TELEMETRY DESIGN FOR A BOBSLED ANALYSER

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ABSTRACT

This paper was prepared as part of the team design competition for a graduate level course given at the University of Canterbury, in Christchurch, New Zealand. It presents a high level design of a bobsled data acquisition system which is intended to aid athletes and coaches in achieving the maximum benefit from their time at the bobsled track. The system will measure every applicable aspect of the bobsled's performance down the track, and provide real time and near real time feedback for the athletes and the coach.

This system implements an inertial navigation and position system, monitors wind speed, measures the drivers steering input and effort, measures individual pushing effort in the critical start stage of the run, and provides cue signals to the runners when to mount the sled.

A robust packet format and error correction in conjunction with a E^2ROM backup system ensure data integrity. The data is transmitted utilising a GMSK signalling scheme, operating at a frequency of 400MHz. A space conserving patch antenna is mounted on the bobsled and a leaky wave antenna placed alongside the track for the transmission system. A link budget and the error performance of the transmission system are analysed. A graphical front end at the coach's base station provides real time data display and analysis.

KEY WORDS

Telemetering System Design, New Applications, Bobsleds

INTRODUCTION

The sport of Bobsled racing originated in Switzerland, when an Englishman connected two toboggans together in tandem with a flexible coupling between, allowing primitive steering to be used. It involves a team of two or four athletes piloting a sled down a 1200 to 1500 meter ice coated track, reaching speeds of up to 130 kilometers per hour. Once out of the start area the run becomes a test of the drivers skill in negotiating turns, and choosing the best "line" down the track.

This paper describes the design of a telemetering package for a competition bobsled, which will capture real time data about the state of various sled parameters as it speeds down the track. This information will be down-loaded in real time via a radio link, to a computer near the course. This will mean that performance can be analysed on the spot. It is foreseen that this information can aid the bobsled team in several ways, including optimizing performance during the critical starting phase, increasing the benefits of time on the track to enhance training, aiding coaches in assessing team performance and acting as a tool to enhance bobsled simulators. An important goal of the project was to design a telemetering system that would allow the practical achievement of the above goals, and that can be fitted to any bobsled and used at any bobsled track.

SYSTEM CONTROL

The bobsled system controller manages all aspects of the telepack's operation. It is responsible for sampling the data from each sensor, assembling the data into packets and then sending them back to the ground station. It also stores all packets generated during a bobsled run into on-board memory as a precaution in case of radio link failure. Each packet has a unique identifier so only erroneous packets need be retransmitted. Commands from the ground station are also received and processed by the system controller.

The system consists of a MC68302 integrated multiprotocol microprocessor with 512K of RAM, 128K of FLASH ROM, a real time clock and two RS232 ports for communicating with the radio modem and pitch/roll/yaw module. The data acquisition system consists of two 8 channel 12 bit A/D converters. An on board voltage reference is used for calibration. Data acquisition is locked to the 70Hz interrupts generated by the pitch/roll/yaw module.

It was decided to adopt a packet format for the telemetry data because in this mode information is only transmitted when it is generated. A packet format is also more compatible with modern data communications systems. [1]. Telemetry packets are assembled in software before being forwarded to the transceiver for transmission over the radio link. Figure 1. Shows the telemetry packet format.

912 bits

24	8	32	8	48	504	84	84	60	12	4	12	32
sync	Length	pid	bsid	time	x7 pitch/roll/yaw	x7 angle	x7 torque	x5 strain	wind	seats	batt	crc

Figure 1. Bobsled Telemetry Packet Format

A simple fixed length packet format is used for commands. It is important that commands reach the bobsled during its run. For this reason the command field is duplicated three times in the command packet. If the CRC indicates that there are data errors in the command packet then a majority decision will be taken on the three commands. If no majority exists then the command will not be executed, and the bobsled will ignore any command packets which do not have its own bobsled identifier. Figure 2. shows the command packet format.

