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April 21, 2007

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
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Re: ENSC 440 Postmortem of the Motorcycle Headlight Correction System Project

Dear Dr. One:

The enclosed document, *Postmortem of the Motorcycle Headlight Correction System Project*, outlines the results and what we learnt through our ENSC 440 project. The goal of our project was to design and implement a system to automatically correct motorcycle headlights, when a motorcycle is travelling along a curve, in order to optimize driver safety.

Veiro Technologies Ltd. consisted of four highly capable SFU undergraduate engineering students: Christopher Martens, Raul Fernandes, Tania Kwan, and Reena Bhullar. Each of these individuals brought their own unique and valuable experiences to our team.

If you have any questions or comments, please do not hesitate to contact us at veiro-ensc440-grp13@sfu.ca.

Sincerely,

Reena Bhullar
Chief Financial Officer, System Integration Engineer

Enclosure: Postmortem of the Motorcycle Headlight Correction System Project

Postmortem of the

Motorcycle Headlight Correction System Project

Project Team: Chris Martens
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                       Reena Bhullar
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Submitted to: Lucky One – ENSC 440
                       Steve Whitmore – ENSC 305
                       School Of Engineering Science

Issued Date: April 21, 2007

Revision: 1.0

Executive Summary

The staggering statistics of motorcycle injuries and fatalities when a rider is travelling at night and before he negotiates a curve implored the members of Veiro Technologies Inc. to investigate methods that would decrease the dangers associated under these scenarios. The innovative solution founded by Veiro Technologies will vastly increase the safety of all riders, motorists, and pedestrians.

Veiro Technologies Inc. produced a Motorcycle Headlight Correction System that automatically obtains data from the motorcycle while it is in motion and relates the information to the motors controlling the headlight. Whenever necessary, the system permitted the headlight to twist and pan. The structure of the headlight and motors allowed for the headlight to be situated parallel to the road at all times. Thus, the rider's perception of his environment was immensely improved.

This proof of concept system showed the advantages and benefits of installing the Motorcycle Headlight Correction System on any sport bike. We showed videos that demonstrated how well the system performed at high and low speeds during the night, and compared the illumination from our system to that from a fixed headlight. We also physically demonstrated the system on the bike to show how it responded to the slow movements of the motorcycle.

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1   Introduction

The Veiro team - consisting of Chris Martens, Raul Fernandes, Reena Bhullar, and Tania Kwan - was formed over a year ago. Preliminary planning on the project started early on, we brainstormed through several ideas and finally settled on tackling the problem of motorcycle safety. Motorcyclists are constantly in danger of injury or fatality when riding at night and around curves due to the limited visibility of their local environment while riding. We began constructing the Motorcycle Headlight Correction system four months ago to increase a rider's vision under these circumstances. The completed system enabled the headlight to twist and pan automatically such that the light emitted maximized the path seen ahead of the rider. This document describes the results of the Motorcycle Headlight Correction System prototype. We analyze how well the system works and what we learnt from the project.

2   Current State of the Device

The following section will describe the current state of the Motorcycle Headlight Correction System. The overall system block diagram is shown in Figure 1.
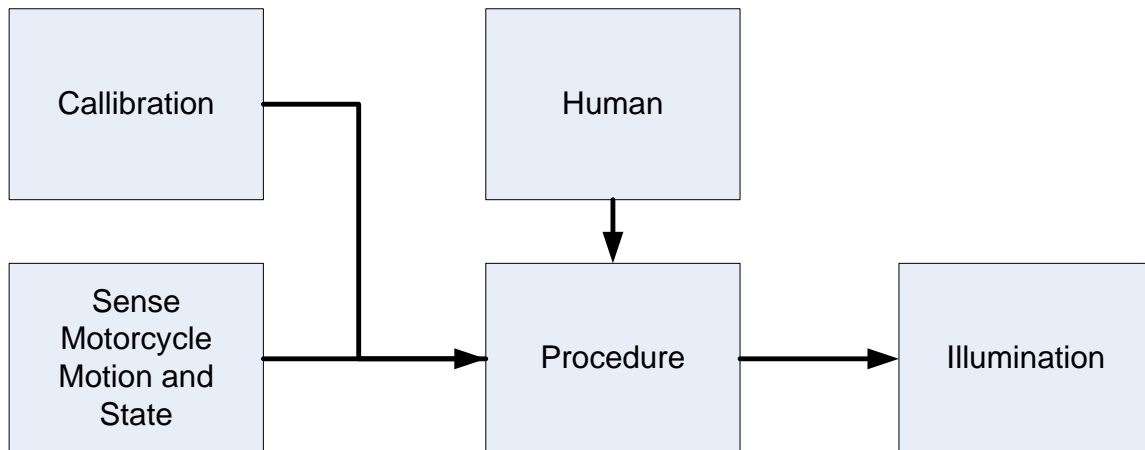

