

**A wireless positioning measurement system based on Active  
Sonar and Zigbee wireless nodes**

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## **Abstract**

3D games being ubiquitously popular and the cost of Zigbee modules as well as microcontrollers being increasingly cheaper; it is our argument that a wireless positioning measurement system that could be applied to a desktop model or to a human being would be useful and interesting. Ergo, we propose a system that will use active sonar to track the motions of a human-like model or an actual human and consequently translate these movements into 3D coordinates for use in software animation.

## **Introduction and Motivation**

3D games and animation has become one of the most popular forms of modern entertainment. Hours and hours have been spent in both making these products and enjoying them. However, controlling these 3D simulations in either development or in game play has always been a problem. High end studios can afford to use expensive motion capture systems to create somewhat realistic simulations. Even then, they are forced to hand adjust key frames to make it look correct. Home producers must start from scratch and build up. Furthermore, game play is limited to a few limited animations for the character based on decoding key presses on a controller.

A simpler, cheaper motion capture system would be ideal to improve on these problems. 3D animators could build miniature models that they could use to control the “bones” of their 3D figures. Game players could move their characters by moving themselves. It would even allow movement toward complete VR system.

## **Project Stretching**

If possible within the time constraints of the project, the team will make the system such that it is accurate to more than 3m. The individual nodes will be no more than 1cm<sup>3</sup> and will be mm accurate. Furthermore, the nodes will be able to be sampled at real time speeds, such that they can be used to control more complex 3D models in games and animation applications.

The team will attempt to build more nodes and construct a full body suit type set up, such that a person can move in real life and have their 3D avatar move in a simulation. Also, a construction could be composed to allow a user to build physical skeletons used to animate the bones of their 3D characters in animations situations.

Furthermore, where possible it will be attempted to implement Zigbee wireless. The ideal solution would be a Zigbee mesh network where every transducer and receiver can send its ancillary information directly to the Receiver Controller. This ancillary information is that which is necessary to

keep the system running and not the actual sonar signals being sent from the emitter to the receiver.

## **Project Tasks**

This team will construct a wireless position measurement system that can be used to capture the position of physical objects relative to a reference point. These measured positions will then be supplied to a computer to be used in a selected 3D application to position simulated objects. The system is composed of three major components: a command module, a transmitter array module, and a series of receiver nodes.

The command module, as its name implies, directs the rest of the system components. It will be composed of a microcontroller with built in zigbee and IC2 serial capabilities. It will handle finding and adding new receiver nodes to the system. Also, it will poll these nodes to find out the data that they measure as they receive. It will also direct the transmitter about which transmitter should be broadcasting. It will forward the current transmitter to the receiving nodes as well. Finally, it will be connected to a computer via a USB interface that it will use to relay the measured data from each receiving node.

The transmission array module will also be base on a zigbee implementing microcontroller. It will receive data from the controller module and use this data to determine which transmitter to turn on and off. It ideally will have some calibration routines as well to make sure the system as whole gets more accurate readings.

Finally, the series of receiver nodes will a disconnected set small, less than an inch cubed volume, wireless nodes. They, like the other two components, will be based on a microcontroller with built in zigbee. This will be interfaced with a receiver to take measurements from the signal of the currently transmitting transmitter.

It has been decided that a sonar system will be the most practical. The receiver would then be a sonar receiver (aka high frequency microphone), the nodes as a whole would have a synchronized counter. The individual receiver nodes would take a time stamp at the reception of each sonar transmission. These time stamps would then be collected and then divided by the current speed of sound to yield distance to the currently transmitting transmitter.

The data will be collected and transmitted to the computer. The distances will be calculated and then translated to an x, y, and z coordinate system by software running on the computer. This data will then be used in a desired application on that computer.

## **Project Base Line**

For the base line of the project, the team will construct the individual receiving nodes such that they are less than one cubic inch in size. Furthermore the system will be accurate to at least 2 cm when measuring distances out to at least 3m. The team will also interface with or construct a simple 3D program to move objects in that program according to the current position of at least two different nodes.