320 bits

24	8	32	8	8	32	32	72	72	32
sync	length	pid	bsid	cmd_id	p1	p2	rpt_cmd	rpt_cmd	crc

Figure 2. Bobsled Command Packet Format

SENSORS

Steering Angle and Force Measurement For analysing the behaviour of the sled and driver, the steering angle and the steering force are to be measured. For the steering angle this means the angle of the front blades in reference to the sled. The driver of the sled can adjust this angle. The steering angle is a major part in the sled performance. Too much steering will slow the sled down; on the other hand it is very important to keep the sled in the ideal line. The Absolute-Encoder CE-65-S from the company TR Electronic was selected for sensing steering angle.

Instead of measuring the steering force it was decided to measure the steering torque in the turning point. This is a measure for the torque between the blades and the steering bar, which is operated by the driver via two strings. It is clear that this torque is a sum of the forces introduced by the driver and the blades. Even though this torque can be measured, it is difficult to tell what the source of it is. It could be either the driver pulling the steering strings or the blades being pushed aside (mostly it is going to be a mixture of both). Nevertheless this tells us about the link between driver and blades. Together with the information of the rotary position of the blades from the encoder this will provide valuable information for analysing the drivers performance.

To choose the right measuring device for this application, the maximum possible torque that would occur in a race must be known. It is very difficult to estimate a this value. The maximum force the driver could introduce into the handle depends on the blades turning friction. Therefore a device was selected that has a wide range and can be ordered with different ratings. This is the general-purpose reaction type shaft torque sensor from the company Transducer Techniques. This device can be ordered with a maximum torque rating from 70 Nm up to 1350 Nm.

Wind Speed Wind speed needs to be detected for its impact on the bobsled when it running on the track. A constant temperature difference anemometer was selected for this project. This unit operates on the principle that as the wind speed increases, increased current flow is needed to maintain the heated wire at a given temperature. (This system was used on the Viking landers on Mars.)

This kind of transducer has two sensor elements, one of which is heated electrically, which are housed in two plastic foam ellipsoids on a single shaft. The heated sensor contains three heated coils. Temperature and heat loss is measured on the middle one. This provides a better frequency response. The eccentricity of the ellipsoids and the length of the heating coils are optimised to give the smallest possible variation in directional sensitivity. The controlled electrical heating maintains a constant temperature difference, independent of the ambient temperature, between the two sensors.

This kind of transducer is able to respond to very rapid fluctuations in velocity. It also has a small probe which causes only insignificant interference to the original wind speed. A TSI Air Velocity Transducer was used to satisfy the project requirements**.**

According to our requirements, the air velocity transducer must have a range from 2 m/s to 30 m/s, to include any possible wind speed which the bobsled may meet. Furthermore, the transducer should have a resolution of 0.01 m/s

Push Force At the start, of a run the bobsledders push the sled off in a quick explosive motion, and leap in as it gains momentum. The whole pushing procedure lasts no more than 5 seconds. The start is the most critical time of the race. A explosive start can result in fast finish times. Therefore it is very important to record the push force applied by each team member.

Three people push the push bars located on the side of the sled and the fourth person pushes from the back, using two hands to push on both sides of the sled. Hence five force sensors are needed to detect the push force of the team. A strain gauge was required which must have a range from 10lbs to 500lbs, to include any possible push force encountered. The transducer should have a resolution of 0.5lbs. The strain gauge load cell model 13 from SENSOTEC LVDTS was chosen because it has a fairly linear behaviour over a range of 5lbs to 1000lbs. There will be one sensor mounted at each of the three push bars and two at each push point on the back of the bobsled.

Pitch, roll and yaw sensor The requirements for the pitch, roll and yaw sensor include the ability to operate in a harsh, temperature extreme environment. The bobsled can generally move in any direction in the horizontal plane (yaw = ±180°), can roll up high onto the banking of the track in sharp high speed turns (roll = ±90°), but has a limited pitching movement due to the maximum slope of the mountain (pitch = ±40°). The sensors will be subjected to sub-zero temperatures (-20°C - 0°C), and must be weather resistant. A high sampling rate is required as well as accuracy and repeatability.

