

POWER ASSISTED STEERING IN MOTORCYCLES

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Abstract

The aim of this project is to develop a prototype for motorcycle power-assisted steering system through research into the dynamic behaviour of a 2 wheeled vehicle. This finished system could potentially have a large impact on several sectors of the motorcycle industry. The system would reduce the amount of force needed to be produced by the rider to steer the bike. This is beneficial for all riders, but specifically for those with injuries/mobility issues, racing riders (e.g. MotoGP riders where long run times and downforce devices contribute to more rider exhaustion) and riders of heavier, larger capacity bikes with a large amount of trail which contribute to more effort needed to steer a bike in a transient situation. By implementing additional recovery functions, greater stability could be achieved in situations such as tank slappers.

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1 Roles

1.1 Shared

- Initial research into transient steering behaviour
- Research into potential applications/target market
- Costing
- Management of the project
- Research into current steering technologies, relevant projects & patents

1.2 Matt

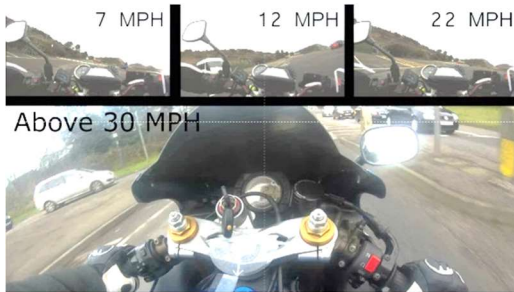
- Steering torque data analysis
- Explaining steady-state steering torque
- Deriving equations for transient state cornering
- Simulation of rider input with power-assisted steering
- Feasibility study
- Electronic system layout & schematic
- Construction of an electronic system
- Programming

1.3 Nathaniel

- Taking measurements
- Calculation of working forces & factor of safety
- Manufacturing & construction process theory
- 3D CAD modelling & printing
- Packaging the product in confined space (inc. ergonomics)

2 Research

2.1 Initial research into transient steering behaviour



By carrying out practical research (video available in the interim viva presentation), the point at which steering angle becomes negligible and where counter steering becomes fully noticeable to the rider has been identified

to be ~ 30 MPH. While applying constant torque to the handlebars, steering angle progressively reduces with increased speed. At lower speeds, the steering points in the direction of travel. While some form of counter-steering seems to be present at all times, its effects seem to be more noticeable with higher speeds. Due to tyre slip and flex in suspension as well as the triple clamp, the effects of counter-steering can be observed by looking at the very small amount of steering angle which is opposite to the direction of travel (at higher velocities).

With a motorcycle at the exit of a low-velocity corner (below 30mph), its lean angle & trajectory begins to change before the steering angle starts to return to its neutral position, confirming that to some extent, the effect of counter-steering is present at low speed. Furthermore, the results suggest that at low velocity, where gyroscopic effects are small in magnitude (thus where the bike will be more unstable), steering angle helps the rider keep the motorcycle from falling over.

2.2 Further research into transient steering behaviour

Gyroscopic torque:

$$G_m = I\omega\Omega\cos\theta$$

There are several reasons why heavier motorcycles have been selected to be a key target market. Seeing as it is the gyroscopic effect that enables the rider to steer, it can be determined from the formula above that a rider of a heavy motorcycle (typically with higher wheel inertias) is likely to notice counter-steering at somewhat lower velocity than a rider of a lighter motorcycle.

At high velocities, considering a constant rider steering input, a heavy motorcycle without power-assisted steering will have a lower roll rate due to increased wheel inertias when compared to a lighter motorcycle. At low velocities where steering angle is significant, due to increased mass and thus increased tyre friction, a heavier motorcycle would require more rider steering input.

2.3 Current assisted steering technologies

Electro-hydraulic (power steering)

This is a motor-assisted version of hydraulic power steering, with a direct link between the steering and wheels.

- Motor varies pressure
- Responds based on demand

Advantages:

- Better fuel economy when compared to a pulley driven motor-less system
- Much more low-speed driver effort needed compared to non-assisted steering

Electro-mechanical (power steering)

This technology eliminates the need for hydraulics, but it still has a direct link between the steering and the wheels through a mechanical component such as a steering rack.

- Only on when needed
- Responds based on demand

Advantages:

- No hydraulics = less complexity
- Provides extra safety functions
- More programmable than the electro-hydraulic system

Steer by wire

This system has no direct link between the steering and wheels, relying on two main electrical motors, one for steering feedback and another for steering.

- Current industry focus

Advantages:

- The control system has full control over steering – very programmable
- Opens up the possibility for fully autonomous vehicles
- Greater flexibility - steering can be placed anywhere

Steer by wire looks like the ideal solution, but there are legal barriers which currently make this technology not ready for mass production.

