EE20100: Integrated Control Systems
Mouse Group Design Project
Report

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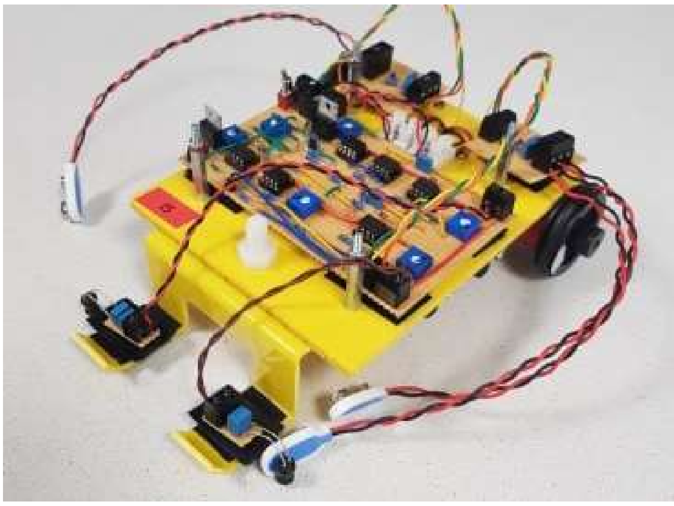

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Abstract

The aim of this project is to design a small light weight autonomous vehicle ('mouse') to complete a predetermined track as quickly as possible. The group of four worked well together and through a solid design process settled on an analogue lay out with the track sensing being carried out by two small inductors. The mouse then competed, finishing with one full lap in 18.02 seconds and two failed laps. The full cost of the design came to a total of £16.49 which is well below the £30 budget.

1 Introduction

The applications of control theory in modern electronics are far reaching and it is a pivotal part of many commonly used modern devices. The aim of this project is to design a vehicle to follow a pre-determined course in the quickest possible time. The track contains a length of wire covered by black tape through which an AC current is passed, allowing for a few different positioning systems to be used. From this there are many potential solutions to the general problem of getting the car around the track, all equally valid meaning the design process must be structured and logical to best choose the most relevant solution. It should be stated, however, that the primary aim of the task is to get the mouse round the course, with the lap time being a secondary objective.

1.1 Track

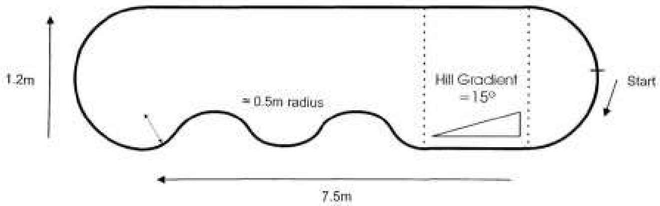


Figure 1: Race track specifications

The track on which the final race will take place on the 20m track shown above in *figure 1.* It involves a short decline, following into a slalom of 4 relatively sharp turns leading into a larger softer bend finally giving way into the straight and back up a small ramp to the finish line. The hardest section of the track to pass is the slalom, as this is where the corrective steering will be most important. On top of this, The corners are very close to the edge of the table, meaning any slight error with anyone not paying attention could lead to a fatal disaster for the design. The current passed through the track wire is an AC current at a frequency of about 20kHz depending on the room temperature.

1.2 Specifications

- Chassis
  a. The Chassis must be one of the pre-built chassis provided by the department store.
  b. The chassis will be set up for either front wheel (servo motors) or differential drive steering.
- Control
  a. The electrical power to the on-board control must be supplied from batteries provided by the department store
  b. The control system should only contain analogue designs and small ready made modules (i.e. PID controllers)
- Design
  a. The height and width of the mouse are not restrained however due to the ramps there should be a minimum clearance beneath the mouse
  b. There should be an accessible start/stop switch
- Cost
  a. The price should not exceed £30

2 Design Outline

2.1 Input

The first step to the design process is conditioning the input signal. The simplest solution to receiving an input signal is to use inductors to detect the fluctuating magnetic field that the AC current in the wire produces. Other potential options discussed were methods such as using a camera and digital analysis of the video feed to find the black line, or in a similar vein, reflecting electromagnetic waves off the circuit to detect were the black tape would absorb the waves. Both of these additional solutions, whilst valid, add considerable complexity for little to no gain and therefore the induction sensing method is chosen to be implemented in the final design.