Figure 1: Block Diagram of System Overview

The detection of the position and orientation of the motorcycle is the first step of the process. The calibration of the system sets how the headlight correction system behaves relative to the inputs; the calibration is factory set and not end user adjustable. This process adjusts the headlight such that the longer side of the headlight is parallel to the road and pointed in the direction of travel, thus providing maximum exposure of the rider's surrounding environment. Note that the "Human" block of the system interacts with the motorcycle which leads to an adjustment of the headlight.

Adjusting the motorcycle heading into the desired position requires the tilt and pan angles from the motorcycle. Figure 2 shows the twist and pan angles of the headlight.
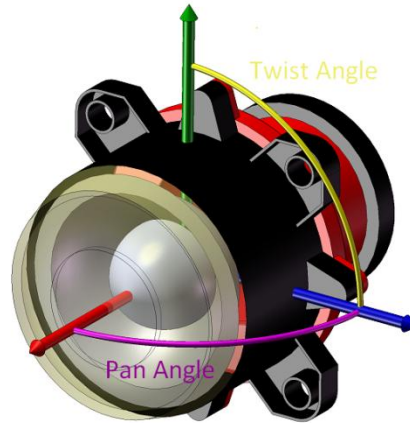

Figure 2: Headlight Twist and Pan Angles

To find the angle to pan the light, we had to determine how the light needed to be oriented. In Figure 3, we can see the bird's eye view of the motorcycle headlight direction. It was assumed that for panning, the headlight always needed to be focused 2 seconds ahead of the rider. This is applicable with current laws, stating that drivers need to be 2 seconds apart.
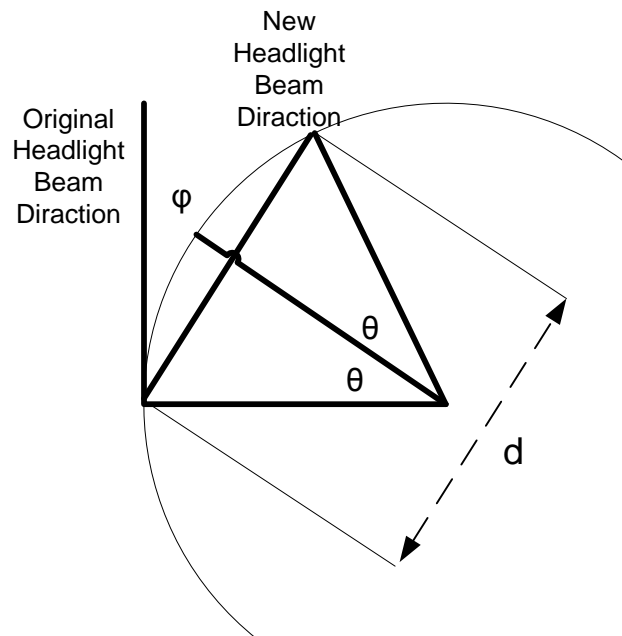
Figure 3: Bird's Eye View of Motorcycle Headlight Direction

The twist angle was found using the x-direction of an accelerometer, an ultrasonic sensor, and a gyroscope. A different gyroscope is used to find the panning angle.