The *3DMÔ* by *MicroStrainÒ* is a solid state device that offers a wide, accurate measurement range, is robust and compact, while able to be sampled at a high rate. Compared to gyroscope based devices and inclinometers, the 3DM offered 3 axes of rotation and an extremely wide angle range in a single package.

The 3DM measures pitch and roll using DC accelerometers which act like an inclinometer, measuring the device's orientation with respect to the Earth's gravitational field vector. Magnetometers act like a compass and measure the Earth's magnetic field vector. The pitch and roll information is used perform a coordinate transform onto the magnetic field vector, providing yaw information. We can operate this device at a higher sampling rate by operating it in the raw data mode, which outputs the measurements from the accelerometers and magnetometers which can be post-processed to calculate the pitch, roll and yaw angles.

Power Supply The voltage and power requirements of all the devices on the bobsled require the use of two *DatelÒ XPB series* DC-DC converters and two *National Semiconductor's* low drop out voltage regulators in forming the power supply unit. This will be supplied by a lead acid battery which will give a battery life of 2 hours between charges.

The Enclosure A weather resistant (IP65), shielded enclosure and cables are used to ensure our telemetry system receives no interference from noise and stray RF signals.

THE RADIO TRANSMISSION SYSTEM

The radio transmission system provides the link between the bobsled and the base station. The bobsled is travelling at high speed and the measurements must be sampled at a high frequency to reduce the loss of information. The radio link also requires a low bit error rate to reduce the amount of coding and complexity of decoder.

The block diagram of the radio transmission system is shown in
Figure 3.

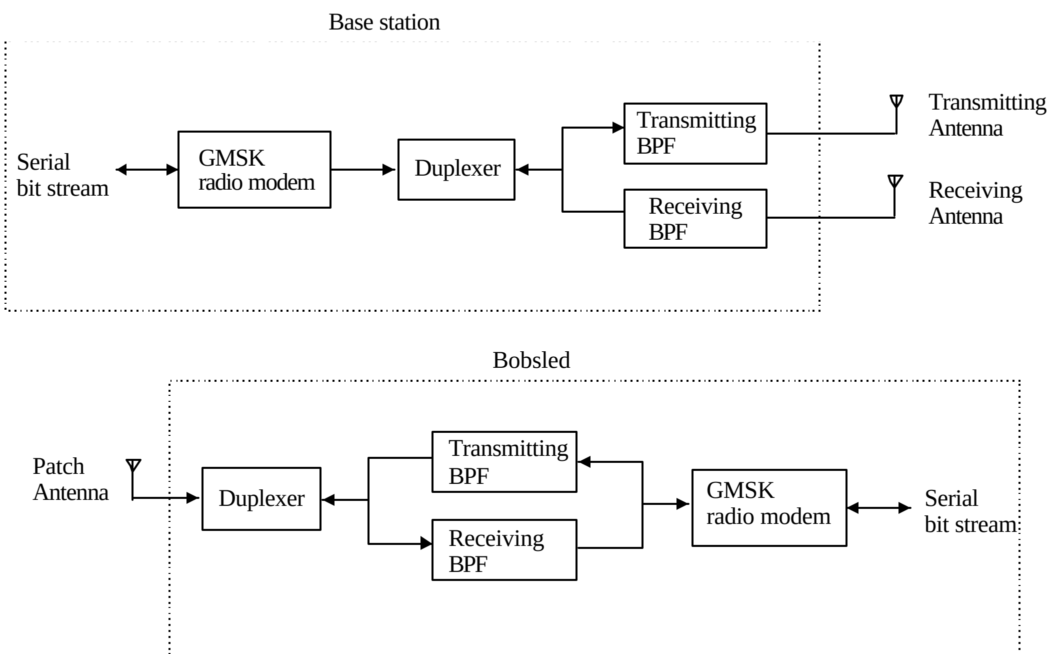

Figure 3: Block diagram of radio transmission system.

Signal transmission is via a pair of GMSK radio modem operating at 9600bps. A patch antenna is chosen for the bobsled, while the base station will use a high frequency twisted pair cable (leaky wave antenna). The orientation of the antennas is illustrated in Figure 5. Since the bobsled track is made of concrete the twisted pair cable can be permanently mounted on the back of the track and an interface provided to connected to the base station equipment.

