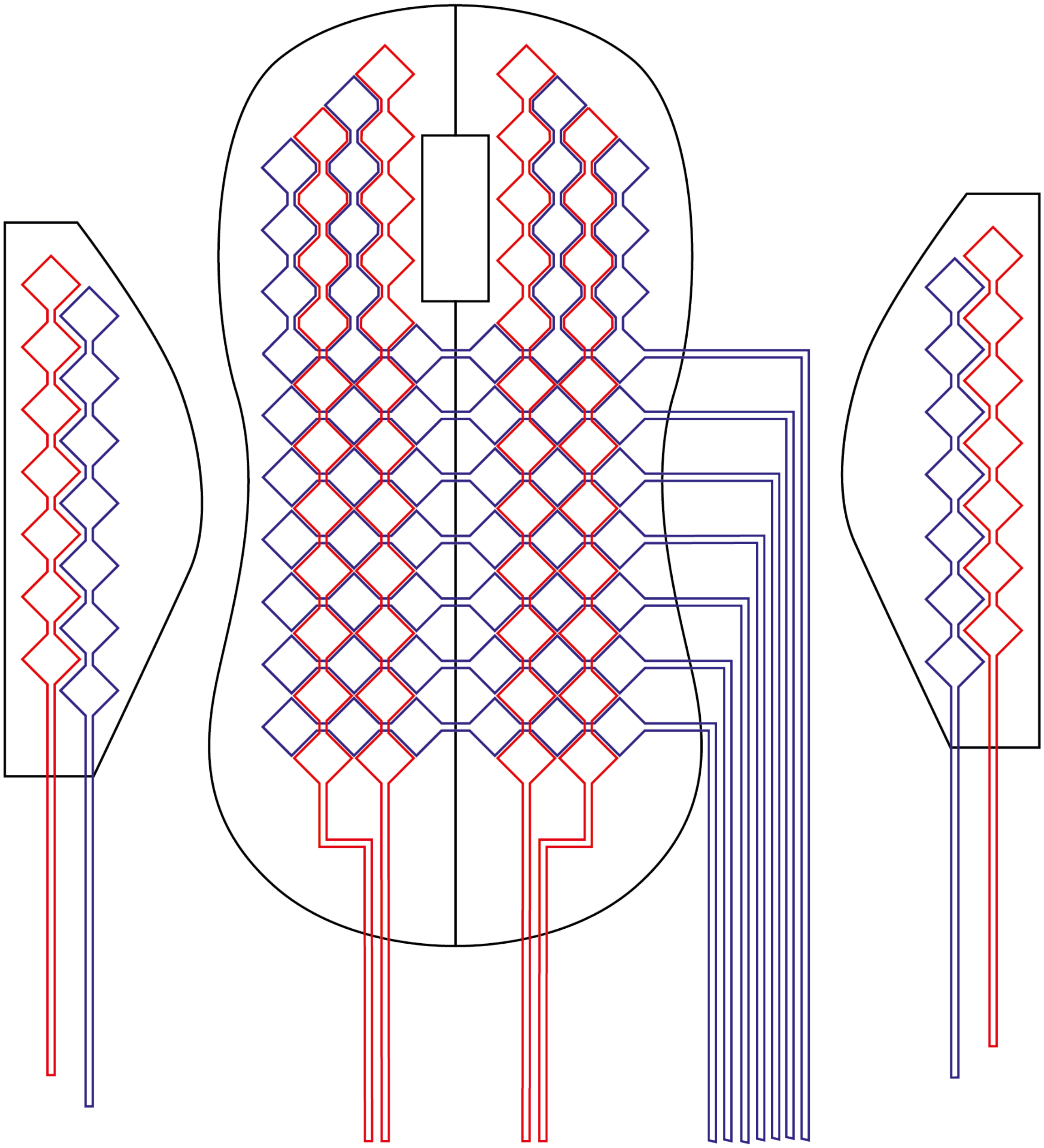


Fig. 5. An illustration of the first design of the MTK on the surface of the mouse. The soft multi-touch pad is designed in the shape of 2D diamond pad, which can be attached to any non-planar or planar surfaces. The 2D diamond prototype pad has two rows on the sides of the mouse, and the top is covered in 4 columns and 7 rows of diamonds. The number of rows is limited due to the traces that need to be wired without creating short circuits with the other traces.