A ±75°/s yaw rate gyroscope was one of the sensors used to determine the tilt angle of the motorcycle. Since it is very unlikely for the motorcycle to be tilting at a rate greater than ±75°/s, the gyroscope is an ideal sensor for detecting the tilt angle. It was also

decided to have a cutoff frequency of 1 kHz in order to remove any sampling data that was unnecessary.

The accelerometer also helped determine the tilt angle (for the slow speed model). The x-direction of the sensor was used in an arcsine function to determine the output tilt angle of the motorcycle.

$$tilt\ angle = \sin^{-1}\left(\frac{accelerometer\ output}{k}\right) \qquad (1)$$

The constant *k* was found by assigning it a number such that when the accelerometer was tilted +90º from the vertical position the value in the brackets was +1 and when the accelerometer was tilted -90 º from the vertical position the value in the brackets was -1, thus assigning the full range of the arcsine function. When the motorcycle tilts, a reading of ±*degree* would tell use the angle of tilt and the direction of tilt. The accelerometer was given a cutoff frequency of 1.2 Hz.

Similarly, the ultrasonic sensor was use for the high speed model. This sensor made use of geometry in order to relay information with respect to the motorcycle's vertical orientation. The sensor is angled out from the bike and returns a value representing the distance to the ground. When the motorcycle is situated vertically, it meets an equilibrium value. If the bike is tilted in either direction, the sensor would provide a reading and if the value lies outside the threshold range around the equilibrium value the integrator used to determine the twist angle would be reset.

Another gyroscope, ±180°/s yaw rate, was chosen for the panning angle because of its greater rate sensing range. Since it is possible for a motorcycle to turn at high speeds, this particular gyroscope met the requirements for our panning. As with the gyroscope used for measuring the tilt, a cutoff frequency was also applied to this sensor. It was decided to set the cutoff at 6 Hz.

A velocity sensor was also utilized. This sensor was placed by the front tire, detecting the spokes (rising edges). Through some geometry and calculation to find the distance, and by recording the time between each rising edge, the velocity of the motorcycle could be found.

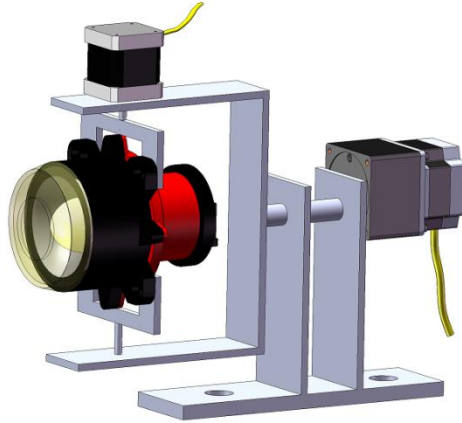Figure 4 shows an overview of the mechanical system.

Figure 4: Overview of Mechanical System

This mechanical assembly gave the headlight two degrees of freedom, along the twist and pan angles. Aluminum was used for most of the construction, with an effort made to keep the system sturdy and yet lightweight. We calculated the inertia of the system and made sure the motors had the necessary torques to drive the system. A driver circuit was built to be able to control the motors via the microcontroller. Hardware based safety limits were installed to ensure that the motion of the headlight was limited to avoid damage to the system.

A Motorola HC12 microcontroller was employed as the brains of the system; most of the firmware was written in C and converted into assembly that was then loaded onto the microcontroller. Smart algorithms were employed to keep power consumption as low as possible. The microcontroller read the status of the motorcycle from all the sensors and decided on the required headlight position using pre-computed look-up tables. These look-up tables were created using a single universal speed model for the panning angle and separate high and low speed models for the twist angle.

3   Deviations from the Original Design

3.1   Magnetic Compass

In the initial design, a magnetic compass was used to determine the pan angle. This method of determining the angle was found to be undesirable after the realization from testing, that the compass was too sensitive to the magnetic fields from the motorcycle. Also, in order to obtain accurate results, the compass needs to be parallel to the ground at all times, which is close to impossible on a motorbike.

