ADVANCED LANDMINE PROOFING SYSTEM – TELEOPERATION CONTROL SYSTEM DESIGN

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ABSTRACT

The Defence Science and Technology Organisation (DSTO) as part of their Rapid Route and Area Mine Neutralisation System (RRAMNS) project, wish to develop a vehicle-based landmine proofing system that is capable of fast and efficient route clearance of land mines, for the safe passing of army vehicles and troops. The purpose of our involvement in the RRAMNS project is to produce a generic design of a tele-operation system for a vehicle that incorporates skid-steering style control. The design of such a system forms the basis of this paper, and concentrates on areas such as the human interface, communications between the vehicle and the operating station, computer control of the system, vehicle actuation, and the types of vision systems available.

KEYWORDS: Tele-operation, Human Interface, Signal Processing, Vision System

1 INTRODUCTION

Landmines are prevalent in many areas of the world, and pose a problem for military personnel and civilians who attempt to pass over areas of land that have not been cleared of unexploded mines. There are a number of landmine clearing systems in operation that are capable of clearing routes through areas containing landmines, although most systems are quite expensive and only operate at low speeds. The aim of the Advanced Landmine Proofing System is to be capable of clearing routes at high speeds, to ensure easier and more efficient movement of army vehicles and troops to their destination.

The Advanced Landmine Proofing System is in its second year of development. The first year involved the conceptual design of a vehicle that met specified requirements based on cost, mobility, clearance effectiveness, casualty level and logistic burden. The concept originally chosen to form the basis of a feasibility study was called the Ultimus Spider, which is a tele-operated vehicle that uses skid-steering, however the final design of this vehicle has not reached its conclusion. Due to the requirement that the system be safe to operate (ie remotely operated), and the fact that the final vehicle design has not been decided upon, our role in the project has switched to focusing on the design of the tele-operation of a skid-steering style vehicle.

2 TELE-OPERATION OF SKID-STEERING VEHICLE (BOBCAT 863G)

After consideration of cost, ease of use and suitability in the environment it was decided that the most appropriate vehicle to be tele-operated is the BobCat 863G. Therefore it is this vehicle that the tele-operation system is designed for. Figure 1 below describes the interaction of components with the generic tele-operation system.

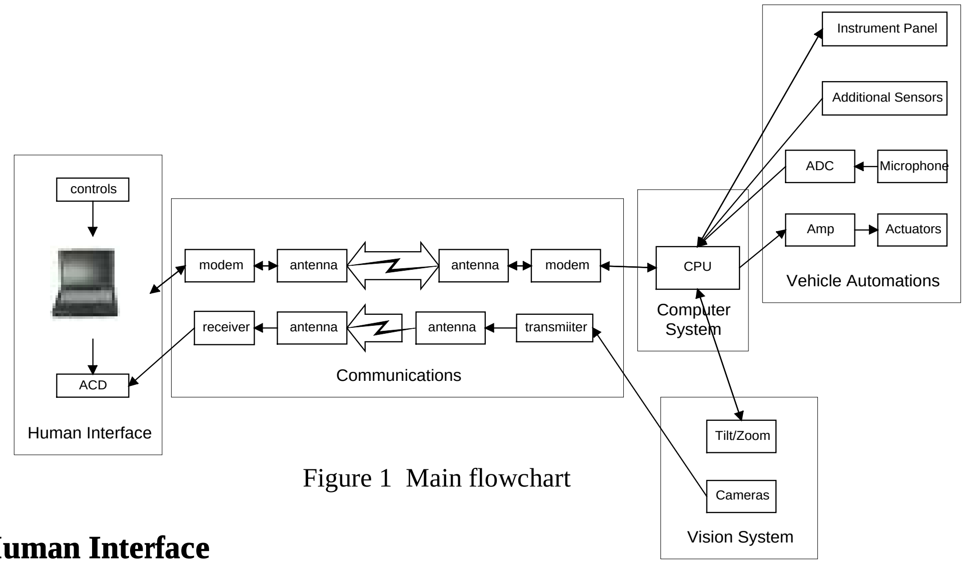

Figure 1 Main flowchart

2.1 Human Interface

The purpose of the human interface within the control system is to present data required for the safe operation of the vehicle to the operator, and to allow the operator to input instructions into the control system. A well-designed human interface will allow the operator to quickly and easily react to variations within the system, while maintaining complete control of the vehicle in question.

