



INSA TOULOUSE

PROJECT RELEASE REPORT

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## Autonomous Drone Guide

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# Autonomous target-guided navigation in low obstacle enviroment

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### **Abstract**

Being fifth year students at INSA Toulouse, we saw that many visitors had difficulties to find the Electrical and Computer Engineering Department (DGEI) and they were late for there lectures. At the end of our study in Critical and Embedded System, we have an opportunity to work with a drone so we decided to make our project more useful. Our Pink team is working on developing a UAV that can go to DGEI wherever it was.

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# 1 Introduction

Our team has been in charge of developping a guide to help people find their way at INSA. Our drone is able to converge to a target thanks to GPS coordinates. It's naturally able to fly autonomously without human interactions and it avoids obstacles like trees, cars and human beings.

This document explains how to use our work for people willing to set up our experiments or just to take some parts of our project for theirs. It could also be a good starting point to those who would like to continue and improve this project.

This document is divided in fours parts. Firstly, a general presentation of the project will be presented with its goal and all the relative documents produced that can help and complete this one. In the second part will be explained all that is in relation with the hardware and how to integrate and use it. Then the software part will be described with the architecture, codes that have been made and libraries you need to install. Before concluding results obtained will be detailed.

## 2 General project presentation

### 2.1 Goal of our project

Our project, proposed by our tutor D. Le Botlan is titled “Adptive Flight”. It is composed of two main parts.

The first one is about target detection and autonomous flight.  
The other one is obstacle avoidance.

Actually, our UAV must be able to detect a target, flight to this point and above all, avoid the human obstacles.

### 2.2 Documentation & deliverables

In the beginning of the project we have created a website on our project. It can be accessed at :

<https://sites.google.com/site/projetsecinsa/projets-2012-2013/projet-de-la-mission-pink>

We have also written technical documentation : PMP, SRS and STD. They can be downloaded in the “Sources” section of our website.

Regarding software production, we have used the versionning manager git. Our code is hosted at this url :

<https://github.com/insadrone/InsaQuadDrone>

Finally, various documents, unsorted, like mid-term presentations, hardware benchmarks can be seen in the included folder named “google\_drive\_dump”

## 3 Hardware considerations

### 3.1 Parrot 2.0

The Parrot AR.Drone is a radio controlled flying quadrotor helicopter built by the French company Parrot. The drone is designed to be controlled by any electronic device having wi-fi connection and sufficient ressource to run a control software. Only android, iOS and windows have officially distributed control applications. In other hand, only Windows and Linux OS are supported as a development platform. The choice of the department for this drone as a base for the project is due to the harmless character of this quadrotor. Two versions of the Parrot AR.Drone exists. For our project only the new version(Ar.Drone 2.0) is supported.

#### 3.1.1 Ressources

Many ressources could be found on this UAV and this what make it one of the best choices:

- <http://www.parrot.com/fr>
- <http://ardrone.parrot.com/parrot-ar-drone/usa/>
- <http://projects.ardrone.org/>
- <http://devzone.parrot.com/>

#### 3.1.2 Specification

Here a quick overview of the general specification of the drone:

- Autonomy : Approximately 12 minutes, recharging time of 1h30.
- Maximum range : 50m average, 100m in a wide-open space with few Wi-Fi waves.
- Maximum altitude : 6m is the stability limitation, 50m the wi-fi limitation (which could be hacked with wi-fi booster to go up to 75m).
- Maximum additional supported weight : 80g is the limit of stability, 100g is the limit of motors propulsion.
- Maximum speed : 18 km/h.
- Maximum supported wind speed : 2km/h.

#### 3.1.3 Hardware

The hardware reference is as follow:

- \* AR.Drone 1.0 : carte Mykonos, processeur ARM926EJ-S rev 5 (v5l) Wi-Fi: AR6000 Memory: 128MB RAM
- \* AR.Drone 2.0 : Mykonos2 card, Processor OMAP 3640 1GHz 32 bit ARM Cortex A8 with a video DSP 800MHz TMS320DMC64x

### 3.1.4 Software

The board has an embedded Linux with these reference :

- \* Linux myhost 2.6.27.47-parrot-01227-g93dde09 #1 preempt Fri Jul 2 15:23:06 CEST 2010 armv5tejl GNU/Linux
- \* Linux 2.6.32 kernel: Linux uclibc 2.6.32.9-g0d605ac #1 preempt Fri Apr 6 12:01:59 CEST 2012 armv7l GNU/Linux

This embedded linux contains these basic packages :

- BusyBox
- Mtdutils
- zlib
- ethtool
- procpfs
- udev
- dsp bridge
- lcms dsp codec
- wireless tools
- exif
- iptables
- usbmodeswitch
- lsusb
- alsa lib
- barry
- busydroid
- webkit

We added multiple modules in order to be able to communicate with usb port:

- cdc-acm
- usbserial
- ftdi\_sio

you need to cross-compile these modules you can use the following steps :

1. Download an ARM Cross-compiler you can find one on the website of Mentor Graphics (successor of Code sourcery)  
<http://www.mentor.com/embedded-software/sourcery-tools/sourcery-codebench/editions/lite-edition/arm-gnu-linux>
2. Install the cross-compiler :  

```
# : chmod +x arm-2012.03-57-arm-none-linux-gnueabi.bin  
# : ./arm-2012.03-57-arm-none-linux-gnueabi.bin
```



3. Compile the module :

```
#: /opt/CodeSourcery/Sourcery_CodeBench_Lite_for_ARM_GNU_Linux/bin/arm-  
none-linux-gnueabi-gcc -march=armv7-a toto.c -o toto.elf
```

4. Download and unzip Linux kernel:

```
#: wget --no-check certificate https://devzone.parrot.com/wiki/oss-  
ardrone2/Listing  
#: tar zxvf linux.tar.gz  
#: telnet 192.168.1.1  
#: uname -a  
#> 2.6.32.9-g0d605ac
```

Edit the Makefile in the root of Linux directory. The first fourth lines are VERSION (2), PATCHLEVEL, SUBLEVEL (32) et EXTRAVERSION (.9). Replace EXTRAVERSION = .9 by EXTRAVERSION = .9-g0d605ac to have the same version as the embedded linux.

5. Configure the kernel :

```
#: cd linux  
#: cp kernel.config .config  
#: make ARCH=arm menuconfig
```

Using the tool menuconfig , go to Device Drivers|USB Support . Tag the module as (M) in the corresponding ligne USB Serial Converter support with the space key and then press enter to see the subdrivers. Tag (M) the ligne USB FTDI Single Port Serial Driver, finally, exit and save the file .config .

6. From the directory linux, compile the module :

```
#: make ARCH=arm CROSS_COMPILE=/opt/CodeSourcery/  
Sourcery_CodeBench_Lite_for_ARM_GNU_Linux/bin/arm-none-linux-gnueabi-  
modules
```

7. Get the compiled modules The compiled modules are in the linux/drivers/usb/serial directory

```
#: cp drivers/usb/serial/usbserial.ko ~  
#: cp drivers/usb/serial/ftdi_sio.ko ~
```

8. check the installed modules If you have doubt on the installed modules, Before to send them, you can check using the following command:

```
#: /opt/CodeSourcery/Sourcery_CodeBench_Lite_for_ARM_GNU_Linux/bin/arm-  
none-linux-gnueabi-readelf -A ftdi_sio.ko
```

you should have probably have something like this output :

```
File Attributes  
Tag_CPU_name: '7-A'  
Tag_CPU_arch: v7  
Tag_CPU_arch_profile: Application  
Tag_ARM_ISA_use: Yes  
Tag_THUMB_ISA_use: Thumb-2  
Tag_ABI_PCS_wchar_t: 4  
Tag_ABI_FP_denormal: Needed  
Tag_ABI_FP_exceptions: Needed  
Tag_ABI_FP_number_model: IEEE 754  
Tag_ABI_align_needed: 8-byte  
Tag_ABI_align_preserved: 8-byte, except leaf SP  
Tag_ABI_enum_size: int  
Tag_ABI_optimization_goals: Aggressive Size  
Tag_CPU_unaligned_access: v6  
Tag_DIV_use: Not allowed
```

if the CPU\_name is 7-a, everthings is ok !