## **Hardware Design**

A passive SONAR system will be used to bring this project to life. Sonar is a good choice because of the accuracy that can be achieved with ultrasonic waves. Companies like Olympus use ultrasonics for thickness gauging and can achieve distance accuracies on the order of, +- 0.002mm - +- 0.1mm.

The system will consist of multiple targets and multiple receivers. The targets will propagate the sound wave and the receivers will receive the sound wave. It will be necessary to synchronize the transfer and receiving of signals to an oscillator. This synchronization will most likely be done with a wireless signal. The receivers will need to know when the signal was sent and which target sent the signal.

With this information the Distance can be calculated using the Equation 1.

$$D = V_s * (T_{\text{propagation}})/2 \qquad \text{Eqn 1.}$$

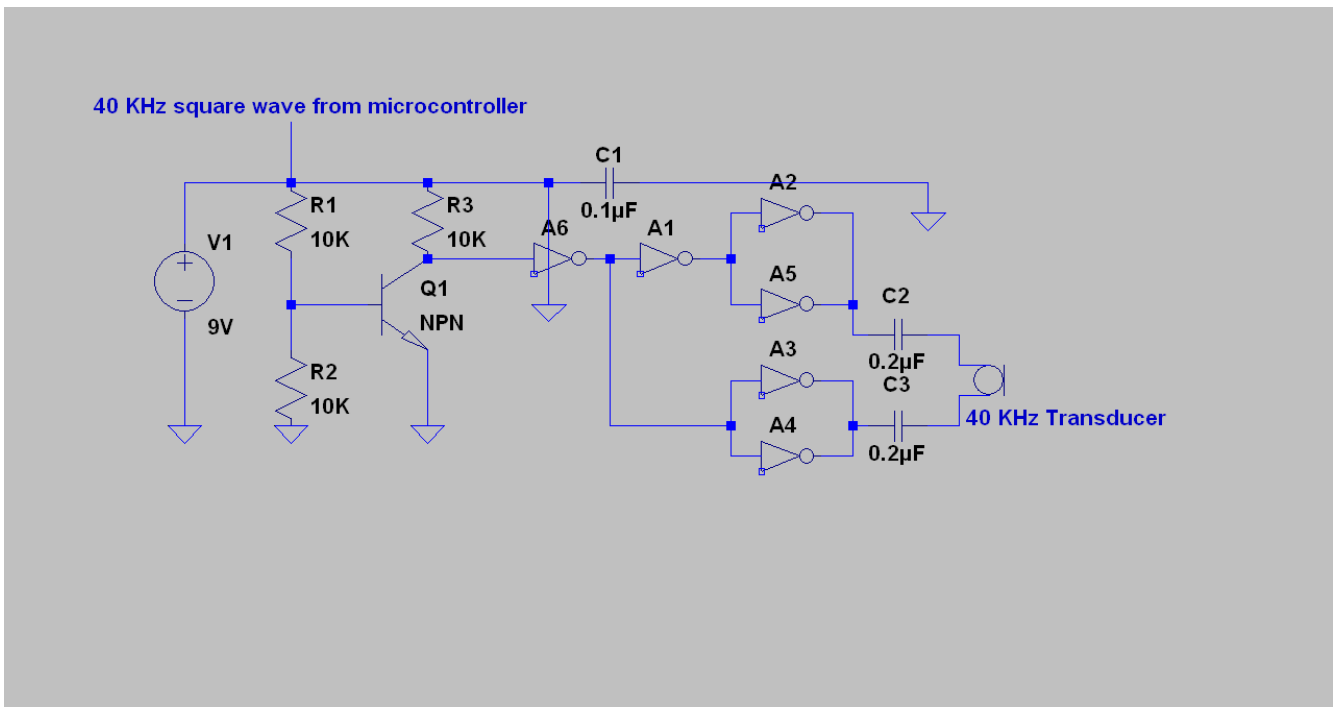
Where:  $V_s = 340 \text{ m/s}$  -is the propagation speed of acoustic waves in air, and;  
 $T_{\text{propagation}}$  -total propagation delay of acoustic waves.

To get the exact position of each target it will be necessary to triangulate the position with an array of receivers. Hopefully these receivers can be placed into an array with a small footprint.