From the perspective of a manufacturer releasing such system to the public, It is still required by law to have a physical link between the steering input and the steering mechanism, so a steer-by-wire system,

although possible to do, is illegal at this point in time - 6 Jun 2016. Safety and fail-safe modes should be carefully looked into when implementing such steering system.

With the way the industry heading right now, it is expected that steer-by-wire technology will be implemented into many vehicles in the near future, with expected market growth share at a CAGR of 23.4% over between 2018 and 2026 (researchandmarkets.com, 2018).

2.4 Relevant projects



behaviour of a human rider.

Yamaha MOTOBOT (Yamaha, n.d.)

The Motobot project is Yamaha's attempt at making an autonomous motorcycle-riding robot.

Relevance to the project:

MOTOBOT artificially applies steering torque to the handlebars, simulating the



Yamaha MOTOROiD (Yamaha, n.d.)

The Motoroid project is Yamaha's attempt at making a fully autonomous motorcycle, without the use of a riding robot.

Relevance to the project:

Counterweight mass stabilises the MOTOROiD at low speeds, with steer by wire on the rear end.



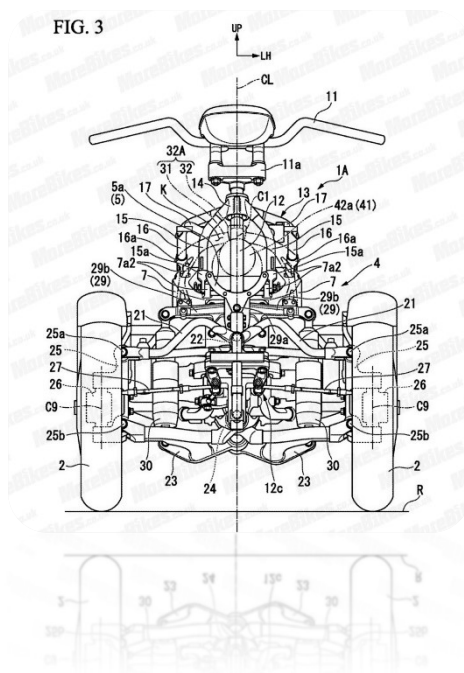
Honda Self Balancing Motorcycle – ‘Riding Assist’ (Honda Global, n.d.)

The Honda riding assist project is a self-balancing motorcycle that can ride on its own at low speeds

Relevance to the project:

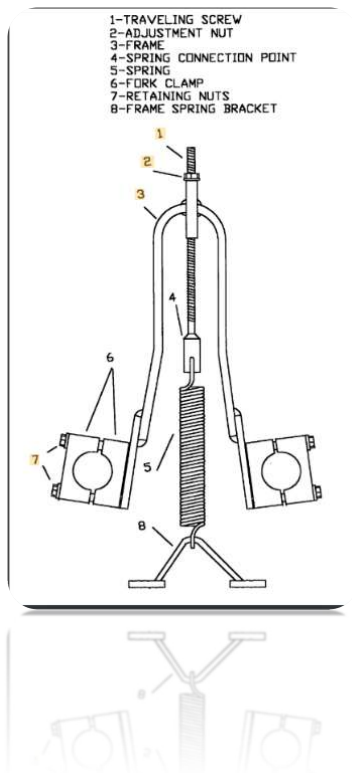
Steer by wire system is used below 3mph, with locking pins engaging above this speed.

2.5 Relevant patents & research papers



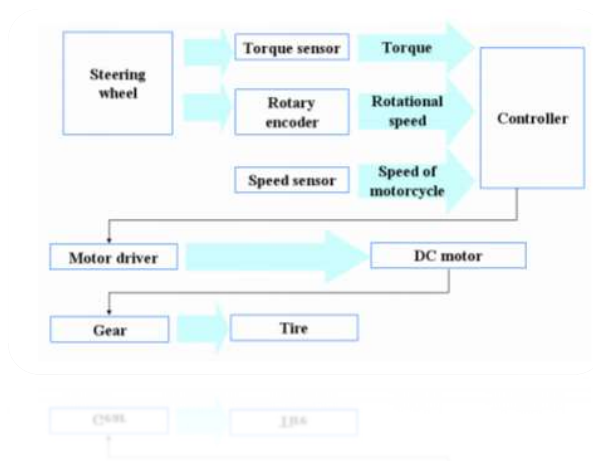
Honda Neowing (Yotaro Mori, 2019)

The Honda Neowing patent shows how power-steering is integrated into a 3 wheeled vehicle. Due to large mass, the Neowing would require a lot of effort to steer at low velocities, thus, Honda decided to implement a power-steering system through use of an electrical ‘assist’ motor, while maintaining a direct link between the steering and wheels.