9. Loading the modules on the UAV You can put the modules on the drone using ftp :

```
#: cd ~
#: ftp 192.168.1.1
#: mput *.ko
#: exit
```

10. Mount the modules The modules are in the /data/video and the you can load them dynamically :

```
#: telnet 192.168.1.1
#: cd /data/video
#: insmod usbserial ou insmod usbserial.ko
#: insmod ftdi_sio ou insmod ftdi_sio.ko
```

if needed you can use the two command lsmod to list the loaded modules and rmmod to remove a module.

### 3.1.5 Development

#### Install

To install the SDK of the parrot please use the following script :

```
#Create A project Directory
mkdir ~/Document/Projet_SEC && cd
#Download the SDK
wget --no-check certificate https://projects.ardrone.org/attachments/
download/434/ARDrone_SDK_2_0.tar.gz
#Decompress the archive
tar -zxvf ARDrone_SDK_2_0.tar.gz
rm ARDrone_SDK_2_0.tar.gz
#Set the enviromment variables (Update the Enviroment Variable and
downloading the required packages)
source ARDrone_SDK_2_0/ARDroneLib/Soft/Build/check_dependencies.sh
#Test the configuration ( you will see 'Ok' at the end if everthings is
ok)
./ARDrone_SDK_2_0/ARDroneLib/Soft/Build/check_dependencies.sh
#Prepare the build for Linux (warning do NOT remove the spaces)
perl -p -i -e 's/USE_LINUX_=====no/USE_LINUX_=====yes/'
ARDrone_SDK_2_0/ARDroneLib/Soft/Build/custom.makefile
#Compile the SDK
cd ARDrone_SDK_2_0/ARDroneLib/Soft/Build/ && make
#If New Curses is not installed you should do it
apt-get install libncurses5*
#Compile the examples
cd ../../../../Examples/Linux/ && make
#Checking If examples Work (do not forget to connect to the drone wifi)
./Build/Release/ardrone_navigation
#Memorising SDK Path maybe you should put it in the .bashrc to avoid doing
it every time
export ARDRONE_SDK=/home/<myuser>/Documents/Projet_SEC/ARDrone_SDK_2_0
```

#### Connect to the drone:

You could easiely use the the telnet commandline :

```
telnet 192.168.1.1
```

## Change the configuration

To change the default parameters used by the uav edit the file as follow :

```
emacs -nw /data/config.ini
```

## Building An example

The typic application structure is the following :

```
keyboard_control
├── bin
│   ├── key_test
│   └── sym_ardrone_testing_tool
├── Makefile
└── src
    ├── ardrone_testing_tool.c
    ├── ardrone_testing_tool.h
    ├── keyboard.c
    ├── keyboard.h
    ├── Navdata
    │   ├── navdata.c
    │   └── navdata.h
    └── Video
        ├── video_stage.c
        └── video_stage.h
```

you can use the makefile sample :

```
SDK_PATH:=$(ARDRONE_SDK)/ARDroneLib
PC_TARGET=yes
USE_LINUX=yes

ifdef MYKONOS
    include $(ARDRONE_CUSTOM_CONFIG)
    include $(ARDRONE_BUILD_CONFIG)
else
    include $(SDK_PATH)/Soft/Build/custom.makefile
    include $(SDK_PATH)/Soft/Build/config.makefile
endif

ifeq "$(RELEASE_BUILD)" "yes"
    ARDRONE_TARGET_DIR=$(shell pwd)/bin
else
    ARDRONE_TARGET_DIR=$(shell pwd)/bin
endif

TARGET=key_test

SRC_DIR:=$(shell pwd)/src

# Define application source files
GENERIC_BINARIES_SOURCE_DIR:=$(SRC_DIR)
```

```

GENERIC_BINARIES_COMMON_SOURCE_FILES+= \
    Navdata/navdata.c \
    Video/video_stage.c \
    keyboard.c

GENERIC_INCLUDES+= \
    $(SRC_DIR) \
    $(LIB_DIR) \
    $(SDK_PATH)/Soft/Common \
    $(SDK_PATH)/Soft/Lib

GENERIC_TARGET_BINARIES_PREFIX=

GENERIC_TARGET_BINARIES_DIR=$(ARDRONE_TARGET_DIR)

GENERIC_BINARIES_SOURCE_ENTRYPPOINTS+= \
    ardrone_testing_tool.c

GENERIC_INCLUDES:=$(addprefix -I,$(GENERIC_INCLUDES))

GENERIC_LIB_PATHS=-L$(GENERIC_TARGET_BINARIES_DIR)
GENERIC_LIBS=-lpc_ardrone -lgtk-x11-2.0 -lrt

SDK_FLAGS+="USE_APP=yes"
SDK_FLAGS+="APP_ID=key_test"

export GENERIC_CFLAGS
export GENERIC_LIBS
export GENERIC_LIB_PATHS
export GENERIC_INCLUDES
export GENERIC_BINARIES_SOURCE_DIR
export GENERIC_BINARIES_COMMON_SOURCE_FILES
export GENERIC_TARGET_BINARIES_PREFIX
export GENERIC_TARGET_BINARIES_DIR
export GENERIC_BINARIES_SOURCE_ENTRYPPOINTS

# Bug fix ...
export GENERIC_LIBRARY_SOURCE_DIR=$(GENERIC_BINARIES_SOURCE_DIR)

.PHONY: $(TARGET) build_libs

all: build_libs $(TARGET)

$(TARGET):
    @$(MAKE) -C $(SDK_PATH)/VP_SDK/Build $(TMP_SDK_FLAGS) $(SDK_FLAGS)
        $(MAKECMDGOALS) USE_LINUX=yes
    mv $(ARDRONE_TARGET_DIR)/ardrone_testing_tool $(TARGET)
    mv $(TARGET) $(ARDRONE_TARGET_DIR)/

$(MAKECMDGOALS): build_libs
    @$(MAKE) -C $(SDK_PATH)/VP_SDK/Build $(TMP_SDK_FLAGS) $(SDK_FLAGS)
        $(MAKECMDGOALS) USE_LINUX=yes

build_libs:

```

```
@$(MAKE) -C $(SDK_PATH)/Soft/Build $(TMP_SDK_FLAGS) $(SDK_FLAGS) $(
MAKECMDGOALS) USE_LINUX=yes
```

You can test the application using these commands:

```
#Open a new shell where you wish redirect the output of the example and
  check its id using **ps -p **
# here in example the id is 5
./keyboar_control >> /dev/pts/5
```

## Building a video example

To build or understand video you can use this example :

```
cd $ARDRONE_SDK/Examples/Linux
wget --no-check-certificate https://projects.ardrone.org/attachments/
  download/466/ARDrone_SDK2_Video_Demo.zip
unzip ARDrone_SDK2_Video_Demo.zip
rm ARDrone_SDK2_Video_Demo.zip
make
```