2.2 Control

Control of this devices final build will pivot mainly on two main options. The control of this circuit can be managed completely in analogue signals using simple components such as capacitors, resistors and op amps. This method would require hands on soldering skills and a keen eye for error detection, but allows the entirety of the circuit to be built and tested on a breadboard before final production starts, allowing for very quick and simple changes if the design is changed. The downfall of this method is a less obvious method of interfacing with the devices parameters. To change different aspects of the device, resistor and capacitor values are changed, which can sometimes make it hard to see how to get the result that is required. The other option is the use of a digital micro-controller. The benefits of the micro-controller are that a lot more versatility is available for nearly zero change in physical layout. The downfall is that it requires programming of its behaviour in a single chunk of code, which can often be difficult to pinpoint why the car is not behaving as is required. In the end an analogue design was chosen to fit the groups strengths of understanding of analogue designs, and to allow for fast hands on prototyping.

2.3 Output

The chassis chosen for the project is the two-motor differential drive set up. This means the output of the system is the motor voltage to each motor, as this will decide the frequency of the wheel spin and hence the turn and speed of the car. To obtain this, a system where a baseline voltage is supplied to the motor combined with an error voltage allows the car to have a straight line speed, with the turning on top of that voltage level.

3 Initial Testing

3.1 Motors

Some initial simple testing of the chassis is done to get an idea of the voltages required for different wheel speeds. If the course is assumed to be 20m long and the wheel diameter is measured to have a diameter of D = 45mm, the wheel speed required to complete the circuit in a time of 20 seconds is about 425rpm. The voltage required to reach this wheel speed is then recorded and the results are unloaded motor voltage $V_{noload} = 2.5V$ and when the wheel is loaded, a voltage of $V_{load} = 2.6V$

3.2 Inductors

Some basic measurements to test which orientation of inductor is most effective and are shown below in *figure 2*. From this it is decided that a vertical inductor is more applicable, due to holding a greater reading for longer. The value directly above the track is also partially irrelevant, as the inductor should not reach a point where it is that close to the track. This is because the design of the sensors is such that if the track does not remain in between the the two inductors, it will not function as required.

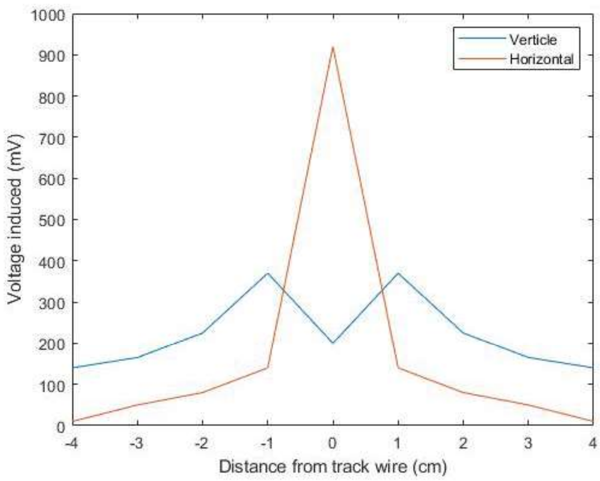


Figure 2: Comparison of the different angles of inductor for track detection

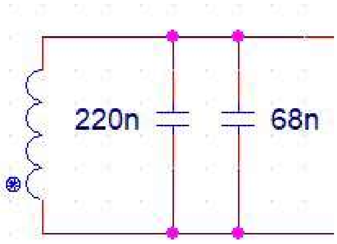


Figure 3: Low pass filter

The signal received from the track by the inductors is inherently noisy and therefore a filter (shown in *figure 3* is added in the form of capacitors in parallel with the inductor. The capacitance is calculated below using an inductance value of $220\mu H$ and a frequency of 20 kHz

$$C = \frac{1}{(2\pi f)^2 L} \tag{1}$$

This equation predicts a capacitance value of $C = 2.87x10^{-7}$ which is made by the two capacitors in parallel shown in *figure 3*.

