

# Hypertension Detector for Developing Countries

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**Abstract— For low-income countries, hypertension is the leading cause of death. Preeclampsia, a disorder often characterized by high blood pressure, is the second leading killer of pregnant women globally. Preeclampsia can be treated cheaply and effectively but very few women receive appropriate prenatal care. There are many different devices to measure blood pressure but they are poorly suited for use in developing countries. Great care has to be taken to engineer a device that incorporates the human-factors involved while maintaining affordability. A prototype of a low-cost device engineered specifically for semi-literate volunteers in developing countries has been created. Preliminary testing has shown reliable hypertension detection and plans have been made for field testing in rural communities this August 2010 in Nepal.**

Global health care needs vary largely with the income level of the country so it is difficult to generalize what the biggest problems are worldwide. Consistently, countries with lower incomes have higher mortality rates; however the most fatal disorders differ with income level. For developing countries, high blood pressure is the leading cause of death [2]. While it may be challenging to combat the causes of death directly, identifying the risks appropriately and dealing with those problems will have a large impact on preventable deaths.

According to Gaziano et al, suboptimal blood pressure can have a severe economic impact. Healthcare costs due to blood pressure problems have been estimated to be upwards of \$370 billion or 10% of the world's healthcare expenditures in 2001. Over a 10-year period, suboptimal blood pressure has been predicted to cost nearly \$1 trillion globally with indirect costs reaching \$3.6 trillion annually [3]. High blood pressure incurs costs far beyond that of the medication used to combat it. Hypertension often leads to more complicated conditions such as heart disease which may demand expensive treatment or surgery. In developing countries, very few people are even screened for suboptimal blood pressure. This is due to the downfalls in the design of the devices currently available, and the amount of training that is often required to operate them.

## I. INTRODUCTION

One of the biggest disputes in the government right now concerns the astronomical deficit generated primarily by health care. The United States spent more than \$2.3 trillion on health care in 2008 according to the Kaiser Family Foundation, and it does not appear to be slowing down anytime soon [1]. In addition to tightening the reins on wasteful spending and changing health insurance policies, it is necessary to find innovative new solutions to these very expensive problems. Luckily, the investigation for low cost solutions can be greatly beneficial for people in developing nations who face similar problems with excessive spending.

One example of a disorder that is receiving a lot of press and funding recently is preeclampsia. Preeclampsia occurs during pregnancy and the postpartum period, and can have negative effects on both the mother and the unborn child. It is the second largest killer of pregnant women; characterized by proteinuria (protein in the urine), and hypertension (systolic blood pressure greater than 140mmHg or diastolic blood pressure greater than 90mmHg). After onset, there is typically damage to the mother's liver, kidneys, and endothelium in addition to vasoconstrictive factors being released which account for the increase in blood pressure. Preeclampsia refers to a set of symptoms rather than an underlying cause, which makes it relatively easy to screen for with the appropriate tools. Preeclampsia is very treatable through the injection of magnesium sulfate, which is both cheap and effective. But this relies on an accurate and early recognition of the disorder [4]. Extremely few mothers die from preeclampsia in developed countries where prenatal care is very common. Unfortunately, very few women in developing countries receive the appropriate prenatal care required for diagnosis.

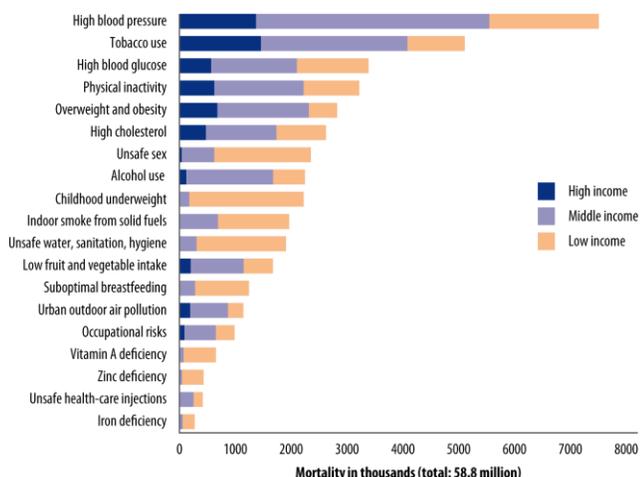


Figure 1 Mortality for countries at different income levels by cause [2]