Mechanical power steering (Carr, 2004)

This patent shows a mechanical approach to implementing assisted steering into 2 and 3 wheeled vehicles, without the use of an electrical motor. The disadvantage of this purely mechanical method is that the assist force is based on the steering angle. This means that at higher velocities (30+ mph as previously established), this concept will not provide enough amplification due to negligible steering angle.

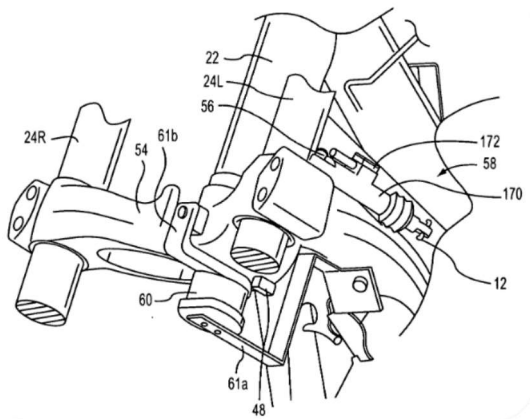


Modal Analysis Topics, Volume 3 pp 491-496

(Proulx, n.d.)

This source contains a feasibility study for implementing power steering in motorcycles, with various flowcharts for system design. This is a very useful source that will be used for making decisions on how the system will work.

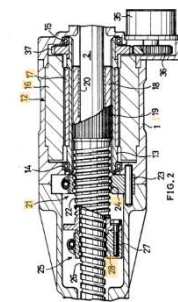
A power-assisted system is fitted to zxr400 by use of an electrical motor, mentions the use of a torque sensor, rotary encoder and speed sensor. Also mentions the use of a warp gauge on the steering wheel acting as a torque sensor.



Steering assist system for motorcycle (Suzuki, 2008)

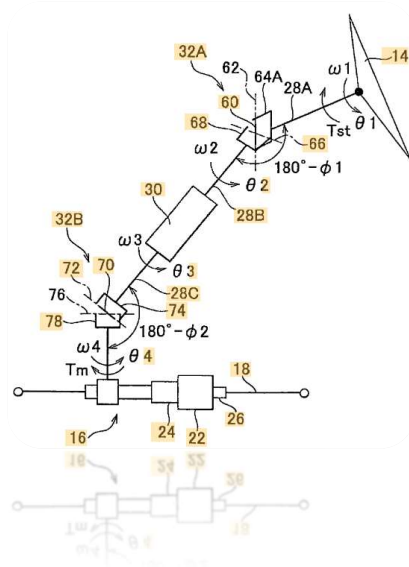
Assist actuator mounted by the bottom yoke. A detecting unit is implemented to read the steering angle. The system calculates steering torque using vehicle speed, steering angle and acceleration of the motorcycle in the vehicle-width direction.

U.S. Patent Apr. 8, 1994 Sheet 2 of 2 5,299,649



Steering device utilising a track-pinion construction (Osamu Sano, n.d.)

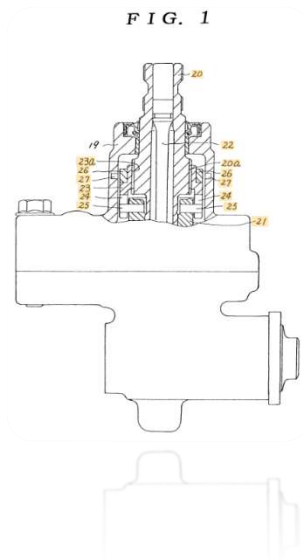
This method of controlling steering utilises a track-pinion construction.



Steering control method – car (Shibata, 2006)

This method could apply to a low-velocity scenario on a motorcycle. Steering torque transmitted to the steering wheel is computed as multiplication product of:

- the ratio of angular speed
- Steering torque of the pinion shaft

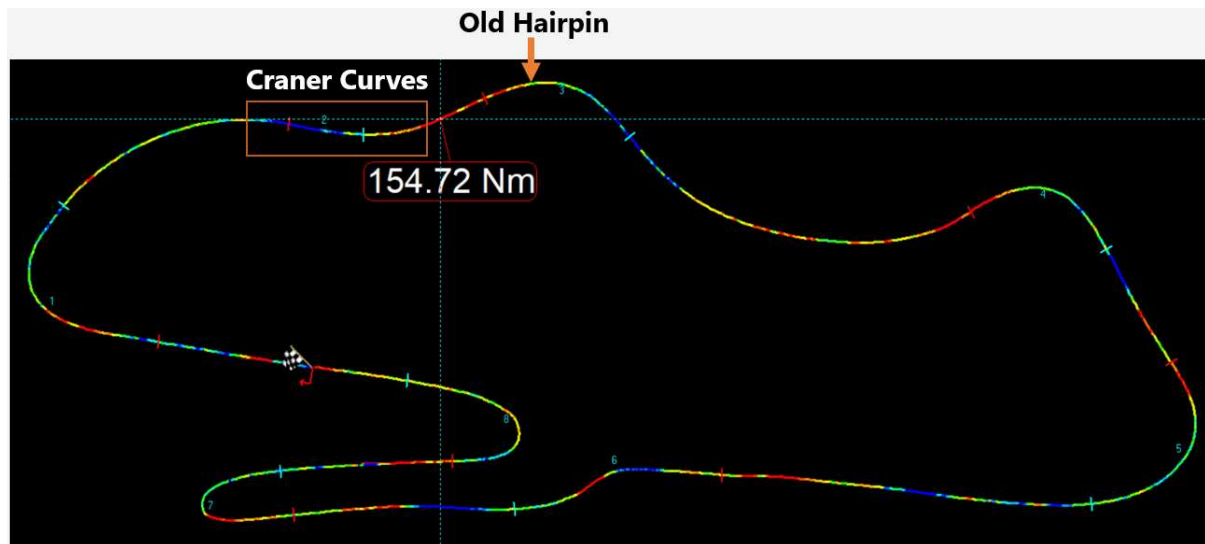


Compact torque detector (Yoshinori Kogiso, 2001)

This compact torque detector can be used to measure the steering torque (relative to the rotation of its input shaft). The output shaft of this module can be connected to the steering. This component works by utilising magnetically sensitive devices that detect torque as voltage.

2.6 Steering torque data (initial research for simulation)

Alexander Przibylla's data has been used to analyse steering torque data for a transient application. This data was recorded from Donnington Park (GP layout), with Michael Neeves as the rider of the Ducati Panigale 1199S.



Measuring values	
Lap	190604 100317
Time tot	1:44.293
m total	8:36.479
Time Lap	16784
m Lap	0:22.807
Banking	952
V_GPS	54.40
Banking_GPS	169.0
AngleRoll	34.69
AngleRateX	-25.9
SIF_RHT	62.7
SIF_LHT	125.43
ST_RHT	390.31
ST_LHT	37.63
STTorque	117.09
	154.72

Looking at the steering torque data, it is visible that Craner Curves to Old Hairpin transition is one of the most demanding parts of the track, requiring a peak of 154.72 Nm of torque (file: Exit 3.19), with the rider applying 125.43 N to the right handlebar and 390.31 N to the left handlebar. This is an equivalent to vertically lifting a 53 kg weight between both hands. Having spoken to riders who have previously been

on this track, they agree that this is the most physically demanding section.

The force readings are direction sensitive. Pushing left handlebar forwards (e.g. under braking) will produce a negative result, while doing the same to the right handlebar will produce a positive result.

It is also worth noting that a small amount of steering force is needed during steady-state cornering.

2.7 Explaining steady-state steering torque

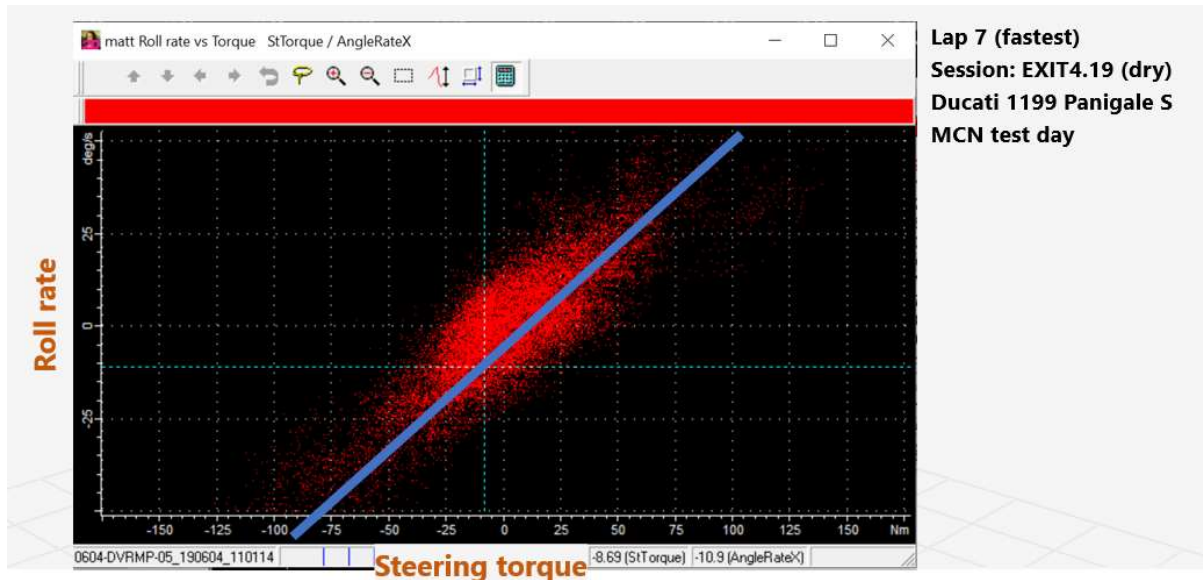
The presence of steering torque applied by the rider during steady-state cornering in the data is due to various forces acting on the front section of the motorcycle (Cossalte, 2006). It is important to note that those forces will still have a (relatively small) effect in transient state. The transient derivation section of this report is based on real data, thus the derivation will include the forces below;