The targets will be placed on the limbs of the skeleton, on the arms, head, legs, etc... Each target will consist of a piezoelectric element which is excited by a short electrical impulse to generate a burst of ultrasonic waves. It will be necessary to use waves above 20 Kilohertz (the upper threshold of human hearing) so as to not be annoying, and below the Megahertz range due to the inefficient propagation of waves of this frequency through air.

The targets will need electrical power and they will need to be synchronized with a clock or an oscillator. There will need to be some duty cycle hardware (Model Controller, MC) on the model which activates each target (sending power to the piezoelectric element) and does this according to a clock where each target has a time slice to send its signal. This hardware will have a power source, preferably a rechargeable NiCad battery or something similar as well as a wireless module that will be used to synchronize with the receivers through a receiver controller.

In Figure 1 we see a possible hardware design for the target (emitter). We will be using the CSM12C32 [1] microcontroller (MCU) from Freescale Semiconductor. The MCU will most probably be located near the desktop model or on the human model and will be connected to the emitters via wires. With the wires we would be able to power each emitter through the wires and thus eliminate any batteries. If we have the time and resources we will get rid of the wires and instead use a Freescale MC13213 [2] for each emitter. The MC13213 [2] is a Zigbee node and MCU in one package. In the wireless scenario we would need to power each emitter/MC13213 [2] combination with a battery.



**Fig. 1 Emitter (Target) Schematic**

In any case we would need to send a 40 KHz square wave to the piezoelectric transducer so that it can propagate its sonar signal. This 40 KHz square wave could be produced by the microcontroller using input capture and output compare.

With the wireless scenario the emitter/MC13213 [2] combo would be able to communicate directly with the Receiver Controller to get its commands. In the case of the wires each emitter would be connected to the CSM12C32 [1] which would then communicate with the Receiver Controller on behalf of the emitter.

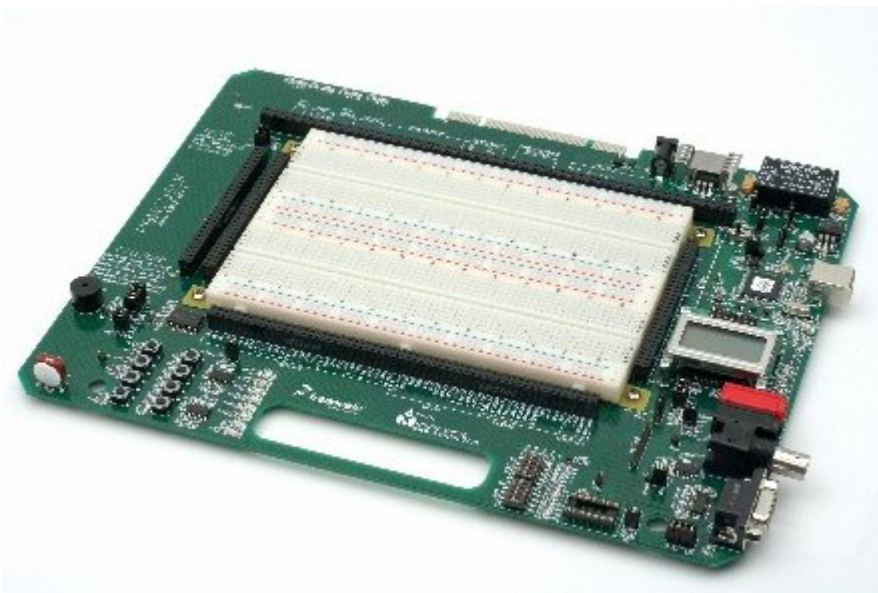
To simplify our arguments we will assume for now that we will be using the wired model. We will be using the CSM12C32 MCU in conjunction with the MCU PROJECT BOARD -2 [3] which is a prototyping board with microcontroller interface. We will have two of these combinations, one for the Receiver Controller and one for the Model Controller. These units will communicate wirelessly using either Zigbee technology or the IEEE 802.15.4 Wireless Standard [4]. To communicate wirelessly between the Model Controller and the Receiver Controller we will also be using the MC13192U [5] which is a 2.4 GHz (ISM) band transceiver. The MC13192U [5] will use SPI (Serial Peripheral Interface) to communicate with the MCU via project board connections. The wireless module, MCU and project board can be seen in Figures 2, 3 and 4 respectively.



