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# Subsystem Four: Communications

This section details the analysis, design, implementation, and results of the subsystem responsible for communication between the actuation systems and the controls/perception systems.

## Requirements and Functional Decomposition

The overarching purpose of subsystem four (SS4) is to communicate the desired action to the actuation system.



Figure 1: SS4 Breakdown

As detailed in Figure 1: SS4 Breakdown, to communicate the desired action to the actuation system:

* Messages would need to be received; and,
  + This process would involve receiving the messages; and,
  + Parsing them into useable data.
* Messages would need to be sent.
  + This process should involve creating messages; and,
  + Transmitting them.

To ensure that messages where properly interpreted and created by all parties a communication protocol and packet protocol would be need.

To store messages, received or sent, numerous methods were considered and tested. Ultimately, Direct Memory Access (DMA) was used which required that the DMA on the selected microcontroller be enabled.

### Communication Protocol

The requirements of the communication protocol where as follows:

* ASCII messages must be transmittable;
* Synchronisation or dependency between systems is to be avoided;
* Systems which required addresses for communication were to be excluded.

### Packet Protocol

The requirements of the packet protocol where as follows:

* Generic data types must be transmittable;
* Signed values (plus/minus) of either integers or real numbers would be sent; and,
* Start and stop bits characters would be used to indicate the beginning and the end of messages (in the case of incomplete messages, the message should be invalid).

### Connection Method

The requirements of the connection where as follows:

* Wired connection method;
* A common ground should be established (where relevant); and,
* Where possible standardised jacks/sockets should be used.

## Background and Prior Art

Parallel communication is the method of communicating a multibit message over multiple channels. With enough channels, parallel communication may be used to communicate a message of *any* size in a single clock cycle. However, communication channels can be resource intensive (i.e. using lots of cables and pins, the physical size of the interconnect).

Instead serial communication involves sending data over a single channel sequentially. While often slower than parallel communication, serial communication is often preferable due to the scarcity of I/O lines on microcontrollers. A protocol of encoding messages is used to transmit messages in a consistent intelligible manner.

Serial communication may be synchronous or asynchronous. Synchronous uses a clock signal to synchronise communication. This can result in faster more reliable communication but depends on a centralised clock signal; to maximise demarcation between the project sections, synchronous communication shall not be used.

Asynchronous serial communication may be accomplished by the use of a pair of wires (one for transmission, one for receiving) and by transmitting messages in binary. Messages which can be encoded in binary (e.g. ASCII) may be transmitted in this manner.

A universal asynchronous receiver-transmitter (UART) is a hardware device for asynchronous serial communication that may be integrated into a microcontroller. UART may be used to implement asynchronous serial communication on a microcontroller via I/O lines.

Direct memory access (DMA) is a mechanism by which hardware systems (like UART) are able, independent of the central processing unit (CPU), to interface directly with the main system memory. By bypassing the CPU read and write operations can be completed faster, while the CPU is dedicated to other tasks. For example, messages received via UART may be directly stored in memory, and messages to be sent via UART may be loaded into buffers directly.

## Approach and Execution

### Communication Protocol

For details relating to the microcontroller selection see section (kt). As noted in section kt, two communication channels were required per microcontroller.

Two UART channels where implemented in C for the STM32 Nucleo boards. The pin used by each channel is shown in Table 1: UART Pins.

Table 1: UART Pins

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| UART | Function | STM32F303k8 Pin | Nucleo Connector Pin | DMA Channel |
| UART 1 | RX | Port A Pin 10 | D0 | 5 |
| TX | Port A Pin 9 | D1 | 4 |
| UART 2 | RX | Port A Pin 3 | A2 | 7 |
| TX | Port A Pin 2 | A7 | 6 |

Much of the peripheral initilisation was completed used STM32CubeMX. The configuration file used can be found in kt. The configuration of both UART channels may be found in Table 2: UART Configuration.

Table 2: UART Configuration

|  |  |
| --- | --- |
| Parameter | Value |
| Baud Rate | 9600 Bits/s |
| Word Length | 8 Bits (Including Parity) |
| Parity | None |
| Stop Bits | 1 |
| Alternate Function (for GPIO) | 7 |

Each UART was configured to use DMA to receive and transmit messages. The DMA settings can be found in Table 3: DMA Configuration.

