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Weapon Control System for Airborne Application

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ABSTRACT

The integrated fire control system (IFCS) plays an important role in the present-day fighter aircraft and helicopters. Weapons, such as missiles (active/passive), rockets and guns may be present on the fighter aircraft or helicopter. IFCS monitors the status of the weapons present on the vehicle and passes the information to pilot/co-pilot. Depending upon the health/availability of the weapons, IFCS selects/fires the weapons. An attempt has been made to bring out the details of one such IFCS. As a stepping stone, smaller version is developed and same philosophy can be used for integrating more and more weapons. Here, emphasis has been made on design and development of weapon control unit which is the heart of IFCS, both in hardware and software. The system has been developed using a 486 DX2 processor, and an elaborate software has been developed in PL/M.

1. INTRODUCTION

During the last five decades, helicopters and aircraft have been playing an important role in warfare. Weapons, such as missiles (active/passive), rockets and guns may be present on the fighter aircraft or helicopters. The integrated fire control system (IFCS) monitors the status of the weapons present on the vehicle and passes information to the pilot/co-pilot. Depending upon the health/availability of the weapons, IFCS selects/fires the weapons.

In the present configuration, only two weapons are present, one on either side of the helicopter. Generally, an IFCS consists of a sighting system, a control panel (CP) and a weapon controlling unit (WCU) which is the heart of the system.

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2. METHODOLOGY

2.1 Target Recognition

The weapon may have the capability of tracking the target of interest. A target of interest has to be assigned to the weapon before it is launched. Acquisition and recognition of the target depends on the field-of-view (FOV), target size, optics size, sensor resolution, etc. With the weapon control system constraints, a typical target at maximum range may occupy only a few pixels in the image plane. As per the Johnson's criteria, at least six to seven lines through target (LTT) are required for recognition. Hence, target recognition is not possible through the weapon. A high resolution sensor–CCD sight, with narrow FOV satisfies the LTT requirement. After recognising the target through CCD sight and pressing a button, the scene around the centre of FOV is converted to make it compatible (in spatial resolution) with the image acquired by the weapon. The converted image is used as the reference image. This reference image is used for locating its position in weapon FOV through image correlation techniques. Once the reference is located in the image seen by the weapon, the weapon is automatically trained to bring the located area to the centre of FOV. Image correlation techniques continue updating the reference image at faster rates and the weapon keeps tracking the target area. The sensors onboard the weapon and the CCD sight from which the reference image is generated have different spatial resolutions. To accomplish correlation between them, the two images are made similar by applying an image preprocessing technique[1].

2.2 Spatial Resolution

The spatial resolution depends on FOV and number of horizontal and vertical pixels of both the sensors. The horizontal scaling factors (W_h) and vertical scaling factors (W_v) are given as

$$W = [\{(\text{Vertical FOV of low resolution (LR) image}) / \text{Vertical FOV of high resolution (HR) image)}\} \times \{(\text{No. of vertical pixels in HR image}) / (\text{No. of vertical pixels in LR image})\}]$$

$$W_h = [\{(\text{Horizontal FOV of LR image} / \text{Horizontal FOV of HR image})\} \times \{\text{No. of horizontal pixels in HR image}) / (\text{No. of horizontal pixels in LR image})\}] \quad (2$$

If W_h and W_v become integers and greater than one, then the preprocessing will be averaging the first W_h columns of the first W_v rows of HR to get LR (1,1) pixel of the reference image, and the next W_h columns of the first W_v rows are averaged to obtain the LR (1,2) pixel of the reference array and the procedure repeats for the other pixels. But, if W_h and/or W_v become a real number, then problem becomes more complex. The algorithm[2] is:

$$\begin{aligned}
\mathrm{R}(i,j) = (1/A) & \sum_{m=u+}^{x} \sum_{n=v+1}^{y} \mathrm{HR}(m,n) \\
& + \sum_{n=v+1}^{y} [(u-(i-1)W_v)\mathrm{HR}(u,n) + (iW_v - x) \\
& + \mathrm{HR}(x+1,n)] \\
& + \sum_{m=u+1}^{x} [(v-(j-1)W_h)\mathrm{HR}(m,v) + (jW_h - y) \\
& \mathrm{HR}(m,y+1)] + (u-(i-1)W_v)(v-(j-1)W_h) \\
& + \mathrm{HR}(u,v) + (jW_h - y)\mathrm{HR}(u,y+1)] \\
& + (iW_v - x)(v-(j-1)W_h)\mathrm{HR}(x+1,v) \\
& + (jW_h - y)\,\mathrm{HR}(x+1,y+1)
\end{aligned} \quad (3)$$

where

u = Greatest integer $\leq \{(i-1)W_v + 1\}$

v = Greatest integer $\leq \{(j-1)W_h + 1\}$

x = Greatest integer $\leq (iW_v)$

y = Greatest integer $\leq (jW_h)$ and $A = W_v * W_h$

Equation (3) is the final transformation equation which converts HR (i, j) image into LR (i, j) image with W_h and W_v scaling factors.

In the present study, by substituting the values in Eqns (1) and (2), one gets W_h and W_v scaling factors as 17.802 and 16.22, respectively. Thus to get a 16 x 16 reference image, an image of 285 x 260 pixels (approx.) has to be captured from the centre of FOV of CCD camera (around the target) and convert it to get the LR image compatible to the weapon sensor resolution.

WCU gets CCD camera video information from sighting system in CCIR format. The composite signal consists of horizontal and vertical sync signals, and a target video. The target video will be digitised in real-time using the fast flash analog to digital (A/D) converter. and stored in memory. After receiving the target designate command, WCU has to freeze the image and apply the image preprocessing algorithm on the captured image and generate the reference image. The reference image will be transmitted to the selected weapon through a serial link. WCU gets the target range from laser range finder (LRF) through sighting system, temperature, altitude, speed, etc. and all this information has to be passed on to the onboard system for its optimum performance. WCU has to check the health of the weapons at regular intervals and inform the operator. It also gives the fire command as per the sequence of operations after satisfying the interlock conditions. The servo system stabilises the visible sighting system. It has electronics to control CCD camera (like zoom, focus, etc.). It has an interface with LRF, a control panel, a monitor/display and a power supply. WCU is connected to sighting system through a serial link and all the commands/status signals are routed through sighting system to WCU.

3. HARDWARE SYSTEM DESIGN

The composite video signal consists of horizontal sync (Hs), vertical sync (Vs) and a target video. The sync signals are separated using a sync separator. The video is sampled at 16 MHz clock and 8-bit digital data can be stored in dual port RAM (DPRAM) memory.

In this hardware design, there are two main and critical signal paths, (i) digital video data has to be written in HR memory at 16 MHz rate or more, and (ii) once the data is ready in the memory, CPU reading the data and generating the LR image. The digital video data can be achieved by reducing the signal path (i.e. number of gates), using faster A/D, faster memories and ACT/FCT logic components. By storing the pre-computed address of each pixel, execution time can be reduced, i.e. instead of computing the address of each pixel, in real-time, addresses can be pre-computed and stored. Thus for all the required W_h x W_v x 16 x 16 pixels, address can be pre-computed and stored in an array.

As per the system specifications/requirements, the hardware has been designed around 80486 DX2 processor operating at 25 MHz. Figure 1 shows the hardware block diagram. The total hardware is partitioned into four PCBs. These are: (i) processor card (ii) I/O card (iii) analog card, and (iv) motherboard.

3.1 Design of RESET Signal

RESET input forces the CPU to begin execution at the known state 0FFFF0H in real mode. CPU takes 1ms (217 clocks) for booting from cold start and at least 15 clock cycles to reboot from a warm start. The system needs to be resetted by either remotely pressing the RESET button of the control panel or of the unit. Power ON RESET is generated using a MAX-691 component. All the three RESETS are properly combined and generate a single RESET signal which is given to CPU.