- Disaligning influence – weight force
- Aligning influence – centrifugal force
- Disaligning influence – normal load
- Aligning influence – lateral force
- Aligning influence – gyroscopic effect
- Disaligning influence – twisting torque of tire

3 Simulation & feasibility study

Please ignore the simulation summary found in the interim viva. It contains errors.

3.1 Deriving equations for transient state



Laps containing entrance/exits from the pit area have not been used for analysis due to steering torque vs roll rate data being very widespread at low velocities. Even during a flying lap, the data is somewhat widespread (mainly due to the variance in velocity over a lap, but also other factors such as oversteer), however, a linear trend line can still be determined to find an approximate mathematical relationship between the two in a generic high-velocity scenario. Those equations can also be used to relate steering torque and roll rate for a simulator or to approximate steering torque as part of a fail-safe system which compares strain gauge calculated steering torque to the results from the equations below.

The following equation can be derived from the X/Y plot in the form of $y = mx + c$:

$$\textbf{Roll rate} = \mathbf{0.54 * steering torque}$$

Thus;

$$\textbf{Steering torque} = \frac{\textbf{Roll rate}}{\mathbf{0.54}}$$

(This method has a margin of error of about +/-25% through the Exit3.19 file.)

Where steering torque can be determined by multiplying the resultant steering force by the distance to the handlebar (0.3m), therefore:

$$\textbf{Resultant force at handlebars} = \frac{\textbf{Roll rate}}{\mathbf{0.54 * 0.3}}$$

Because it is easier to push a handlebar away from the rider than towards the rider, the inner handlebar (closest to the apex) typically experiences more resultant force being applied to it (~75% of the total resultant force) than the outer handlebar. In a situation where trail braking is involved, this value is closer to 100%. In the case of the Craner Curves to Old Hairpin transition:

$$\textbf{Approximate steering force inner handlebar} = \frac{\textbf{Roll rate}}{\mathbf{0.54 * 0.3}} * \mathbf{0.75}$$

$$\textbf{Approximate steering force outer handlebar} = \frac{\textbf{Roll rate}}{\mathbf{0.54 * 0.3}} * \mathbf{0.25}$$

Those equations can be used to implement a .cal channel to find approximate steering torque for a motorcycle with similar mass, inertia and geometry without the need of a steering torque sensor. The only requirement is a roll rate reading which can be gained through finding the change in lean angle. A modern smart-phone with a gyro sensor and an accelerometer is realistically all that's needed to calculate the approximate steering torque.

3.2 Power steering simulation & feasibility

The system is designed to apply assist force that is proportional to the rider steering force. In theory, using this method should make the steering feel natural to the rider. In practise, using a multiplier that is too high for the inertia of the bike could make it unstable, hence the maximum multiplier at this point has been assumed to be X 1.45. It is also very important that the sampling frequency of the system is sufficiently high. Furthermore, the output of the system needs to respond to rider input very quickly, with no noticeable lag, otherwise, the rider might experience a feedback loop similar to one that can be seen on force feedback enabled steering wheels.

The simulation below shows the effect power steering would have on the Craner Curves to Old Hairpin transition. It shows that the system could make a big difference to the rider input force required, reducing rider fatigue.