## Integrate Open CV

We prepared open CV integration in case we need image processing. To install open cv please use the following steps.

```
apt-get install build-essential libgtk2.0* git Subversion pkgconfig python-
  dev python-numpy* ffmpeg libavcodec-dev libavformat-dev libswscale-dev
  libdc1394* libjpeg-dev libpng-dev libtiff-dev libjasper-dev
apt-get install cmake-gui
wget http://sourceforge.net/projects/opencvlibrary/files/opencv-unix/2.4.3/
  OpenCV-2.4.3rc.tar.bz2
#Or
cd ~/<my_working_directory>
git clone https://github.com/Itseez/opencv.git
cd ~/opencv
mkdir release
cd release
cmake -D CMAKE_BUILD_TYPE=RELEASE -D CMAKE_INSTALL_PREFIX=/usr/
  local ..
#use this advanced mode
cmake-gui ..
#get rid of all 3d party lib not downloaded
make
sudo make install
#loading opencv.pc (opencv pkg configuration)
cd unix-install
pkg-config opencv
#Configurer les librairie partager
export LD_LIBRARY_PATH=/usr/local/lib:$LD_LIBRARY_PATH
#or
#Library path can be specified in /etc/ld.so.conf.d/ by creating a file
  called 'opencv.conf' which contains the opencv library path (Default #
  configuration is /usr/local/lib)Once the file is created, execute
sudo ldconfig -v
```

You need to add into your project makefile pkg-config -cflags for the includes and pkg-config -lflags for the linker.

## 3.2 Arduino

### 3.2.1 Ressources

- Home Page : <http://www.arduino.cc/>
- Arduino Playground Tutorials : <http://www.arduino.cc/playground/Learning/Linux>
- Arduino Troubleshooting FAQ : <http://arduino.cc/en/Guide/Troubleshooting>

### 3.2.2 Requirements

- \* Arduino SDK
- \* Udev “Udev is the device manager for the Linux kernel. Primarily, it manages device nodes in /dev. It is the successor of devfs and hotplug, which means that it handles the /dev directory and all user space actions when adding/removing devices, including firmware load.” source wiki
- \* avr-gcc
- \* avr-libc
- \* binutils-avr
- \* avrdude
- \* RXTX Package (librxtx librairie COM JAVA)
- \* arduino-cmake

### 3.2.3 Install

```
apt-get install arduino
wget http://arduino.googlecode.com/files/arduino-1.0.1-linux.tgz
tar zxvf arduino-1.0.1-linux.tgz
sudo usermod -aG dialout <myuser>
gnome-session-quit --no-prompt
sudo chmod 777 /run/lock
cd arduino-1.0.1
./arduino-1.0.1 # or use ‘‘arduino Uno’’ command line
#Troubleshooting
avr-gcc --v
avrdude
ls /dev/tty*
```

To test follow these instructions :

1. file->examples->basic->blink
2. croquis->check/compile
3. tools->serial port-> ttyACM0
4. file->upload

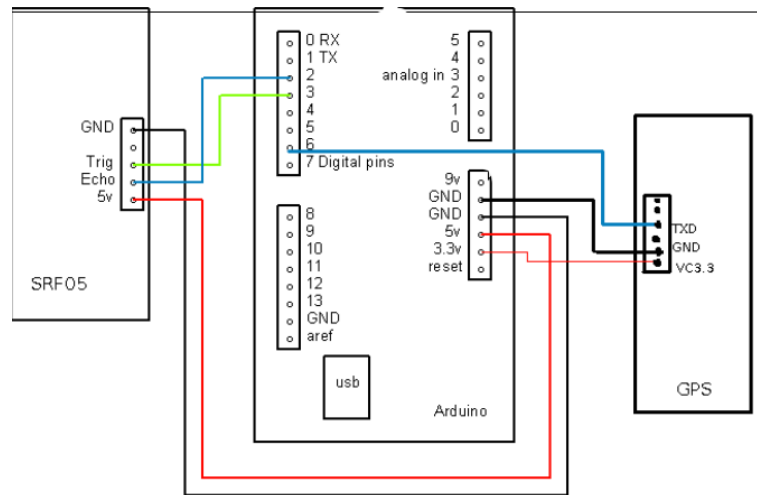


Figure 3.1: Arduino schematics

### 3.2.4 Development

We have used the arduino board uno, without any shield or add ons. The electrical schematics is just below.

Then, to upload a specific code into the board, the arduino application is needed. We used the 1.0.1 version of the application.

The code uploaded is :

```
#include <SoftwareSerial.h>

// GPS PINS
#define SoftrxPin 2
#define SofttxPin 7
// SRF PINS
#define ECHOPIN1 3 // Pin to receive echo pulse
#define TRIGPIN1 4 // Pin to send trigger pulse
#define ECHOPIN2 5 // Pin to receive echo pulse
#define TRIGPIN2 6 // Pin to send trigger pulse

// initialisation de la liasion serie
SoftwareSerial gps = SoftwareSerial(SoftrxPin, SofttxPin);

int incomingByte = 0; // Pour stocker les donnees entrantes
// Stocke la chaine GPS
char line[300] = "";
// Position dans la chaine
int index = 0;
// La chaine recherchee
char commandeGPR[7] = "$GPRMC";
// Chaine ok
int commande_ok = 0;

int i,j = 0;

int readExtractGpsGPRMC(){
```

```

// Envoie des donnees que quand on en recoit
int ret = 0;

while (gps.available () > 0)
{
    // On lit le byte:
    incomingByte = gps.read ();
    line[index] = incomingByte;

    if (incomingByte == 10)
    {

        // Verifie si la chaine est bien de type $GPR
        for (int i = 0; i < 4; i++)
        {
            if (line[i] != commandeGPR[i])
            {
                commande_ok = 1;
                break;
            }
        }

        //-----

        // Si on a recupere la bonne chaine, on l'affiche
        if (commande_ok == 0)
        {
            for (int pc = 0; pc <= index; pc++)
            {
                Serial.write (line[pc]);
            }
            ret = 1;
        }
        //-----
        index = 0;
        commande_ok = 0;
    }
    else
    {
        index++;
    }
}
return ret;
}

float calculateDistance(int pinEcho, int pinTrig){
    digitalWrite(pinTrig, LOW);           // Set the trigger pin to low for
    2uS
    delayMicroseconds(2);
    digitalWrite(pinTrig, HIGH);           // Send a 10uS high to trigger
    ranging
    delayMicroseconds(10);
    digitalWrite(pinTrig, LOW);           // Send pin low again

    int distance = pulseIn(pinEcho, HIGH); // Read in times pulse
    return distance/58.0;                 // Calculate distance from time of

```



```

    pulse
}

void setup(){
  Serial.begin(9600); // ouvre le port serie et regle le debit a 9600 bps
  gps.begin(9600); // pareil pour les ports digitaux
  pinMode(ECHOPIN1, INPUT);
  pinMode(TRIGPIN1, OUTPUT);
}

void loop(){
  unsigned long time;
  int r = readExtractGpsGPRMC();

  while(r == 0) {
    r = readExtractGpsGPRMC();
  }
  time = millis();
  gps.flush();

  while ((millis() - time) < 600) {
    Serial.print("$SRFR,");
    Serial.println(calculateDistance(ECHOPIN1, TRIGPIN1));
  }
}

```

Basically, in the main loop, we are extracting GPS strings and srf data.

About GPS data, we just have to extract the GPRMC string of the 6 lines we receive every second. We need to test the beginning of the string. If is equal to "\$GPRMC" string, we store the string and send it via serial connection to the UAV.

To catch SRF data, it is necessary to read the datasheet, and do the following tasks :

1. Set the trigger pin to low for 2uS
2. Send a 10uS high to trigger ranging
3. Read the time at high level, it corresponds to the duration of ultrasonic roundtrip.
4. Dividing this duration by 58, we obtain the distance to obstacle

We have to send this distance to the UAV, like for the GPS strings.

