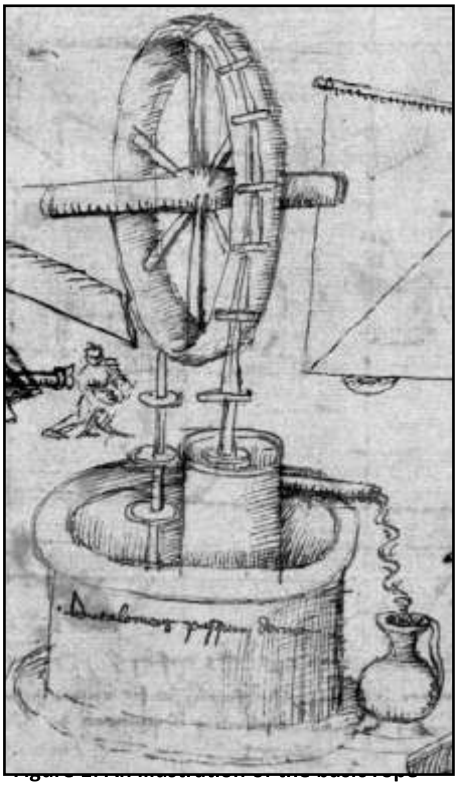
Field Trials of the Solar Rope-Pump: Project Proposal

1. Background

The rope-pump is a very simple type of water lifting device. The almost intuitive design is known by many other names including the paternoster (after the beaded prayer chain it resembles), liberation or rope-and-washer pump. It is a relatively recent development of the ancient chain-and-washer pump. Evidence of the chain-and-washer pump dates back as far as two thousand years, to feudal China [1]. The earliest report of the design in the west is cited [2] as that illustrated by the Sienese early renaissance engineer, Tacolla, circa 1433 [3], a copy of which is given in Figure 1. In the 1980s the basic design was developed by numerous individuals, the most prominent of which were Lambert [5], Haemhouts [6] and Alberts [7]. They applied the simple design as a tool aimed at economic and social development. They took advantage of low cost and versatile modern plastics to produce the modern rope-pump design.



pump design in the west circa 1433 [3, 4]

The rope-pump consists of a continuous loop of rope with pistons spaced evenly along its length. When the rope is driven up through the rising-main by a pulley located at ground level, the close fit of the pistons draws water up the rising-main. A useful animation of the rope-pump can be found at: http://www.youtube.com/watch?v=N3BQsjRKnHo

Due to its high achievable head, low cost and ease of manufacture and maintenance, the hand powered rope-pump has been highly successful across Africa, South America and beyond [7]. These attributes when combined with its rotary operation and low starting torque identified the rope-pump as the most appropriate design to base the development of a low cost automated pump on. If the remaining system components could be selected to match the simplicity, low cost and ease of maintenance of the rope-pump, it was hoped that the as yet unfilled niche, of an appropriate step up from a hand pump, could be manufactured [8, 9, 10]. An affordable automated pump would allow a greater amount of water to be extracted than would be possible by hand alone. The water could then be used to improve levels of sanitation and increase crop yields. This in turn would improve nutritional levels and provide a potential income from the sale of excess produce. It would also free up the time of the users, which would otherwise be spent manually lifting limited amounts of water. This time could then be used for education and other income generating activities [15].

Various types of power supply for the rope-pump have previously been explored, including water wheel [1], pack animal, internal combustion engine and wind-turbine [11, 12, 13]. The solar powered rope-pump, a design suggested by Lambert [15], was researched by Williams and Stitt [16,17] as a contribution towards their third year of a mechanical engineering degree at the University of Bristol. Williams then spent the summer of 2008 in Malawi carrying out a proof of concept of the solar rope-pump [14].

2. Proposed Project Objectives

- Source all materials (excluding motor and solar panels) locally, making appropriate substitutions and/or modifications.
- Manufacture the solar rope-pump with the capability of integrating a range of rising-main diameters .
- Test smallest, largest and medium sized rising main on a wide range of heads (ideally at 1m, 30m and 10m)
    - Measure output and power demands of the system
    - Measure durability of system
- Suggest/make any modifications/improvements to the system
- Carry out cost-benefit comparison of the twin motor-pump assembly compared to a singular configuration, see section 4 for details
- Investigate current market for system including competition from other photo-voltaic pumps (PVPs) as well as hand operated, petrol and other automated pumping systems

3. Product Design Specification

The below table presents a product design specification (PDS) for the systems, it is based on previous work [15, 16, 17] related to the project, research of relevant standards [18] and a dialogue with the industrial links of the project [19].