The display of information to the operator must be done in a manner to enable operators to obtain information on the current state of the vehicle quickly and efficiently. To enable the operators to maintain a reasonable level of situational awareness utilising a single visual display has been proven to be highly difficult [4]. The combined use of both audio and visual signals is best suited for the operation of a tele-operated vehicle due to the difficulty in maintaining situational awareness through a limited number of cameras. The relatively high speed of 40 km/h desired by the Australian Army for vehicles within the countermine role also increases the difficulty involved for the operator to gain complete awareness of the surrounding environment. Utilising multiple methods of information presentation enables the operator to spend a greater period of time concentrating on the video display and the track ahead.

The current specifications of the tele-operation control system limits the system to being fully operator controlled. To enable the operator to efficiently input all controls technology form the military aviation industry, the Hands On Throttle And Stick (HOTAS) will be adapted. HOTAS was developed for fighter aircraft and currently in use within nearly every frontline combat aircraft in the world today, to enable the pilot to control the critical systems of the aircraft without removing his hands from the throttle and control stick during an engagement reducing the response time to a threat. The utilisation of the HOTAS concept, having all the major controls on the joystick including camera zoom control, and gear selection, should enable the operator to control the vehicle while it is travelling at high speed.

The preferred arrangement for the human interface incorporates both of the above innovations. The layout involves the integration of a laptop, a headset and up to two input devices (usually joysticks). The laptop's to be used are Industrial Workstations currently used by the Australian Army primarily within the Command, Control, and Communications role. There are currently three models in service the NB100 APC Toughbook manufactured by APC and Opentec's Openfire Warrior P1 and P2. The choice of these laptops as the primary platform for the human interface is due to the flexibility that it provides in the visual display, and the minimisation of the required logistics support. The flexibility the laptop has been utilised to allow the operator to customise the display and audio warnings depending on both the vehicle that is being controlled, and the operator's personnel preferences. The laptop enables a variety of control input devices to be used including joysticks, mice, trackballs and keyboards, with the operator being able to select their preferred configuration, however the standard configuration would be a dual joystick arrangement, one for vehicle drive functions and one to control the vision system.

While the laptop has been selected principally due to its flexibility and portability, it also enables a standard interface to be utilised across a variety of vehicles being controlled using tele-operation. This enables operators to quickly acclimatise to another vehicle, as the control system is the same. This principle was developed in the aerospace industry by Airbus Industries to allow airlines to cross train flight crews across the A320, A330 and A340 families of aircraft [1]. This will enable greater flexibility within the Australian Army's tele-operated vehicle fleet, both within and external to the countermine role.

2.2 Vision Systems

The main function of the vision system is to scan the immediate terrain for obstacles or terrain features that are dangerous or that would impede progress, to search distant terrain for landmarks that can be used for navigation, to monitor pitch and roll of the vehicle to ensure the safety in stability and to assess size and separation of objects to allow judgement of thoroughfare.

Information gathered from experience by such organisations as the Sandia National Laboratories on vision systems for tele-operation recommends colour video for a significant advantage to the operator in terms of performance and comfort. The other common recommendation is to maximise the horizontal field-of-view (HFOV).

There are three methods to increase the HFOV. The simplest method is to install a wide-angle lens on a fixed camera. The disadvantage of this is a decrease in controller performance due to lack of detail and the non-linearity of the distortion of the image. To eliminate the problem of distortion and lack of detail a system of multiple (three or more) cameras can emulate the same HFOV. These cameras can each have their own display or the controller could switch between them as required. Obviously if they each had their own display and were appropriately located, it would increase the ease of operation for the controller compared to a switching display. A third method is to mount a single camera on a remotely controlled rotating base. This method has the advantage of possibly being able to rotate 360°, but would involve a control system for the rotation and would be difficult to operate during normal driving.

An important function of the vision system is the identification of objects. This is generally achieved by using a zoom lens. The camera with the zoom has to be able to rotate horizontally and vertically to be effective. Ideally this would incorporate 360° horizontal rotation and enough vertical rotation to see the vehicle below and directly vertical.

The quality of the picture can affect performance and therefore an alternative system is required in low visibility conditions. An infrared camera is ideal for these situations and would ideally be a function of the zoom camera.

The best combination of these options for our application would be a two-camera system. A Sony colour CCD-SSCDC14 Camera, a wide-angled lens will be used for normal driving and the Patrol CCTV Camera, a vertically and horizontally rotatable zoom camera with an infrared function would be utilised for gaining greater detail of the surrounding environment.