4 Full Design

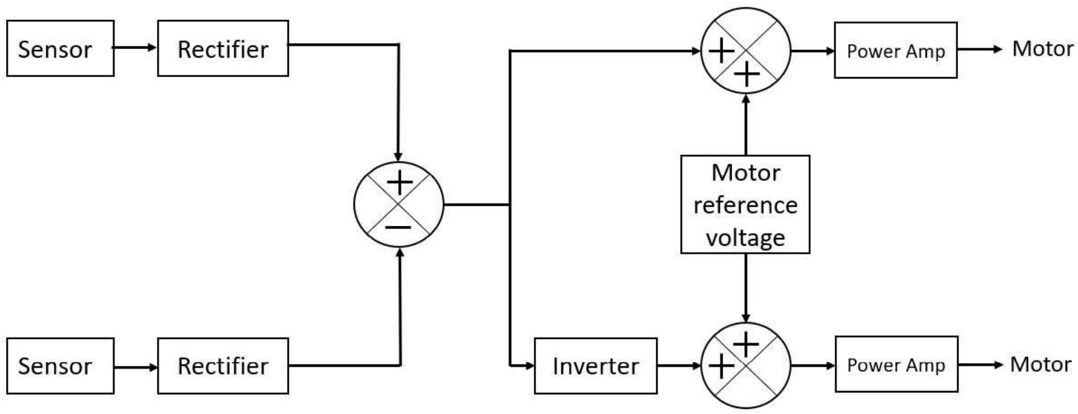


Figure 4: Initial layout of the control circuit

Above in *figure 4* the schematic that will be followed for the design is shown. This is a preliminary design and aspects for the layout will change through the design process, however the overall architecture remains roughly the same throughout.

4.1 Peak Detector

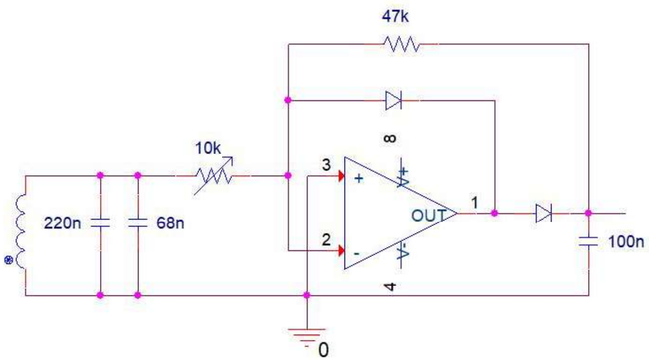


Figure 5: Peak detection circuit

To use the inductors as a position sensor, there must be a simple voltage response to the distance from the wire for the circuit to use. The current input is an AC wave, so the signal is first put through a peak detector circuit to transform the wave to DC. This circuit is a full wave rectifier using a 741 op amp and has little effect on the voltage peak recorded. Any impact on the voltage peak does not have too large of an impact as if the signal requires boosting, the gains of any of the amplifiers can be tweaked to tune the output. This circuit is shown in *figure 5*. The op amp is supplied by a voltage of $\pm 9V$. The $10k\Omega$ variable resistor is for tuning of the design later in the design process, as there is a lot of potential variance in the analogue components, and therefore future proofing against such uncertainties allows for a smoother tuning process.

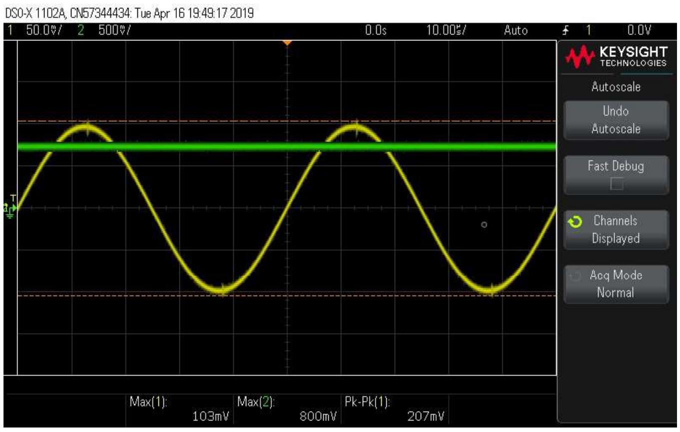


Figure 6: Peak detection output

4.2 Differential Amplifier

As the two inductors signals have been converted to DC signals, the two positions can be compared to give a distance away from the track in volts. To do this a differential amplifier is set up using the two rectifier's outputs as its inputs, as shown below.