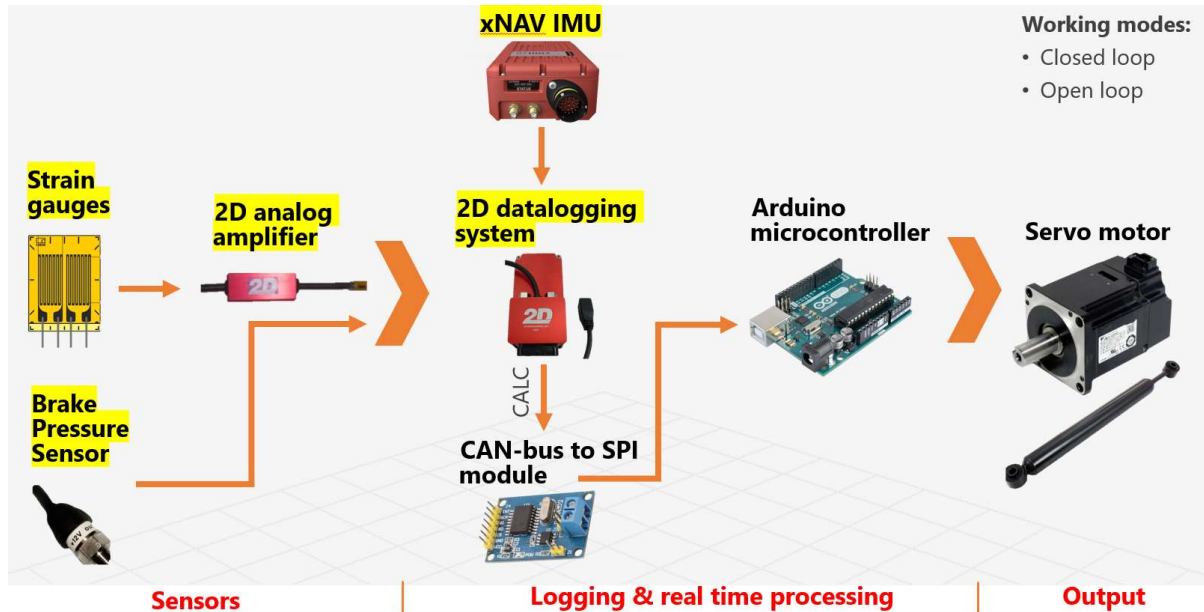
1X multiplier	1.15X multiplier	1.30X multiplier	1.45X multiplier
↓	↓	↓	↓
516 Newtons Equivalent: 53kg (no power steering)	439 Newtons Equivalent: 45kg 15% reduction	361 Newtons Equivalent: 37kg 30% reduction	283 Newtons Equivalent: 29kg 45% reduction

The system could also enable riders to achieve higher roll rates if they have reached the point of physical exhaustion. The simulation below shows the roll rates at constant rider steering input but with different power steering settings, using the formula derived in the previous subsection.

1X multiplier	1.15X multiplier	1.30X multiplier	1.45X multiplier
↓	↓	↓	↓
46 deg/s (no power steering)	53 deg/s 15% increase	60 deg/s 30% increase	67 deg/s 45% increase