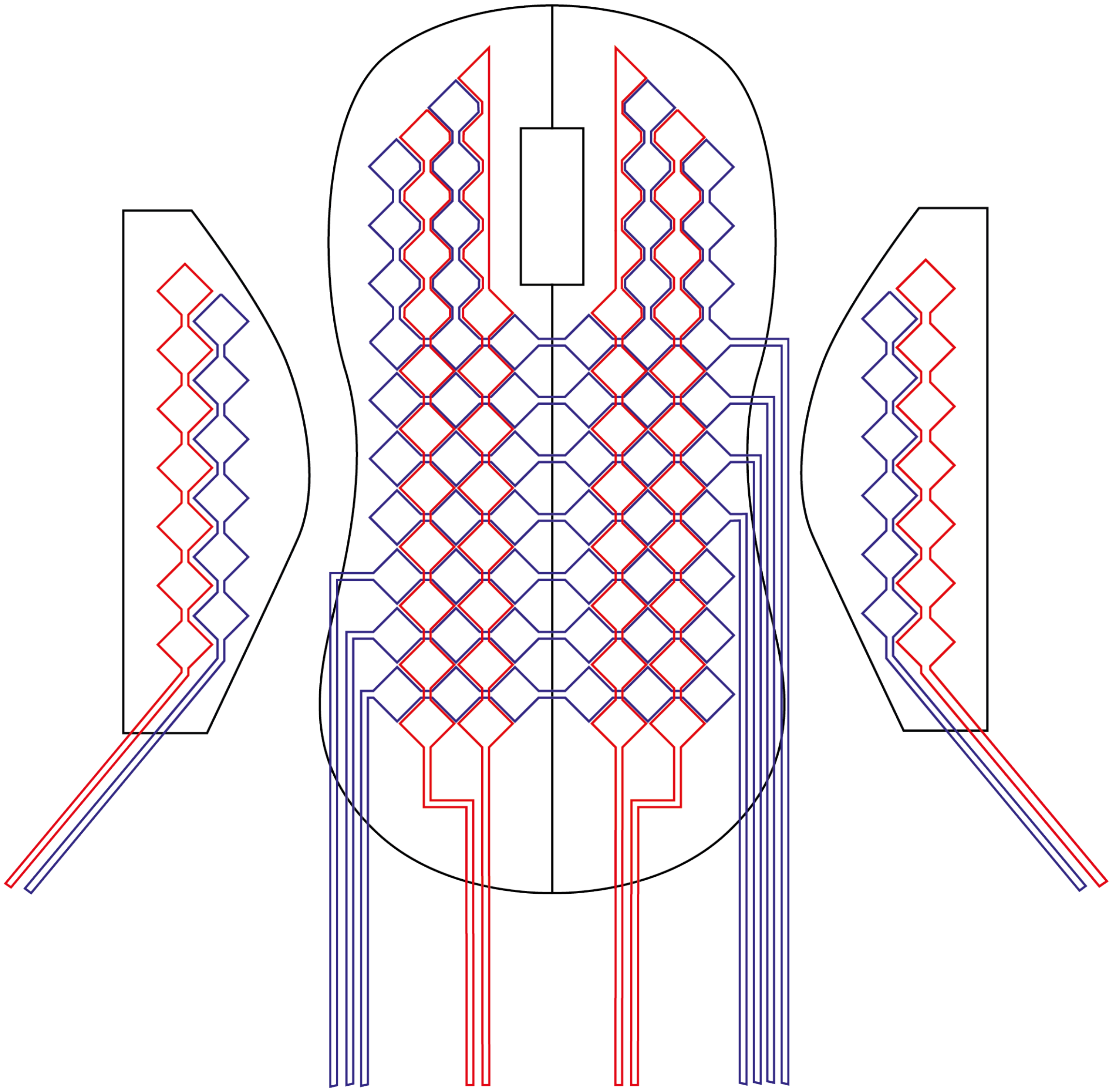


Fig. 6. An illustration of the second design of the MTK on the surface of the mouse. The number of rows and columns are the same, but the traces are relocated and distributed over the left and right areas to reduce the area that needs to be insulated to protect the traces. The traces that are covering the sides are also redesigned to better fit the shape of the mouse.

