Energy Supply System in Robotics Machines

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Abstract

This analysis is explained the energy source for working of the robotics operations and also power supplying from the source to the robotics machines. This report is evaluation, discussion and comparison of the potential source of electrical power for robotics machines due to Conventional batteries, fuel cells, ultra capacitors, and solar cells. At present, however, lithium polymer batteries are the only developed; alternatives include batteries, fuel cells and generators, thermoelectric generators, super capacitors, flywheels and even non-storage options such as tethers. Actually robot design is divided into four primary areas: energy storage, actuation, power and control, can result in severe and adverse effects on the system, such as excess weight, size, heat and operational limitations. On the bases of the physical properties of the robotics we want to provide the suitable power/energy supply systems means utilization different energy sources.

Keywords: robotics operations, Robotics Machines, Energy Supply System.

I. INTRODUCTION

An autonomous robot is an intelligent machine with the skills to moment and motion of the machine without explicit human intervention. A real-application autonomous robot must also exhibit energy autonomy; the greater the autonomy, the better. Both sorts of autonomies are required for real operative mobile robots. [1], the innovations on energy efficient technologies and renewable energy technologies are key factors to achieve the sustainable development. At the same time, the availability of novel energy efficient, energy conversion and energy storage technologies is very important to improve the usability and cost efficiency of industrial and building automation systems, robotics and electric vehicles. The intelligent energy Systems thematic strand are the research on advanced electrical technologies, renewable energy and energy storage technologies, in the scope of industrial and building automation systems, robotics and electric vehicles.[2]. Power sources are indispensable while designing robotic systems. Hence, the selection of power sources should be the primary focus owing to its impact on the mechanism, packaging, weight and size of the system. At present, batteries are more commonly used power sources. Many different types of batteries ranging from lead acid batteries that are safe to silver cadmium batteries that are smaller in volume. Weight of the robot, cycle lifetime and safety are the factors that need to be taken into account while designing a battery-powered robot.[2], with in more energy sources for motion or action of the robots as like photo voltaic cells, batteries, fuel cells, mechanical energy, air pressure, chemical fuels, thermoelectric, generators, super capacitors, flywheels and even non-storage options such as tethers. The selection of the energy source of robotics mechanism is not easy or obvious. Its should have be the energy storage medium that provides the highest power or energy density a new technology a hybrid of one source to provide satisfactory overall power and energy levels. [3], the power supply performs energy to drive the controller and actuators. It may convert ac voltage to the dc voltage required by internal circuits of the robots, or a pump or compressor its help that may be generated hydraulic or pneumatic power. In this technique there are three basic types of power supplies are electrical, hydraulic, and pneumatic. The most common energy source available, where industrial robots are used, is electricity. The second most common is compressed air, and the least common is hydraulic power. These primary sources of energy must be converted into the form and amount required by the type of robot being used. The electronic part of the control unit, and any electric drive actuator, requires electrical power. A robot containing hydraulic actuators requires the conversion of electrical power into hydraulic energy through the use of an electric, motor-driven, hydraulic pump. A robot with pneumatic actuators requires compressed air, which is usually supplied by a compressor driven by an electric motor. [4].

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II. ROBOTICS POWER SOURCES

For automation of the robotics we can used different types power source. This power sources are we can used on the bases of the size, shape and weight of the robotics machines. Its have contents more sources