2.3 Sensing and Signal Conditioning

All basic systems that involve data acquisition and interpretation involve the components shown in Figure 2.

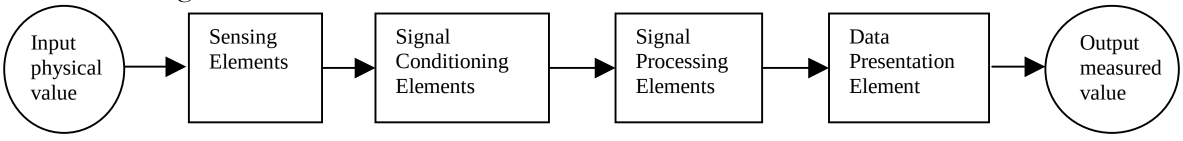

Figure 2 Signal manipulation process

For our system the variables that we want to measure are system stability and information that will help in the running of the tele-operation system. As with any vehicle, there is a large amount of importance placed on the engine system running correctly, this is especially important when the driver is not in the vehicle and cannot sense problems. Thus engine diagnostics that appear on the dash must be acquired and sent. These diagnostics can be broken down into two different groups. (1) The signals that have two states (ie warning lights – on or off) and can be sent as individual bits, and (2) signals that need to be sent as values (8-bit data).

Other sensors implemented in the system should assist the operator in achieving the task and keeping the system stable. There are a number of sensors that can achieve this function (ie gyro, inertia or proximity sensors [7]).

Most signal conditioning elements related to vehicle diagnostic sensors will not be necessary as this is already performed by the circuitry already existent on the Bobcat. Signal conditioning will need to be performed on additional sensors that will convert their signal to an acceptable voltage or current level using deflection bridges, amplifiers and current or voltage transmitters. When the signals are at an acceptable state, they can be further manipulated using signal-processing techniques.

Processing is usually required so that calculations can be performed on the conditioned signal. This requires a microprocessor, read only memory (ROM), random access memory (RAM) and an input/output interface, all of which are interconnected by data bus, address bus and control lines. This can be configured specifically for the system, but it is generally much easier some specific components integrated with a micro controller, which has all of the desired processing features integrated on a single board [3].

The eventual processing system greatly depends on the total number of data bits being transmitted and the data rate required, as it will deal with all incoming and outgoing information.

1.4 Communications

This section is dedicated to the communication link between the controls station and the tele-operated Bobcat™. The link between the two will have a significant bearing on the overall performance of the tele-controlled manipulation. It is crucial to design a system, which will give the best quality of performance, judged on design parameters such as responsiveness (or the speed at which a signal sent from the controls, is received and actuated by the vehicle), simplicity, cost and reliability. Because the communication link is basically the lifeline to the tele-operated vehicle the latter parameter, reliability, is a factor, which should be thoroughly understood. The end product ultimately should be able to operate in hostile environments, specifically suspected land mined areas. For this reason any sort of miscommunication which would lead to a lost in control would be detrimental to the effectiveness of the mission.

Two separate signals will be used for communication between the control vehicle and Bobcat™. The first signal is analog and transmits television. The second is the telemetry, which will be transmitted digitally.

The choice of antennas is important in achieving high signal strength at large ranges. If an antenna system is not properly selected then the difference between actual and predicted antenna patterns could be within several tens of decibels variation. This is a relatively large difference compared to that observed by using a more efficient modem or increasing the transmission power by a few dB. [6]

The study of antennas is very broad and involved. However for our purposes we need only mention the main areas involved so that enough background knowledge is presented to make suitable antenna choices for this project. Available on the market today are antennas of all shapes and sizes specifically built for numerous RF applications. The Antenex Antenna Catalogue is an example of a large range of antennas. The antennas in this catalogue can be categorised into different types such as whip, patch, helix or yagi, and gives gain and bandwidth for each of these types. Gain, usually expressed in dB, is defined as [5]

$$G = \eta D_{max}$$

Where the maximum directivity, D_{max}, is the ratio of maximum power density over the power density radiated by an isotropic source. Directivity is a function of geometric angles. The symbol η is the antenna's efficiency in radiating energy from the input source. The losses resulting in the efficiency deviation from unity could be conductive or dielectric in nature.

The equation below [5] shows how G_t and G_r, the gains of the receiver and transmitter antennas respectively vary with R_{max}, the theoretical maximum value of the distance between antennas.

$$R_{max} = \frac{[P_t G_t G_r \lambda_0^2]^{1/2}}{[(4\pi)^2 S_{i,min} L_{sys}]^{1/2}}$$

Where L_{sys} is a total loss factor, λ_0 is the free space wavelength and P_t is the power of the transmitting signal. The important thing to note from this equation is that if we increase the antennas' gains we increase the maximum range.