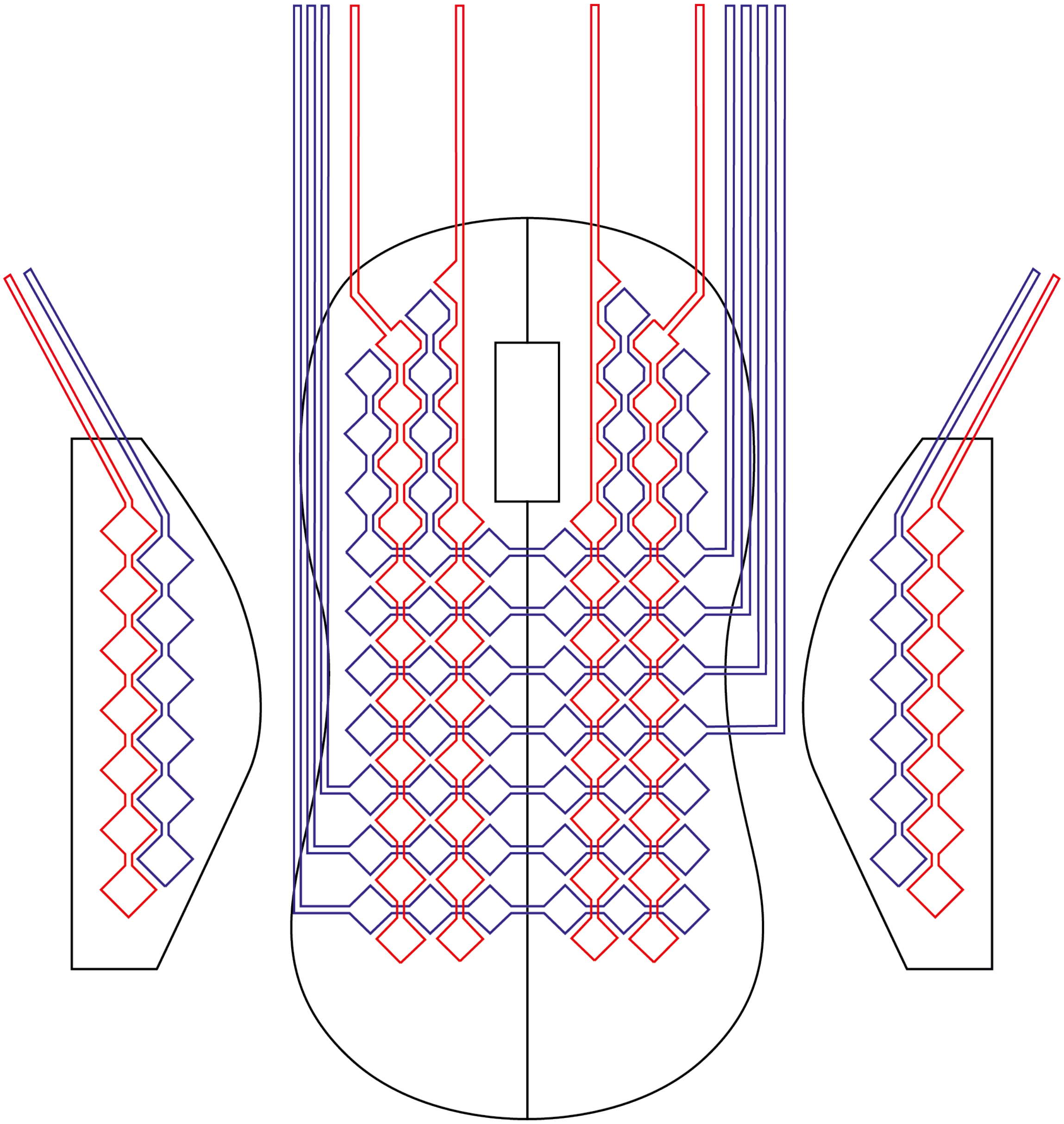


Fig. 7. An illustration of the final design of the MTK on the surface of the mouse. The diamonds are resized and the traces are redesigned to go to the front of the mouse instead of the back, in order to better implement the wiring with the existing wiring of the mouse.