From Figure 4 the maximum distance between the antennas is estimated to be a maximum of 5 meters. This will ensure high signal to noise ratio since most energy transmitted will be detected within close proximity of both antennas.

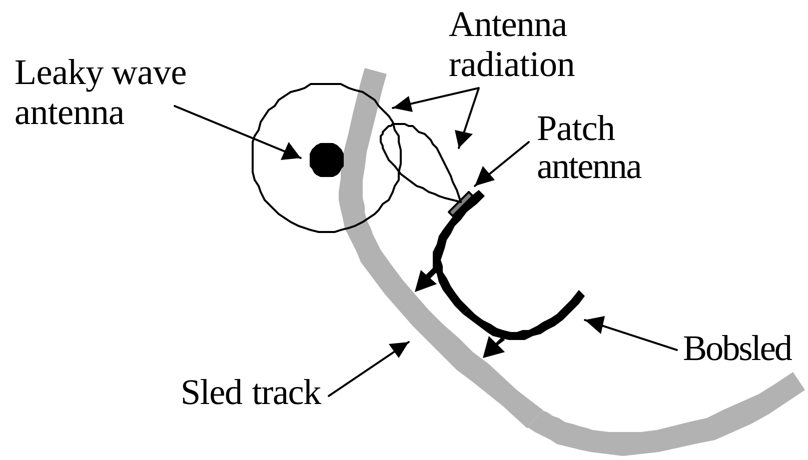

Figure 4. Antenna Orientation

The operating frequency of the antennas was chosen as follows:

	Transmit	Receive
Base station	UHF 440.5MHz	UHF 465.5MHz
Bobsled	UHF 465.5MHz	UHF 440.5MHz

Both the transmitting and receiving frequencies are allocated for telemetry usage [10] and conform to international standards [5].

The leaky wave antenna is a long wire antenna that acts as a transmitter or receiver. As illustrated in Figure 4 use of a leaky wave antenna allows a simpler structure for the radio link. It allows low power and localised transmission.

The radiated power for the antennas will be at 100mW. A high frequency twisted pair wire will be laid along the back of the bobsled track with low noise amplifiers boosting the signal strength at every 500m. The nominal attenuation for high frequency twisted pair cables are rated at approximately 19dB/500m for an operating frequency of 400MHz [6]. Low noise amplifiers that amplify signals over a narrow frequency range will be used to increase signal strength at every 500m.

The parameters for the leaky wave antenna are as follows:

Radiated power: 100mW (rated)
Gain, G_d: 1.64dB
Power Gain, G_p: 1.64dB
EIRP: -8.4dB

The patch antenna will be used on the bobsled for both transmission and reception of signals from the leaky wave antenna. It is low profile and rugged, which is well suited for a bobsled race environment. Since the leaky wave antennas are within close proximity to the patch antenna, the link can be realised with relatively low transmission power.

The patch antenna parameters were calculated as follows:

Physical size (L×W×h): 5cm × 12cm × 6.5cm
Efficiency: 99.99%
Gain: 16.4dB
EIRP: 7dB
Input impedance: 300Ω
Radiated power: 118mW
Polarisation: Linear

The transmission system will use GMSK (Gaussian Minimum Shift Keying) as the digital modulation scheme. GMSK is a constant envelope modulation method that allows a compact spectrum by introducing a premodulation Gaussian filter. This is to ensure that the system will conform to the IRIG power emission standard [3]. This system will use the frequency detection (FD) method for GMSK since it is more immune to frequency drift and fading [4].

The radio transmission system will be built using off the shelf products to reduce the design overhead. The Wood and Douglas RQX450 intelligent radio modem uses GMSK modulation with a maximum data rate of 9600bps. It allows carrier frequencies between 400-500MHz. Coupled with an appropriate transceiver (the Wood and Douglas TCV450 UHF Telemetry Transceiver), this device forms the core of the transmission system [9]. By matching the antennas to the transceiver and providing an appropriate power to meet the required radiation level, the transmission system can be built with relatively low design overhead.