Using separately ultrasonic sensors and GPS works perfectly well. However it is difficult to use both components at the same time. The GPS extraction is using SoftwareSerial class and all incoming data are stored in a buffer of this class. Data's are written every 1 second, and if we are listening this buffer all the time (except for extraction), this buffer won't overflow. But, if data are written in this buffer while we are capturing ultrasonic wave, the writting will overflow the buffer and cause the loss of some information.

It is impossible to multithread this program, so we have to schedule manually the execution of GPS and sensor listening. We know GPS data are incoming every second, and the execution of gps extraction last 100 ms, so we dedicate 600 ms to ultrasonic listening, and then we wait for GPS data.

This solution is not very satisfying because we take a margin of 300ms, and we don't have SRF data during 400ms, but we didn't find a better way to combine GPS and SRF sensors.

### 3.3 Bluetooth

This part explains how to connect and read data from an android smartphone that sends information via bluetooth. ShareGPS, an application running on the phone is sending its GPS coordinate to the computer. The aim of the document is to give the process to get this coordinate.

First step: with the smartphone

- Turn on the bluetooth and the GPS
- Launch ShareGPS and share coordinate via bluetooth
- Make the bluetooth visible by other devices

Second step: with the computer on Linux

- Turn on the bluetooth and open a terminal (you may need to be root) Scan devices with: “hcitool scan” -> Write down the MAC address of the corresponding device
- Find the good channel which gives GPS coordinate with: “sdptool records MAC\_ADDR” -> This command displays all channels and their functions -> Look for the one called “ShareGPS” and write down the corresponding channel
- Create the connection with: “rfcomm bind X MAC\_ADDR CH” -> X: positive integer corresponding to the rfcomm you want to bind -> MAC\_ADDR: MAC address of the smartphone -> CH: channel of the ShareGPS application

You can now check that /dev/rfcommX exists. The last step is to read data. To kill it use the command “rfcomm release rfcommX” or “rfcomm release all”.

Third step: read data

- Using PuTTY: connect via serial to /dev/rfcommX with a 9600 baudrate
- You can also use a self-made program Note that we have built an automatic script which do all the tasks for you (configuring the bluetooth, reading data and sending them by UDP). You can find it in the folder “bluetooth” located in the roots of our repository. You will need to change the MAC address of the device in the file “config\_bluetooth\_connexion.h” and if you want to change the IP address where data will be sent you need to modify the main function in the file “Get\_GPS\_data\_bluetooth.c”. To compile you just need to type “make” in the folder then “sudo ./test” to execute it.

Source: [http://www.thinkwiki.org/wiki/How\\_to\\_setup\\_Bluetooth](http://www.thinkwiki.org/wiki/How_to_setup_Bluetooth)

## 4 Software produced

### 4.1 Repository architecture

The general architecture of our code repository is explained in this tree :

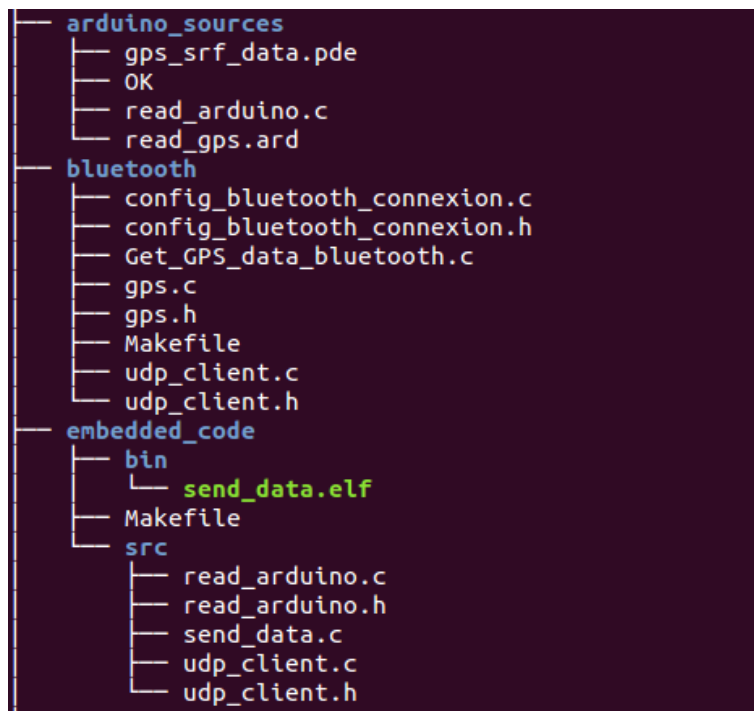


Figure 4.1: 1st part of the repository

In `arduino_sources` folder, all the code related to the arduino board can be found. The software used to program the arduino is expecting `.pde` or `.ard` files.

In the following parts, we will provide more details for each files.

The `bluetooth` folder contains C sources et headers used on the target to catch informations sent by the smartphone.

The `embedded_code` section includes all the programs we created to run on the UAV embedded linux.

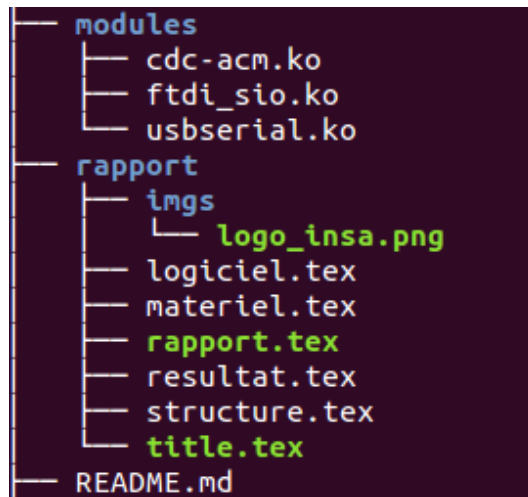


Figure 4.2: 2nd part of the repository

All the compiled modules we added on the embedded linux can be found in the module folder.

The “rapport” directory contains the sources of the documentation you are reading !

Finally, the most important folder is the one named `sdk_apps`. It contains one application named `auto_flight`. Like most of the c projects, you can find a Makefile, a `bin/` and a `src/` folder. The Makefile is configured to create the application binary and to move it to the `bin/` folder. You can find additionnal informations about the Makefile in the appedices.

About the `src/` folder :

The most important C file is named `ardrone_testing_tool.c`. This file is making the link between our application and the ARdrone library. Moreover, it is launching and joining all our threads.

The `Auto/` folder contains code related to the `auto_control` thread.

The `Avoidance/` folder contains code related to the `avoidance` thread.

The `Comm/` folder contains code related to the `receive_gps` thread.

The `Comm_target/` folder contains code related to the `gps_target` thread.

The `Control/` folder contains an small library we wrote to handle UAV travelling.

The `GPS/` folder contains algorithms used to manipulate GPS strings and make distance and angle calculation.

The `Navdata/` folder contains the fonctions used to read and store navdata sent by the UAV.

The `STMachin/` folder contains the fonctions generated by SCAD KCG compiler.

The `Target/` folder contains code related to the `target` thread.