**Fig. 2 MC13192U Wireless module**



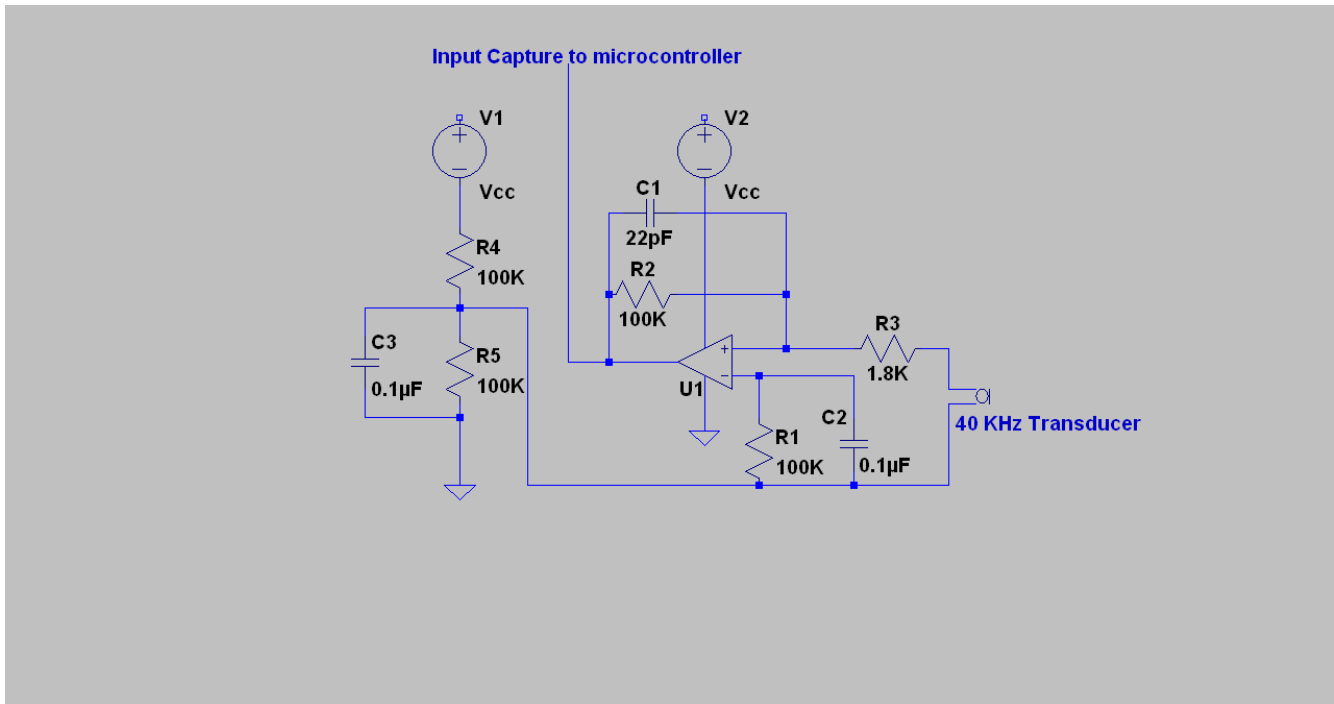
**Fig. 3 CSM12C32 MCU**



**Fig. 4 MCU PROJECT BOARD-2**

The Receiver Controller (RC) will be in charge of gathering the electrical signals received by the receiver array. These signals will come in according to a time schedule that will be sent wirelessly to the hardware on the model. This time schedule will be determined by the RC. The incoming signals can either be processed by the RC, which will probably be a microcontroller similar to the Motorola 6812, or they could be sent directly to the computer via a USB interface to be processed by software on the computer.

The following hardware schematic is a possible solution to the ultrasonic receiver. You can see in Figure 5 that an input capture could be used every time a signal is received. When this signal is received a time stamp would give the elapsed time from emitter to receiver and using triangulation we will be able to determine the position of the emitter in relation to the model.



