NSRP | National Shipbuilding Research Program

Miniature Torch Speed Sensor Based Adaptive Manual Arc Welding

YuMing Zhang – University of Kentucky

OUTLINE

1. **Background and Idea**
2. **Previous Work at the University of Kentucky**
3. **Objective and Team**
4. **Work Plan**

Idea

- The UK Welding Research Lab (UK-WRL) has used a low cost compact miniature sensor using Inertial Measurement Unit (IMU) to measure position, orientation and speed. The invention recently received a US patent (Y.M. Zhang and W.J. Zhang, 2018. Measurement of three-dimensional welding torch orientation for manual arc welding process. US Patent # 9,975,196). IMU is mass produced for smartphones at low cost; potentially more accurate than GPS; is less obtrusive than cameras and can be concealed inside the torch body.
- This sensor can be encapsulated inside the torch body to monitor its motion (or weld) for position, speed, angle etc. and the weld sequence in manual welding
- The torch motion data can be used to ensure the torch movement by human welder be in compliance of the welding procedure specification (WPS) in ship production, such as proper weld size.
- The data has the potential to be used for low cost, in-situ training of weld operators, on real production part, at real fabrication site, and in all positions without the line-of-sight limitation of camera-based training tool.

What Is IMU Sensor?

- **Inertial measurement unit**. An **inertial measurement unit** (**IMU**) is an electronic device that **measures** and reports a body's specific force, angular rate, and sometimes the **magnetic** field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

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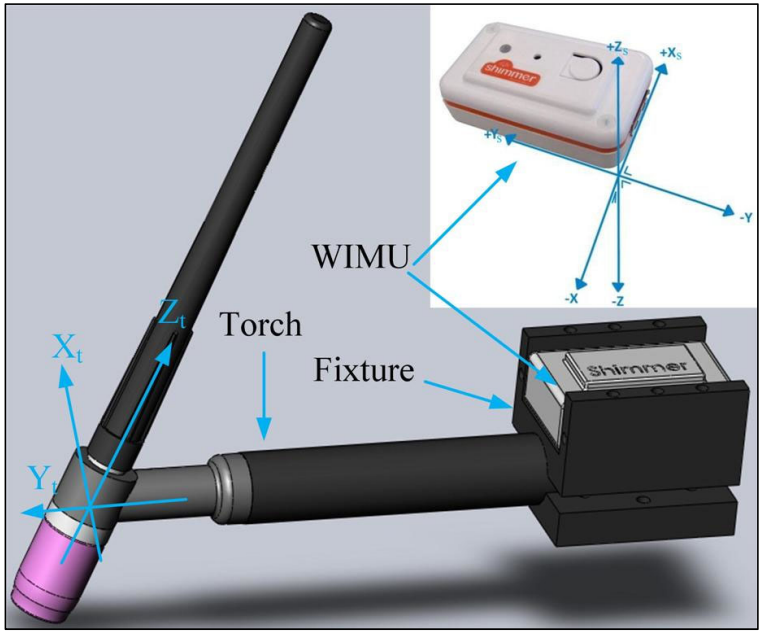
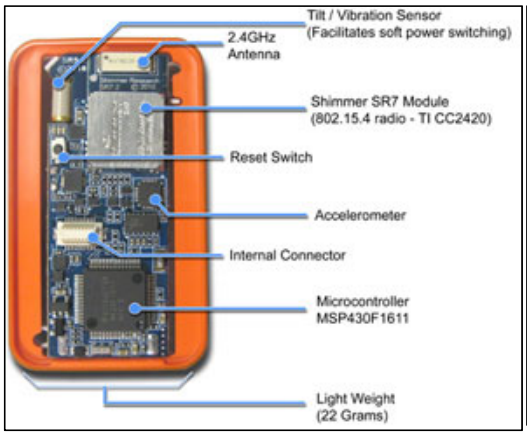
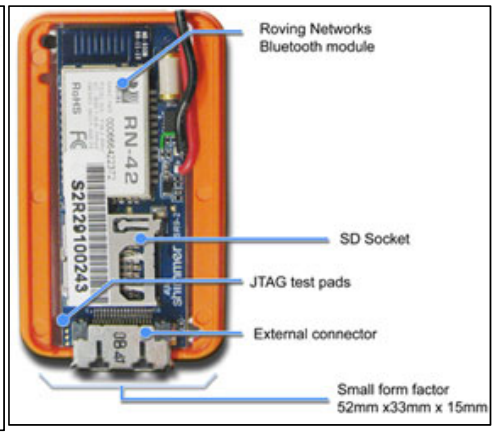
Experimental System