A. Photo Voltaic Cells

Photovoltaic or solar cells can be used to charge the batteries of the robotic systems. They are used in conjunction with a capacitor and it can be charged up to a set voltage level and then be discharged the movements of motor. The photovoltaic cells are chiefly used in BEAM robots. These are generally consist of charges a capacitor and a small circuit which allows the capacitor to be charged up to a set voltage level and then be discharged through the motor making it move.[2]. So for batteries and/or capacitors are used as power sources. The battery supplies only a DC voltage used for the control board of a robot; the capacitor supplies AC voltage for the control of the mobility of a robot by electrical servomotors. The battery uses the capacitors to charge and to discharge energy. They have two strategies for recharging batteries and capacitors: solar panels on the robot and power stations. The main power source for the robot. Normally this system consists of a combination of switched mode DC power converters. [5]. Photovoltaic (PV) cells, generally known as Solar cells or photoelectric cells, are devices which absorb sunlight and transforms them into electricity by a method known as photovoltaic effect. PV cells are clean, renewable energy with unlimited potential.). If these solar cells are coupled with batteries and/or capacitor (usually this is a must), they can even run when there is insufficient or no light source for a few hours. BEAM robots best exploit the energy from these solar cells. BEAM is an acronym for “Biology, Electronics, Aesthetics, and Mechanics”, and BEAM robotics deals with building robots using simple components and analog circuits creating flexible and efficient robots. Some common rules for building a BEAM robot are: simple design, lowest possible number of electronic components and using energy from electromagnetic waves like heat, sunlight, radio waves etc. Amongst all the other forms of energy, solar energy is easily available and as easily be converted into electrical energy using a solar cell. If you are interested in making your own solar energy based robot, then BEAM robots are the way to go. Solar cells and panels have numerous opportunities in this field, and you can make each of your designs as unique as possible. [6]

B. Fuel cells

Fuel cells supply direct energy via a non-combustion process by directly deriving power from a hydrocarbon source at high efficiencies of up to 75%. This includes two electrodes sandwiched around a conductive electrolyte. The electrons are released from the anode in the presence of a platinum catalyst, and they are used to generate an electrical current through a load. The efficiency of fuel cells can be increased to nearly 80% by utilizing the waste heat.

Other potential power sources of robotic systems include:

- Flywheel energy storage
- Hydraulics
- Compressed gases
- Super capacitors
- Organic garbage. [2].

Fuel cells, like batteries, provide direct current through a non-combustion process. They derive power directly from a hydrocarbon source at higher efficiencies than combustion processes, up to 75%. Combustion processes typically can only extract 30-40% of the energy from such fuels. Because fuel cells are not a heat engine process, they are not limited by Carnot efficiencies. Fuel cells use gas cathodes and anodes and fuel is supplied with reactants from an outside source. Finally, the relatively new breed of metal-air batteries utilize gas (air) cathodes and solid anodes and are considered semi-fuel cells. [3]. A fuel cell (FC) is a renewable electrochemical device that directly combines fuel (hydrogen) and oxidant (air) as a means to supply pure energy. They operate with high power density and low temperatures and provide fast startup. the combining of fuel cell hybrid power system with a high energy density device (battery or ultra capacitor) to provide transient power. A hybrid power system source can have many favorable characteristics for energy conversion: high efficiency and performance, high power density, faster transient response and reduced fuel cell system volume. The diagram represents an active hybrid system, where the power distribution between the PEM cell fuel stack and ultra capacitors can be actively controlled by the different dc-dc converters. In this configuration the Ultra capacitors substitute the battery system and they are link to DC bus by means of a bidirectional converter, which is parallel to the fuel cell terminals to provide the mobile robot. A regulation strategy for active control is presented to manage the proposed hybrid system, which senses the voltages and current in PEM Fuel Cell and ultra capacitors to estimate the power flows. [3, 7].
Micro-fuel cell is a membrane that has some unique property; it is impermeable to gases but can transmit protons. This membrane acts as the electrolyte; it is located between the porous conductive electrodes. Hydrogen ions move across the membrane and the electrons released by the hydrogen thus can be used to form a current through a load. Most options promising fuel cell technologies are the Proton Exchange Membrane PEM which uses a platinum catalyst on the anode and polymer membrane in the electrolyte. Due to the dimensions of the robot and its small size, a metal hydride storage tank with a capacity of 30 litres (it's based on the intermetallic compound LaNi5), it was redesigned with object of accomplishment to prototype. A pressure regulator developed for metal hydrides was used to control the hydrogen flow from the tank to the stack. In this way, the supply pressure to the stack was fitted to 3psi (250mbars), approximately. A manual valve allows the opening or closing of the hydrogen tank. Unlike the lead acid battery, which would normally require 8 hours recharge after being fully depleted, a hydrogen tank or a 10 minutes refill has been enough to get the robot going again. A direct comparison of material energy densities used in fuel cells and batteries ignores the contributions to weight and voltage that their support system need. High purity hydrogen (99.997%) and air -oxygen- were utilized as anode and cathode supply, respectively. In this application the micro-fuel cell is composed of 14 cells connected in series (fuel-cell H30, manufacturer Horizon Company). Thereby his maximum power is 30 watts, while that the open circuit voltage (OCV) is +12.8V that is an average voltage of +0.92V/cell. Micro-fuel cell selected has total dimensions of 80 × 47 × 75mm approximately. The hydrogen is provided by a metal hydride container. This indicates that the stability and reliability of the present fuel cell stack are, to certain extent, satisfactory. PEM fuel cell will generate heat during his operation while the metal hydride will absorb heat when the system is working, the more serious part is that the fuel-cell stack will be shut down if the temperature is over 60ºC, and the metal hydride could not release hydrogen if the temperature is too low.[7].

