Rocket Science for the Aspiring Brain Surgeon

or

How and Why you should play with a ThumbSat

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23rd April 2015 ➛ v.0.31

The main reason why cavemen and dinosaurs did not work together to create a space program was that Sir Isaac Newton had not yet invented gravity. Before him, Kepler knew how the planets moved, but he didn't quite have the full picture. The point is, thanks to Newtonian mechanics (not the sort who get their hands dirty fixing engines), we know more-or-less where things in space will go. And that brings me to my first point:

Gravity

ThumbSats in orbit are not free from gravity, they have just come to an agreement where the fictitious gravity force pulling them towards earth is equal to the fictitious "centrifugal" force trying to fling them away from it. This is known to space geeks as "microgravity" and normal people as weightlessness. The important point is this; to balance these things, the orbital speed and period (the time it takes to go around the Earth once) vary with the orbit height. Things in LEO (Low Earth Orbit, ThumbSats' preferred home at 300-500km above the Earth's surface) travel approximately 17,500mph and orbit the Earth in around 90 minutes. So the miniature ThumbSat astronaut will witness a sunrise and sunset every 90 minutes, and more than half of that very short "day" in space will be in sunlight. Which brings me to the temperature in space. People ask about this a lot.

Temperature

The scary answer is that the temperature in true space is just a few degrees above absolute zero on the Kelvin scale, which in ordinary terms is -459°F or -273°C. Without any other intervention, ThumbSats would get that cold, which is to say very cold. However, luckily, the solar system is a pleasant place to be. The sun warms us, and even when we are hiding from the sun in the shadow of the Earth, we can still warm ourselves a little from the infrared radiation emitted by the warm planet below. So the less scary, but longer answer is this: The temperature in orbit is a balance between the radiation absorbed and emitted by the ThumbSat, it varies with how much of the sun and Earth we can see, and also with the surface colour and finish and mass of the spacecraft. To achieve a good "thermal" balance, you see spacecraft in all sorts of colours. The gold and silver blankets on the outside of spacecraft and spacesuits are not just to look cool. (Well, there was one exception. The original US Mercury astronauts could never leave their capsule and so they did not need nice shiny space suits. In fact they admitted to wearing just ordinary military boots painted silver, just to look cool.) ThumbSats are white, which is sort of neutral in thermal terms, allowing them to remain in a pleasant range of say +60 to -20°C, (140 to -4F).

The outside of ThumbSat experiments (we refer to them as "payloads" even if they are not paying) can be any colour, but remember that a colour like black can get very hot when directly exposed to the sun.

Anyway, back to microgravity, vacuum and radiation. These are the real selling points of being in space, rather than tucked up in the nice warm, oxygen-rich and relatively radiation-free environment of the International Space Station with the softy human astronauts.

You don't need me to tell you how things behave in microgravity, astronauts are demonstrating this all the time. Well… you may need me to point out some things, like having no up or down means that bubbles in a fluid don't know which way to go and so don't bother forming, which makes Coke rather boring. But it makes crystals grow nice and evenly. Or drugs. Or….? I don't know, ask a rocket scientist!

Having a several-week long source of the good vacuum of space is useful too. Vacuum sucks all of the volatile materials like water and oils out of a material. It's useful for growing drugs. There you go, drugs again.

There's more radiation in LEO than we have on Earth. Earth's atmosphere filters out some UV radiation, and the atmosphere and electromagnetic field combine to stop X-rays and gamma rays from reaching us, but above that blanket in orbit we can see the universe with different eyes; a piece of X-ray sensitive film may start to capture images or spots, or if you're lucky you might witness a mysterious "gamma ray burst" somewhere in the universe. LEO is an interesting place. You can't necessarily see it, but you're floating in space dust. Who knows what it contains? Some of it may have risen from Earth on mysterious currents, some may originate from Earth-deployed space missions, but certainly some has come from other places and times in the universe. There may be extremophiles, either dormant spores waiting to spring into life or "living" already, whatever that means. Some people suggest that we are all Martians, because life on Earth began with hitch-hiking extremophile bacterial from Mars. Hitch-hiking without a thumb has got to be a challenge, so living in space would have been relatively easy in comparison.

Don't be boring!

One of the first (and most boring, to me) applications that people suggest with ThumbSats is taking ordinary images of Earth. If that's your main interest, there are far better platforms than ThumbSat. But the topic does bring me nicely back to orbits and attitude control.