3.2 Design of Address, Data & Control Logic Generation

The processor card is designed to work at 25 MHz using a 80486 DX2 25/33 MHz processor in real mode. To increase the processing speed, internal 8k cache memory is used.

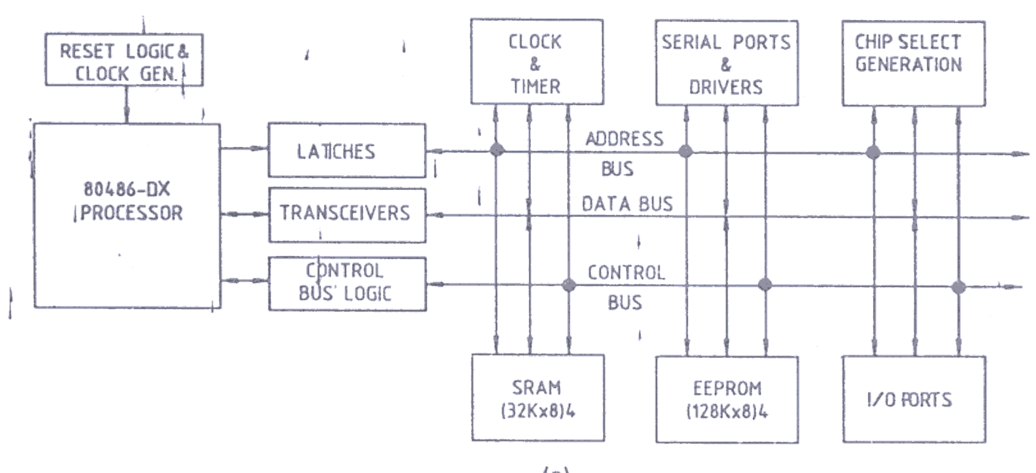
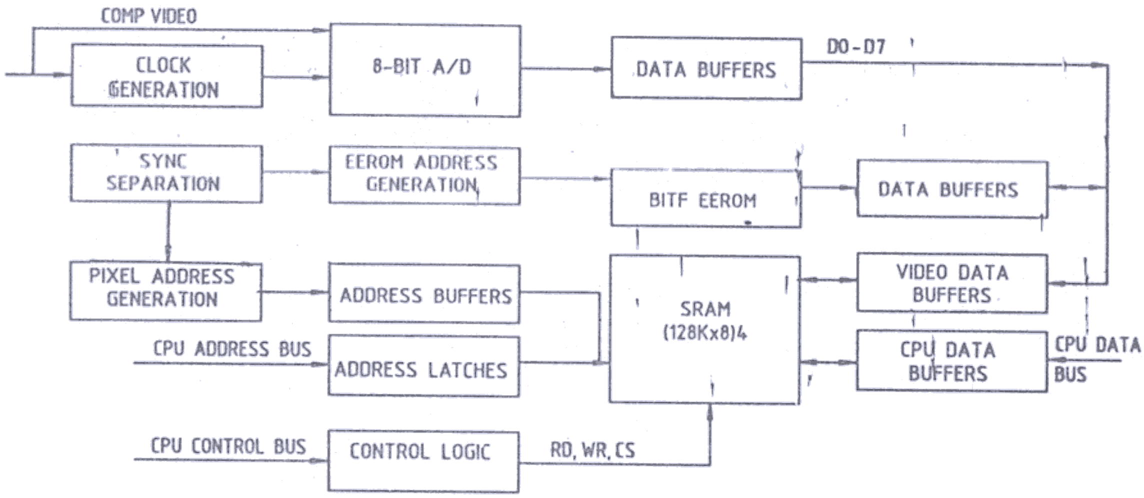


Figure 1(a). Hardware block diagram



(b)

Figure 1(b). Hardware block diagram

To store the application software and monitor program, a boot EPROM of 256k x 8-bit is provided. To reduce the code fetching time, that is to increase the execution time, it is planned to download the application code into the SRAM area on booting and executing the SRAM. Thus, entire application software and monitor program downloaded on to SRAM, organised in 32-bit format and CPU executes as 32-bit code.