**Fig. 5 Receiver Schematic**

There are number of different transducers that we could use; the transducers that we will start with are the 40KT08 [6] and the 40KR08 [7] from SensComp. They are within the 40 KHz range that we are looking for.

## Software Design

There will be three major pieces of Software for our system to work properly.

1) The first piece of software will be on the PC and it will get the data from the Receiver Controller (either preprocessed or not). It will then put this data into a format that a third party software package can use to build our 3D model along with it's time bound movements.

This software could possibly be implemented in C# since C# is a much more user friendly interface for application programming. It will be on the highest level of abstraction of the three pieces of software.

2) The second piece of software will be that running the Receiver Controller. This software will need to use a timer to schedule the propagation of ultrasound by the various targets on the model. It will need to relay this information wirelessly to the model then it will need to wait to receive the signals. Once the signals are received in their order they will need to be sent via USB to the computer. The data can either be processed (triangulated) here or sent to the software on the PC.

The software on the Receiver Controller will need to interface the MC13192U [5] wireless module with the CSM12C32 [1] MCU using a Serial Peripheral Interface. It will need to gather data from all the sonar receivers and will most likely use input capture to put a time stamp to the signal



received. This software will be a low level implementation in C. It will also be necessary to implement a USB interface with the host PC.

3) The third piece of software will be on the Model Controller and will need to receive the wireless signal, interpret it and then activate the target transducers. Again, the software on the Model Controller will need to interface the MC13192U [5] wireless module with the CSM12C32 [1] MCU using a Serial Peripheral Interface. It will then most likely use an output compare to send the 40 KHz square wave to the emitter circuit. This software will also be low level written in C.

## **Specific Task Interfaces**

Important interfaces include but are not limited to:

1) MC13192U [5] wireless module with the CSM12C32 [1] MCU. This will be an SPI interface as discussed above. The code will be low level C. These issues will reside on the Receiver Controller and the Model Controller.

2) CSM12C32 [1] MCU and the host PC. This will be a USB interface and will be low level C.

3) Receiver Controller to Model Controller. This interface will be implemented using either Zigbee or the IEEE 802.15.4 Wireless Standard [4]. This will be low level C.

4) CSM12C32 [1] MCU to sonar circuitry. This interface will be low level C using input capture and output compare.

5) Potential interfaces would exist if we were able to go fully wireless. In this case we would have something like the MC13213 [2] which are an MCU and a Zigbee radio in the same package. These units would have to interface with the sonar circuitry as well as with the Receiver controller. In this case the Model Controller would be eliminated.

## **Testing and Integration Strategy**

Of course the overall strategy is to complete the project but we can break this overall goal into specifics.

- 1) Obtain all hardware components. Completing this first task will then give us the impetus to get the project done. In the meantime we will continue research to make sure that our idea is indeed feasible.
- 2) Establish wireless communication between the Model Controller and the Receiver Controller.
- 3) Build and troubleshoot the sonar circuits then interface them with the Model and Receiver controllers.

- 4) Throughout the process the Software pieces will be built to facilitate interfacing.
- 5) Get the USB interface from the MCU to the host PC working.
- 6) Develop the higher level software that will do all the data crunching on the PC then send this data to the third party 3D software.

## **Group Management and Communication Plan**

It will be necessary before the summer to delegate specific tasks to individual group members. Communications will probably be via email and the occasional group meeting when a particular task of interest has been completed or integration needs to take place.

We will also need to maintain the web updates with our progress on a regular basis so that we can keep tabs on one another and make sure that we do not fall behind schedule.

It is 3:15 A.M and I am really tired [9] so this paragraph is here simply to fill up some more space so that we can get our report closer to 20 pages. Dangit! We are still 8 pages away from perfection.

## **Schedule and milestones**

The following is a list of tentative dates for the project flow to completion. They may be modified as they are encountered. Of course we will not work in serial mode but we will multithread our thought process and hopefully with the hard task above as a goal we can converge (don't you love calculus).

May 1 – make ideas concrete through research.  
May – August – Perform task 1, 2 and 3 above.  
August 15 – all individual components constructed  
September 1-decide on application to implement  
October 1- Complete tasks 4, 5 and 6  
October-November- optimize and improve

## **Risk Assessment**

The risk of the learning curve can never be underestimated. Fortunately for us we have all taken the embedded systems course and so are familiar with Freescale products.