## II. METHODS/DESIGN

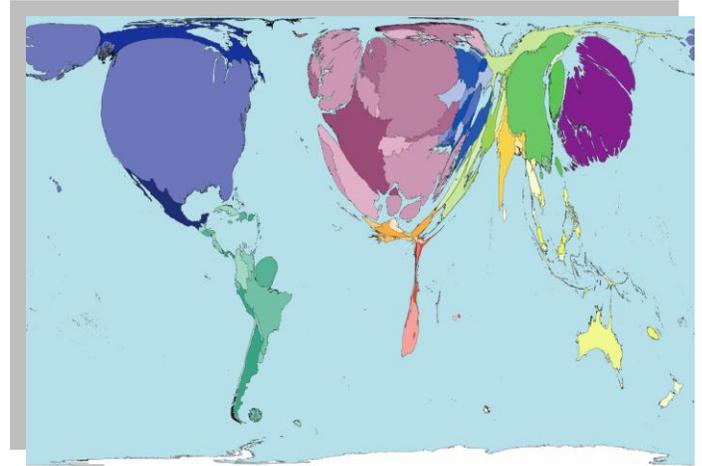
### A. Need

There are many devices to measure blood pressure with varying functions and price tags. However, these are poorly suited for use in developing countries. Great care has to be taken to engineer a device that incorporates the human factors involved while maintaining affordability. Through collaboration with JHPIEGO, a non-profit affiliated with the Johns Hopkins University, certain needs have been isolated to ensure that the device will be readily accepted in the field.

Aside from being able to detect hypertension, the device must be user-friendly. According to the World Health Organization, over half of the births in Africa and Southeast Asia were not attended by skilled health personnel and over 40% in the Eastern Mediterranean region were conducted without professional guidance [5]. This means that the device for detecting hypertension will be used by a semi-literate community volunteer who may not be able to read/interpret systolic and diastolic measurements. Additionally, training and user-input should be minimized in order to limit possible errors. JHPIEGO has requested the device be operable in one step and that the user should be able to go from training to competency in under one hour.

It is important to note that the testing will be done during visits to the homes where pregnant women live. Women in deeply conservative societies will be unwilling to expose their upper arm to a volunteer to allow the application of a typical blood pressure cuff. It has been recommended that a wrist cuff or finger-unit be incorporated with the design in order to limit these complications. Additionally, most homes in isolated villages have very limited power supplies. A system that requires a power outlet will never be adopted by the healthcare workers in the field. The device must utilize batteries or an alternative source of power in order to maintain mobility.

Finally, since the device is intended for developing countries such as Africa, Southern Asia, and the Middle East, certain design elements must be handled carefully. Figure 2 illustrates the countries of the world with territory sizes drawn proportionally to how much public spending goes towards healthcare. While the spending on public health services per person (PPPUSS) for North America, Western Europe, and Japan is well over \$1600, everywhere else it is less than \$400 and often far less [6]. It is important to engineer the device cheaply and robustly so that countries can afford to buy these and be confident that they will survive extreme climates in addition to exposure to dirt, falls, and water.

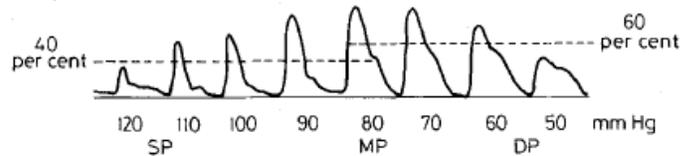


**Figure 2 Countries of the world with territories drawn proportionally to spending on public health [6]**

### B. Solution

The Hypertension Detector for Developing Countries proposed in this paper has taken into account the above design criteria and is a working prototype appropriate for these unique needs. All the design elements have been discussed and approved with JHPIEGO and optimized for use in developing countries by volunteers with minimal training.