Satellite Orbit

ThumbSats stow away on whatever rocket is going into orbit, and without using a lot of fuel to change direction, satellites tend to remain at an orbital inclination equal to the launch site latitude. Got it? If not, take a look at one of those cool mission control tracking screens:

1 : How great would it be to be one of these guys?
Look carefully at the wavy lines on the high-tech big screen

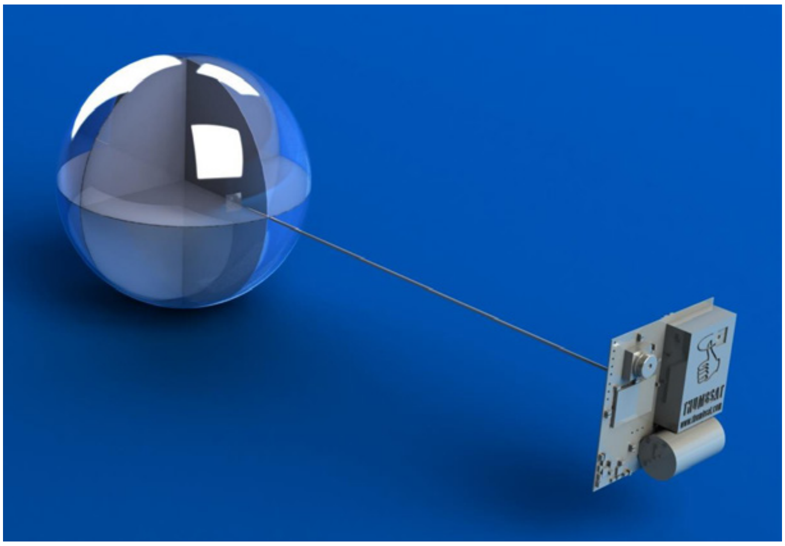
In most cases, you will see that the satellite does not get to a higher point on the Earth than the location of the launch point, and this is symmetrical either side of the equator. There are some interesting exceptions; Russians launch from Baikonur (46° latitude), but their spacecraft have slightly higher orbital inclination (51.6°), because they launch slightly away from China to avoid the Chinese thinking that World War III is beginning. I like 51.6°.

My point is that we can't direct ThumbSats to whatever point in orbit that we like, we're pretty much stuck with the orbit that we're launched into. However, looking back to the cool mission control board, you'll see that the wavy sinusoidal ground tracks are repeated and shifted in longitude, this is because the Earth is rotating below while the ThumbSat is going about its regular orbit. This means that we will be fairly close to all points on Earth within +/- the launch latitude at some times in our relatively short, 7–8 week life in orbit.

Attitude Control

That doesn't mean that our eye can see Earth, though, and that's where attitude control comes in. Sir Isaac tells us that without another force acting, ThumbSats will just remain in the last orientation that they were placed in, pointing out to a fixed position in space, which means that they may sometimes be looking at the Earth and most of the time looking into space. Well, it's not quite as simple as that. Newton said that they won't accelerate unless acted on by an external force, so if the ThumbSat is already tumbling, it will just keep tumbling at the same rotational velocity *(hard part over, wake up!)* unless we do something about it.

Even if you, the genius ThumbSat experiment designer, can tolerate tumbling, we don't like it so much, because we like the radio antenna to be pointed in a particular direction, parallel to the Earth's surface. Our solution is a simple one. ThumbSats have deployable tails that may look something like this:



2 : ThumbSat and tail ➛ just like an arrow

Even though there's no appreciable atmosphere at 300–500km, there are some molecules, and bumping into them at 17500mph should (fingers crossed) cause enough "drag" on the tail to make ThumbSats fly like arrows, flying parallel to the Earth's surface on a slowly decaying orbit, i.e. spiralling towards the Earth before burning up as a tiny shooting star. The only orientation that isn't controlled then is roll about the arrow's shaft. We could control that with a rotating weight (rocket scientists call them "reaction control wheels") or magnets, but we'll only do that if people need us to.

If you've read and understood the last couple of paragraphs, you'll get an idea about what a camera pointing in any direction will see, and the camera can be fixed in pretty much any direction you want.

Camera

What about this camera then? It has HD resolution (2048 x 1536 pixels). As with any camera, it can be fitted with lenses to make it a telescope or a microscope or something in between. It can be fitted with various filters, or its infra-red filter can be removed so that it becomes a "near infra-red" camera, which sounds pretty impressive.

There's plenty of memory for storage of images, but bear in mind that ThumbSats aren't about sending back huge amounts of data like videos, especially at high resolution. Think in terms of a handful of megabytes, rather than a bucketload. You don't need to use the camera at all. Your data could be something else. A message from space, a tune…?