The highest risk is the fact that we know little about sonar electronics and so each circuit will need to be tested and for these tests we will need access to equipment. There seems to be documentation and reports of people implementing sonar systems, in particular a report by Texas Instruments at the following link. [8] <http://www.focus.ti.com/lit/an/slaa136a/slaa136a.pdf>

The sonar system will add more components to the overall system, but distance with sonar is a simple matter of time of arrival measurements at the outlying nodes. As long as the clocks are kept in

sink, this would be to keep the node clocks in sync with a global clock. This is a common constraint in wireless system however, and would be easily implemented. Components that do sonar range finding are available and reasonably priced.

There is also low risk in the system as a whole, as the Team has not used zigbee before. This seems to be fairly low risk, as there is much documentation and examples to base zigbee systems on.

In addition there is medium risk in meeting the size goals for the receiver nodes, as the system may require more space. The base line however can be adjusted before final proposal to reflect actual components. Components of appropriate size seem to exist however, and so this seems a medium risk.

## **Tentative Task List**

Tentatively, Matthew will be in charge of constructing the transmitter array. Christopher will be delegated the task of constructing the nodes, and Spencer will be in charge of the command module. These assignments put a head over each of these components, but all individual will lend a hand on each component.

Standards of packet sending will be established during group meetings as players know the exact needs of their individual components.

Furthermore, the final Computer software component will be a collaboration of all three team members to build or interface with a 3D application.

## **Bill of Materials**

- Host PC
- MC13192U [5] wireless module from Freescale  
[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=ZIGBEESLK&fsrch=1](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=ZIGBEESLK&fsrch=1)
- CSM12C32 [1] MCU from Freescale  
[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=HCS12C32SLK&fsrch=1](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=HCS12C32SLK&fsrch=1)
- MCU Project Board-2 [3] from Freescale  
[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=PBMCUSLK&parentCode=HCS12C32SLK&nodeId=0162469544#](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=PBMCUSLK&parentCode=HCS12C32SLK&nodeId=0162469544#)
- 40KT08 [6] Transmitter from SensComp
- 40KR08 [7] Receiver from SensComp  
<http://www.senscomp.com/specs/40KT08%20%20spec.pdf>

## **Vendor List**

- Freescale Semiconductor: <http://www.freescale.com>
- Freescale contact Andy Mastronardi: [andy.mastronardi@freescale.com](mailto:andy.mastronardi@freescale.com)
- SensComp: <http://www.senscom.com>

The Microcontrollers, Project Boards and wireless modules have been given to Matthew Fisher by Freescale. The piezoelectric transducers will need to be purchased as well as any other circuit

components.

## **Conclusion**

We have an exciting and very feasible project ahead of us. We have the skills we need with embedded systems, software, electronics and motivation to make things happen.

## **References**

### **In bibli:**

#### **[1] CSM12C32**

[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=HCS12C32SLK&fsrch=1](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=HCS12C32SLK&fsrch=1)

#### **[2] MC13213**

[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=MC13213&fsrch=1](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC13213&fsrch=1)

#### **[3] MCU PROJECT BOARD-2**

[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=PBMCUSLK&parentCode=HCS12C32SLK&nodeId=0162469544#](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=PBMCUSLK&parentCode=HCS12C32SLK&nodeId=0162469544#)

#### **[4] IEEE 802.15.4**

<http://www.ieee802.org/15/pub/TG4.html>

#### **[5] MC13192U**

[http://www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=ZIGBEESLK&fsrch=1](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=ZIGBEESLK&fsrch=1)

#### **[6] 40KT08**

<http://www.senscomp.com/specs/40KT08%20%20spec.pdf>

#### **[7] 40KR08**

<http://www.senscomp.com/specs/40KT08%20%20spec.pdf>

#### **[8] Ultrasonic Distance Measurement with the MSP430**

<http://www.focus.ti.com/lit/an/slaa136a/slaa136a.pdf>

#### **[9] Caffeine is a xanthine alkaloid compound and a very useful molecule**

<http://en.wikipedia.org/wiki/Caffeine>