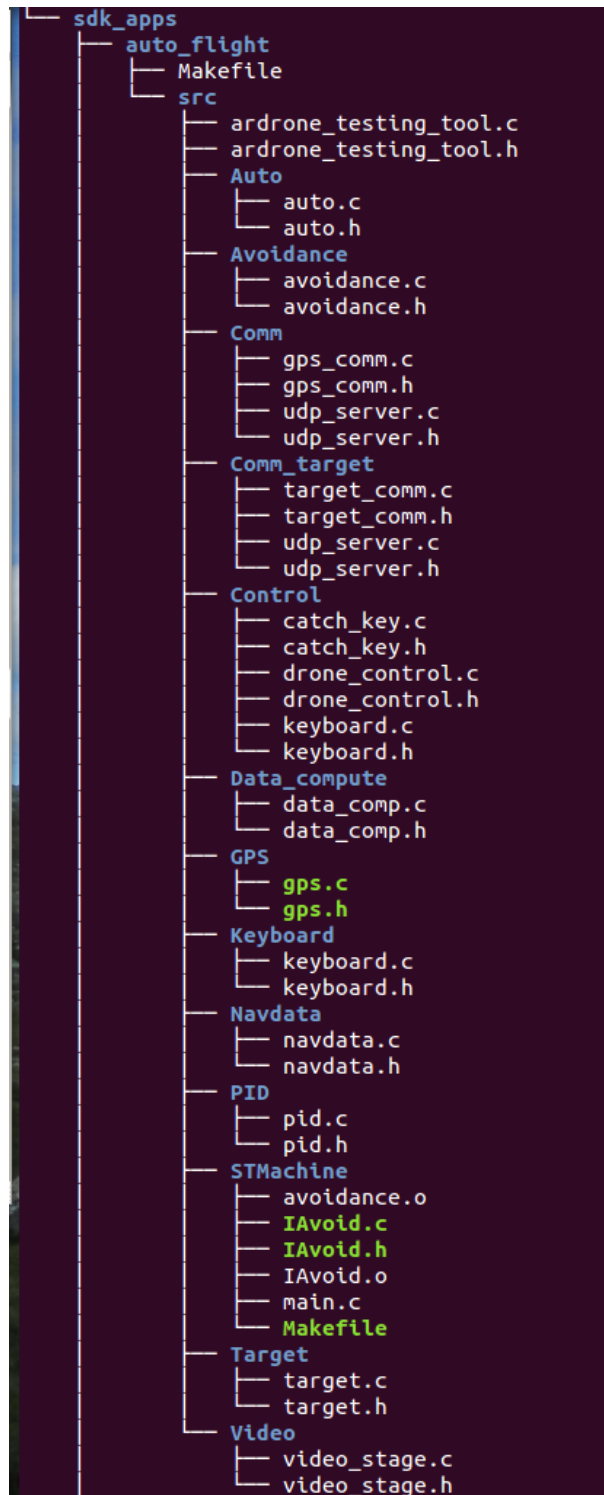


Figure 4.3: 3rd part of the repository

Thread name	Period	Description
ardrone_control	2	Library related thread
navdata_update	20	Library related thread
auto_control	20	Thread allowing manual command of the UAV
receive_gps	50	Thread used to received gps coordinated sent by the UAV
avoidance	60	Thread used to perform autonomous obstacle avoidance
gps_target	50	Thread used to received gps coordinated sent by the target
gps_target	50	Thread used to perform autonomous convergence to the target

This table summarizes all the thread launched in our application. In the following sections, we will detail the operations of each threads.

## 4.2 The auto thread

The auto thread is mainly based on the movement API we developped with the Brown team.

### 4.2.1 Movement API

This API is an overlay of the Parrot API, it allows more intuitive UAV control. It also provide movement quatification, which means you can quantify an order by speed, distance or duration. For example, you can emit orders like “go forward on 300 cm”.

#### Les mouvements élémentaires

Les commandes de déplacement sont définis dans le fichier Control/drone\_control.c, elles ont toutes le même format :

The travelling commands are all defined in the file Control/drone\_control.c, they have the same format :

```
C_RESULT ordre (void *arg)
```

The list of available travellings :

- turn\_left
- turn\_right
- forward
- backward
- up
- down
- right
- left
- stop

### 4.2.2 Send an order

The above order can be passed to both functions depending on whether you want to make a move that will be termed “elementary”, or a longer trip by specifying the distance.

#### Elementary move

An elementary movement allows for a sudden displacement of around 10 cm. You must use the following function:

```
C_RESULT small_move(ORDER* order)
```

Sample code :

```
small_move(turn_right);
```

## Long move

All orders to send move commands accept an argument of type `void *`. This argument must be cast to `void *` but available commands manage only the type arguments `mov_t` which includes different arguments :

```
typedef struct mov_t{
    int32_t power;      //engine power between 0 and 100
    int32_t distance;   //distance in cm
    int32_t time;       //time in usec
}mov;
```

Before sending orders, it's important to fill correctly this structure. Unused fields must be initialized to -1. To send an order, this function must be used :

```
C_RESULT send_order(ORDER* order, void *arg)
```

Sample code :

```
/* 30% on 70 cm*/
mov mv = {30, 70, -1};
send_order(backward, &mv);
```

### 4.2.3 Using of this API

In the auto thread, we need to control the UAV with the keyboard of the station. This automatic control is really useful in case of problems occurring during the automatic control.

Basically, we are just running a `scanf` in an infinite loop. Depending on the key pressed, we just have to call the right function of the API.

```
while (1) {
    usleep(100000);
    scanf("%c", &c);
    printf("%c\n", c);
    switch(c){
        case 'f':
            small_move(forward);
            break;
        case 'b':
            small_move(backward);
            break;
        case 'u':
            small_move(up);
            break;
        case 'd':
            small_move(down);
            break;
        case 'o':
            //small_move(left);
            printf("Batt␣:%d\n", sauv_ndata.bat_level_current);
            break;
```

Very helpful functionalities are battery control, by pressing the “o” key, and recover from emergency mode by pressing “x”. All the other command are pretty basic (“land”, “go up”, “go down”).

#### 4.2.4 Storing navdatas

We also use this thread to store the navdata received. To achieve this goal, it is necessary to declare three functions, defined in the ARDrone library :

```
/* Initialization local variables before event loop */
inline C_RESULT auto_navdata_client_init( void* data )

/* Receving navdata during the event loop */
inline C_RESULT auto_navdata_client_process( const navdata_unpacked_t*
const navdata )

/* Relinquish the local resources after the event loop exit */
inline C_RESULT auto_navdata_client_release( void )
```

We just keep the informations we have to use later, like battery level, control state, altitude or psi angle.

```
sauv_ndata.psi_current = nd->psi / 1000;
sauv_ndata.bat_level_current = nd->vbat_flying_percentage;
sauv_ndata.ctrl_state_current = nd->ctrl_state;
sauv_ndata.tag_detected = nv->nb_detected;
sauv_ndata.tag_tab = nv->camera_source;
sauv_ndata.alt = nd->altitude / 1000.0;
```

We store all these informations in a global structure that will be accessed by the other threads.

### 4.3 The avoidance thread

This thread is mainly based on SCADE generated code. The statechart modeling the avoidance is printed below :

Then, the KCG compiler gave us some independent code, that we included in our project.

```
switch (AvoidMachine_state_sel) {
  case SSM_st_Travelling_AvoidMachine :
    outC->AvoidMachine_reset_act = inC->obstacle_detected;
    break;
  case SSM_st_Hovering_AvoidMachine :
    if (br_1_guard_AvoidMachine_Hovering) {
      outC->AvoidMachine_reset_act = 1;
    }
    else {
      outC->AvoidMachine_reset_act = br_2_guard_AvoidMachine_Hovering;
    }
    outC->init = 0;
    break;
  case SSM_st_Avoidance_up_AvoidMachine :
    if (inC->obstacle_detected) {
      outC->AvoidMachine_reset_act = 1;
    }
    else {
      outC->AvoidMachine_reset_act = br_2_guard_AvoidMachine_Avoidance_up
      ;
    }
    outC->init2 = 0;
    break;
```

The top-level function is defined in the file IAvoid.h.