In this system 512k x 8-bits of SRAM is configured as a DPRAM for storing CCD image. For writing CCD digital 8-bit data, 20-bit address is generated. For processing data, CPU has to access the captured data from the memory. Thus, these two-address buses are multiplexed. To reduce the signal path, the conventional multiplexes are replaced by buffers on the processor side and latches on the video side. The outputs are shorted to form the address bus for DPRAM. All these latches are clocked using a pixel clock. The inverted pixel clock is used for writing in memory. The memories have the accessing time of 25 ns and with these memories, writing data at a rate of 20 MHz is achieved.

The system is also having built-in-test-facility (BITF). In BITF, it is planned to capture the image stored in ROM into DPRAM and run the preprocessing algorithm. The results (256-bytes) are to be compared with the stored ones and the number of mismatches (if any) will be displayed on a terminal. For this purpose, a ROM is provided with a (0-255) gray-level pattern. In this BITF mode, tests activate most of the hardware modules and clear the hardware.

3.3 Serial Communication Ports

In the system, six serial communication links are provided. One is required for the 486 monitor, one for sighting system and four for weapons. All serial ports are configured in asynchronous communication mode. It receives the data on receive data (RxD) line serially and converts into parallel and puts on the data bus. Similarly, it takes the parallel data from the data bus and sends serially on transmit data (TxD) line. Only one RS-232 serial link is provided for the monitor and the other five serial ports are designed for RS-422 format. All the RS-422 serial links receiving lines are taken through opto-couplers and the transmitted lines are connected through the drivers.

3.4 Sync Separation & A/D Conversion

The composite video signal coming from CCD camera consists of Hs and Vs signals, and a video. LM1881 sync separator is used to separate the sync signals from the composite video. It also generates TL signal to indicate the odd or even field. This signal is used to store the data in DPRAM as even/odd lines. The input video signal from CCD camera is buffered using an AD811 operational amplifier, and 75 Ω termination is also provided. The buffered video is given to flash A/D MP8785. The digitised output is latched with the pixel clock.

Design is made to select either the real video data or the stored gray-level data (for BITF) for writing into DPRAM.

3.5 Data for Built-in Test Facility

A separate set of counters are provided to address the 128k x 8-bit EPROM which is loaded with gray-level data, and the output data is taken through a latch. Pixel address is generated using three counters, and line address is generated using two more counters. So, EPROM and the data latches are enabled only in the self-test mode for testing both the software (algorithm) and the related hardware. To monitor the processor status, hexadecimal display HP-7340 is provided on the unit.