ThumbNet

There are people all over the world waiting to receive your amazing image or data from space. With great imagination, we have called this network to receive ThumbSat data *(drumroll, please)*… "ThumbNet." Like the "Skynet" in the Terminator films but with many of the robots and all of the killing removed. Even now we have this many ground stations, manned, womanned and childrened by enthusiasts with a small radio receiver, some software, a home-made antenna, a small amount of bandwidth and a huge amount of passion:

3 : The growing ThumbNet that's a lot of great people!

To be energy efficient, ThumbSats transmit old-school slow, just 300 or 600 bits per second. Remember Newton and 17,500mph? ThumbSat is only within a few hundred km of each ground station for 5 minutes or so, which means that with such slow data rates, each only grabs a piece of your data jigsaw puzzle. The pieces are uploaded to a central server, to reconstitute the whole picture.

This is one of the reasons why you have to eke the most out of a small amount of data, and by the way that is what we call fun. In 1984, some

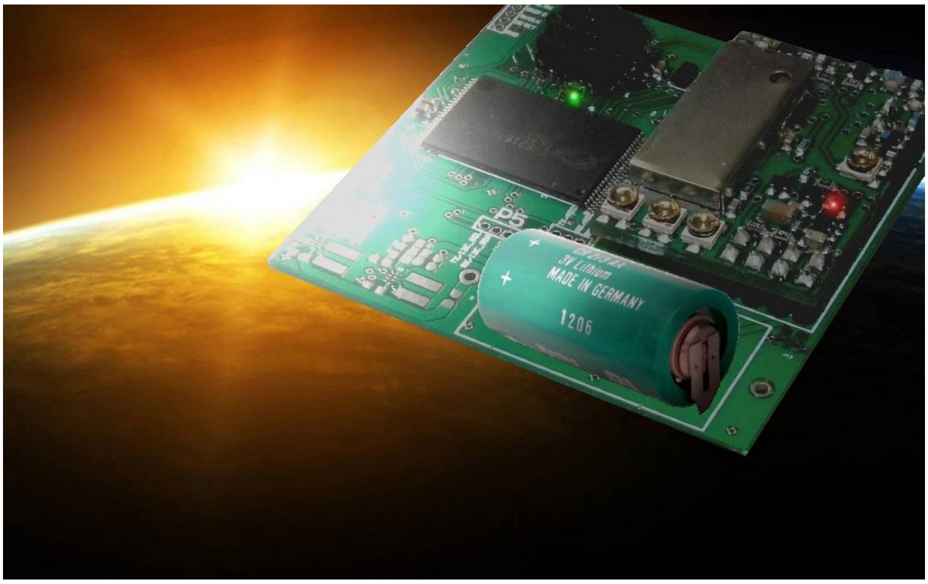
Brits with just 22kb to play with created a computer game called Elite. The game fully described eight galaxies, each with up to 256 stars and each one of those with a multitude of unique planets, all of which could be interacted with and traded on, in a number of spaceships and all in glorious wireframe 3D. And look at the very complex life-forms that are encoded in the relatively small amount of DNA data.... Where was I again?
Oh, one of the nicest aspects of ThumbNet is it's ours and it's personal. You are not relying on NASA or some other big government or commercial organisation to get your data back, it's a whole bunch of people around the world who are talking to each other and doing it because they love doing it. You won't be neglected because of an emergency on the space station, and it doesn't cost us a lot to retrieve your data.

Don't be scared!

By the way, there are still risks—big risks. Rocket launches are often delayed. Rockets still blow up. Mechanisms fail, satellites tumble out of control. Data gets lost in the ether. We can't promise that everything will turn out just right. Just watch any NASA flight from end to end. A mission described as "textbook" at the end actually looks more like a textbook with some pages missing, words crossed out, coffee spilt, etc.