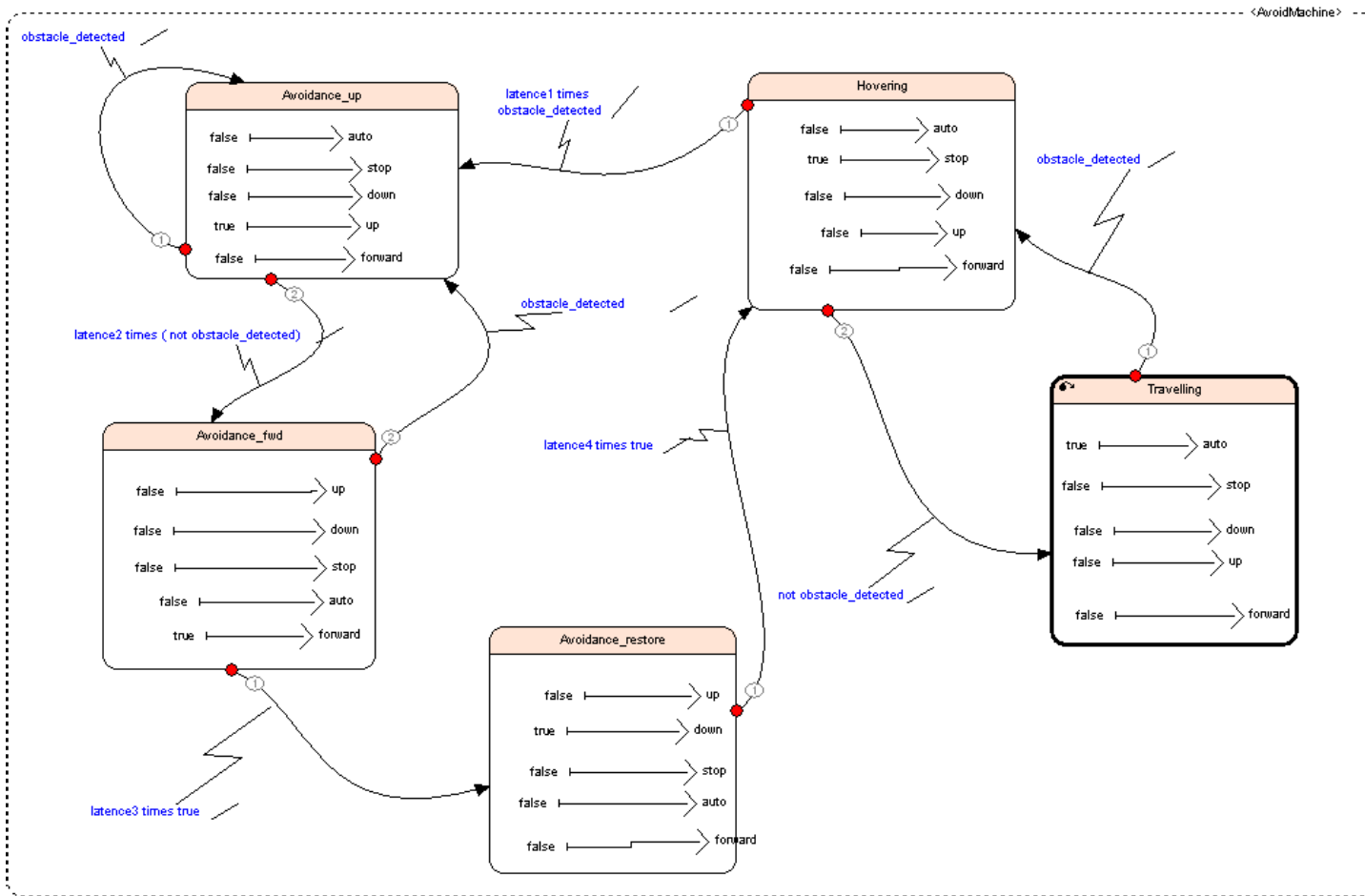


Figure 4.4: SCADE statechart

```
extern void IAvoid(inC_IAvoid *inC, outC_IAvoid *outC);
```

The inputs of this statechart are a boolean named “obstacle\_detected” (its value is 1 if there is an obstacle and 0 otherwise) and 4 integers describing latencies between transitions.

The outputs are 5 booleans : 4 orders (up, down, stop, forward) and a neutral order (if there is nothing to do).

Each call to the function represent a cycle. We have planned to execute a cycle each 10ms. The following code is illustrating the use of the auto-generated function :

```
DEFINE_THREAD_ROUTINE(avoidance, data) {

    comm_datas datas;
    double dangerThreshold=100;
    int detection;
    double average_left;
    int ret;

    init_array_obstacle_pos2();

    IAvoid_reset(&output);
```

```

input.obstacle_detected = 0;
input.latence1 = 100;
input.latence2 = 100;
input.latence3 = 300;
input.latence4 = 100;

while (1) {
    usleep(10);
    if (auto_ready) {
        //get srf datas
        datas = get_comm_datas();

        ret = average_obstacle_pos2(&datas.srfr, &average_left);
        printf("Moyenne capteur(%d): %f\n", ret, average_left);

        //check threshold
        if (average_left < dangerThreshold) {
            detection = 1;
        } else {
            detection = 0;
        }

        input.obstacle_detected = detection;
        IAVoid(&input, &output);
        command(output);
        usleep(10000);
    }
}

return (THREAD_RET) 0;
}

```

And the command function is :

```

void command(outC_IAvoid comm) {
    mov speed;

    if (comm.up) {
        speed.power = 8;
        send_fast_order(up, (void *)&speed);
    } else if (comm.down) {
        speed.power = 3;
        send_fast_order(down, (void *)&speed);
    } else if (comm.stop) {
        send_fast_order(stop, NULL);
    } else if (comm.auto1) {
        speed.power = 1;
        printf("avance\n");
        send_fast_order(forward, (void *)&speed);
    } else if (comm.forward) {
        speed.power = 1;
        printf("avance\n");
        send_fast_order(forward, (void *)&speed);
    }
}

```

## 4.4 The receive\_gps & gps\_target threads

Those threads are designed to receive and store the GPS strings sent by UAV and Target. The receive\_gps thread also handle SRF datas sent by the ultrasonic sensor.

We have created a small library with functions to receive udp datas. This library is described in the udp\_server.h file.

This function is reading udp datas on port 6444 (sent by the UAV).

```
/*
    Start listening the buffers sent from uav
*/
int start_comm(void)
{
    udp_struct udp_uav;
    int msglen_uav;

    if(udpserver_init(&udp_uav,UDP_UAV,1)) diep("udp_UAV_init");

    while (start_listen) {

        do {
            msglen_uav = udpserver_receive(&udp_uav, buf_uav, 512);
        } while(msglen_uav<=0);

        record_data(buf_uav);

    }

    udpserver_close(&udp_uav);
    return 0;
}
```

Then, depending on whether it is a sensor or GPS data, we fill a structure.

```
int record_data(char *buf) {
    char *gprmc_begin = "$GPRMC";
    char *gpgga_begin = "$GPGGA";
    char *srfl_begin = "$SRFL";
    char *srfr_begin = "$SRFR";

    int ret_val = 0;

    if (!strcmp(gprmc_begin,buf,6)) {
        strncpy(ret_datas.gprmc_string,buf_uav,sizeof(ret_datas.gprmc_string));
        ret_val = 1;
    } else if (!strcmp(gpgga_begin,buf,6)) {
        strncpy(ret_datas.gpgga_string,buf_uav,sizeof(ret_datas.gpgga_string));
    } else if (!strcmp(srfl_begin,buf,5)) {
        ret_datas.srfl = atof(buf+6*sizeof(char));
    } else if (!strcmp(srfr_begin,buf,5)) {
        ret_datas.srfr = atof(buf+6*sizeof(char));
    } else {
```

```

    printf("ERROR_NO_STRING_DETECTED\n");
}
return ret_val;
}

```

The other thread (receiving from target), uses similar functions.