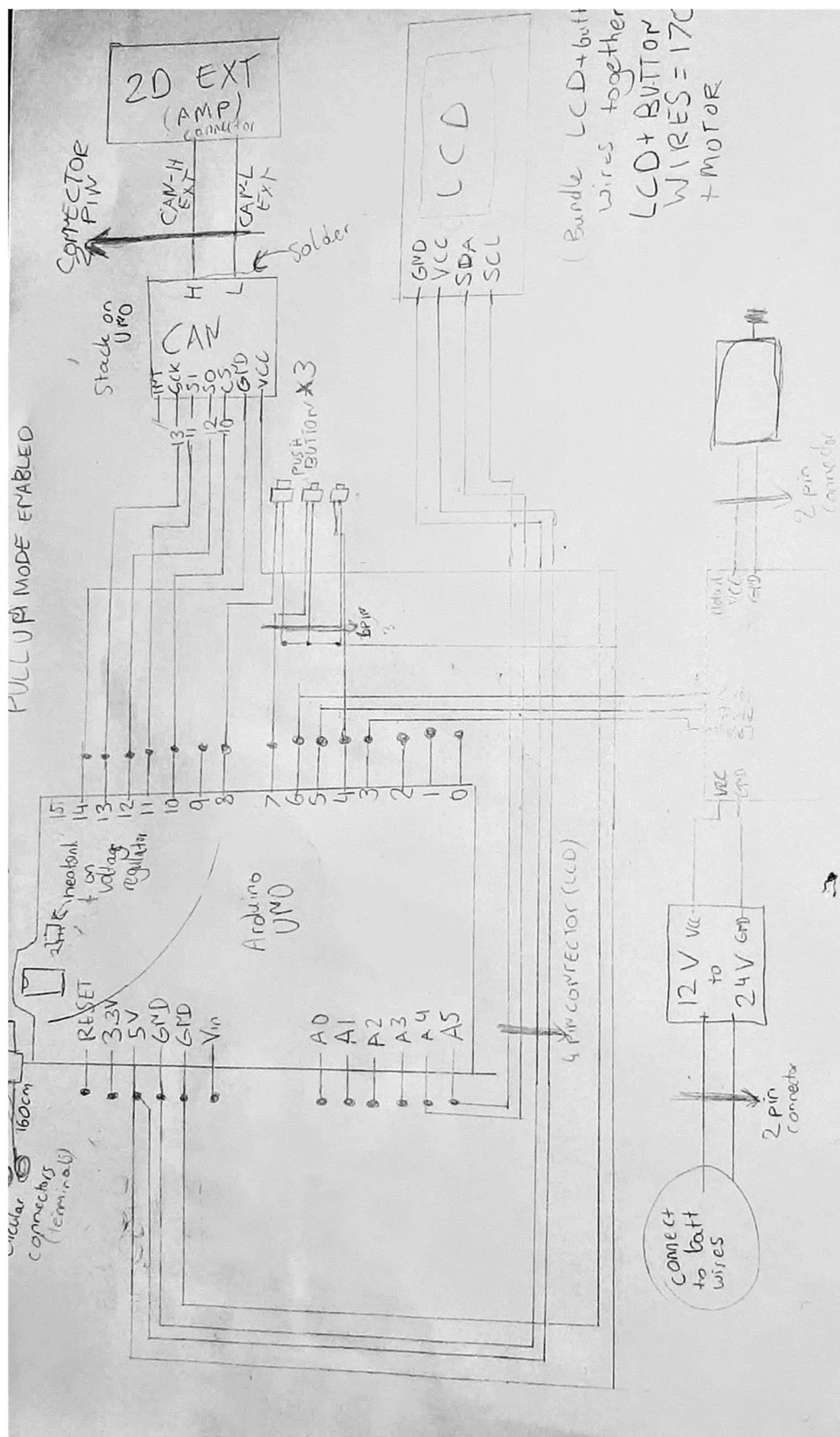
4 Designing the system

4.1 System layout



(Components highlighted in yellow have already been implemented by Alexander Przibylla on the Ducati 1199S)

4.2 Electronic system schematic



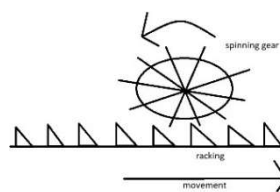
4.3 Mechanical hardware & integration with electrical components

Before starting the build, additional research was also completed into the costing of materials, construction and the assembly methods which would be used.

It was decided between team members to use an electric motor, powered by the existing motorcycle battery (torque controlled by PWM output), which would have a driving gear fixed to a rotating shaft. This gear would mesh with the teeth on a rack system which can slide forwards and backwards and would be partly encased in a fluid to enable sufficient lubrication and reduce resistance, creating a smooth operation. At each end of the rack, there would be a cylindrical section used to mount the device to the motorcycle chassis, with the use of 'fish-eye' bearings to allow slight rotational movement and avoid jerking. The use of rubber seals will be used on the cylinder sections to prevent leakage of the fluid, similar to the operation and methods used by a steering damper but with a rack and pinion instead of pistons. The device would be side-mounted and attached via the main frame and a fitted collar around the fork leg. This design would then be mirrored and manufactured to fit the other side of the motorcycle, enabling both forks to pivot around the steering stem. Inputs would be sent to individual motors, determined by the programming of the system, and the direction of travel needed.