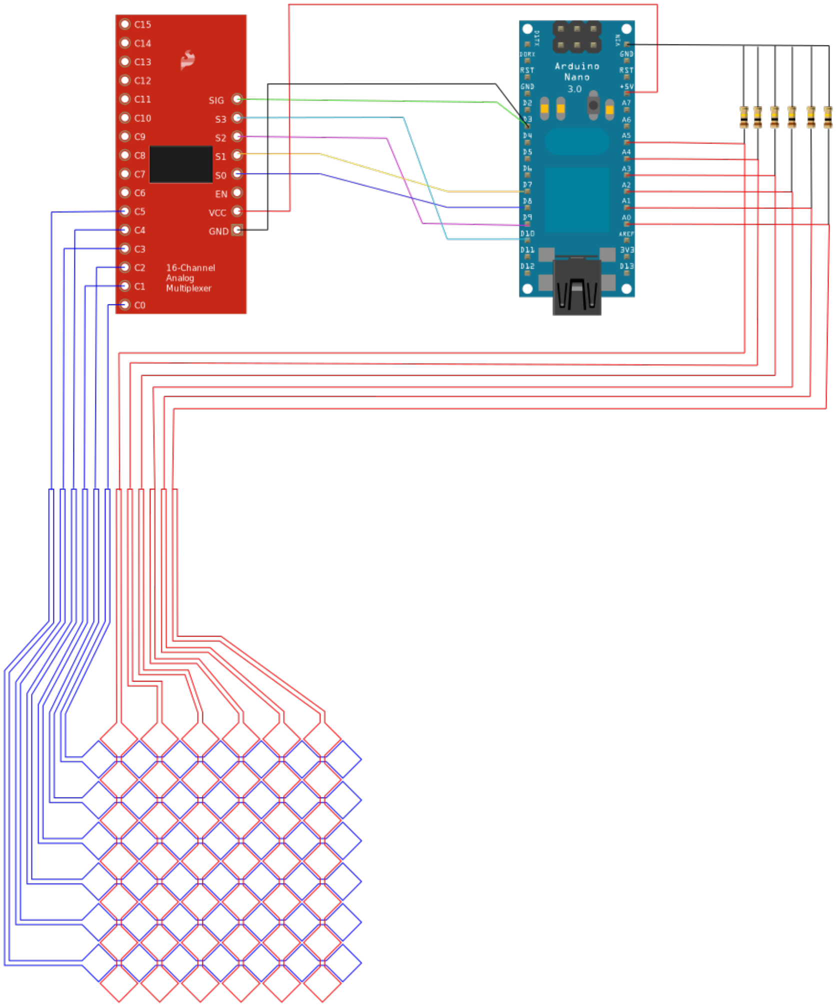


Fig. 8. Current circuit using the setup similar to that from the Multi-Touch-Kit [32]