## 4.5 The target thread

This thread contains functions related to auto-convergence. We have implemted different algorithms, described thereafter.

### 4.5.1 Turn angle algorithm

When it converges to the target, the UAV need to turn to an absolute angle between 0 et 360 from north. Depending on the UAV angle, it can be better to turn right, or to turn left, to reduce the turning duration.

The UAV will turn to reach the angle given as an argument. We have defined a tolerance. Indeed, because of transmission delays, the UAV can keep turning even if the angle is ok. A tolerance of 5.0 degrees is acceptable and always working.

```

/*
  INPUT: angle    (float)
  tolerance (float)
  This function will make uav turn to the direction of target with an error
         of +- tolerance
*/
void turn_angle2(float target_angle, float tol) {

    fdata sauv_ndata = get_ndata();
    float angle_360 = sauv_ndata.psi_current;
    float angle_inf, angle_sup;

    angle_inf = target_angle - tol;
    angle_sup = target_angle + tol;

    if (sauv_ndata.psi_current < 0) angle_360 = 360 + sauv_ndata.psi_current;
    if (target_angle < 0) target_angle += 360;

    if (target_angle > angle_360) {
        (target_angle - angle_360) < 180 ? send_order(turn_left, NULL) :
            send_order(turn_right, NULL);
    } else {
        (angle_360 - target_angle) < 180 ? send_order(turn_right, NULL) :
            send_order(turn_left, NULL);
    }

    while (!(sauv_ndata.psi_current > angle_inf && sauv_ndata.psi_current <
        angle_sup)) {
        sauv_ndata = get_ndata();
        usleep(100);
    }

    send_order(stop, NULL);
    sleep(1);
}

```

```
}
```

#### 4.5.2 Convergence algorithm 1

Let's describe the first algorithm :

1. Magneto calibration (the UAV has to be flying)
2. Receive GPS datas
3. Turn to wright angle
4. Go forward 2 seconds
5. If target reached, land otherwise, jump to step 3.

```
if ( (landed == 1) && (calibration == 0) ){
    printf("start_calibration\n");
    calibrate_magneto(NULL);
    sleep(4);
    calibration = 1;
    printf("Calibration_done\n");
}

if ( (landed == 1) && (calibration == 1) && (mission == 0) ) {
    datas = get_comm_datas();
    extract_coord(datas.gprmc_string,&depart);

    datas_target = get_comm_datas_target();

    if ((check_gps_coord_struct(&depart) > 0) && (check_gps_coord_struct(&
        datas_target.dest) > 0)) {
        navigation(&depart, &datas_target.dest, &distance, &angle, NULL); //&
        relatif_error

        turn_angle2(angle,5.0);

        if (distance > 5.0){
            fprintf(redir_sortie,"La_distance_restante_est_%f\n",distance);
            fflush(redir_sortie);
            speed.power = 3;
            send_order(forward,(void *)&speed);
            sleep(3);
        } else {
            send_order(land,NULL);
            printf("LANDING\n");
            mission = 1;
        }
    }
}
```

#### 4.5.3 Convergence algorithm 2

Let's describe the second algorithm :

1. Magneto calibration (the UAV has to be flying)
2. Receive GPS datas
3. Turn to wright angle
4. While distance is decreasing, go forward
5. If target reached land, otherwise go to step 3.

```

if ( (landed == 1) && (calibration == 0) ){
    printf("start_calibration\n");
    calibrate_magneto(NULL);
    sleep(4);
    calibration = 1;
    printf("Calibration_done\n");
}

if ( (landed == 1) && (calibration == 1) && (mission == 0) ) {
    datas = get_comm_datas();
    extract_coord(datas.gprmc_string,&depart);

    datas_target = get_comm_datas_target();

    if ((check_gps_coord_struct(&depart) > 0) && (check_gps_coord_struct(&
        datas_target.dest) > 0)) {
        navigation(&depart, &datas_target.dest, &distance, &angle, NULL); //&
            relatif_error

        turn_angle2(angle, 5.0);

        while (last_distance > distance) {
            fprintf(redir_sortie, "La distance restante est %f\n", distance);
            fflush(redir_sortie);
            speed.power = 3;
            send_order(forward, (void *)&speed);
            last_distance = distance;
            sleep(1);
        }

        if (distance < 10.0){
            send_order(land, NULL);
            printf("LANDING\n");
            mission = 1;
            fflush(redir_sortie);
            exit(0);
        }
    }
}

```

## 4.6 GPS algorithms

### 4.6.1 GPRMC string

After receive GPRMC strings sent from UAV, at the ground station, we can extract some necessary informations such as coordinates GPS : latitude et longitude and data status.

The GPRMC sentence consists of twelve comma-delimited words:

```
$GPRMC,hhmmss.ss,A,llll.ll,a,yyyy.yy,a,x.x,x.x,ddmmyy,x.x,a*hh
1    = UTC of position fix
2    = Data status (V=navigation receiver warning)
3    = Latitude of fix
4    = N or S
5    = Longitude of fix
6    = E or W
7    = Speed over ground in knots
8    = Track made good in degrees True
9    = UT date
10   = Magnetic variation degrees (Easterly var. subtracts from true course)
11   = E or W
12   = Checksum
```

First, we check if Data status is valide (A) or not (V). If status is not valide, coordinate GPS will be set -1. Then we only interest in Latiude (3) and Longitude(5) data. We know also that the data of (4) and (6) are always N and E so the coordinate GPS is positive. For others informations, we don't count in.

```
void extract_coord( char str_gps[], struct gps_coordinate *point )
{
    char delims[] = ",";
    char *result;
    result = malloc(sizeof(char));
    int j,i = 0;
    result = strtok( str_gps , delims );

    char *degree ;
    degree = malloc(sizeof(char));
    char *minute ;
    minute = malloc(sizeof(char));

    while( i<6 )
    {
        i++;
        result = strtok( NULL , delims );
        //printf( "result is %d \"%s\"\n", i, result );
        if (!strcmp(result, "V") )//sortie la boucle quand GPS ne fonctionne
            pas
        { i = 7;
            point->longitude = -1.0;
            point->latitude = -1.0;
            printf( "coordinates_\undetermined_\n" );
        }

        if (i==3) //effacter la valeur de latitude
        {
            for (j=0;j<2;j++) //extract degree
            {
                degree[j] = result[j];
            }

            while (j< strlen(result)) //extract minute
```

```

    {
        minute[j-2] = result[j];
        j++;
    }

    point->latitude = atof(degree) + atof(minute)/60.0 ;    /    if (
        point->latitude > 90.0 || point->latitude < -90.0) {
        point->latitude = -1.0;
        point->longitude = -1.0;

    }
    //printf( "latitude %f\n", point->latitude);
}

if (i==5) //effacter la valeur de longitude
{
    for (j=0;j<3;j++) //extract degree
    {
        degree[j] = result[j];
    }

    while (j< strlen(result)) //extract minute
    {
        minute[j-3] = result[j];
        j++;
    }

    point->longitude = atof(degree) + atof(minute)/60.0 ; //convert into
    degree
    if (point->longitude > 180.0 || point->longitude < -180.0) {
        point->latitude = -1.0;
        point->longitude = -1.0;
    }

    }
}
}

```

#### 4.6.2 Navigation

##### Bearing

Bearing is the angle measured in a clockwise direction from the north line. Thanks to this, we can know the direction to reach the target. The formula is given :

$$\theta = \text{atan2}(\sin(\Delta\lambda) \cdot \cos(\phi_2), \cos(\phi_1) \cdot \sin(\phi_2) - \sin(\phi_1) \cdot \cos(\phi_2) \cdot \cos(\Delta\lambda))$$

where  $\phi$  is latitude,  $\lambda$  is longitude.

```

//calcul direction // North

y = sin(dest->longitude - depart->longitude) * cos(dest->latitude);

x = cos(depart->latitude)*sin(dest->latitude) - sin(depart->latitude)*cos(
    dest->latitude)*cos(dest->longitude - depart->longitude);

```



```
*angle = (atan2(y,x) * 180.0/M_PI);
```

## Distance

We use the 'haversine' formula to calculate the distance between two points – that is the shortest distance over the earth's surface.