Simmer Inertia Measurement Unit



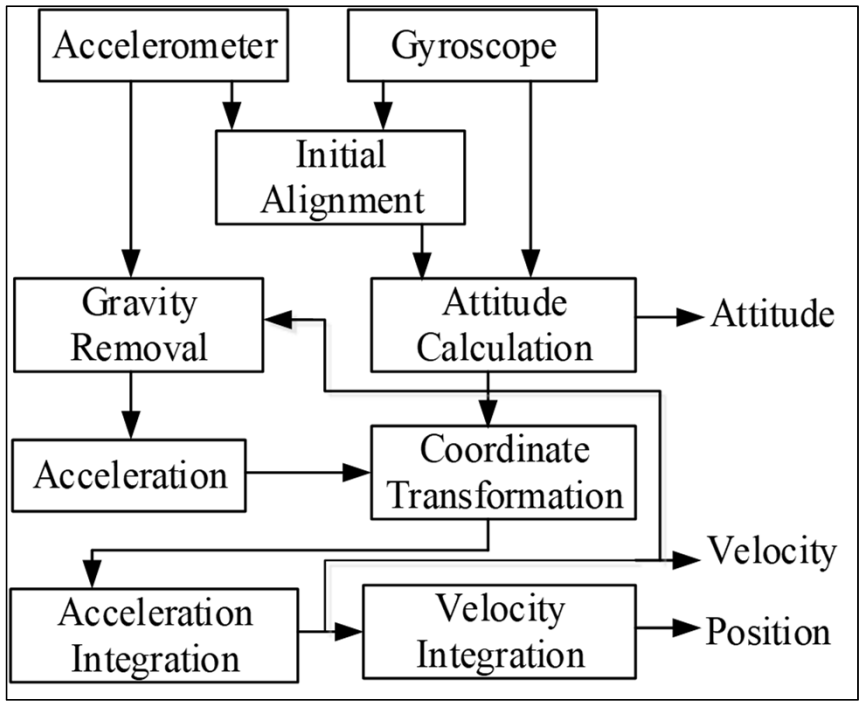




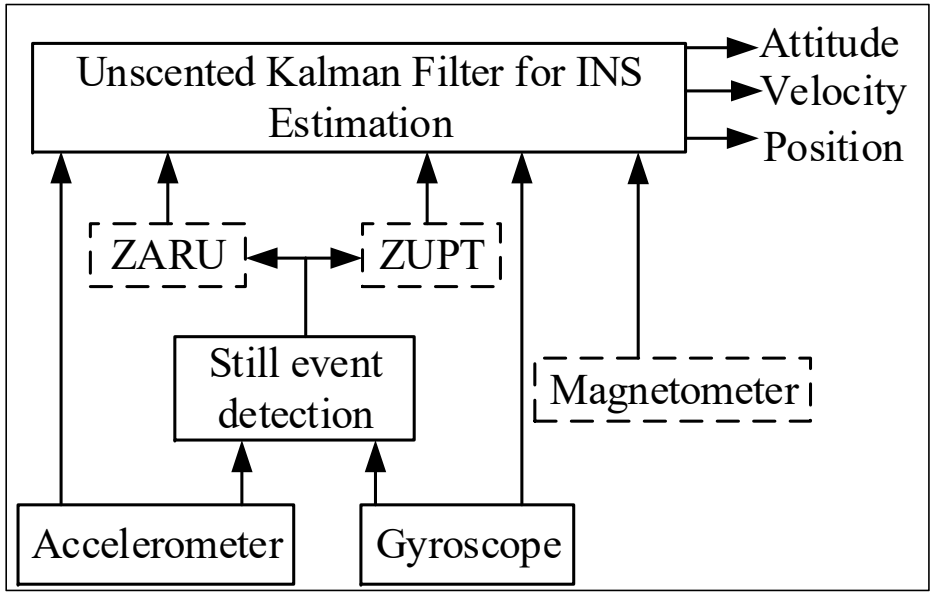
(1) tri-axial accelerometer (Freescale MMA7260Q); (2) tri-axial gyro sensor (InvenSense 500 series); (3) a magnetometer; (4) a microprocessor (MSP430F1611); (5) a Bluetooth unit.

