Spring-loaded catapult system for low-cost portable emergency observation projectile

Final summary,   Dec 17, 2011
Jakke Mäkelä, N. Porjo, T. Tokkonen.
(Jakke dot Makela at gmail dot com)

Summary

The proposal presented here may be doable technically, but the achievable image quality is questionable. More crucially, the fast development of radio-controlled drone/helicopter technology means that better performance will be achieved by other methods. There may be other potential uses for the launcher system on its own, but good applications have not been identified. **Thus, this imaging technique is not worth pursuing, and the idea is being archived.**

Background

The idea was inspired by mast (telescope) camera systems that can be used to map and monitor for example disaster zones. A Google search shows many manufacturers of such systems, targeted for remote surveillance, documenting of accident scenes, emergencies, real estate photographs, and so on. Typical weights for such systems appear to be a few tens of kg, and are capable of supporting camera weights of 4 kg or more. Typical costs for commercial systems appear to be some thousands of EUR. Typical heights that can be reached 10 meters, up to 20 meters in some cases (especially if supported by guy wires or balloons.

Typical installations, gathered from several commercial Web sites.

There is a technology which is capable of reaching altitudes well above 10 meters: small remote-controlled aircraft (helicopters or gliders). These are however not cheap technologies, and are not necessarily very robust in extreme circumstances.

Two questions rose:

1) Could there be completely different technical solutions which could reach higher than 10 meters, and yet be compact and have potential for low weight and cost than the existing solutions?

2) Is there any practical need for such a solution, or are existing technologies sufficient in practice?

A technical proposal for question 1 is described here. The answer to question 2 is not known.

Objective

Objective: build a system to launch a camera a few tens of meters in the air, capable of estimating damage and/or fires within a large area. The distance to the horizon scales as approximately Z=3.5*sqrt(H) with H in meters and Z in km, so that at eye altitude 2 m the horizon is about 5 km. This is however a theoretical upper limit, valid only for flat ground. At an altitude of 10 meters, the theoretical distance to the horizon is 10 km; again, the practical distance will be smaller if there are obstacles (for example, a four-story apartment building would block the view). A 10 m altitude is achievable with current telescope masts. An altitude of 40 m is not easily achievable with telescope masts; not only is the theoretical distance to the horizon doubled to 20 km, but there are fewer obstacles of this height.

A useful projectile would at minimum have a normal and infrared camera, taking reasonably high-resolution video or still images that can be parsed to form a panorama image. Very miniature cameras already exist, but it is not clear if their resolution and sensitivity are sufficient. The projectile may be attached by a line to the launcher so it can be rolled back, the images downloaded, and more launches made if needed. Alternatively, the projectile can be untethered but emit light or noise so it can be easily found.

The design philosophy needs to emphasize robustness, low cost, and usability even when no electricity is available. It would be highly advantageous if the system is multi-purpose and be usable for other purposes even if performance degrades (i.e. some component breaks). It should also withstand long storage times and be ready on the go.

Several principal solutions exist for the launcher system: a) pressurized air system, b) systems based on explosive propulsion, c) spring-loaded system. Solutions a and b are potentially interesting and should be studied further, but in this document the focus is on solution c, which would seem to offer the ultimate in low cost and simplicity. It is also capable of launching anything at all that fits within the tube (act as a line thrower using any available projectile).

Description of idea

The idea consists of an observation camera system that can be launched to an altitude of ~40 meters. It could therefore scan the horizon to a much larger length than standing at ground level. The imagery should in particular be able to spot fires. The projectile should be (partly) spin-stabilized so that a consistent 360 degree panorama is formed, or more advanced optics or several cameras can be used (pushing up the cost of the projectile, however) The data are downloaded from the camera after each launch to a computer, which creates a panoramic image.

The size and form factor of the projectile fundamentally determine the specifications of the launcher system. Several compromises need to be made with the projectile: it needs to aerodynamically suitable to achieve a stable flight and minimize air drag, but on the other hand the mass of the projectile must be quite small and the surface area quite large to avoid damage when it falls back to the ground. As a first starting point, we suggest that a large soft-drink bottle (diameter 9 cm, height 30 cm) would have a form factor that could realistic. A plastic soft-drink bottle weighs about 120 g, so a reasonable payload of 380 g would give a total mass 500 g. This is equivalent to a large soft-drink bottle which is 1/3 full; it can be painful and may cause some damage, but should not be lethal especially if the outside is somewhat flexible.