Haversine formula:

$$a = \sin^2(\Delta\phi/2) + \cos(\phi_1)\cos(\phi_2)\sin^2(\Delta\lambda/2)$$

$$c = 2.\text{atan}(\sqrt{a}, \sqrt{1-a})$$

$$d = R.c$$

where  $\phi$  is latitude,

$\lambda$  is longitude

```
// calcul distance
x = sin((dest->latitude - depart->latitude)/2) * sin((dest->latitude
- depart->latitude)/2) + sin((dest->longitude - depart->longitude)
/2)*sin((dest->longitude - depart->longitude)/2) * cos(depart->
latitude)*cos(dest->latitude);
y = 2 * atan2(sqrt(x),sqrt(1-x));
*distance = RAYON * y;
```

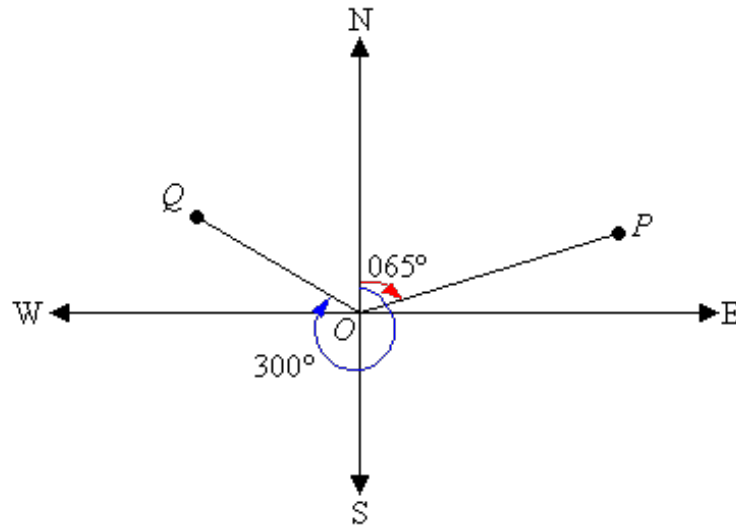


Figure 4.5: Bearing angle

The point O is position of UAV, if we want to go to the point Q, we must turn to left an angle of  $60^\circ$  relative to the north. According to the formula above, it gives us a negative angle  $-60^\circ$  that means the point of destination is on the left. Another case, we have an angle of  $65^\circ$  on the right if we want to reach to the point P. And the Haversine formula will also give us the distance of OQ or OP.

## 4.7 Data Averaging Algorithm

To avoid big errors or prevent incoherent sensor values given by the ultrasonic sensor and the GPS we decided to calculate the average of the last X previous values (X is a number that can be modified in the header

file). Moreover this function checks new incoming values by comparing them with the average plus or minus a tolerance that can also be chosen.

This function uses a circular array to store data and calculate the average. It is created and initialised with all values equal to -1 by using the function `init`.

## 4.8 PID Control Implementation

The implementation of a PID controller is very simple. The function used the classic equation:

$$commande(n) = P[erreur(n) + TECHsommeerreurI + D(erreur(n) - erreur(n - 1))] \quad (4.1)$$

which is equivalent to:

$$commande(n) = commande(n-1) + P(erreur(n) - erreur(n-1)) + ITECHerreur(n) + DTECH(erreur(n) - 2 * erreur(n-1) + erreur(n-2))$$

with  $erreur = consigne - val\_capt$ . *Consigne* is the the value to reach and *val\_capt* is the current value given by the sensor. These two variables are the parameters of the function.

P, D, I and T<sub>ech</sub> are constants defined in the headers.

The function return *commande* which is the command to apply to your system.

Moreover three global variables need to be used to store previous values which are  $commande(n - 1)$ ,  $erreur(n - 1)$  and  $erreur(n - 2)$ . They can be reset by calling the function `init`. Note that this function has to be called once before the first use of the PID.

Here is the code of these functions:

```
void init_pid(void) {
    u_1 = 0;
    e_2 = 0;
    e_1 = 0;
}

double calcul_commande_pid(double consigne, double val_capt) {
    double erreur, commande;
    erreur = consigne - val_capt;
    commande = u_1 + P * (erreur - e_1) + I * T_ECH * erreur + D / T_ECH * (
        erreur - 2 * e_1 + e_2);
    // update variables
    u_1 = commande;
    e_2 = e_1;
    e_1 = erreur;
    return commande;
}
```

## 5 Final results

### 5.1 Autonomous flight

At this point, we are able to launch a preplanned movements sequence. The movement library is quite sufficient to our needs. The drone is stable even with additional weight. The following points could be improved:

1. The movement library precision could be improved if the drone control model is developed.
2. The stability could be improved if the vertical speed is correctly boosted (it can be changed on the config.ini).
3. A PID could be used to add more fluency in the movements.
4. A study may be performed to report more efficiently the addition weight.

### 5.2 Obstacle avoidance

In the current state, the avoidance is performant. The drone is capable to avoid a fixed obstacle without any problem. It can also avoid moving obstacles but it's still not reliable. The following points could be improved:

1. The fluency of the avoidance could be improved with a PID (an implementation is already done still need to be tested).
2. The avoidance could be extended to every obstacle using a second ultrasonic sensor, an arduino Mega because arduino Uno don't have sufficient hardware serial ports.
3. A more sophisticated automaton modelisation then the actual would make the avoidance highly performant.

### 5.3 Target convergence

Currently, the target localisation and convergence is operational. The drone is able to localize the target, join it direction and stop within a defined range from it. The proximity convergence is not implemented yet but it will reuse programming blocks already developed like tag detection and small navigation movements defined in the movement library. The algorithm is pretty accurate and gives as an output the angle and the distance. Unfortunately, the accumulated GPS errors make the distance precision very low but this fact is compensated by the proximity algorithm who uses image processing.

The following points could be improved :

1. The GPS errors could be very reduced using a kalman filter. (please take note that the implementation of this filter is pretty complicated but the improvement will be tremendous).
2. A sophisticated image processing could be used to improve the calculated path.
3. A sophisticated scade automaton combined with a PID would improve the fluency of the movements. (A scade automaton already developed but not yet integrated neither tested)

## 6 Conclusion

In conclusion we achieved our main goal which was to fly from a point A to B autonomously and by avoiding obstacles like trees, cars and human being. The second purpose was to promote our department and has also been successful.

Nonetheless and because of the lack of time this project is improvable in many points. Algorithms can be made more efficient and reliable. For example, the convergence alone works very well but much less with the obstacle avoidance algorithm.

Here are some ideas to improve and continue this project. Building can be integrated in the avoidance code by setting their GPS coordinates in memory and consider them as areas the drone can't fly.

We also wanted to be very precise concerning the landing on target by finishing the convergence with the camera because of the uncertainty of position given by the GPS. For example the drone can detect tags at approximately eight meters. Thus the drone can converge to the target by looking for a tag. Then another tag on the ground can be laying in front of the other tag so the drone can precisely land on it thanks to its bottom camera.

To finish we have also programed a PID correction that we did not have time to use. It can be implemented to regulate the trajectory of the drone and the positioning of the drone to have tags in the center of its camera.