Proposed Method

- Inertial Navigation System (INS)

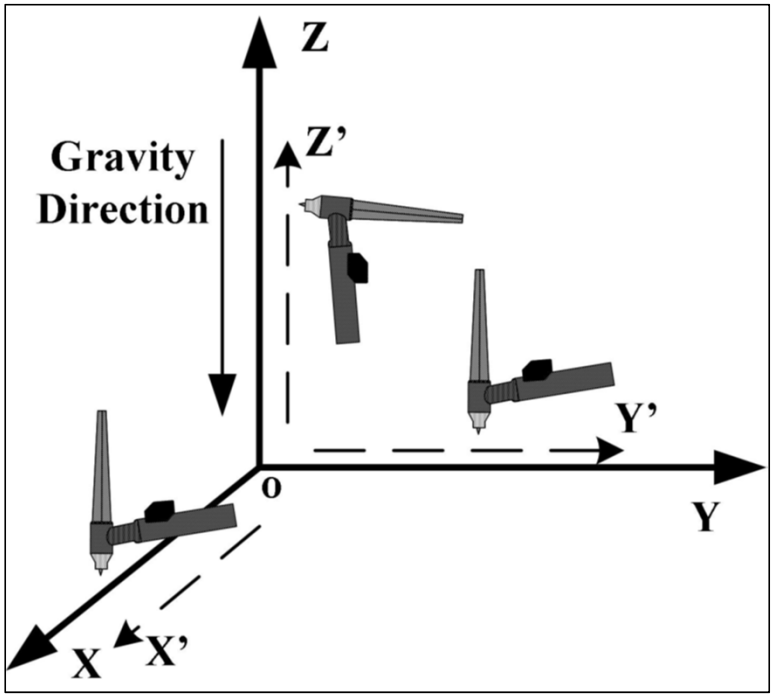


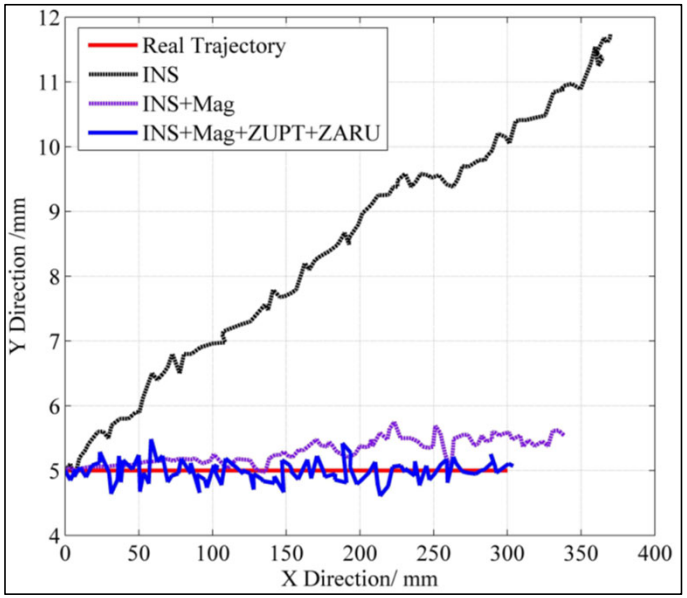
- Any errors in the initial alignment or the integration blocks will propagate over time.
- **A self-correction mechanism is required for accurate measurement.**
- Unscented Kalman filter(UKF): Wan (2011), Julier (2009), ..