3.2   Pan Angle Models

Upon initial design of the pan angle model, it was decided to have a dual model to account for high speeds and low speeds attained by the motorcycle. This was agreed upon because the formula derived to find the pan angle incorporated the tilt angle of the motorcycle. This is acceptable at high speeds, however at low speeds the

motorcycle has very little to no tilt angle. Thus, a second formula was derived to determine the pan angle at low speeds which did not utilize the tilt angle. Once these models were employed during testing, it was found that the low speed model was accurate at both low and high speeds. As the high speed model utilized two input variables, resulting in a vast look-up table, it was decided to make use of just the low speed model for all speeds.

3.3   Integrator Reset

The noise from the gyroscope utilized to find the twist angle resulted in a constant drift in the output angle when the rate was integrated. To resolve this problem, a method needed to be determined to reset the integrator when the motorcycle was travelling straight and not maneuvering a turn.

Initially, it was decided to use the output from the x-accelerometer to determine when the motorcycle was travelling in a straight path. However, it was found the output from the x-accelerometer was very noisy and even with high filtering could not be used to distinguish between when the motorcycle was travelling straight and when the motorcycle was in a turn. We believe this was due to the fact that it is nearly impossible to mount the x-accelerometer perfectly parallel to the ground. Any slight deviation from this desired position would result in the sensor picking up motion in the y-direction of the motorcycle caused by bumps in the road.

The second method employed to reset the integrator was using the output from the gyroscope measuring the angular velocity of the motorcycle. The output from this sensor was very clean and easily allowed a distinction to be made between when the motorcycle was travelling straight and when it was in a turn. Assuming that a motorcycle only tilts when it is in a turn, this would allow the integrator to be reset when there was no angular velocity. Through testing of this method it was found that the physics of motorcycles was not as we had thought in order to make this method usable. When a motorcycle maneuvers a turn, it tilts before it enters the turn. This means that the motorcycle has a tilt angle while there is no angular velocity. Thus resetting the integrator to determine the tilt angle using the angular velocity was not a practical solution.

Finally, an ultrasonic sensor was used to determine when the motorcycle was not vertical. The sensor was mounted on the side of the motorcycle and returned a value corresponding to its distance to the ground. By initially setting a threshold of acceptable length, when the value returned by the sensor was out of this threshold it was reasonable to conclude that the motorcycle was in a turn. When the sensor's value was within the threshold, this meant that the motorcycle was not tilting and that the integrator could be reset.

3.4   Driver Circuit

When the driver circuit was being constructed, the chopper was to be built. However, it was found that the number of components required and the complexity of the resulting circuit was too high and prone to errors. In an attempt to minimize the size of the circuit, driver controller chips (L297) were bought and incorporated into the final design.

3.5   Mechanical Design

There were many changes made to the mechanical design in an attempt to achieve a less bulky yet sturdy design. The initial design used a much larger headlight and had only one degree of freedom. The design was then improved to incorporate two degrees of freedom, gears, and minimal framework. Through various other design prospects, it was finally decided upon to remove the gears, have a sturdy and light weight frame, and a smaller headlight.

4   Future Plans

There are many future improvements that can be made to this project to make it even more desirable to users. A third degree of freedom can be implemented to stabilize the pitch of the headlight. The pitch of the headlight needs to be changed, as it varies according to how many people are seated on the motorcycle (weight being supported) and whether the motorcycle is being driven uphill, downhill, or straight.

Another factor to be considered is 'out-of-turn' improvements. When the driver is weaving the motorcycle, the headlight is not able to maintain the same movements. The headlight is not able to foresee what the driver will do and therefore stays in the turn longer than the motorcycle. This is not a problem for single turns and most likely will not be encountered unless the driver is weaving through traffic or another scenario which requires similar motions. It is interesting to note that the current automobile providers (such as Audi) have the same problem with four-wheeled vehicles. To solve this issue we would need to incorporate driving pattern recognition and build in some smart predictive algorithm into the system.