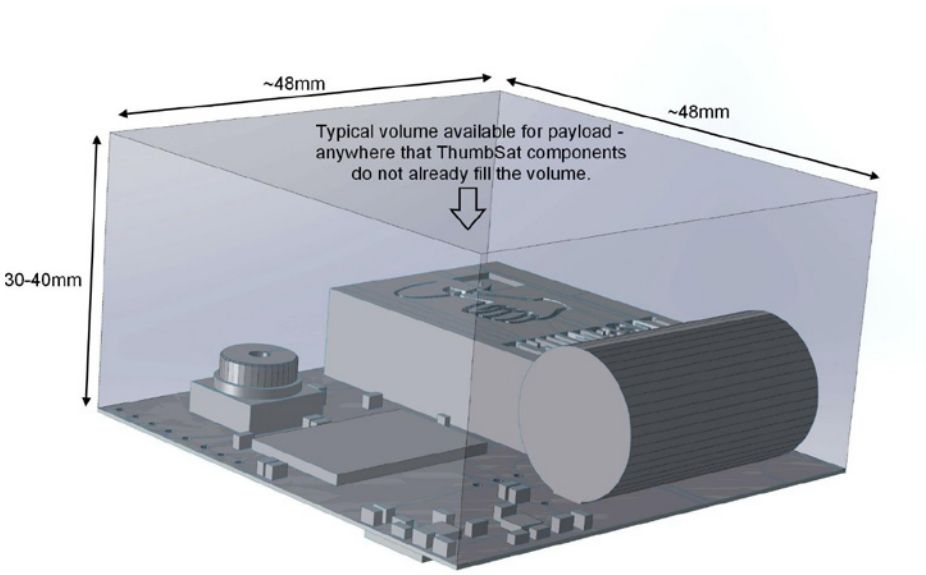
The ThumbSat

Let's take a closer look at ThumbSats.
The basic circuit board looks something like this:



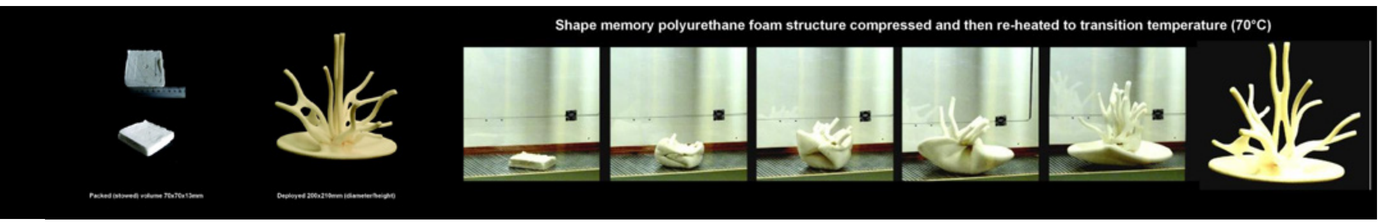
4 : Basic ThumbSat board or "bus" as rocket scientists might call it

Each dimension is no larger than the average human thumb (48mm to be precise) and you can see that the basic ThumbSat itself is not very thick. This means that the rest of the volume is available for payload. It's flexible, but this gives you around 48x48x25mm to play with. Luxury:



5 : Typical volume available for experiment payload.

Within reason, you can incorporate deployable structures to maximise the use of this space, like the pop-top bedrooms on the cute VW camper vans. This means that you can incorporate quite large and fancy camera optics etc. You can incorporate shape memory alloy or foam support structures, so you can hold an object of interest far enough away from the camera to be able to see it fully.



6 : Example of shape memory foam deployable structure.

You can have sealed volumes (e.g. for fluids), open volumes (to take advantage of the great vacuum) tiny valves, mechanisms, etc. It is possible, and probably legal, to release things from the "capsule" and to photograph them, or to keep them in the capsule and image them there too. The capsule can be an expanding one, like a transparent Mylar or Kapton balloon. The main thing to bear in mind here is that we may need to balance the drag to keep it flying like an arrow. If you want a big structure at the front, we look at the overall shape to ensure that it still flies straight and true, if you can't accept getting a little dizzy.

We can help with everything, or you can build it all yourself.

To be corny; the only limit is your imagination.

The Specs

We can reprogram the main computer to interact with the payload pretty much any way that you like. Getting technical, the payload interface includes, but is not necessarily limited to:

- 3.6V unregulated power, 1.8Wh
- 5V regulated power
- 6x analogue in
- 1x analogue out (may be expanded using PWM channels)
- 2x USART interfaces
- 1x I2C interface
- 1x SPI interface
- 10x digital I/O

In layman's terms, that's a lot of switching on and off, measuring, talking, assessing etc.

Bearing in mind the attitude control constraints mentioned above, it's perfectly possible for ThumbSats to see something taking place on Earth. We're trying to avoid any requirement to "uplink" radio data from Earth to ThumbSats while they are in space, but it's quite possible that the camera can see and recognise a laser being shone at it from Earth. An astronaut on the ISS participated in an experiment where someone did just that. Obviously, we wouldn't want to go crazy and have people around the world shining high power lasers randomly into space, but if it's done in a controlled manner then yes, ThumbSat can potentially see (and therefore interpret) a message from ground-dwellers.

Let's go!

I think that's enough to be going on with.