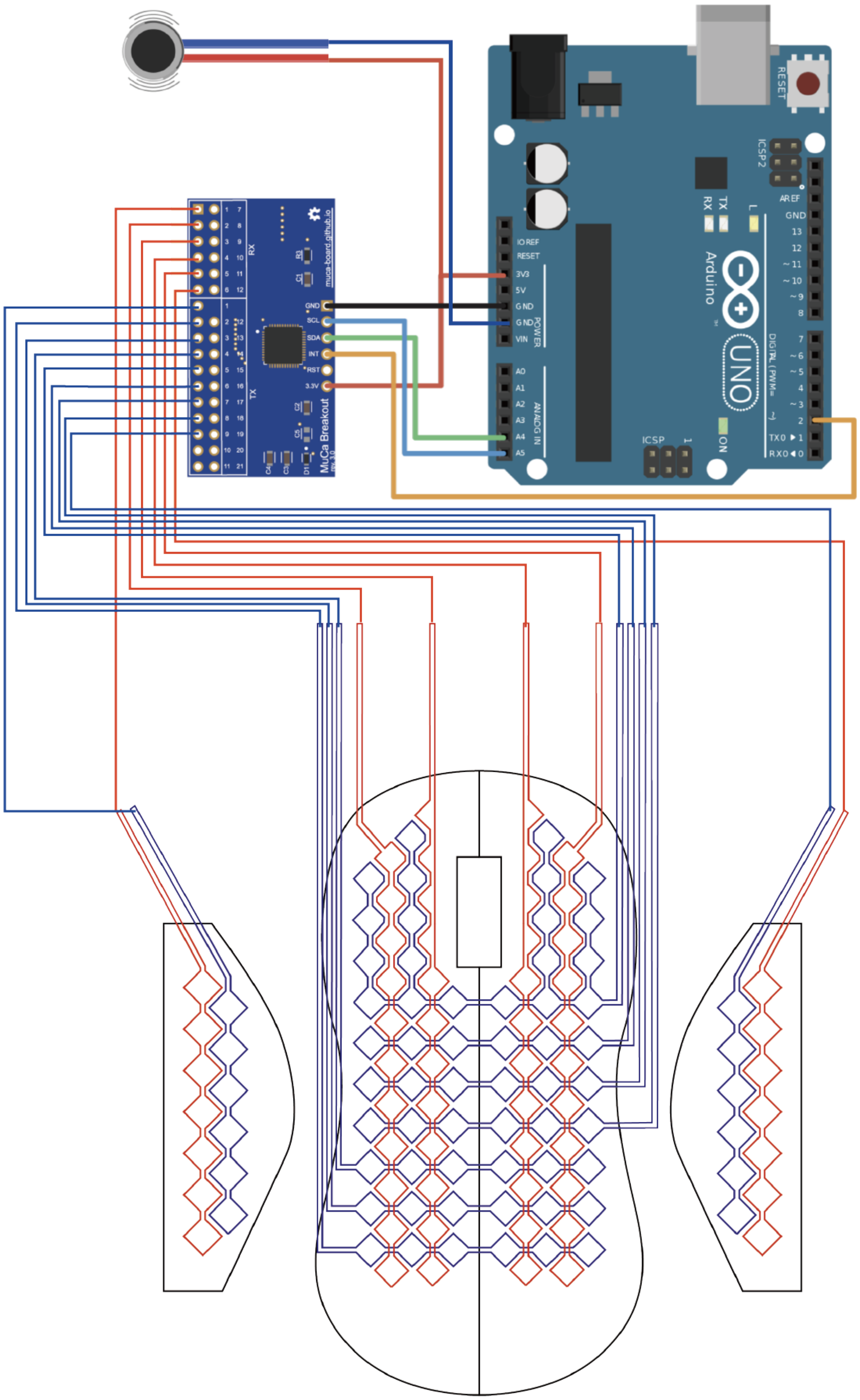
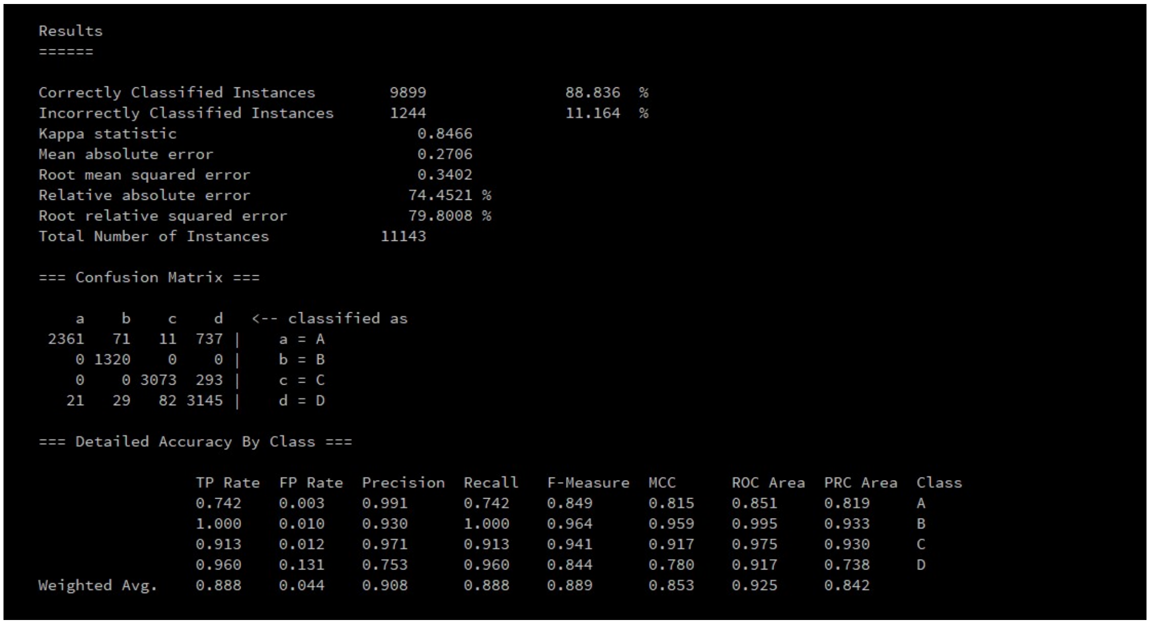


Fig. 9. Future circuit with Muca board and vibration motor



```
Results
======

Correctly Classified Instances        9899               88.836  %
Incorrectly Classified Instances      1244               11.164  %
Kappa statistic                          0.8466
Mean absolute error                      0.2706
Root mean squared error                  0.3402
Relative absolute error                 74.4521 %
Root relative squared error             79.8008 %
Total Number of Instances            11143

=== Confusion Matrix ===

    a    b    c    d   <-- classified as
 2361   71   11  737 |    a = A
    0 1320    0    0 |    b = B
    0    0 3073  293 |    c = C
   21   29   82 3145 |    d = D

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
                 0.742    0.003    0.991      0.742    0.849      0.815    0.851     0.819     A
                 1.000    0.010    0.930      1.000    0.964      0.959    0.995     0.933     B
                 0.913    0.012    0.971      0.913    0.941      0.917    0.975     0.930     C
                 0.960    0.131    0.753      0.960    0.844      0.780    0.917     0.738     D
Weighted Avg.    0.888    0.044    0.908      0.888    0.889      0.853    0.925     0.842
```

Fig. 10. Results from training, testing and evaluating the dataset