4. SOFTWARE DESIGN

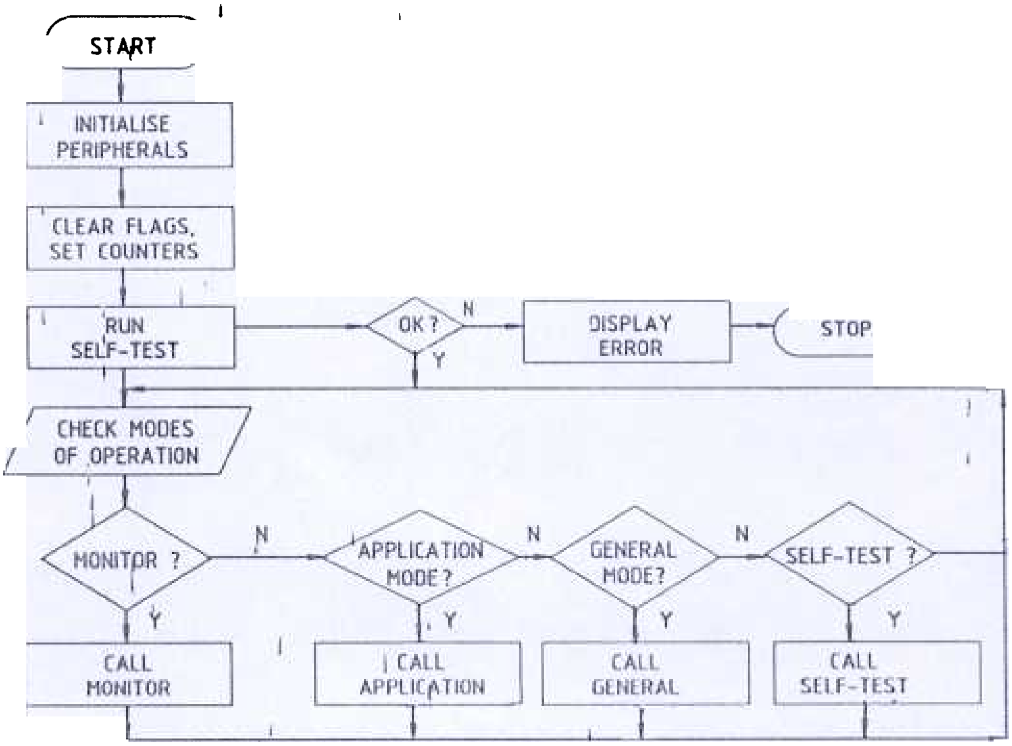
4.1 Application Software

The application software is developed in PL/M 86 language[3]. The main system flow chart is shown in Fig. 2(a). The software is developed in a modular format. The function of each module is described. The system can be resetted on power ON and/ or by pressing an external switch. CPU initialises all the peripherals USARTs, timers and the I/O ports, including the math processor. The commands invoked from the control panel/grips are routed to WCU to scan all the commands and take necessary action.

The system has two stages of self-test: the first stage is brief and the second stage is elaborate. On power ON RESET, it performs only first level testing. In this level, after clearing the LR memory area, it checks the presence of both Hs and Vs signals. Once these are proper, it allows the DPRAM to fill with the ROM data for six fields' time and reads the data. Preprocessing algorithm is applied on the data and re-sampled image is generated. The generated image is compared with the stored result. If any mismatch occurs, it is displayed on the terminal. The switch activates the next level of self-test.

4.2 Modes of Operation

Once after passing the preliminary self-test, it checks the modes. It has four modes of operation like monitor mode, application mode, self-test mode and general mode. Depending upon the



(a)