First, in order to reliably detect blood pressure, the oscillometric method has been utilized. According to Sapiński, et al. blood pressure can be determined by inflating the cuff to a high pressure and monitoring the pressure oscillations that occur with each heart beat as the cuff slowly deflates. By keeping track of the pressure corresponding to the largest oscillation (representing the mean arterial pressure), the systolic blood pressure can be determined by checking what the pressure was directly before the oscillations increased above 40% of this height. Similarly, the diastolic blood pressure is computed by finding the pressure at which the oscillations have decreased to 60% of the max as shown in Figure [7].



**Figure 3 Standard algorithm for the oscillometric method of blood pressure measurement [7]**

In addition to the implementation of this algorithm in the software of the microcontroller used in the device, there is signal processing of the pressure sensor output. First there is DC filtering to bring the signal down to oscillations around 0 volts. Next there is amplification so that these oscillations are easily recognized by the analog to digital input ports of the microcontroller. In conjunction with appropriate signal filtering, a very robust signal can be acquired. A circuit

diagram in addition to a flow chart summarizing the software algorithm can be found in the appendix.

Once blood pressure can be reliably calculated, human factors were taken into account. Rather than spending money on an expensive LCD screen to portray exact numbers that may be difficult to interpret, the microcontroller will classify the blood pressure as hypertensive or healthy and display a binary red/green LED feedback. To limit user error, the process has been reduced down to simply turning on the device, inflating the cuff until a yellow LED lights, and waiting as the cuff automatically deflates. Once the microcontroller has calculated and interpreted the results, there will be LED feedback to let the user know if the mother is fine or needs to report to a hospital/local clinic for further testing and treatment.

Since the device is intended for use during a trip to a woman's home by a volunteer, a wrist cuff has been utilized to comply with conservative cultures. Moreover, wrist sizes will be more consistent from patient to patient compared to upper-arm sizes which are highly variable. Since power can be hard to come by in developing countries, an alternative solution has been developed.

Batteries are often expensive and have limited life. The same is true even for rechargeable batteries which are typically even more expensive and harder to come by if a replacement is needed. While enough energy can be harvested from the sun to power the system, solar cells are relatively expensive for their efficiency and are too fragile. Instead, a crank charger like those found in crank flashlights or radios has been incorporated in conjunction with a super-capacitor. The crank is more robust than solar panels and provides more than enough energy. A partially-charged super-capacitor can be fully charged with merely twenty seconds of cranking. Additionally, the super-capacitor has the advantage of being cheaper than batteries while supporting far more charge/discharge cycles. The crank-charging system will be able to provide power for the entire life of the device in even the most remote parts of the world.



**Figure 4** Examples of different power options suitable for developing countries: batteries, cranks, and solar panels

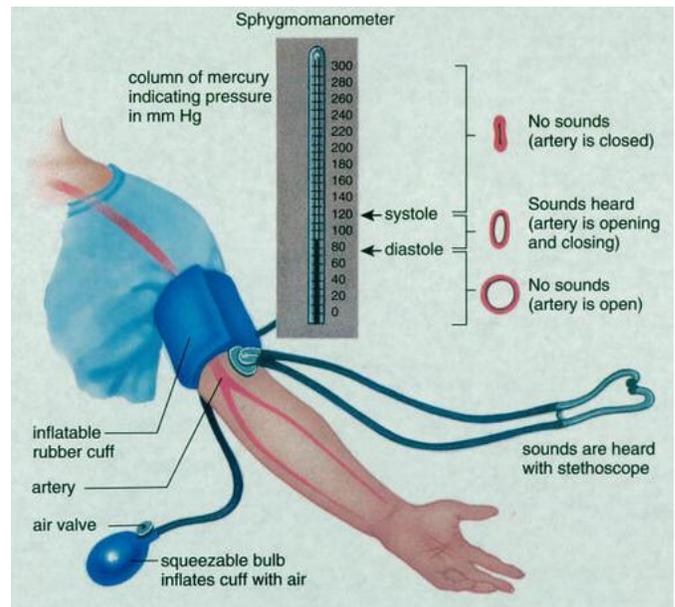
### III. RESULTS

In order to illustrate the advantages of the new system, a thorough comparison must be made against what is currently

on the market. For a number of reasons, the new device satisfies developing countries' needs in ways that intra-arterial measurement, sphygmomanometers, assorted automatic blood pressure devices, and proteinuria measurement cannot.