A third improvement to be considered is the use of an inertial measurement unit. This device incorporates three gyroscopes and three accelerometers in the x, y, and z directions. This would further minimize the size of the circuitry and remove error in the mounting of the individual sensors.

We are currently exploring the prospects of patenting our design.

5   Budgetary and Time Constraints

As there was little funding for this project, we were able to buy basic sensors to employ our solution to this problem. If we had more funding we may have been able to

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incorporate the use of an inertial measurement unit which would have made our solution more feasible to users. The initial budget was exceeded because of the various redesigns that were made during the duration of the project. However, even though the budget was exceeded, the team members only had to shell out $30 each from our own pockets.

Had there been more time provided, a package could have been designed for aesthetic purposes. As this was a proof of concept project rather than a development project, it was not an essential factor in the completeness of this endeavor. However, having a smoother motion of the headlight would have been an advantageous improvement to the current solution. This could be achieved had the numerous redesigns not been needed.

6 Interpersonal and Technical Experiences

6.1 Chris Martens

Building the Motor Cycle Headlight Correction System was an extremely rewarding experience. Being the Chief Technical Officer, it was up to me to plan out the details on how the different technologies in the system would interact with each other.

Developing the firmware required me to be extremely flexible; firmware was the component that integrated everything together and so it meant that I needed to know exactly how each of the sensors and motors worked. As we proceeded through the project, we realized how much non-idealities in each sub-system would affect us; this needed me to be flexible and creative with how the firmware would acquire and send data to the various devices.

Time management and communication were extremely important on this project. I had to coordinate with all the other team members to make sure we knew what each other were doing and stayed on schedule. We worked really well together, and helped each other when anyone needed it.

The performance of our final was the best part; it was great to see it finally come together after a several weeks of hard work. The accuracy of the final system amazed even us; it definitely couldn't have worked out better!

6.2 Raul Fernandes

The Motorcycle Headlight Correction System was an awesome project to work on. It proved to be the project that let me apply the knowledge gained from my several years of engineering education.

Designing the motor driver board immensely improved my electrical hardware design skills. We needed to keep the size of our components compact to fit snugly on the motorcycle; this meant that the components on the driver board had to be squeezed into a very tight space – not a very easy task when you're working with high power components like thicker wiring, ceramic resistors, high current diodes and heat sinks. The design experience showed me the importance of properly circuit layout, how to solder components on properly and, of course, how to debug circuits when they don't work the first time.

Time management and proper communication were the other vital skills that I had put to maximum use. Along with working on the 440/305 project this semester, I was registered fulltime in courses and also doing a co-op. This forced me to get very efficient at managing my time; it also made proper coordination with other team members critical to the success of the project.

Final system integration was the point where most of our ingenuity had to come in. For example, the use of the ultrasonic sensor to reset the integrator was something we came up with in the last minute. We'd tried several different approaches, until we came across this extra sensor that one of the other groups had lying around. When everything finally worked, it felt awesome. The recognition we received for the project made it all feel worth it.

6.3   Reena Bhullar

Working on this project was an exceptionally worthwhile experience from which I learned a great deal. Working with the theory allowed me to appreciate the difference between real life values and theoretical values. Seeing how great a change external factors can make to desired variables showed me that once the theory is obtained the models must be further compensated in order to obtain the ideal results. Also, working with the hardware components of this task gave me a chance to vastly improve my skills and to apply the many things I learned in the various classes I've taken. Before this project, it was difficult to comprehend how to use the information learnt in previous classes but once faced with a situation in which the information was needed it was almost an immediate response to apply that knowledge.

Time management was a skill that was needed to be enhanced as soon as entering the engineering program. However, even after many years of improving this skill, it was tested throughout the course of this project. As most our team is in the final year of their degree, many of them are working at engineering companies or writing a thesis at the same time as attempting this project. As a result of this, time management grew from managing various course projects and personal activities to managing very important personal goals. As difficult as this is individually, we now had to manage our own time with each other's time. We were all willing to meet and work during late nights and weekends in order to accommodate everyone's needs and to complete the project as best as possible. This also shows the importance of team dynamics.