Table 1: Product Design Specification of Solar Rope-pump

Performance	The pump will need to provide between 1000 and 10,000 litres of water per day, enough water for between 65 and 650 peoples domestic use, based on Sphere Minimum standards [18].
	The water will need to be pumped from a maximum depth of 30m but with a nominal depth of 10m.
	Water will be pumped to a water tank with the storage capacity for one day duty cycle and sufficient head to supply a drip feed irrigation system.
	The pump will be powered by either a wind turbine or PV array or both, either directly or via a battery. Enough power should be provided to run the pump continuously with a maximum of 3 hours manual backup per week.
	An alternative manual hand crank option should also be included for emergency demand.
	An option should be provided that would allow the surplus electricity produced to be made available for other uses such as lighting, phone charging and other low power uses.
	Once started, turbine should be able to rotate at wind velocities as little as 3-4mph.
	The turbine should have an automatic braking mechanism such that when the wind velocities exceed maximum operational levels the turbine no longer rotates.
	Manual starting of the turbine is acceptable due to potentially low wind velocities.
	The turbine should be balanced dynamically.
Environment	The system must be able to function normally in heats ranging from 0˚-50˚C.
	The system should be protected from heavy rain and dusty winds.
	The package will need to be put together with security in mind as theft may be a problem in the target areas.
Project Life Span	Demand for inexpensive water pumping will not reduce in the foreseeable future. Design must therefore be flexible such that, if a certain part goes out of production, a replacement can be found.
Life In Service	The product should run for approximately 15 years, with only the occasional repairs and replacement of parts, e.g. the bearings.
Target Costs	The main priority for the system should be to keep cost to an absolute minimum.
	A range of systems with a range of prices at the lower end of the market should be investigated.
Maintenance	Tools required for maintenance should be readily available in the local area. (See below).
	Turbine to require minimal maintenance. Maximum of weekly light lubrication and a yearly service.
	PV cell should be maintenance free for 15 years, requiring only occasional surface cleaning.
	The only pump part not readily available are the pistons, a simpler manufacturing technique should therefore be developed than the current injection moulding or milling options. The pistons produced should match the tolerances of the current method and approach the current life of the pistons which is between 4 and 10 years for the higher quality plastic pistons and less than this for the pistons cut from rubber tyres.
Marketing	The system should be aimed at use by community groups (hospitals, schools, small hamlets etc) and small hold farmers. Acknowledgement should also be noted that the system may be purchased by the user, but it is most likely that it will be purchased by the Government and Non-Governmental Organisations.
	The modular and optional nature of the system will make it appropriate to the broadest range of customers.
Size & Weight Restrictions	Size and weight of components must not restrict the ability of local people to construct and use the system.
	Mass of the system should be sufficient to aid the stability of the turbine.
Shipping	Depending on availability of parts in local areas, some components may have to be shipped in either directly or indirectly depending on local industry capabilities. These components may include the PV panel, motor, epoxy resin, fibre glass and magnets.