Intra-arterial measurement is the act of inserting a catheter equipped with a pressure sensor on the tip directly into the blood stream. While this can be highly accurate, extensive training is required to operate the expensive recording equipment necessary [8]. Additionally, this is highly invasive and not appropriate for a volunteer visiting a patient's home due to sterility and power needs.

Sphygmomanometers are a very portable and low-cost method for measuring blood pressure. They require no power but extensive training is necessary to be able to interpret the sounds heard through the stethoscope. As the cuff is gradually deflated by a manually controlled air valve, Korotkoff sounds appear and disappear at the systolic and diastolic pressure respectively [9]. Great care must be taken to deflate the cuff at the correct rate (2-3mmHg). While these kits are relatively affordable, it is unreasonable to expect a large number of volunteers to become expertly trained in this skill.



**Figure 5** Measurement of blood pressure with a sphygmomanometer [9]

There are a wide range of different automatic blood pressure systems currently on the market. These operate in a similar fashion to the proposed device but lack key design elements that keep them from being accepted for wide use in developing countries. Most devices are powered by batteries which have numerous drawbacks as detailed previously. They are also quite expensive with the cheapest costing \$20 and of poor quality, while units with more functionality can cost well over \$100. There are numerous features such as

memory, heart rate calculations, and irregular heartbeat detection that are confusing and increase the cost of the device. In fact, very few devices have a hypertension detection feature which is the most important for our application. Some devices boast automatic inflation and deflation to minimize user input but these implementations are power-hungry and can easily be replaced with a manual inflation pump in conjunction with a leaky valve.

One example of a blood pressure device that has tried to focus on the needs of developing countries is the Microlife 3AS1-2 [10]. The device is battery-powered (with a solar-power charger being developed), but still displays the results on an LCD screen for interpretation. At \$30, it is three times the desired cost put forward by JHPIEGO and would most likely fail to be accepted by the users it is targeting. No thought has been put into engineering a device that is easy to use and interpret. For example, it is unclear how much inflation is needed to ensure accurate results. Additionally, the current upper-arm cuff it utilizes would be difficult to dispatch to volunteers for screening purposes due to certain cultural problems.



**Figure 6 The Microlife blood pressure device for use in low resource settings [10]**

In addition to hypertension, preeclampsia may be diagnosed by the presence of proteinuria. As an indication of early renal damage, a cheap way to determine the presence of dangerous levels of protein in the urine would work well in conjunction with a blood pressure device as a screening tool [11]. Machines costing upwards of \$700 are available with reflectance photometers used to analyze the color and intensity of the light that reflectin off the reagent area of proteinuria strips. The data from the machine must then be interpreted. This requires training in addition to funds with which to purchase such a machine, along with electricity to power it.

A more reasonable approach is the dipstick currently under development by JHPIEGO. Proteins in solution will interfere with a dye-buffer combination causing a display panel to transform from yellow to green [12]. This color-

coding provides a way for volunteers to easily interpret results. Additionally, this can be very portable as no power is needed. Currently at \$1 per use, the main drawback is the cost. Since blood pressure devices can be reused on hundreds of patients, the cost per use is far less. Until the price is further reduced, an affordable blood pressure device remains the better option.

Device	Detect Hypertension	User-Friendly	Respect Culture	Developing Countries	Price
New Design	yes	yes - gives binary result and user only needs to inflate cuff	yes - used on the wrist	yes - crank power	less than \$10
Intra-Arterial	yes	no - requires extensive training	no	no - requires sterility due to invasiveness and an outlet for the measurement device	expensive
Korotkoff Sounds	yes	no - requires extensive training	no	yes - no power required	\$15 for a kit
Complete Care BP System	yes	yes - has hypertension indicator	no	no - battery-powered	over \$100
Microlife	yes	no - user has to interpret results	no	yes - solar power charger is being developed	\$30
Gitway Inc BP Monitor	yes	no - user has to interpret results	yes - used on the wrist	no - battery-powered	\$20
Preeclampsia Dipsticks	yes	yes - color coded	yes	yes - no power required	Around \$1 each

**Figure 7 How different preeclampsia screening devices compare**

#### IV. DISCUSSION

In conclusion, not one of the methods or devices currently available is appropriate for preeclampsia detection in developing countries. A table comparing each device and how well it satisfies the needs of the project is shown in Figure 7.