The proposed launcher is a tube, open at one end and shut at the other, with a sliding plate attached to the bottom by a spring. As a starting point, the following values are suggested: 50 cm to 1 m length for the tube to achieve easy portability and low weight, and an inner diameter of about 9 cm. The projectile is assumed to weigh 500 g. These values have been used in the calculations below, but other values can easily be plugged into the equations. Aerodynamics have not been considered, and drag on the projectile will decrease the altitude somewhat from what is calculated here.

The plate is at rest when it is near the open end and can be pushed back mechanically. It should lock when at the extreme point (or ideally at any intermediate point). When triggered it pushes to the open position, throwing any object in the tube outside. The spring constant and length should be optimized so that a projectile of about 500 g weight will rise to an altitude of about 40 meters. The spring must be loadable by the weight of one person (80 kg).

In fall-back mode, the launcher can be used to launch any module, in effect acting as a line thrower.

None of the components by themselves are novel, but so far have not been able to find a product like this.

Existing technology

Line throwers are a standard tool at sea, and lots of pneumatically operated systems exist. (http://www.linethrower.com/ , http://www.restech.no/). Nothing new there. Cameras have been put on rockets for a long time (http://www.gearcam.com/). A spring-loaded catapult is trivial enough that it's difficult to find anything commercial for real use. Systems with solid-fuel rockets exist: http://www.hansson-pyrotech.com/prod_linethrower.htm Weight of system is 4 kg.

Physics of the launcher system

The system is simply a tube open at one end, with a spring attached to a plate at the other end. At rest, the plate is near the open end of the tube. When pressed fully, it is locked to the bottom. The spring is loaded e.g. by a person standing on a pedal.

The basic equations can be derived with the help of high-school physics.

M=mass of person
m=mass of projectile
g=gravitation constant (about 9.8)
D=distance to which spring is compressed (length of tube)
v=maximum velocity of projectile at the of the tube
a=maximum acceleration of the projectile.

If the catapult is to be loaded by a person standing on the pedal, then the spring constant must be
$k=Mg/D$.

The potential energy of the spring is then $kD^2/2$.

This is transformed into kinetic energy at end end of the tube, $mv^2/2=kD^2/2$, or
$v = D*\mathrm{sqrt}(k/m) = \mathrm{sqrt}(MgD/m)$

The kinetic energy is transformed into potential energy at the top of the trajectory, $mv^2/2=mgH$, or
$H = v^2/2g = MD/2m$

Maximum acceleration can also be calculated from $v=at$, $D=at^2/2=v^2/2a$, and since from above $H=v^2/2g$ we get the simple equation $a=gH/D$.

Time spent aloft T is given by $H=g*T^2/2$.

In simplest form, the equations then are

H= MD/2m (independent of spring constant)
k=Mg/D (relevant to determine what type of spring is needed)
a=gH/D (relevant to determine whether projectile will be intact)
v=sqrt(MgD/m) (relevant to estimate air friction)
T=sqrt(2H/g) (relevant to determine frame rate and resolution)

Some reasonable estimates:
M = 80 kg (adult man)
m = 0.5 kg (mass of plastic soft drink bottle is ~120 g, 380 g of electronics is reasonable).
D= 0.5 m (this is carryable and loadable)

Then
H=40 m (more or less minimum useful height)
k=1600 N/m(can be achieved, for example car suspensions have k > 40,000 N/m)
a= 80 g (quite a large acceleration)
v=30 m/s (this will also be the value when projectile falls to the ground)
T=3 s (Time spent above 10 m is approximate 2 s).

As a first approximation, the values seem to be realistic. The only parameter that can really be varied is tube length D, with H linearly related to D. A one-meter tube will give height 80 m, spring constant is halved to 800 N/m, acceleration is halved to 40g, v increases to 42 m/s).

If the mass m is doubled, the height is halved to 20 m and v decreases to 20 m/s.
DRAFT, QUITE POSSIBLY NONSENSE

Weight of launcher system

The weight needs to be manageable. In this solution, the tube itself does not necessarily need to be of steel, as the outward pressures are not very high (it could even have holes without degrading the operation, as could the plate.

Define Wx to be the thickness of part x and Sx to be the density of the material
With a radius of R cm, (approximately 4 cm) we get
Mass of bottom: Mb=pi*R²*Wb*Sb
Mass of tube: Mt=pi*R²*H*Wb*Sb
Mass of plate: Mp=pi*R²*Wp*Sp
Mass of spring: Not known.

Calculate first the weight if everything is made of steel. Density of steel ~8 g/cm³.
Bottom will need to be the sturdiest, assume 1 cm thick steel, then Mb~400 g
For symmetry, assume plate to be same as bottom, so Mp~400g
Tube really does not need to be as thick, so assume 5 mm is enough, then Mt=10

kg
No really good estimate for spring, so will make rough guess 5 kg.