Table 3: DMA Configuration

|  |  |
| --- | --- |
| Parameter | Value |
| DMA Mode | Normal (Not circular) |
| Data Width (Peripheral) | Byte |
| Data Width (Memory) | Byte |
| Increment Address | Memory |
| Priority | Medium |

The process of transmitting a message was as follows:

* Ensure UART 1 and 2 were ready for transmission;
  + Via isTransmitting, which may be found in /Src/main.c
* Load message into buffer; and,
* Direct UART to transmit buffer via DMA.
  + Via HAL\_UART\_Transmit\_DMA, which may be found in /Drivers/STM32F3xx\_HAL\_Driver/Src/stm32f3xx\_hal\_uart.c

### Packet Protocol

As seen in Figure 2: Packet Protocol, a packet protocol was established to ensure that messages could be understood.



Figure 2: Packet Protocol

The protocol is detailed in Table 4: Packet Protocol:

Table 4: Packet Protocol

|  |  |
| --- | --- |
| Value | Notes |
| Type Designator | The non-case-sensitive type designator indicated what type of value was being transmitted. For example, ‘T’ (or ‘t’) indicated that the value represented the desired torque of an actuator. Size: 1 char |
| ID | The integer representing which value of a given type was being updated. For example, an ID of 03 referred to the right foot. Size: 2 chars |
| Sign | Used to indicate if the value was positive or negative. Size: 1 char |
| Value | The value being updated. This could be of any length. A left-hand side and right-hand side value (even if 0) was required for a valid message (e.g. 11 or .5 was invalid, but 11.0 and 0.5 was valid. |
| Decimal | Used to punctuate the value received. Indicated the end of the left-hand side of the value. Size: 1 char |
| End Character | Used to indicate the end of a message. Upon reading a valid message this value would be changed to an ‘@’ to prevent the same message (within the DMA buffer) from being ready twice. Size: 1 char |

This protocol was used for all communicates to, from, and within the controls/perception system.

### Connection Method

As UART was to be used over a two-wire connection three wires in total were required:

* RX;
* TX; and,
* Ground.

A common ground ensures that all RX an TX messages where read correctly and had the same reference voltage. While numerous cable options where viable, Category 5 cable, or CAT 5, cables where selected to connect devices together.

CAT 5 cables are twisted pair cables (4 sets) commonly used in ethernet connection. CAT 5 cable were terminated with 8P8C modular connectors and plugged into female RJ45 connectors. As CAT 5 cables feature more than three wires it became possible to provide 5V across boards, this is discussed in further detail in kt. These connectors were then mounted on the controller PCB, see kt.

## Results and Discussion

SS4 was tested by daisy chaining multiple controller boards together via 1.5m CAT 5e cables. Each board would transmit the messages relevant to it on both UART 1 and UART 2. Messages received would be parse. Invalid messages were discarded. Valid messages where then passed along the chain to ensure all controller boards were informed, e.g. valid messages incoming to UART 1 were sent outgoing to UART 2.

For the thesis demonstration, two boards where connected and sensor readings from one board were used to communicate actuator commands to the other.

In both these test case the communication system was perfectly functioning. Messages were sent and transfer, no corrupt messages were interpreted as valid, and messages where interpreted correctly.

The interface between the actuation system and the controls/perception system was never completed. Provisions were made for connection to another system (these were also used for debugging), see kt, but were tested as the actuation system was never completed. While one can be confident that the communication system would function as required, it cannot be said for certain without testing.

### Communication speed

It is difficult to say if the communication system would have been fast enough to allow for real time control of the system. While messages were kept short and DMA was employed to speed messaging the baud rate of 9600 may have been simply too low for the communication speeds required.

Given an 8-bit char (ASCII character) approximately 109 messages (of standard size) could be sent per second, or about 9ms per message. Given the potential for a message to be passed on up to 6 times before being interpreted by the actuation system, and that up to 5 messages may be queued to be sent by each controller, a maximum delay of 192ms (21 message periods) could be expected. Given a human reaction time of 150 – 300ms (Yuhas, 2012), a system with a reaction time of 192ms will lag behind the user and not react sufficiently quickly.

Going forward it is recommended that the baud rate of the system is raised to 115200 bits/s. Transmitting messages twelve times faster will result in a reaction time of 16ms and reduce the possibility of lag.

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