Linear actuator using rack and pinion system

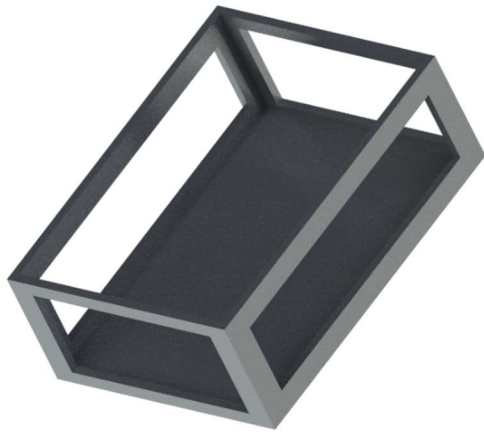


Simple sketch of method used to create movement



Fish-eye bearing rod end

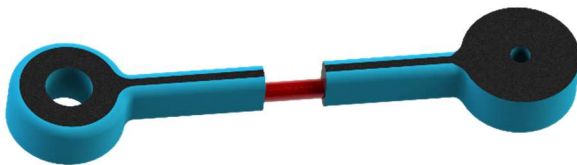
4.4 CAD models



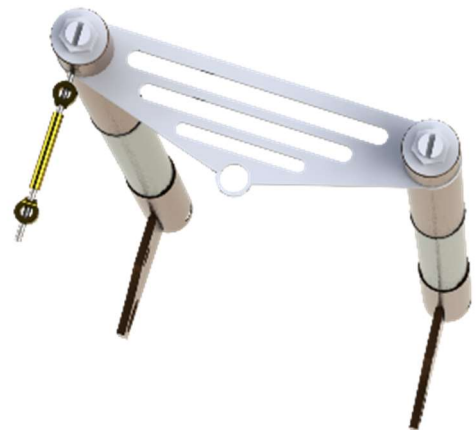
Case insert for circuit board



CAD model of electric motor



Early CAD model to illustrate design...
modifications have now been made to final
design which can be sent over once access to
computer rooms is permitted



Assembly model to demonstrate the
mounting

5 Manufacture

A personal note from Mateusz:

Due to the outbreak of Covid-19 and therefore the closure of workshops and computer facilities, the power-steering system was not built in time for the report deadline. I, therefore, decided to allocate the time assigned for software development and electrical hardware construction to making further research into transient and steady-state handling (which can be found in previous sections of this report).

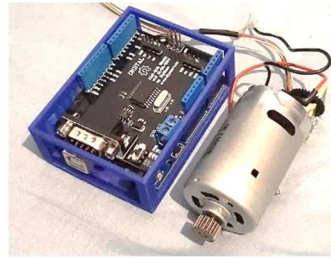
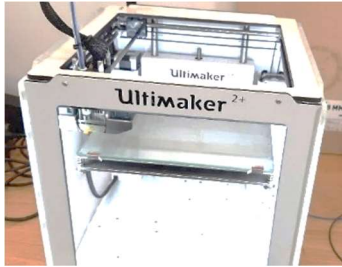
A personal note from Nathaniel:

Unforeseen Limitations – workshop and university closures, lack of software accessibility and materials due to UK lockdown due to Corona Virus. Personal laptop is located at my usual term residency; however, I am staying with vulnerable parents out of area during the outbreak to assist and am unable to retrieve my work until further notice. I have also been deemed to be a key worker at Royal Mail and have been asked to work additional night shifts to assist the situation in a time of need. I am unable to meet the other team member.

Due to this, although I did make some progress, I have been unable to finish the process of integration of mechanical hardware with software. The construction process has been made impossible due to the closure of workshops and hardware stores. Stress analysis can't be carried out due to the closure of computer facilities (no access to SolidWorks). I have allocated the assembly/manufacturing time into making further research for mechanical components & relevant patents/research papers.

5.1 What we have so far: manufacturing

The outer casing would be made of plastic for the test model, later switching to a combination of steel and aluminium for the actual construction of the body. Initially manufactured using 3D printing techniques, the use of plastic during the initial test phase was deemed cost-effective and allows easy modification to design files if needed. Once happy with the test model, the final piece would be



constructed using the lathe, milling machine and the use of a water jet cutter to cut and form the aluminium and steel into the required shapes.

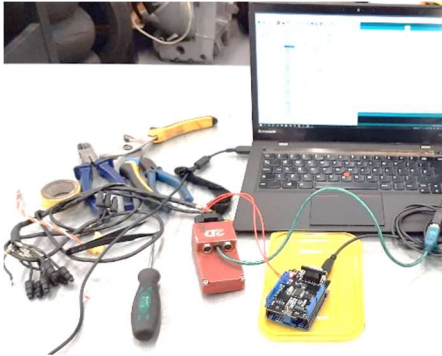
The parts needed to be constructed are:

- a collar to fit the forks
- a mounting bracket which bolts onto the main frame of the motorcycle
- outer casing
- bed for the circuit board
- rack

Parts to order:

- 2 rubber seals
- 2 bolts
- 2 washers
- 2 nuts
- 2 fish-eye rod ends

5.2 What we have so far: the electronic system



The electrical system has only been partially finished due to Covid-19. Currently, the system is receiving strain gauge readings through CAN-bus utilising the CALC (real-time online calculation) function of the 2D datalogger. Alexander Przibylla's CAL steering torque calculation code has been ported to the Arduino. Currently, no outputs are connected to the Ducati 1199S, therefore, the system is not fully functioning.

6 Conclusion

The inclusion of power steering on motorcycles has been proven to be feasible and useful. We hope to finish this project outside of the deadlines, once the outbreak of Covid-19 is under control and workshop facilities/hardware stores return to their normal operating schedule.

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