Our proposed device is capable of accurately detecting hypertension according to the oscillometric algorithm as used in most automatic blood pressure systems. However, it is far more user-friendly due to the reduced number of steps required for use and the binary result feedback. All the user must do is turn the crank until the green LED lights, pump until the yellow LED lights, and wait while the device automatically deflates and calculates the blood pressure. A red light indicates: go to a hospital/local clinic while green indicates: normal blood pressure. The wrist cuff included with the device accounts for conservative cultures while the crank eliminates any power supply issues.

All of this for \$15 manufacturing costs results in an elegant solution for an unmet global problem. Moreover, the device is designed in a modular fashion. Any available cuff, inflation bulb, or tubing, can be connected or disconnected via a universal port. It is important to note that many countries support the use of crank powered flashlights and radios. If the crank were to fail, it could easily be removed and replaced with only the attachment of two wires. This can be completed by a local worker with basic electrical knowledge. There is no need to completely replace the device or send it back to a developed country if certain parts

fail. As a first prototype, this device shows terrific potential to have an impact on the lives of many mothers and infants all over the world.



**Figure 8** A photograph of the new device. Of note are the power crank and LED feedback

Further work continues for the improvement of the device. It will soon require only a single step to use. With the implementation of battery power in conjunction with a crank backup, the user would simply start pumping the inflation bulb which would wake up the device. Next, an LED will alert the user when the cuff has been sufficiently inflated and the microcontroller will automatically determine the blood pressure, and give binary LED feedback as before. Now that the device has been shown to work at low cost and low-power, the focus has been shifted to human-factors. In addition to ease of use, more care will be taken to improve the robustness of the device. It will be water-proof in addition to shock-proof so that it can survive if a flood or drop occurs.

Great interest has been shown in the development of this device towards large-scale manufacturing. JHPIEGO has estimated a need of nearly 10 million of these devices and field testing in rural communities has been planned for August 2010 in Nepal.