I learned how important it is to have a team willing to put in time and effort to complete as project and to do well. Having even one group member not in sync with the rest of the group can cause great damage with respect to the end product. I joined this group knowing that all members were hard working and put their all into everything they did. This proved to be a great decision and I can only hope to have groups like this in future projects.

6.4   Tania Kwan

The motorcycle headlight correction system was an extremely rewarding project. I have learnt a lot about the safety issues a motorcycle rider incurs while traveling at night, both through research and testing. I have also discovered a great deal about sensors. I encountered various problems with the sensor components, such as their sensitivity towards the motorcycle's noise and vibrations when they were mounted onto the motorbike. Flexibility was an extremely important characteristic to have. When a sensor was discovered to be undesirable, such as the magnetic compass, the component had to be removed from the sensor board and connection wires had to be rerouted. At times, this was time-consuming and frustrating, but I had to learn to adapt. I also learnt to be persistent and have a 'keep at it' attitude. When creating filters for the sensors, I had to redesign the filters numerous times, which included removing a current one and connecting a new one. Seeing results improve with each new filter gave me more motivation each time redesigning was required.

I also learnt that it was important to take my time to solder components and wires correctly when the parts were initially put together. While testing, I encountered an issue with one of the gyroscope and realized after 3 hours of testing, that it was a soldering problem. Something as little as taking another minute to ensure that the solder was not cold would have saved me a lot of time later on. I also think it would have been beneficial to have a soldering demonstration for students that rarely solder. We learnt from Brad that cold solder could cause bad connections when wiring components.

Another aspect I learnt from this project was the benefits of having a positive group dynamic. The members of this group worked well together and helped each other out when someone ran into problems. When people were away, others would take over the part that was being built. I found that this type of group dynamics was advantageous because decisions could be made together as a group since everyone was aware of current issues.

Having a well organized filing and documentation system was also very important. The use of Microsoft Groove allowed each member to have access to all documents, such as data sheets, project proposal & design specifications reports, current firmware, circuit diagrams, mechanical designs, and meeting minutes. The calendar was also particularly useful for scheduling meetings around exams. I found that the application was a really

useful archive. As the term progressed, I often forgot about the various items that needed to be done, and by looking at meeting minutes or the calendar, I could determine what reports were due next and what our next goals were with respect to our timeline. The ability of being able to access our resources at any time was very convenient.

I have learnt a lot about sensors and their sensitivity to noise and vibrations, having a positive attitude while trying to resolve a problem, and working together in a group. I also learnt of the importance of being organized when there are many documents and resources that are required to accomplish a task.

7 Conclusion

Escalating motorcycle popularity and motorcycle fatalities in recent years has led to an increasing demand for motorcycle and pedestrian safety. The number of the fatalities occurring at night and while maneuvering curves is alarmingly high. The Motorcycle Headlight Correction System that we built performed remarkably well when going around curves. The accuracy of our system was comparable to the commercially available headlight correction systems currently implemented on several cars; this is especially impressive if you consider the fact that the system for a motorcycle is significantly more complex.

Admittedly, our headlight system is still not perfect; the movement of the headlight can be made smoother. There are times when the system overshoots a little when making steep turns. The system is also a little delayed in responding when the bike is coming out of curves, this is because the system can only base the headlight position on the history of the bike's position. It is impossible to tell when the curve is ending without incorporating some driver pattern recognition algorithm into the system.

Designing and constructing the Headlight Correction System had our group living in the labs for several weeks, but along with the work involved it was also a fun project. We had several setbacks during the project but managed to overcome them. Apart from the several skills we gained, we also realized that having a motorcycle in the engineering lab may not have been the brightest idea. We would like to take this chance to thank all our sponsors for their support; we would not have been able to proceed with this project without their generous contributions. We would also like to thank the lab staff for being cooperative, and Lucky One, Steve Whitmore and Brad Oldham for being there to help us with this project when we needed it. This truly was a rewarding experience!