→ If built from all steel, mass will be > 15 kg.

However, if for example tube walls can be replaced by PVC plastic with density somewhat below ~1.5 g/cm³, even if the thickness needs to be doubled to 1 cm, then the mass is reduced to 30% of the original. The mass would then be ~10 kg assuming that the spring needs to be steel.

Total weights for existing systems are not trivial to find, but seem to be 4 kg and above. Cannot find typical weights of rifle-type pneumatic throwers, but a few kg is probably reasonable. Thus, the spring-loaded launcher is almost certain to be heavier than a comparable pneumatic or explosive one, possibly by a factor of 2. It is up to the user to determine whether this is acceptable.

Of course if the diameter of the tube is reduced then the mass drops as the square of the diameter. A smaller diameter means that the projectile needs to be designed a bit differently. (The currently guessed form factor of large soft-drink bottle seems reasonable and practical).

Optics for the projectile (using Commercial Off The Shelf components)

Commercial cameras:
BoosterVision GearCam
http://www.gearcam.com/gearcam/
1280x720p HD resolution with audio, Micro SD card, up to 2 hours, USB port, rechargable, water resistant, can be made waterproof.
28 mm by 10 cm, mass 64 grams.
Price 129 USD

BoosterVision GearCam DVR-II
http://www.boostervision.com/cart/scripts/prodView.asp?idProduct=124
Video 640x480, 30 fps, audio, runs 30 min, rechargable, 2 GB internal storage, USB port
Weight 28 grams
Cost ~90 USD

Wireless GearCam
http://www.boostervision.com/cart/scripts/prodView.asp?idproduct=86
Size 20 mm x 20 mm x 20 mm
Field of View 60 degrees, CMOS 380 TV lines resolution
Weight w/o battery 8 g, with battery 70 g
Range 300-700 ft in air, 300-500 ft on ground. Higher gain also available.
Cost ~70USD

Requirements for camera speed and resolution

The requirements for the camera have not been fully evaluated yet. The important parameters are the field of view, resolution, sensitivity, and frame rate. The time spent aloft is only 2-3 seconds, which means that a fairly good camera would be needed especially in poor lighting conditions. In practise, the frame rate cannot be signficantly abive 30 fps, so that the whole panorama will have to be stitched from approximately 60 images.

Full system

The launcher system looks to have a weight of 10 kg or above, even if PVC rather than steel can be used.

Masswise, the projectile system seems buildable within the 500 g spec. COTS cameras exist in 100 USD price range which might be directly usable for visible light. The field of view and resolution requirement have not been determined yet.

Since the projectile has a non-zero probability of getting lost, and it may be necessary to launch several projectiles before a good panorama picture is gained, projectile cost needs to be reasonably low. A 100 USD projectile would probably be acceptable for rescue services. COTS components can achieve this if visible light is enough (infrared will be more expensive).

Ideally , the launcher should have a system for ensuring that it is launched directly upright. This can be as simple as a plumbline. Most likely, there should be a separate stand for upright operation, so that the launcher can be shoulder-held when used as a rescue tool.

Open question is the software to view and analyze the images. Unless a reference point is found, interpreting the information would be difficult. An orientation sensor of some type may be an unavoidable need. And a robust netbook (or smartphone) could be included as part of the package so that it can be used in plug-and-play mode.

Based on communication with some experts in the area, image quality is a crucial parameter, and thus the low achievable quality makes it unfeasible in real use.

Competing solutions

The most obvious technology this competes with are radio-controlled UAV's (unmanned aerial vehicles), for example RC helicopters. The cost of high-quality drones is still rather high, but lower-quality toy-level RC helicopters with video cameras are now available in the price range of 50 EUR.

At a more serious level, higher-quality drones are starting to be available in the 300 USD range.
http://ardrone.parrot.com/parrot-ar-drone/en/
It still has limitations (about 10 minutes of flight time while requiring > 1 hour to charge, image quality borderline). However, these are all issues that will be solvable eventually, and there seems no doubt that within a few years drones will do a better job than the catapult could do whille being only marginally more expensive.

→ Without even making exact roadmaps of the technology, it is clear that the competing solutions will be superior in the long run.

Conclusions

This may be doable technically, although the achievable image quality is questionable. Potentially, the catapult could be used as a line-thrower.
However, the fast development of radio-controlled drone/helicopter technology means that better performance will be achieved by other methods. Thus, this imaging technique is not worth pursuing.