C. Batteries
Batteries are the main component of a robotic system. Batteries can be classified into rechargeable or non-rechargeable. Non-rechargeable batteries deliver more power based on their size, and are suitable for certain applications. Alkaline batteries are inexpensive, and lithium batteries, on the other hand exhibit a longer shelf life and better performance. Common rechargeable batteries such as nickel-cadmium (NiCd) and lead acid batteries deliver a smaller voltage than alkaline batteries. They are found in battery packs along with specialized power connectors. Gelled lead acid batteries are widely used and capable of providing power of up to 40Wh/kg. Lithium-ion, nickel metal hydride and silver zinc batteries are some of the other rechargeable battery...
technologies that offer significantly increased energy density. [2]. There are a bewildering array of battery chemistries and types. In this section we summarize several mainstream technologies than have been in use for some time, and that are commercially available from several vendors. For the following sections, [3]

A battery is capable of delivering current, i.e. a continuous electron flow, because the material used to build the negative electrode releases electrons during a chemical reaction. This means that a chemical reaction is releasing electrons at the anode and another chemical reaction is consuming them at the cathode. The anode and cathode are separated by the electrolyte, whose only mission is to transport ions from one side to the other. The electrolyte can be purely liquid and which also acts as electrode separator. The material in the negative electrode has to lose electrons - this is called oxidation. The material in the positive electrode has to absorb electrons - this is called reduction. For a battery we need two chemical reactions, an oxidation and reduction pair, also called a redox reaction pair.

![Graph of Charge Characteristics](image)

**Fig. 2.3:** NiMH charging curve with three different currents.[8]

As an example: the batteries used in the FU-Fighters 2002 robotic soccer team were packs of 8 NiMH units with a nominal capacity of 2000 mAh. With these batteries the robots could be used for several hours. The size of the batteries allows them to be placed at the bottom of the robot. NiCd and NiMH batteries have a flat discharge curve. That means that the energy is extracted from the batteries and the voltage only drops significantly when the capacity limit has been reached. This is important for applications, since we would not like voltage to degrade continuously as the battery’s energy is consumed. energy is extracted at a rate of 3C, then the voltage drops slightly compared to the voltage obtained when the battery is delivering one C. The curve shows that there is no precise way of determining from voltage alone the state of the battery. The battery could be 20% discharged or 80% discharged and it would still deliver almost the same voltage and the same current. The NiCd batteries are rated at 700 and 1200 mAh. The NiMH batteries at 1600 and 2000 mAh. NiMH can store more energy per gram than NiCd batteries. Since Cd is toxic, this higher energy density and greater concreniciency has lead to a gradual substitution of NiCd by NiMH batteries. [8]
1) **How A Battery Works**