## V. REFERENCES

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V. APPENDIX

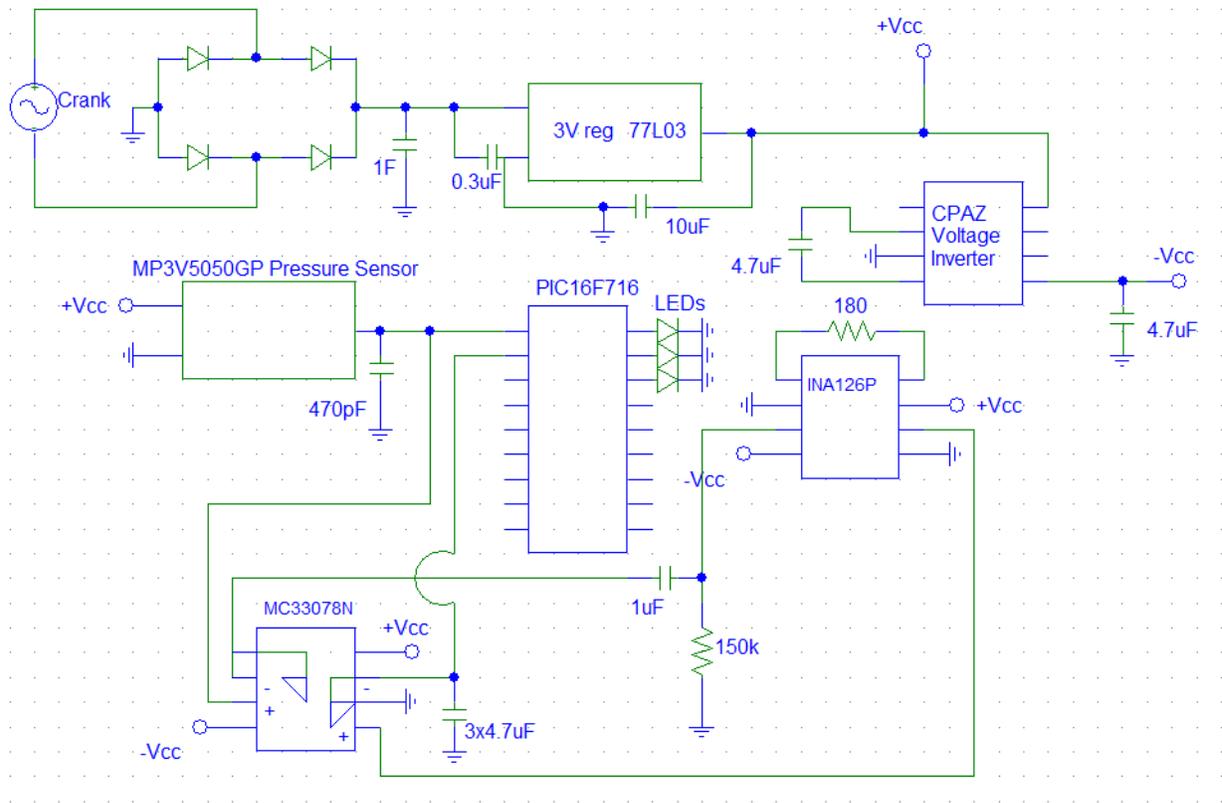


Figure 1 Circuit Diagram

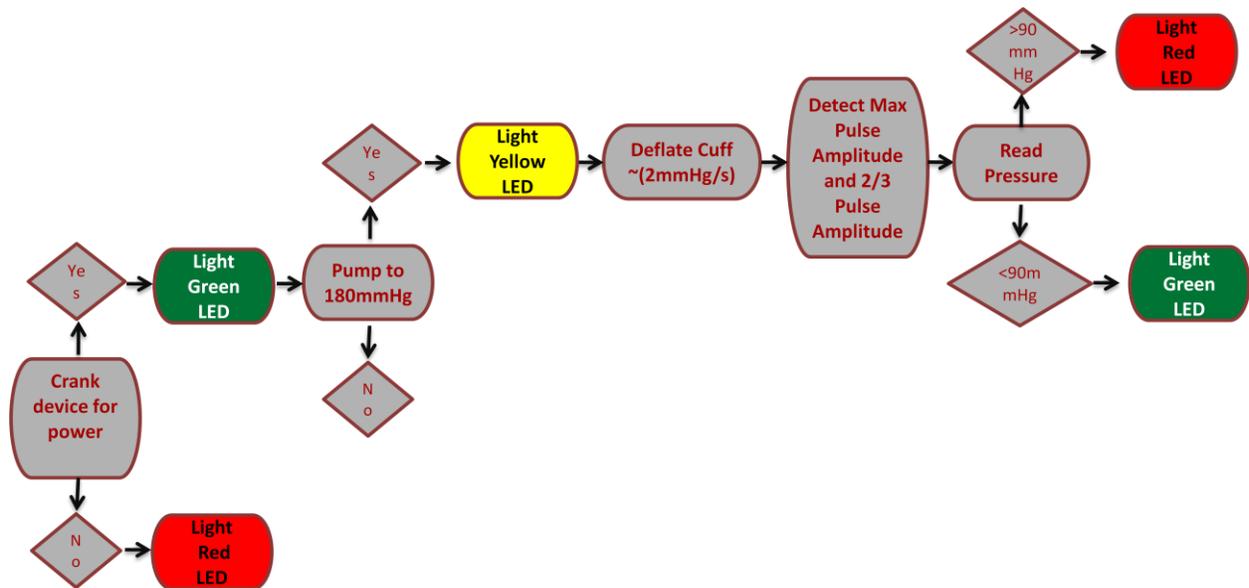


Figure 2 Algorithm Flow Chart