<table>
<tr><td rowspan="24">Manufacturing Processes</td><td colspan="2">The product will be manufactured one at a time.</td></tr>
<tr><td colspan="2">The product must be as simple to manufacture as possible.</td></tr>
<tr><td colspan="2">Parts must be manufactured using tools and materials available to the region. These consist of:</td></tr>
<tr><td rowspan="4">Processes</td><td>Standard workshop hand tools.</td></tr>
<tr><td>Arc welding.</td></tr>
<tr><td>Basic powered hand tools (e.g. drill, grinder etc).</td></tr>
<tr><td>Limited access to fixed specialist workshop tools (e.g. pillar drill, lathe, ban saw) but with low tolerance capability.</td></tr>
<tr><td rowspan="16">Materials</td><td>Reinforcement and smooth steel bar.</td></tr>
<tr><td>Angle, square and flat iron lengths.</td></tr>
<tr><td>Corrugated and flat galvanized steel Sheeting.</td></tr>
<tr><td>GI Pipe and fittings.</td></tr>
<tr><td>Steel Wire.</td></tr>
<tr><td>Variety of nails, screws and bolts.</td></tr>
<tr><td>Assorted Steel Meshes.</td></tr>
<tr><td>Common car, motorbike, bicycle and milling machine spare parts.</td></tr>
<tr><td>Oil drums.</td></tr>
<tr><td>Simply finished (e.g. no dowels) and untreated timber of all sorts.</td></tr>
<tr><td>Basic electrical components (switches connectors etc).</td></tr>
<tr><td>Cement, gravel, river sand and burnt bricks.</td></tr>
<tr><td>Plastic bags and sacking.</td></tr>
<tr><td>Rubber tyres.</td></tr>
<tr><td>PVC and PE Pipe and Fittings.</td></tr>
<tr><td>Polyethylene and sisal rope.</td></tr>
<tr><td>Aesthetics</td><td colspan="2">The product does not have to be aesthetically pleasing. Cost and ease of manufacture are the dominant factors.</td></tr>
<tr><td rowspan="4">Ergonomics</td><td colspan="2">If used, the starting mechanism for turbine should be at an accessible position relative to the operator which can be used by both adults and children.</td></tr>
<tr><td colspan="2">Any controls between turbine/battery/motor/rope-pump should be easily accessible to the intended user.</td></tr>
<tr><td colspan="2">One person should be able to operate the product alone.</td></tr>
<tr><td colspan="2">The manual cranking mechanism should be useable by a large age range, from young children through to the elderly.</td></tr>
<tr><td>Quality & Reliability</td><td colspan="2">Assuming general maintenance is carried out; the system should not generally fail within a period of 2 years and be repairable at least up to the products full life span.</td></tr>
<tr><td>Competition</td><td colspan="2">The system should favourably compare to other low cost appropriate water pumping systems.</td></tr>
<tr><td>Standards & Specifications</td><td colspan="2">Accepting the specifications listed within this document, no further external standards are applicable.</td></tr>
<tr><td rowspan="6">Safety</td><td colspan="2">Consideration must be given to the fact that the product will be used by untrained individuals.</td></tr>
<tr><td colspan="2">A mechanical break should prevent any movement of the turbine during maintenance.</td></tr>
<tr><td colspan="2">Turbine should automatically stop when wind velocities are too high.</td></tr>
<tr><td colspan="2">May be necessary to fenced off area around turbine to avoid risk of injury by falling blades as a result of failure.</td></tr>
<tr><td colspan="2">The system should be made electrically safe by an isolation switch, good earthing, insulation and other necessary safety components.</td></tr>
<tr><td colspan="2">Provision should also be provided in case of a loss of load (if the rope snaps).</td></tr>
<tr><td>Testing</td><td colspan="2">Testing should be carried out on the whole system before being fully commissioned.</td></tr>
<tr><td>Installation</td><td colspan="2">Installation should be carried out by a few trained individuals in under a day.</td></tr>
</table>

4. Suggested System Configuration

Figure 3, Figure 2 and Figure 4 demonstrate how the insolation and hence available current vary during the day. For a given pipe diameter and head of water, a rope-pump will produce an approximately constant torque. A permanent-magnet motor demands a current that is approximately proportional to the torque demanded from it. Therefore for a given pipe diameter and head a constant current will be drawn from the PV panel. To maximise the power extracted from the solar rope-pump it is suggested that two gear-motors connected in parallel are used with effectively twin rope pumps. One motor would be used until there is sufficient current available from the panel to power a second motor. The power drawn would then 'fill' the available current curve as shown on Figure 4. This should be economically viable as the cost of the gear-motor and rope pump are a fraction of the cost of the solar panels, however a more rigorous cost-benefit analysis is needed.

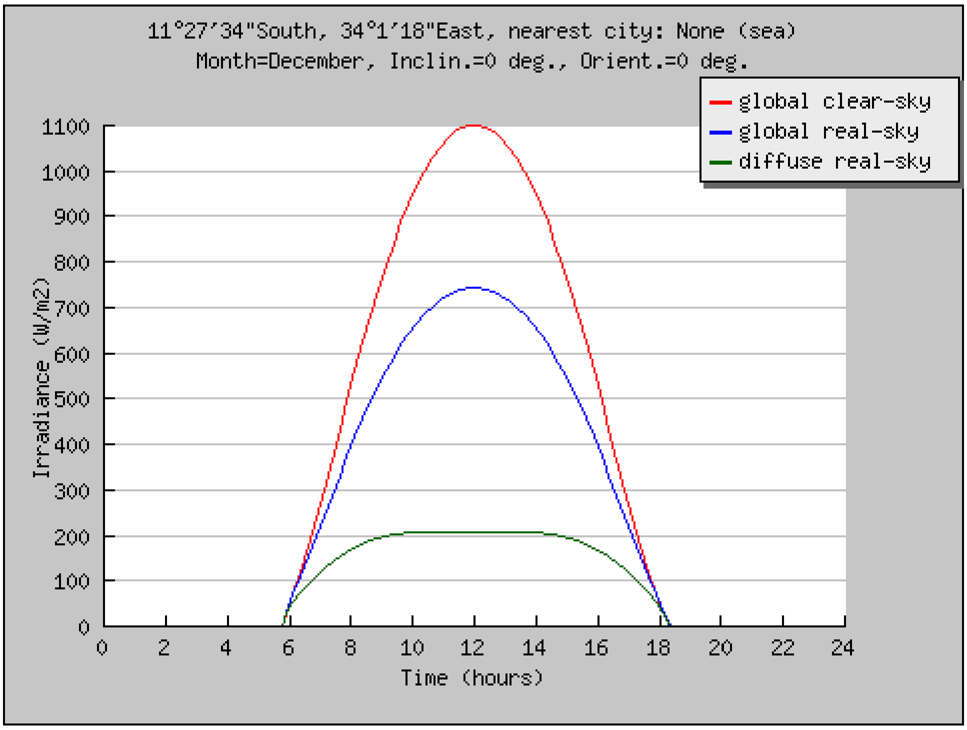


Figure 2: Typical insolation levels in Lilongwe, Malawi [20].