Most batteries have two terminals on the exterior, one end is a positive end marked “+” and the other end is the negative marked “-”. Once a load, any electronic device, a flashlight, a clock, etc., is connected to the battery the circuit being completed, electrons begin flowing from the negative to positive end, producing a current. Electrons will keep flowing as fast as possible until the chemical reaction on the interior of the battery lasts. Inside the battery there is a chemical reaction going on producing the electrons to flow, the speed of production depends on the battery’s internal resistance. Electrons travel from the negative to positive end fuelling the chemical reaction, if the battery isn’t connected then there is no chemical reaction taking place. That is why a battery (except Lithium batteries) can sit on the shelves for a year and there will still be most of the capacity to use. Once the battery is connected from positive to negative pole, the reaction starts, that explains the reason why people have gotten a burn when a 9-volt battery in their pocket touches a coin or something else metallic to connect the two ends, shorting the battery making electrons flow without any resistance, making it very, very hot.[9]

2) **Main Concerns Choosing A Battery**

- Geometry of the batteries. The shape of the batteries can be an important characteristic according to the form of the robots.
- Durability. Primary (disposable) or secondary (rechargeable)
- Capacity. The capacity of the battery pack in milliamperes-hour is important. It determines how long the robot will run until a new charge is needed.
- Initial cost. This is an important parameter, but a higher initial cost can be offset by a longer expected life.
- Environmental factors. Used batteries have to be disposed of and some of them contain toxic materials.

3) **Primary (Disposable) Battery Types**

- Zinc-carbon battery - mid cost - used in light drain applications
- Zinc-chloride battery - similar to zinc carbon but slightly longer life
- Alkaline battery - alkaline/manganese “long life” batteries widely used in both light drain and heavy drain applications
- Silver-oxide battery - commonly used in hearing aids
- Lithium Iron Disulphide battery - commonly used in digital cameras. Sometimes used in watches and computer clocks. Very long life (up to ten years in wristwatches) and capable of delivering high currents but expensive. Will operate in sub-zero temperatures.
- Lithium-Thionyl Chloride battery - used in industrial applications, including computers and electric meters. Other applications include providing power for wireless gas and water meters. The cells are rated at 3.6 Volts and come in 1/2AA, AA, 2/3A, A, C, D & DD sizes. They are relatively expensive, but have a proven ten year shelf life.[9]
- Mercury battery - formerly used in digital watches, radio communications, and portable electronic instruments, manufactured only for specialist applications due to toxicity

4) **SECONDARY (RECHARGEABLE):**

(Will be discussing the two most popular secondary batteries)
a) Lithium-ion Batteries:

These batteries are much lighter than non-lithium batteries of the same size. Made of Lithium (obviously) and Carbon. The element Lithium is highly reactive meaning a lot of energy can be stored there. A typical lithium-ion battery can store 150 watt-hours of electricity in 1 kilogram of battery. A NiMH (nickel-metal hydride) battery pack can store perhaps 100 watt-hours per kilogram, although 60 to 70 watt-hours might be more typical. A lead-acid battery can store only 25 watt-hours per kilogram. Using lead-acid technology, it takes 6 kilograms to store the same amount of energy that a 1 kilogram lithium-ion battery can handle. [9] Lithium Polymer batteries are the new kid on the block, having found their way into electrically-powered model aircraft in a big way. This battery technology was introduced in the late 1990s and stores less energy per pound than lithium ion but is a bit more flexible [12]. Lithium batteries offer significantly increased energy density over NiCd and NiMh technologies. Their self discharge rates are low and their weight is very low for a given amount of energy compared to other technologies. However, the volume may be as high as NiMH for a given amount of energy. Li+ is also power limited and high currents are not usually possible with this technology. [3]

Disadvantages: Begin degrading once they are created, lasting only two or three years tops, used or not. Extremely sensitive to high temperatures, heat degrades battery even faster. If a lithium battery is completely discharged, it is ruined and a new one will be needed. Because of size and ability to discharge and recharge hundreds of times it is one of the most expensive rechargeable batteries. And a SMALL chance they could burst into flames (internal short, separator sheet inside battery keeping the positive and negative ends apart gets punctured). [9]

And different types batteries:

(1) Lead Acid

Lead acid is the oldest and most mature of the battery technologies. Gelled lead acid batteries are safe, widely used and provide energy densities of up to 40Wh/kg. They also have an easily modeled linear discharge curve and a relatively long shelf life. The big drawback is that they are large and heavy relative to other battery technologies. [3] acidaid can do damage, try turning one over in your robot. I saw a single battery that accidentally got turned on its side that not only ate through a robot’s base plate, but ate a hole in the bottom of the van that the robot was sitting in. Even the vapors released when charging can do a lot of damage. Enter the sealed lead acid battery, or SLA. These batteries have the advantage of not leaking acid even if upside-down. A situation that happens in combat robotics. The term ‘gel cell’ came from the gelatinous electrolyte makeup, but designers find their weight excessive and small number of charge-discharge cycles limiting. a full-on robot battle can deplete a battery in as little as five or six minutes. Most experimenters don’t demand such a current draw from their robot’s batteries as is found in combat robotics. One might be tempted to assume that a 12V, 20 AH battery can deliver 20 amps at 12 volts for one hour, when, in fact, it is rated at one amp for 20 hours and maybe only five to six amps for one hour. The cell voltage is a bit over two volts, so six and 12 volt configurations are the most popular. A 12 volt battery typically has a no-load voltage of 13.2 volts when fully charged, and 10 volts when discharged and is replenished at around 14.7 volts. Battery chemistries vary widely and internal plate construction, venting, and other design characteristics can make seemingly similar batteries react very differently under similar charge and discharge situations. Always check the manufacturer’s spec sheets for charging and use requirements. [12]

(2) Nickel Cadmium (NiCd)

The leakage paths back through the battery are separate from the normal electrochemical charge/discharge paths, as the different self-discharge characteristics of the different chemistries show. Most batteries for portable products have low internal series resistance. NiMH, as described above, also has a low parallel leakage resistance that reduces its shelf life on a full charge. If there are long standby times between use and charging, this self discharge rate may be an important factor in technology selection. [3] At 1.2 volts per cell, 10 cells make up a typical 12V NiCad battery pack. NiCads have the advantage of lower cost, even lower than many lead acid types. They have up to three times the energy density of SLA batteries, can be charged and discharged up to 1,000 times, and are easy to fit within a small robot’s internal cavities. They do lose up to 1% of their charge per day; they exhibit what is known as the ‘memory effect’ when partially discharged and then re-charged; and they contain the toxic element cadmium which requires proper disposal. As always, go to the various manufacturers’ sites and learn more about these workhorses of the battery world. [12]

b) Alkaline Batteries

The anode, the positive end, is made of zinc powder because the granules have a high surface area, increasing the rate of reaction and higher electron flows. It also helps limit the rate of corrosion. Manganese dioxide is use on the cathode, or the negative side, in powder form as well. And potassium hydroxide is the electrolyte in an alkaline battery. There is a separator inside the battery to separate the electrolyte between the positive and negative electrodes.etc. [9]

2.3.4. Table – 1

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy density Wh/kg</th>
<th>Power density W/kg</th>
<th>Self-discharge /month</th>
<th>Cycles to 80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-acid</td>
<td>30-45</td>
<td>200</td>
<td>5%</td>
<td>200-1000</td>
</tr>
</tbody>
</table>
D. Mechanical energy

This tutorial will cover the practical applications of understanding energy with respect to robots. I do not want to lecture you on high school physics, so I will just go straight to the juicy stuff. What will make this tutorial very useful is that you can simply use the laws of physics to determine the minimal amount of energy your robot needs to perform any desired task (will help you select a battery) [10].

[a]. Potential Energy

Potential energy is the energy 'stored' within an object 'at rest'. For example, if you hold a rock in your hand, it has a potential energy of:

\[ \text{potential energy (measured in joules)} = \text{mass (kg)} \times \text{gravity (m/s}^2\text{)} \times \text{height (m)} \]

Now unless your robot is a rock, this at first appears to be useless math. Now suppose your robot were to climb a cliff, how much energy will be drained from your robot battery? Well, the energy your robot would need would be equal to the potential energy at the top of the cliff.