The impedance bandwidth is typically defined as the range of frequencies at which VSWR ≤ 2 (called the bandwidth in the Antenex [2] catalogue). VSWR or voltage standing wave ratio is used to measure the amount of reflection in the antenna where VSWR = 1 is the optimal condition indicating no reflection. Using the military spectrum of mid-range UHF from 850 MHz – 950 MHz for telemetry we can recommend choices of either antennas [2].

- Phantom® TRAB9023, frequency 902 MHz – 928 MHz, BW > 70 MHz, Gain 3dB
- A-Base AB8065CTS, frequency 806-896 MHz, BW 100 MHz, Gain 5dB.

The number of different control signals which need to be transferred in both direction indicate the need for a digital modulation when dealing with telemetry. Digital transmissions have a number of distinct advantages over analog transmissions, including increasing channel capability, greater accuracy in the presence of noise and ease of handling [5]. The details into the digital modulation techniques cannot be discussed at length in this paper. However there are multitudes of methods available based on the two formats amplitude shift keying (ASK) and frequency shift keying (FSK). When selecting a modem we will probably choose one, which offers frequency-hopping spread spectrum (FRSS) because it offers good security and interference rejection [5]. One suitable chose of modem is

- Teledesign, TS4000, can operate at 928-960 MHz, spread spectrum, Maximum Radio Output 5 W. Data Rate 300- 38400 baud.

1.5 Vehicle Actuation

The operator would ideally like to have full control of the speed of the vehicle and be able to direct it accurately along the desired path.

The BobCat vehicle, which has been chosen as the basis for our design, has a lever that acts as the throttle to the engine and altering the position of the throttle either increases or decreases the flow of fuel to the engine and therefore increases or decreases the speed of the vehicle.

The steering of the BobCat loader is controlled via the hydrostatic transmission. There are two levers that control the flow of the oil through the transmission, which in turn controls the rate at which the chain drives are driven to move the wheels. There are two chain drives, one which drives both wheels on the left side and is controlled by the left lever, and one which controls the wheels on the right side. If both levers are pushed forward, the vehicle will travel forward in a straight line. If both levers are moved backwards the flow of oil in the transmission will be reversed and the wheels will turn in reverse.

If the right lever is pushed further forward than the left lever, the vehicle will turn left because more oil pressure is applied to the wheels on the right, and as a result the chain drive rotates faster on the right side than the left, and visa versa for turning the vehicle left. If both levers are returned to their resting position the BobCat will come to a standstill.

For the purpose of tele-operating the BobCat, it is not necessary to control the levers as they exist normally. It would be more efficient to place the actuators as close as possible to the physical unit being controlled rather than placing them in the cabin for easy use by the operator. The throttle lever, which is located in the cabin, ultimately controls a smaller lever on the engine itself, which is where the throttle actuator would be best placed. The controls for the steering that exist normally, consist of large levers for the operator to handle easily, these levers can be replaced with actuators which operate closer and more directly with the hydrostatic transmission to achieve a better vehicle response.

3 CONCLUSION

We have discussed issues involved in designing a tele-operation system for a skid steer vehicle. Taking these issues into consideration we have given examples of the possible systems that could be used for the tele-operation of a BobCat loader. We have also selected certain components, which are capable of meeting the system requirements. The design of the tele-operation system still requires a more in-depth analysis, including a more detailed outline of the system, the components used, and the layout. This would form the basis of any future work should the DSTO decide to use the BobCat as the vehicle to be tele-operated.

4 REFERENCES

[1] Airbus Industrie www2.airbus.com

[2] Antenex "Product Selection Guide 2001", www.Antenx.com

[3] J.P Bentley, "Principles of measurement Systems", Prentice Hall (1995)

[4] J. Bicher, K. Burn , L. Maunder. "The man-machine interface in remote Manipulation", Teleoperation and Control International Symposium 1985

[5] K. Chang, "RF and Microwave Wireless Systems", Wiley Inter-Science (2000)

[6] A.T Johnson, "Advance High-Frequency Radio Communications", Artech House (1997)

[7] R.J. Walker, C.J Harris, "A Multi-Sensor Fusion System for a Laboratory Based Autonomous Vehicle", *IFAC Intelligent Autonomous Vehicles* (1993), 105 – 110.

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