Figure 2(a). Main software flow chart

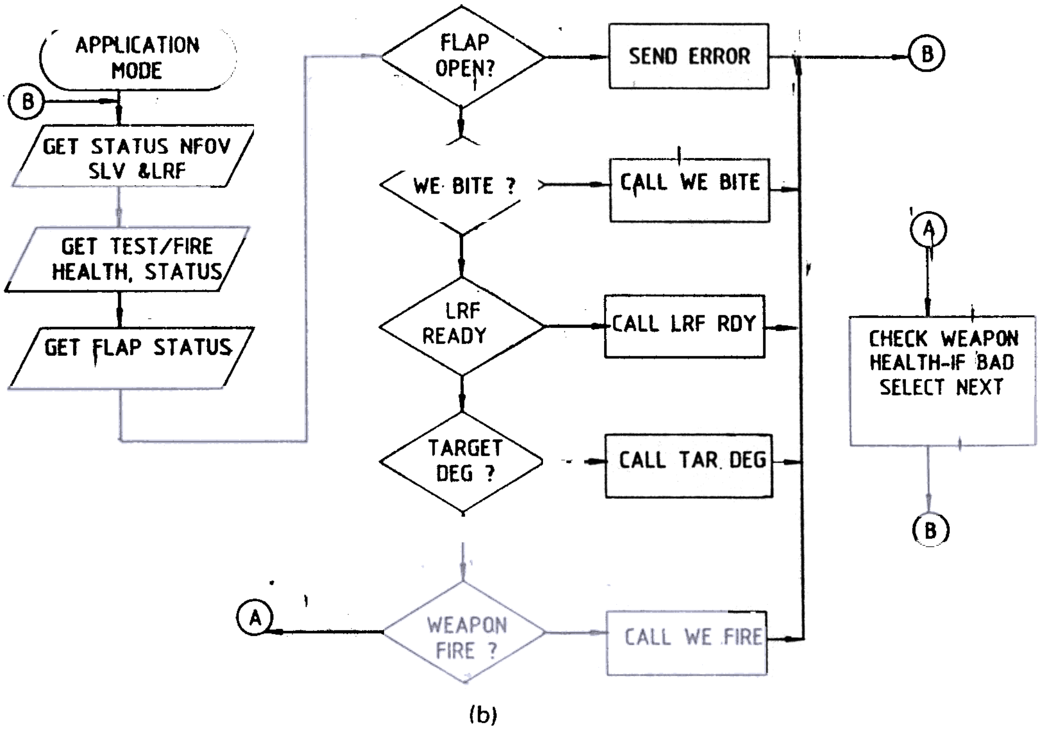


Figure 2(b). Application routine flow chart

switch position (mode selection), corresponding procedures are called and the unique code is displayed on the display device.

4.2.1 *Application Mode*

In this mode, system gets the status of narrow FOV (NFOV), slave, mode of attack, flap open, weapon power ON, weapon mode (test/fire), weapon status, etc. and updates its flags. All the above conditions/status are monitored at regular intervals and the status is used wherever it is required. Application mode flow chart is shown in Fig. 2(b). Once the weapon is powered ON, the WCU checks for the control switches like weapon bite, LRF data ready, target designate or weapon fire and accordingly the procedure is called. If none are active, it does the health check of all the weapons.

4.2.1 *Weapon Select/Health Check*

WCU automatically selects the weapon (left or right) depending on the health and availability. If all are present and healthy then as predefined by pilots (say right) will be selected first. Once the power is ON to the weapons, all the active elements will be checked by weapon system computer (WSC) and WCU will check the health of the weapon as per the protocol by sending 0CCH and receiving 0DDH in a specified time. Monitoring the health of all the weapon systems is carried out at regular intervals.

4.2.1.2 *Weapon Bite Command*

WCU monitors the status of all the weapons and displays the status on the monitor in case of an error. At any point of time, pilot can find the health of the selected (automatic) weapon by pressing the weapon bite (press button) switch. WCU checks the health and displays it on CP.

4.2.1.3 *Laser Rangefinder Data Ready Status*

In LRF data ready (LRD_RDY) status, WCU receives range data, temperature, altitude, and ground speed from a PC or potentiometers. All these values are transmitted to the selected WSC. Once the LRF data ready line becomes high, WCU sets a flag (LRF_F), and gets the range from sighting system/LRF through a serial link using a defined protocol. The flag LRF_F is checked in the fire mode to confirm that all the parameters have been passed to WSC. It also gets mode of attack, weapon selected and correspondingly enables the interlocks. WCU checks the health of WSC as explained above and expects WSC to be in receiving mode for receiving the range data.

WCU sends range low byte and range high byte, waits for range low echo within 60 ms and compares it with the transmitted one. If it fails, then WCU sends 0EEH to WSC indicating that an error has occurred and once again sends range low and range high bytes. It is repeated maximum three times. Otherwise, WCU sends Y to WSC to confirm the correctness. Once range low check completes, WCU waits for range high byte within 60 ms. The received byte is compared with the transmitted one. If it finds any mismatch then after informing WSC about the error by sending 0EEH, WCU repeats sending range low and range high bytes to WSC maximum three times. If still error is present then WCU declares the weapon is bad and informs sighting system and selects next/other weapon. Otherwise WCU sends Y to WSC to confirm the correctness of data. Same procedure/protocol is repeated for sending/receiving altitude low and altitude high, ground speed low, ground speed high, and temperature.

4.2.1.4 *Target Designate Command*

The target designate command can be given by pressing a button on the CP. After receiving the command, WCU has to capture the image around the target and generate the reference image, compatible with the weapon seeker image and transfers it to the selected WSC through a serial link[4]. WCU rechecks the power/flap open status of the selected weapon. Once the power/flap is open, then only it continues, otherwise returns to the main routine ignoring the command. In the present IFCS system, the weapon seeker is slaved to the stabilised sighting system so that the centre of FOV of CCD sighting system and centre of FOV of the weapon will be the same during the helicopter motion.