Or suppose you had a robot helicopter and you wanted to determine the maximum altitude it can go with a particular battery. Then you would simply reorder the equation slightly and get this:

\[ \frac{\text{battery energy}}{(\text{mass} \times \text{gravity})} = \text{maximum height possible} \]

(As like similar to mechanical kinetic energy ) [10]

E. Thermoelectric

An energy source thermo-electric is devices which are convert heat energy directly into electricity energy by action of the Seebeck effect. For power generation, the electrical current or voltage is generated by Seebeck effect in a circuit made of two different conducting materials if the two junctions are held at different temperatures. The Peltier effect is the inverse effect where in an electrical current is used to cooling or heating. This type of power production has some several advantages over other alternatives that convert heat into electricity: it has no moving parts, silent, vibration free and can be scaled/measure to very small sizes with no loss of efficiency. However, the efficiencies of thermoelectric conversion are only 5-10 percent. For power levels below a few kilowatts. [03] There is main function on off between high Seebeck coefficient and high electrical conductivity for bulk materials and many multilayer structures due to the interplay between electronic density-of-states (DOS) and electron group velocity. Also due to the shape of DOS energy curve deep inside a variate. If large barrier heights and high doping concentrations could be achieved solid-state thermionic energy converters would be able to alleviate this trade off, and

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<tbody>
<tr>
<td>Ni-cd</td>
<td>40-45</td>
<td>190</td>
<td>15%</td>
<td>500-1000</td>
</tr>
<tr>
<td>NiMH</td>
<td>50-60</td>
<td>180</td>
<td>25%</td>
<td>500-1000</td>
</tr>
<tr>
<td>Li+</td>
<td>130</td>
<td>800</td>
<td>5%</td>
<td>1200</td>
</tr>
<tr>
<td>Ag-Zn</td>
<td>140-200</td>
<td>100-330</td>
<td>4%</td>
<td>100-250</td>
</tr>
<tr>
<td>Ag-Cd</td>
<td>55-95</td>
<td>100-220</td>
<td>4%</td>
<td>300-500</td>
</tr>
<tr>
<td>Zn-Air</td>
<td>200-300</td>
<td>80-100</td>
<td></td>
<td>N/A</td>
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<tr>
<td>Al-Air</td>
<td>350</td>
<td>500-600</td>
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<td>N/A</td>
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achieving a very high thermoelectric power factor. The electron transverse momentum perpendicular to heterostructure barriers must not be conserved. A comparison between thermoelectric/thermionic devices and thermo photovoltaic energy converters shows a difference in the average energy of the emitted hot carriers due to the difference between electronic and photonic density-of-states in the reservoirs. [11] Thermoelectric generators do not have high specific power or specific energy. Global Thermoelectric, for example, manufactures a model 5015 unit which can supply 15W at 12 or 24VDC, but it weighs 21 kg, without fuel, resulting in 0.7W/kg, but larger units such as their 8550 can provide 550w in 103kg giving over 5.3 W/kg. The consumption of Propane for the 5015 is about 1.1 kg/day (2 liters) of operation. [11]

**F. SUPERCAPACITORS**

Super capacitors are employed in electrical circuits to energy stored as a charge built up on plates separated by a dielectric material. Super capacitors may be say ultra capacitors, because

Provide very high energy storage as compared with conventional capacitors used in electronics. Supercapacitors can be created high-power, low-energy batteries. Its satisfies average power demand and the super capacitors handle relatively of short duration power peaks during acceleration, regenerative braking, and hill climbing. This arrangement can provide improved performance, increase overall efficiency, battery life, And energy storage in the battery and lower life cycle costs. [3]. Ultra capacitor can be discharged or charged faster than batteries -in matter of seconds it can be recharged again for use- and can deliver 10-25 times more power e.g. UCaps typically have a specific power of around 2000W/kg , as well as a much lower charge time when compared to lead-acid batteries. Double-Layer Capacitor also offers 10-100 times the energy density (Wh/kg) of conventional capacitors. In terms of energy and power density, ultra capacitors can therefore be placed between batteries and conventional capacitors. [7]

Fig. 2.6: A chart storage device energy density versus power density on a log-log coordinate system, with discharge times represented as diagonals.[7]

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