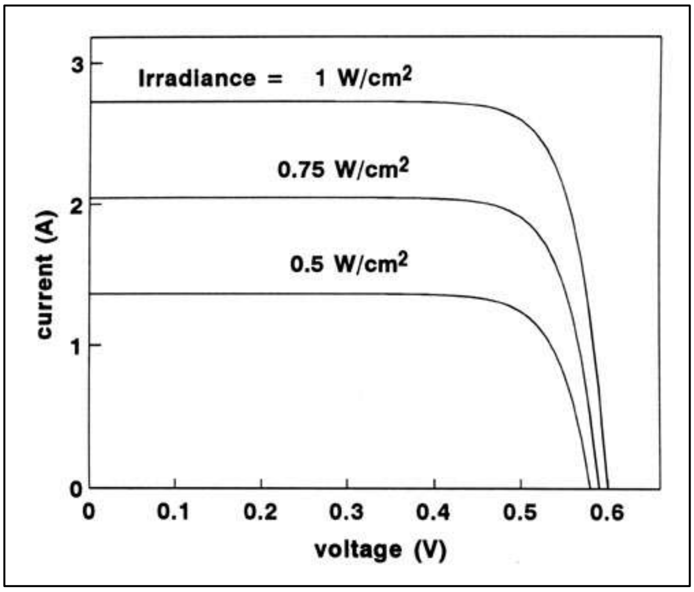


Figure 3: Effect of varying insolation on the I-V curve of a ~1.5W PV cell (adapted from [21])

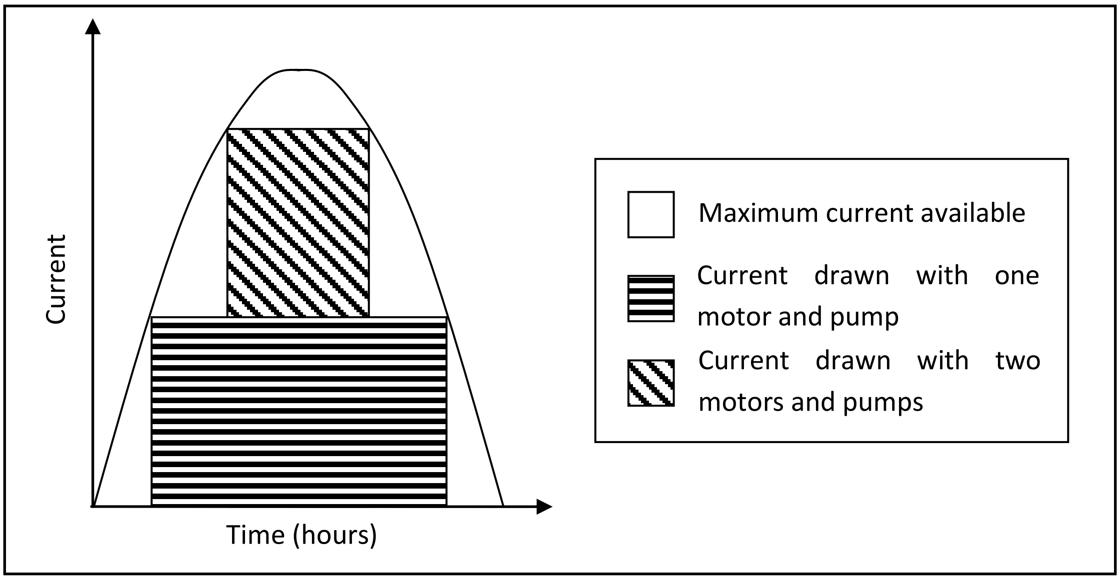


Figure 4: Approximate levels current available and demanded from proposed configurations

5. Conclusion

I hope that this provides enough information to begin with, I hope to be able to provide you with complete engineering drawings and an installation guide within the next couple of weeks. In the mean time I have also sent some additional background reading for you, I do have a lot more background information but I suspect that it is excessive at this point in time and would be of little use to you. Finally I hope you are as excited about this project as I am, it promises to undercut all other comparable solar powered rope pumps by 75%!!

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