Experiments and Results Analysis

- **Position experiment 1:** The torch is smoothly moved along the three axes in the coordinate system.





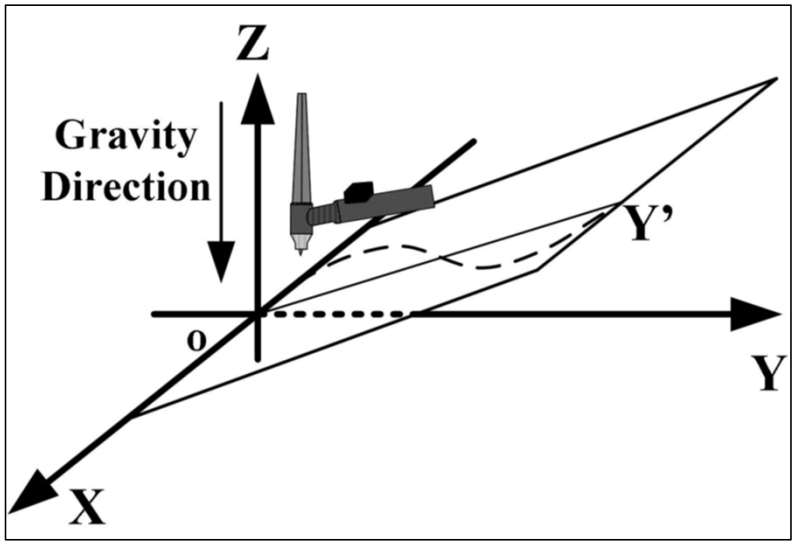
The results of torch trajectory position estimation in X-axis

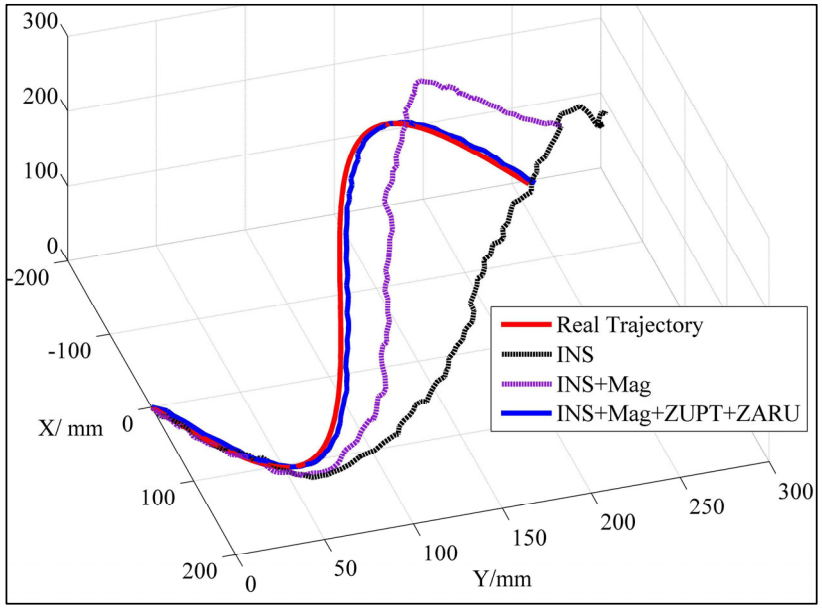
Estimation methods	Position error (% of TTD)
Kalman-based INS	> 20
INS+magnetometer	[5-15]
INS+magnetometer+ZUPT+ZARU	[0.4-1.2]

Measurement errors in Position Experiment 1

Experiments and Results Analysis

- **Position experiment 2:** The torch is smoothly moved along the 3-D since curve.