To have better recognition and identification, the sighting system should be in a NFOV. By giving a target designate command, WCU checks and confirms the slaving and NFOV status of sighting system by reading the two separate status lines provided for the same and enables the interlocks for the selected weapon. If the above conditions are not met in a fixed time (say 500 ms), then WCU returns to the main routine.

DPRAM present in WCU is enabled/initialised to store the image around the centre (i.e. area around the target) on power ON RESET condition. Thus, image around the centre of FOV is present in the DPRAM. WCU applies the algorithm (Eqn. (3)) on DPRAM image and generates the reference image (16 x 16 pixels). The reference image is transmitted to WSC through serial link using a predefined protocol. WSC after receiving the reference image, tries to locate the reference image area in its own image by applying correlation techniques and locks to that area[5]. After locating the target area, WSC confirms to WCU by giving lock-on signal. The lock-on status is through the same serial link. WCU gets the lock-on codes (two predefined bytes) from WSC within the specified time (say 200 ms). The two received lock-on bytes are checked and if they are OK, the third byte/code is received (which gives qualitative measure of registration-confidence) by WCU and transmitted to sighting system for display as a lock-on confidence. After completing the above activity, WCU sets LOCKP status flag to indicate that the WSC is tracking the specified target.

4.2.5 *Weapon Fire Command*

As in other cases, here also weapon power ON condition/flap open condition is checked if it confirms the fire command (by reading the switch once again). Weapon fire command is generated by pressing a push button on the CP or on the grips of a helicopter.

After confirming the valid fire command, WCU checks for the test/fire mode switch status. If it is in test mode, no action will be taken and returns to main. Otherwise, gets the selected missile, and enables the interlocks to the selected weapon. The selected weapon health will be checked once again. If it is bad, selects next weapon, disables the interlocks and unlatches the fire command. WCU also checks and confirms that all the parameters required to WSC have been passed by checking the status flags. Once the health of the weapon is good, WCU gives the fire command. This finishes the firing part and waits for take off. WCU resets the flags, if still the weapon is present then it is declared as hang fire and is informed to sighting system/CP. Otherwise, weapon status is updated and selects the next weapon and disables the interlocks.

4.2.2 *Monitor Mode*

In this mode, system goes to 486 monitor mode. To the terminal port (serial port), a PC is connected to be used for receiving/sending commands to the system. This mode is for testing the system for future applications. Monitor mode can be selected by putting the external switch on monitor side and giving the RESET command.

4.2.3 *Self-Test Mode*

This mode can be invoked by putting the switch in BITF mode and giving a RESET command or powering the system after putting the switch in this mode. Here, the self-test is very elaborate and it tests all the modules of the hardware and the results are displayed on the terminal. It has two modes of operation, quality of the input/output images can be viewed at all stages and in the other mode, the test results are displayed on the terminal. For this purpose, the system checks the presence of a PC or a terminal after initialising the serial ports.

[illegible] 4 *General Mode*

This mode is kept for future application. In this mode, the sighting system and/or sensors specifications can be changed or new sensors can be integrated. Provision is made on the card to store new specifications on an EPROM. In this mode, system checks for the presence of EPROM. If it is not present, it will ignore and give the error. Reading particular location for a particular data can check the presence of an EPROM (0C0FFH-0AAH). Once the EPROM is present, it reads the stored data and computes W_h and W_v. Gate size can be computed by multiplying the reference image size. Once the gate size is computed/known, the image around the target is captured and the reference image is generated. The reference image is then transmitted to the selected weapon as mentioned in the target designate command.

4. CONCLUSION

As a stepping stone towards an IFCS, an attempt is made to realise, qualify and integrate WCU in helicopter with limited weapons. The same or similar philosophy may be adopted for integrating more weapons. The designed and developed system has been qualified for airborne application.

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