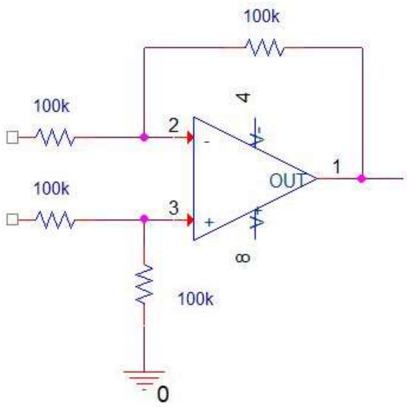


Figure 7: Differential Amplifier

The aim of this circuit is to tie the two inputs together for a tangible signal to be used further on in the circuitry. Before the differential amplifier the available data is the distance of each singular inductor from the wire. This data is useful, but is more useful when combined together to give a reading for the mouse's distance from the centre line. It does this by finding the difference in the two peak detector values, i.e. if the car is centred, the detectors will be reading the same values and therefore the differential amp will give a reading of zero volts, implying the car is centred. If inductor A is closer to the wire, the voltage reading will give either a positive or a negative voltage reading, which can be passed on to the rest of the circuit, and then the motors to allow the mouse to correct its alignment and continue round the circuit.

4.3 Summing Amplifier

Once possible solution to the design problem is using a summing amplifier. If the summing amplifier is used, it would function by adding the differential signal on top of a baseline motor voltage. This would mean that there would be a default motor speed that the mouse travels at, and when the mouse is misaligned or approaches a corner, the voltage supplied to each motor will increase or decrease causing the vehicle to turn. To achieve this one of the summing amplifiers must have a zero-gain inverting amp before the summing amp so that the two signals are the inverse of each other. This means as one motor speeds up, the other would slow down, instead of them accelerating or decelerating in unison.

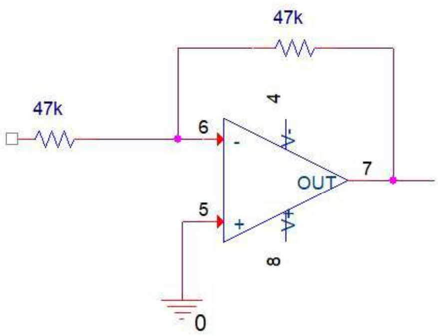


Figure 8: Inverting unity gain amplifier

It is possible for a simple summing amplifier then unity gain power amplifier to be used in series to get the desired output, however, it is possible to merge the power amplifying circuit and the summing amplifier to save on lag times and construction complexity. This design is shown overleaf in *figure 10*