The results of torch trajectory position estimation

Estimation methods	Position error (% of TTD)
Kalman-based INS	> 25
INS+magnetometer	[7-16]
INS+magnetometer+ZUPT+ZARU	[0.5-1.7]

Measurement errors in Position Experiment 2

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Illustration of Sensor Installation

Goal

- The goal of the project is to develop a cost-effective solution for not so highly-skilled manual weld operators to make smaller fillet welds in compliance with the WPS. Therefore, the cost of overwelding and distortion is minimized, the productivity is increased, the welding consumable cost is reduced, without incurring the cost of procedure re-qualification by the shipyards. More specifically, the project aims at (1) developing a miniature sensor and an algorithm to monitor the travel speed (TS) in semi-automatic flux-corded arc welding (FCAW); (2) developing an adaptive control system to automatically adjust the wire feed speed to make uniform fillet joints based on actual travel speed.

Explanation ---

The welding equipment is programmed with tolerance window around the set wire feed speed (WFS). If the operator moves the torch fast, the WFS will be commended to go fast. If the operator moves the torch slowly, the WFS will be commended to go slowly. The ratio of WFS/TS will be maintained so that the fillet size will not significantly exceed the specification. It is also possible that the weld machine output is turned off automatically if the operator grossly moves the torch at an unacceptable speed, and an error message will be displayed. Fillet joint application is selected as the first demonstration case for its simplicity and its extension to other applications may be easily explored using the convenient and accurate speed monitoring sensor developed from this project. More specifically 1/8” or 3/16” fillet size may be selected based on shipyard feedback.

Team

- PI: YuMing Zhang - University of Kentucky
- Shipyard Application: Joe Caron - Huntington Ingalls Industries (Ingalls)
- Equipment and Commercialization Path: Todd Holverson - Miller Electric Company
- TPC: Yu-Ping Yang - Huntington Ingalls Industries (Ingalls)

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Task 1

- **Development of Miniature Sensor Based Troch Speed Monitoring System (9/1/2019-2/28/2020):**

- The system will be suitable for monitoring the travel speed (TS) in semi-automatic flux-corded arc welding (FCAW) and be installed on the torch for a welder to carry without affecting his/her ability to operate the torch. The development includes both hardware and software. The University of Kentucky will carry out this task.

Task 2

- **Testing of Speed Monitoring Accuracy (3/1/2020-4/30/2020):**

- The monitoring system developed will be installed on a robot whose trajectory and speed are precisely known from robot operation data which can be downloaded from robot control system to a computer. The ground true for the speed will be available to compare with that from the monitoring system developed. The robot will simulate the travel and speed typical to semi-automatic FCAW in various patterns. The monitoring accuracy can be accurately assessed. The task will be carried out by University of Kentucky.

Task 3

- **Adaptive Control of Wire Feed Speed in Semi-Automatic FCAW in Fillet Joint (12/1/2019-6/30/2020)**

- When the travel speed is in the tolerant limits, it will be used to adjust the wire feed speed to make the deposition rate (mass/length) to be consistent in compliance with the WPS. If it is out of the limits, the control system will automatically stop the welding process and report the monitored speed. This control system includes a power source which can receive command in real-time to adjust the feed speed, the monitoring system, a computer system with data acquisition system to read data from the monitoring system and send command signals to the power source, and control algorithm that coordinate the actions and determine the adjustment from the wire feed speed per the torch speed. The development will be carried by the University of Kentucky. The University of Kentucky has several such power sources made by Miller Electric and will use a newer model from Miller Electronic if available.

Task 4

- **Trial and Demonstration at Ingalls (7/1/2020-8/31/2020)**

- The system will be installed in Ingalls' welding lab for welders from Ingalls or other shipyards to try out. The resultant welders will be assessed by Ingalls and the data and results will be provided to the University of Kentucky for analysis and improvements of system including algorithms.


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