The modem will be operating at its maximum transmission rate, 9600bps. This requires a maximum frequency band of 25KHz, which is well within the separation specified for the carrier frequencies [9]. For 25KHz-frequency separation, the TCV450 transceiver has a maximum frequency deviation of 3KHz. The required bandwidth for each transmission/reception carrier can be calculated using equation (A-1) in [3]:

$$B_n = 3.86\Delta f + 0.27f_b$$

$$= 14\text{KHz}$$

LINK BUDGET CALCULATION

The proposed bit error rate (BER) for the radio link is 10^{-8}, using GMSK modulation. The ratio E_b/N_o is threrefor required to be 19dB.

Space loss, which is almost negligible, is estimated to be about 1 dB to simplify calculations. The null to null bandwidth per bit for MSK signal is $1.18f_b$, where f_b is the data bit rate. So the required carrier to noise ratio C/N can be calculated as follows.

$$\frac{C}{N} = \frac{E_b}{N_o}\frac{f_b}{B} = 19(1.18) = 22.4dB$$

This is ratio is greater than the minimum required for GMSK signals since it is smoother, due to premodulation filtering, and thus requires less bandwidth. Hence, for transmission from the patch antenna to the leaky wave antenna

$$\frac{C}{N} = \frac{EIRP}{Ls}G_p = 7 - 1 + 16.4 = 22.5dB$$

By the reciprocity theorem [7], the link from the leaky wave antenna should also satisfy the link budget.

The calculated C/N is clearly larger than the required C/N for a MSK modulated signal. This shows that the link is feasible for a GMSK modulated signal since it would require a smaller C/N.

DATA ANALYSIS

The data stream is received and saved to the Base Station computer (running Windows NT) hard disk in the packet format. The packets are decoded and checked, and any errors are noted for later requests to resend. Each output is then converted back to the corresponding physical value, (eg force, velocity, temperature) and this data is also saved to hard disk.

The position and attitude of the bobsled at any given time are derived from the outputs from the on board accelerometers. By twice integrating the output values of these sensors, a continually updated position can be determined. In order to check for errors, known start and finish points will be used on the track to calibrate the system.

The data are analysed by the command routines to check for command parameters. The main command routine affected by changing data is the “all aboard” signal for the bobsled crew, sent at the end of the start run via a lamp at each crew station.

The status of the on-board system, including battery and memory conditions is also monitored, with unusual events triggering alarms.

Not all of the data recorded has any real significance in real time. Therefore, only a portion of the telemetry is actually shown to the operator as the bobsled is running. This information will be displayed in a windows based, mouse operated environment. Graphical displays will be used in conjunction with numerical ones, and where possible the data will be displayed along with a reference point. For example, the speed of the run could be shown along with the speed from the last run. As well as displaying the telemetry to the operator, this real time system will serve as the link to the telemetry package.

The bobsled track itself is entered into the system as an AutoCAD drawing, with an attached coordinate system originating at the start calibration marks. In this way, any position developed by analysis of the sensors can be directly used to reference a point on the AutoCAD model of the track.

The “path” of time stamped coordinates can then be used to generate a run using AutoCAD. This representation could be a trace of the path taken by the bobsled with relevant properties of the sled such as attitude, wind speed etc, tagged to each set of coordinates that make up the path. The trace would be in the form of an overlay on the 3-D model of the track.

By developing a fully rendered animation showing the real path of the bobsled, a run can be re-raced again and again. The path data and associated sled properties can be exported from AutoCAD into a package called 3DstudioMax where a “video” of the run can be generated for later analysis or use in a simulator.

CONCLUSION

The proposed telemetry system allows the performance of a bobsled and its crew to be recorded and analysed. In addition to the basic real-time data analysis, more specialised methods can be used to enhance the value of the telemetry. The system is made from mainly off-the-shelf components.

Given the highly competitive nature of Olympic level sports, and the great effort that goes into perfecting the art of the bobsled, including aircraft engineering expertise and special simulators, the “wired” bobsled could be a valuable asset in the development path to competition.

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