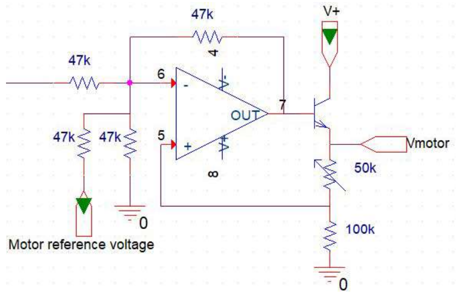


Figure 9: Combined summing and power amplifier

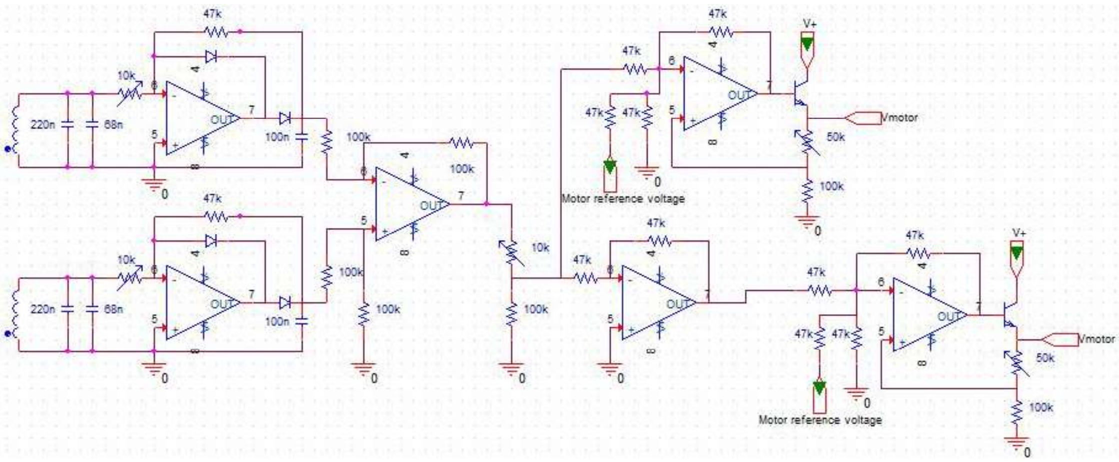


Figure 10: Final full design of the control circuit

4.4 Power Supply

The power requirements for this design is split in two, a 6v requirement and a 9V requirement. Both use a capacitor and a resistor in parallel with the batteries to reduce any parasitic capacitance that may have been created from the leads connecting to the board.

4.4.1 Motor Reference Voltage

The reference motor voltage needs to be adjustable, so the design can be adjusted and tuned for the quickest and safest lap time. A potential divider with a variable resistor is added at the input of the supply voltage to the main circuit.

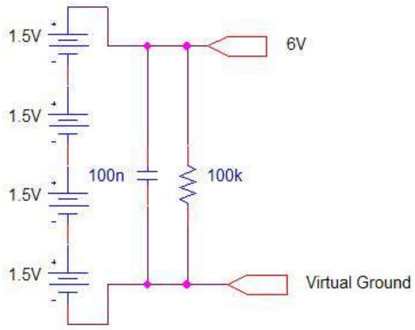


Figure 11: 6V Input circuit

4.4.2 Main Circuit Power

A virtual ground is made and the batteries are connected in such a way that there is a positive and negative voltage supplied to the circuit.

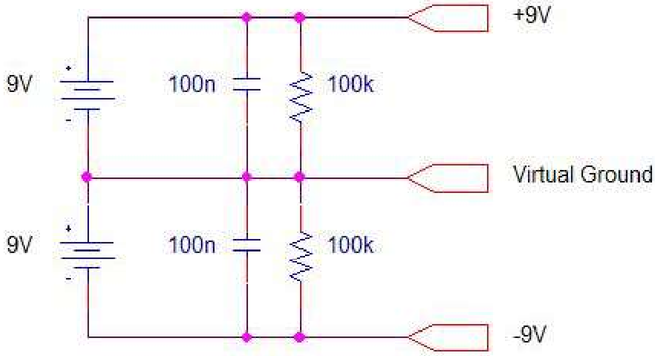
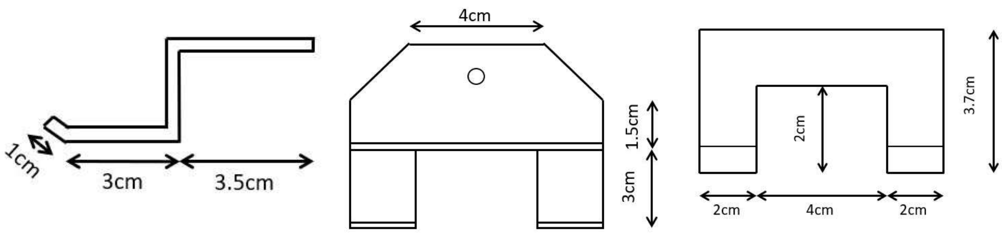


Figure 12: 9V Input circuit

4.5 Chassis Improvements



(a) Side view (b) Top view (c) Front view

Figure 13: Design of the chassis addition

The Chassis design was kept simple as the team agreed it would be silly to sink lots of time into a relatively marginal aspect of the design. Whilst we were still finding our feet with regards to the control systems in week 2, half the team went to work on the skid. A simple design was chosen with plenty of room for the inductors to be added at a later date. In the end the inductors were spread 11cm apart, with the skid having a small 60^o incline to allow the mouse to more easily ascend the ramp with the whole skid being attached to the mouse by an 8mm bolt, replacing the one that held the stock ball and socket wheel.

5 Costing

Component	**Per Unit Cost (£)**	**Quantity**	**Net Component Cost (£)**
Resistor	0.02	22	0.44
100nF Capacitor	0.15	2	0.30
220nF Capacitor	0.15	2	0.60
Diode	0.05	4	0.20
071 Operational Amplifier	0.60	6	3.60
224uH Inductor	0.40	2	0.80
Variable Resistor	0.75	6	4.50
TIP120 Transistor	0.60	2	1.20
9V Batteries	2.00	2	4.00
2-Hole Connector Block	0.05	7	0.35
3-Hole Connector Block	0.05	4	0.20
			Total Cost: £16.49

Excluded from the costing is the use of lab equipment such as soldering irons and materials such as solder. The 4 1.5V batteries are excluded from the cost along with the chassis as these items are returned to the store after use.

6 Testing and Improvement

Once the full circuit was completed, the testing process swiftly began. The primary aim was to get a complete circuit and worry about the speed after. Initially the car was placed on the track and raced off but veered without any change in input. Simply happy that the mouse was running unaided the group headed back to the test bench to begin the tuning process. Using the oscilloscope, it was clear that one of the inductors was giving a stronger signal to the differential amplifier, causing one of the motors to receive a higher voltage. This was quickly adjusted and next session, once the car was re-balanced it headed back to the track, this time with far more success. The car was responding to corners and making an effort to adjust, and once the output from the differential amplifier had been boosted the mouse was completing the slalom consistently. The large sweeping bend caused a little problem with the mouse's path finding, however once the motor reference voltage was brought down a touch, the mouse was completing the course with ease.

7 Race Day

Race day is always going to be a stressful occasion, due to weeks of preparation, but seeing the car complete the circuit is a great feeling, one that I was unable to take part in due to being struck with a relatively severe illness that week. I spoke at length with the group throughout the event and afterwards to continue to remain informed and aware of our performance. Due to our robust design and rigorous testing the first attempt was a very safe bet and we crossed the line with a final time of 18.03s, not the fastest time by any means, but a completed lap was the aim. For our final two attempts, with a safe time secured, the team decided to go pedal to the metal and push the limits of the design. This meant upping the motor reference voltage and the turning sensitivity by changing the resistor values of the potential dividers. Due to not having tested for speed, this left both runs with an unsatisfying DNF, however our groups aims were met and the day on the track was considered a success.

8 Team Dynamic

The team dynamic of group I5 was a comfortable work environment to be a part of. All suggestions were taken into genuine consideration and the design process was not hampered by a lack of attendance. There are always reasons to miss design sessions, such as other coursework deadlines or sporting commitments, however if a session was missed by any member it felt as though they made up for it out of the set lab times. At the start of the project Luke and Lydia designed the improved chassis while Michael and I started working on the bread boarding process. Once the mechanical aspect of the design was sorted, the other two re-joined us and we got through the bread boarding process together by splitting tasks, for example Lydia and I worked on the two power amps whilst Michael and Luke worked on the peak detector. Once it came time for moving the design to a strip board Michael took the lead, being very proficient in soldering and went for a single board design. This left the rest of us a little less involved for a short period, however we found ways to aid his progress by soldering the smaller modules such as the power inputs and the inductor boards, while experimenting with the switch design and implementation. Overall the atmosphere was positive and constructive and I feel that shows in the elegance of our final design.

9 Conclusions

Overall, I believe the project was a success. All of the aims set out by the specification were met and the mouse completed the circuit in 18.02 seconds and coming in at a total cost of £16.49. Although this was not competitive with the top groups, most analogue groups struggled to compete so handily with the micro controller-based designs. If I were to repeat this whole process, a PID controller-based design is something that should be taken into more serious consideration. It should be stated however that the decision for an analogue design still stands strong and the reasons for constructing the mouse in this way, I believe, are well founded. The group aspect of the project was never an issue, and if anything was almost a strength, as we all knew who was best suited for each individual task and acted as such. One improvement that could be made is in the motor reference voltage. Instead of using a simple potential divider circuit, which does function, a more complex but robust circuit using a Zener diode could have been implemented and due to us being so far under budget, would not have been an issue. Another area that could have been improved on is the testing process. The main aim was always to get a successful lap and worry about speed later. If the settings of the potentiometers were recorded and a more in-depth testing process of the mouse's limits of the speed at which it can complete the course was done, a quicker time could have been achieved. Fear of adjusting the set up and not being able to simply undo the change to the working set up held us back in pushing the mouse to the brink of what it could achieve.

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